
# How could local government's policies improve air quality? - Empirical analysis to check local government's policies to deal with air pollution in Hangzhou, China

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***Abstract:***

*Air pollution is a very serious problem facing hznaghou of China. The local government in Hangzhou has implemented lottery system for license plate application, traffic ban in rush-hours and investment in subway system to decrease automobile exhaust. The main research objective of this paper is to evaluate the effectiveness of these policies on the air pollution. The data analyzed in this paper include four pollutants' (PM2.5, PM10, NO2, SO2) daily concentration (unit: μg/m³), which is provided by the Environmental Protection Bureau of Zhejiang province. We use both OLS regression and regression discontinuity analysis to check the effects of the three policies memtion above. From the regression results, we find that the "lottery license plate", "rush hour traffic quota" , and "subway system expansion" all policies improved air quality in Hangzhou.*

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**How could local government's policies improve air quality?**

**-**Empirical analysis to check local government's policies to deal with air pollution in Hangzhou, China

## 1. Research motivation

Air pollution is becoming a very serious problem in China, and poses a threat to Chinese public health. China is suffering from PM2.5, which is a particulate matter with diameter of 2.5 micrometers or less. According to the U.S. Environmental Protection Agency (2017), such fine particles can cause asthma, bronchitis, and acute and chronic respiratory symptoms such as shortness of breath and painful breathing, and may also lead to premature death

Hangzhou of China is suffering from air pollution and it becomes a challenges for municipal government. Hangzhou is the capital city of Zhejiang province, and it is one of the richest area in China. It's population is 9,018,00 in year 2016 and per capita GDP in year 2016 is US$18,029 (China Statistics yearbook, 2017). While Hangzhou is one of the most air polluted city in China. According to the report by Ministry of environment in China (MOE, 2016), more than 200 days in each year is called heavy polluted day according to China's air pollution standard.


In an attempt to reduce air pollution, the Hangzhou municipal government has made the decision to enforce stricter regulations. The main goal of the government's policy is to reduce industrial air pollution by closing polluting mills, factories and smelters and switching to other eco-friendly energy sources. Also, government has implemented policies to control traffic in Hangzhou in order to minimize the automobile exhaust.

The local government in Hangzhou has implemented lottery system for license plate application. Traffic ban in rush-hours is the second policy to deal with the air pollution. The investment on the subway system is another policy to decrease automobile exhaust.

While there are so many related policies implemented by local government, necessary research to check the effeteness of the polices is inadequate. Our paper is trying to evaluate the effeteness of those policy innovations and produce policy implications.

In rest paper, we will firstly check related policies. Then we will provide Theoretical Basis and Econometric Model of this research. Thirdly we will implement Statistical analysis. In last two parts, we will discuss the results and draw conclusions

## 2 Related Policies and Research

Although the original intention is good, the way of implementation of the limit line policy is not smooth, constantly being questioned and criticized the parties to professionals. From a legal point of view, as the chief means of conventional limit line policy is a violation of property rights. Professor of Renmin University of China Mao Shoulong explained: "Every major events or economic circumstances, departments have the right to use emergency management authority, to take temporary control measures, but usually the use of emergency powers is the abuse of power", "limit line policy itself is personal property rights violations, "road traffic safety law," "air pollution prevention law" and other laws and regulations, can not be used as a legal basis for long-term implementation of the limit line policy, because "Property law" priority, long-term line of equal use administrative means to damage "Property law" authoritative " .

Second, the long-term implementation of the limit line policy may not be able to achieve the desired effect, because of travel restrictions but will stimulate the increase of the vehicle, this effect is likely to be overlooked. "Economic Observer reported," (March 21, 2010) published an editorial, "long-term policy should not limit line" of states: the limit line policy and the tax cut will stimulate the families to buy a second car behavior, limit line policy can only be a temporary of measures of long-term result is more harm than good.

Finally, from a cost - Earning angle, the implementation of social welfare policies limit line losses resulting from that it is by no means solve the problem of congestion and pollution the best choice. Eskeland and foreign scholars Feyzioglu (1997) pointed out that the congestion tax, pollution tax or fuel tax policy is the

best choice, because they lead to social welfare losses minimal, similar to the regulation means limit line policy is not reduced due to the opportunity cost of the lowest travel, caused social welfare loss is greater than the welfare losses optimal state.

Limit line policy on whether Beijing effectively alleviate the traffic congestion and improve air quality, existing research does not seem to give a positive evidence. Beijing Traffic Development Research Center released a report in 2009 noted that: limit line policy has achieved good results, compared with the previous limit line, working within the Fifth Ring Road traffic congestion index dropped from "moderate" to "slight", daily reduce 8-10% of motor vehicle exhaust emissions. Zhao Xiaoguang et al. (2010) using the same above-mentioned "Report" in a similar manner to the limit line period before the Olympics and after the Olympics were over the same period, found during the limit line policy implementation, Beijing city atmosphere of nitrogen dioxide and respirable particulate matter concentrations of It was decreased. Xie Xuxuan (2010) pointed out that the "report" does not explain the results of these changes are caused by the limit line policy, Beijing road expansion, subway construction, industrial enterprises and other measures to reduce emissions of pollutants are likely to traffic congestion and air quality positive impact, but the authors did not support the empirical evidence. Chen et al (2011) using the fold difference method (Difference in Difference) discussed the impact of the measures taken before and after the Olympic Games, the Beijing municipal government on air quality. They found that the Air Pollution Index (API) decreased mainly in the start of the Olympics occurred. Within a month, the pollution index began to rise rapidly after the Olympics. Their research, although some of the effects of control factors of national air quality trends, but also unable to distinguish the effects of the policy limit line in Beijing and other relevant policies on air quality. Cao Jing (2014) and other studies in 2008 during the Olympic Games with the vehicle after Beijing adopted the limit line policy on the Air Pollution Index (API), respirable particulate matter

(PM10), nitrogen dioxide (NO 2) and sulfur dioxide (SO 2) and other air effect of quality indicators, although the traditional OLS regression showed that the limit line policy has a strong effect, when using the regression discontinuity method to solve its problem of endogeneity, find the limit line policy, especially the impact of "tail number limit line" on air quality has little .

In fact, other developing countries particularly favor the use of the limit line this idea to solve congestion and pollution problems. Mexico City's most famous HNC (Hoy No Circula) effect of policy implementation is not satisfactory, at least in the test results so economics. November 20, 1989, in order to mitigate air pollution in Mexico City, the government began to implement the "open one day a week less car" limit line policy. Eskeland and Feyzioglu (1997) use gasoline consumption limit line policy implementation before gasoline prices, income data to predict the consumption of gasoline after the limit line policy implementation, and with the actual comparison of the data found that after the implementation of the policy gasoline consumption but increased. Study results will be attributed to more people to buy a second car, or more cars continue to be used, as well as the role played by alternative weekend trip. Davis (2008) using the regression discontinuity (Regression Discontinuity) method (h) data on the high frequency pollutants from 1986 to 2005 in Mexico City (including carbon monoxide, nitrogen dioxide, ozone, nitrogen oxides, sulfur dioxide) were analyzed and we found that the limit line policy distortions brought residents purchase behavior, including the purchase of a second car or use a larger displacement or polluting old cars, gasoline consumption but increased use of public transport has not increased, so did not significantly improve pollution, limit line policy does not achieve the desired results.

Hangzhou, covers an area of 16,596 square kilometers in 2015, the resident population of 901.8 million people (data from Baidu Encyclopedia), rely on the West Lake scenery, world-class garden city, a sharp increase in recent years due to environmental pollution in the country once PM2.5 Ranking top standings,

highlighted by the annual haze surge in the number of days. Gold Equal (2010) by nearly 50 years of Zhejiang haze statistics found that 2000-2008 is the frequency of occurrence of haze in Zhejiang rapid growth, as the provincial capital of Hangzhou, is a high incidence of haze. In addition to topography, climate factors, open terrain, from the viewpoint of human activities, pollutant emissions are the direct cause of increased frequency of Hangzhou atmospheric haze occurred. Development and economic level of the city and the city's vehicle fleet, energy consumption, etc. directly related to the 2005 Hangzhou vehicle fleet 562 000, 1995 58 000 10 times, no ash in 1995 haze occurs, haze days in 2003 to reach 159 days. Of urban PM10 source apportionment components found coal-dust contribution rate of 26.2%, automobile exhaust dust contribution rate of 20.8%, a rapid increase in the contribution rate of car exhaust dust in recent years, while the proportion of coal-dust significantly reduced. Hangzhou type coal-burning pollution from the past gradually transformed into a hybrid vehicle exhaust, direction and focus on pollution prevention has also been a corresponding change in the vehicle license restrictions discussed herein granted, peak hours to limit motorized travel policy and the development of rail transportation, the new situation is the limit exhaust emissions from motor vehicle pollution policy to try.

In this paper, the state-controlled points between 2013-2014 historical air quality observations in Hangzhou (Zhejiang data from the Department of Environmental Protection), includes a single pollutant PM2.5, PM10, NO 2, and SO 2 concentration data, using regression breakpoint methods of the "lottery limit card" policy implementation and Hangzhou "peak shifting limit line", respectively prolonged influence of the main urban air quality, and tested the opening of the southeast section of Metro line 2 whether to improve air quality and other areas along the problem. In this paper, the methods and Davis (2008) is consistent. The benefits of using RD method is to avoid the OLS method is ignored variables (such as other pollution control policies before and after the implementation of the policy) problems caused by endogenous time-related trends.

## 3 Theoretical Basis & Econometric Model

### 3.1 Regression Discontinuity Theory

From the existing literature, evaluation method of neither single difference nor difference in difference is not the appropriate method to test policy effectiveness.

Endogenous problems cannot be solved by using single difference method, which means that whether the improvement of air quality is caused by the driving restriction policy cannot be distinguished. Xie Xuxuan (2010) used the OLS method to compare the change of air quality in Beijing before and after the implementation of driving restriction policy. However, by simply using single difference method to test the effect of driving restriction policy, we not only cannot differentiate the effect of driving restriction policy and other policies of Beijing government but also cannot exclude the inherent trend of city air quality change in Beijing. Similarly, Cao Jing (2014) also used the OLS method when she tested the influence of the Olympics driving restriction policy and the tail number driving restriction policy. The regression result showed that the dummy variable coefficients of both driving restriction policies are significant negative, especially the policy for Olympics. Nevertheless, the regression result of OLS may be unreliable because the implementation time of both the two driving restriction policies is almost the same with that of pollution industry adjustment policy in Beijing, of which we cannot observe the effect directly, which introduces the endogenous problem of the neglected variable.

The basic idea of DID is to pick other cities as a control group. Although DID can partially control the conjunct change trend of air quality in different regions, Beijing is a very special city in China, just like the condition of Mexico City in Mexico, which makes it extremely difficult to find a similar city that has almost the same elements except the driving restriction policy. DID seems perfect, but it is a hard work to find a suitable control group.

The introduction of Regression Discontinuity provides a new and practicable

solution for policy identification issues. RD is actually a simulative random experiment which defines a feature that the probability of accepting the treatment is a discrete function of one or several variables. When RD is applied, we can get a specific variable. If the variable is larger than a critical value, the treatment will be accepted, otherwise, the treatment will be rejected. In the case of continuous variables, the difference of sample near the critical value can reflect the causality of treatment and economic variables very well.

The method of RD can be categorized into two type, Sharp and Fussy. The first type has a sharp critical value, which means the treatment is accepted by all the observation points on the one side of the critical point and not accepted by all the observation points on the other side. Under this circumstance, the probability of accepting the treatment skips from 0 on the one side to 1 on the other side. The second type has a fussy critical value, which means that the probability of accepting the treatment changes monotonously near the critical value. Hahn et al (2001) proved that the causality of treatment and other economic variables can be studied by using the systematic change of sample near the critical value in both types of RD. Lee (2008) thought that RD can avoid the endogenous problem in parameter estimation and consequently truly reflect the causality between variables when random experiment is unobtainable. As for the present study, the location of the critical value is certain. While taking day for denomination, the date when driving restriction policy is executed is the location of the critical value. The policy begun to take effect on the execution day, which means the variables stated to accept treatment.

Take policy effectiveness test for example. The basic idea of RD is that if the policy can be treated as an abruptly changed factor, in which case the driving restriction policy is eligible, some methods can be applied to differentiate its influence and the influence of other continuously changed variables, which contain the observable ones and the unobservable ones, and to recognize its impact consequently. In the case of driving restriction policy, if we can observe an abrupt

change of air quality before and after the execution of the policy, while other factors can be affirmed to be continuously changed, we can believe that the sudden change of air quality is caused by the sudden change of the driving restriction policy. That is to say, the policy of driving restriction is effective. However, if an abrupt change of air quality cannot be observed, we consider the policy is invalid.

Li Hongbin & Chen Yuyu (2013) used the method of RD to research the chronic impact of air pollution on life expectancy, which finds out that the average life expectancy will be shortened by 3 years every time the concentration of TSP rises 100 mg/$m^3$ if exposing in polluted air for a long time. The conclusion means that each person of the 500 million residents in Northern China loses 5 years of life on average. It is very difficult to scientifically assess the impact of pollution on human health because the regions which have different pollution degree may also differ in income level, educational degree, initial health condition, etc. , the interference of which makes it very hard for scientists to extract the damage degree of pollution on health. This study solves the problem of correctly estimating the causality by skillfully using the Huaihe River heating boundary which is unique in China. Although the air pollution condition in China changes smoothly from south to north, it changes abruptly near Huaihe River as a result of the different heating policy in Northern and Southern China. The concentration of TSP in the north of Huaihe River is 200 mg/$m^3$ higher than that in the south because coal heating is widely and heavily used in winter in the north. At the same time, the average life expectancy varies obviously, which shows a 5 years less in the north than in the south of Huaihe River. The abrupt leap provides an ideal natural experiment in studying the relationship between air pollution and health, which means that RD can be used here to evaluate the causality of pollution and health.

Similarly, the influence factors of air quality are hard to identify. On the one hand, influenced by temperature, moistness, wind speed and other natural elements, the air pollution level presents a certain rule changed with time series and has a large randomness. On the other hand, influenced by human activities, industrial

activities, exhaust gas produced by coal and vehicle exhaust are all the main source of city pollution. Other than driving restriction policy, if other policies about air pollution governance are introduced at the same period, such as relocation and reform of heavily-polluting industry and ban of burning coal, which causes a considerable change in industrial output and quantity of coal burning, it will be difficult to separate the effective as a result of policy overlap. In fact, Hangzhou government introduced two implementation plans on air pollution prevention and control from 2014 to 2015. The two plans clearly put forward the performance of concurrent treatment on five types of gas, which means to deeply treat industrial waste gas, and to shut down a large array of heavily-polluting enterprises in central downtown, and to roundly treat waste gas produced by coal burning, and to promote the optimization and adjustment of energy structure, and to realize the full coverage of natural gas usage. All these policies are being performed step by step. Unlike the feature that these policies need time to gradually be executed and chronically take effect, the three traffic polices, which are driving restriction, license plate lottery and open of new metro line, in this passage is introduced almost in one day and take effect immediately. For example, the first day driving restriction policy is executed, the amount of vehicles during peak hours in central downtown was 20% less than the day before. To differentiate the impact of the short-run and long-run policies, the RD method will be used. In the case of "peak hour driving restriction" policy, an abrupt decline of daily vehicle amount in central downtown of Hangzhou was observed on the first day the restriction policy was introduced, while the amount showed a continuous and regular fluctuation in the previous time, which contains ascent and descent. If we can observe an abrupt change of air pollution level in the same region on the same day and make the effort to exclude the impact of temperature, moistness, wind speed and other weather factors, to smoothen the seasonal fluctuation and to regard the industrial output and the condition of coal burning as relatively stable in a short time, we can then speculate that the improvement of air quality is induced by the reduction of vehicle travel. That is to say, the driving restriction policy is effective.

### 3.2 Econometric Model

Based on the basic idea of regression discontinuity, referring to the method of Davis (2008), the regression model is established as follows:

$$y_t = \beta_0 + \beta_i 1(policy_i) + \beta_2 X_t + \mu_t$$

$y_t$ is the observed air quality on the t day, measured by the daily concentration of PM2.5, PM10, $NO_2$ and $SO_2$. $1(policy_i)$ is the dummy variable of traffic policy implementation. Based on the time span of the air pollution data and meteorological data we collected, we finally select three specific policies, which are the "license plate lottery" policy started form May 1st, 2014, the "peak hour driving restriction" policy started from May 5th, 2014 and the opening of the southeast section of the metro line 2 in Nov 24th, 2014. They respectively correspond to $1(policy_1)$, $1(policy_2)$ and $1(policy_3)$ according to their implementation time. We define that the dummy variable $1(policy_1)$ control the "license plate lottery" policy, $\beta_1$ represents the implementation effectiveness of this policy, $1(policy_1)$ is 0 before May 1st, 2014 and $1(policy_1)$ is 1 after May 1st, 2014. We define that the dummy variable $1(policy_2)$ control the extension of "peak hour driving restriction" policy, $\beta_2$ represents the implementation effectiveness of the extension of this policy, $1(policy_2)$ is 0 before May 5th, 2014 and $1(policy_3)$ is 1 after May 5th, 2014. We define that the dummy variable $1(policy_3)$ control the opening of the southeast section of the metro line 2, $\beta_3$ represents the implementation effectiveness of the opening, $1(policy_3)$ is 0 before Nov 24th, 2014 and $1(policy_3)$ is 1 after Nov 24th, 2014.

We set a covariate $X_t$ to control the other elements that affect air quality, which contain the dummy variable of legal holidays and shift leaves (1 on rest day and 0 on workday), the dummy variable of season (spring or not, summer or not, autumn or not) and the weather factors which include the daily highest temperature, the daily lowest temperature, the daily sustained wind speed maximum and dummy variable of special weather (rain, snow and fog).

## 4. Data and Statistical analysis

### 4.1. Data

On the measurement of air quality, the article uses data of four pollutants' (PM2.5, PM10, $NO_2$, $SO_2$) daily concentration (unit: $\mu g/m^3$), which is provided by the Environmental Protection Bureau of Zhejiang province, the data covers two years from January 1, 2013 to December 31, 2014. Among these data, there are mostly no $SO_2$ in motor vehicle exhaust, so we adopt this index to build counter-fact tests by building controls with other three indexes.

In order to obtain more accurate results, this paper chooses regional areas' data rather the overall data of Hangzhou to conduct tests. On examining effects of

'license plate lottery' policy and upgraded the 'peak hour driving restriction' policy, we choose pollution data from observation points of 'Zhaohui-fifth-area' and 'Zhejiang Agricultural University'. Both two observation points are close to the city center, have high traffic flow and are more sensitive to policy. In order to exam effect of the operation of southeast of Metro Line No.2 on the air quality, we choose the pollution data of Chengxiang Town, the observation point which is passing by Metro Line No.2.

Meteorological data is obtained from meteorological stations which NASA's agency set in Hangzhou, and it's an overall data of Hangzhou. Set daily highest temperature (unit: Fahrenheit), daily lowest temperature (unit: Fahrenheit), daily maximum sustained wind (unit: nautical miles per hour), and special weather (such as fog, rain and snow) as dummy variables, so to control special weathers' (temperature, humidity and wind speed) effects.

The characteristics of variable are shown in Table 4.1.

Table 4.1 The main characteristics of variables

| Variable | | Unit | Sample Number | Mean Value | Standard Deviation | MIN | MAX |
|---|---|---|---|---|---|---|---|
| Zhaohui-fifth-area | PM2.5 | $\mu g/m^3$ | 719 | 70.2 | 45.19 | 9 | 450 |
| | PM10 | $\mu g/m^3$ | 625 | 102.03 | 47.24 | 5 | 278 |
| | $NO_2$ | $\mu g/m^3$ | 717 | 62.1 | 22 | 10 | 138 |
| | $SO_2$ | $\mu g/m^3$ | 705 | 20.78 | 11.53 | 3 | 79 |
| Zhejiang Agricultural University | PM2.5 | $\mu g/m^3$ | 720 | 68.76 | 38.77 | 12 | 314 |
| | PM10 | $\mu g/m^3$ | 636 | 108.46 | 52.52 | 7 | 419 |
| | $NO_2$ | $\mu g/m^3$ | 698 | 56.55 | 22.32 | 8 | 142 |
| | $SO_2$ | $\mu g/m^3$ | 690 | 25.2 | 14 | 3 | 92 |
| Chengxiang Town | PM2.5 | $\mu g/m^3$ | 697 | 68.98 | 44.46 | 12 | 437 |
| | PM10 | $\mu g/m^3$ | 643 | 115.21 | 57.96 | 9 | 508 |
| | $NO_2$ | $\mu g/m^3$ | 705 | 52.8 | 22.92 | 6 | 170 |
| | $SO_2$ | $\mu g/m^3$ | 712 | 33.6 | 21.41 | 3 | 205 |
| Legal holiday/paid leave | | Dummy Variable | 730 | 0.31 | 0.46 | 0 | 1 |
| Daily Highest Temperature | | Fahrenheit | 730 | 72.3 | 17.07 | 30.4 | 106 |
| Daily Lowest Temperature | | Fahrenheit | 730 | 56.26 | 16.59 | 24.1 | 86 |
| Daily Maximum Sustained wind | | Nautical Miles per hour | 730 | 9.93 | 3.31 | 3.9 | 29.1 |
| special weather or not | | Dummy Variable | 730 | 0.51 | 0.5 | 0 | 1 |
| spring or not | | Dummy Variable | 730 | 0.25 | 0.43 | 0 | 1 |

| | | | | | | |
|---|---|---|---|---|---|---|
| summer or not | Dummy Variable | 730 | 0.25 | 0.43 | 0 | 1 |
| winter or not | Dummy Variable | 730 | 0.25 | 0.43 | 0 | 1 |

### 4.2 Statistical analysis

In order to observe the change trend of air quality, we mapped scatterplot of four pollutant concentration changing over time. As shown in Figure 4.1, Figure 4.2 and Figure 4.3, they are diagrams of pollutants' (PM2.5, PM10, $NO_2$ and $SO_2$) daily concentration data varied as observation in Zhaohui-fifth-area, Zhejiang Agricultural University and Chengxiang Town, the data covers two years from January 1, 2013 to December 31, 2014. Ordinate represents pollutants concentration, abscissa starts from 1, which is correspond to January 1, 2013, ends in 730, which is correspond to December 31, 2014. The two reference lines in Figure 4.1 and Figure 4.2 respectively indicate the implementation time of 'license plate lottery' policy(May 1, 2014) and the date of extend peak hour driving restriction(May 5, 2014), the reference line in Figure 4.3 shows operation date of southeast of Metro Line No.2(November 24, 2014).

Contrast Figure 4.1 and Figure 4.2 we can find that, because Zhaohui-fifth-area and Zhejiang Agricultural University are geographically close, the change trend of four pollutants' concentration is close. There are several low points of concentrations of pollutants PM2.5 and PM10 shows during a few adjacent days after two policies executed one after another( the implementation time of two policies are so closely that we can't divide their effect, so we discuss them together). But concentrations of pollutants PM2.5 and PM10 is not lower than before, there even a rise (on the right of reference line) after policy implementation. There is no continued decline of PM2.5 and PM10 after the implementation of the "license plate lottery" policy and upgraded the "peak hour driving restriction" policy.

The concentration of $NO_2$ presents a down trend after policy implementation (on the right of reference line), but the trend has existed before the policy implementation (on the left of reference line), we can't identify this trend as the effect of the policy. And there are no significant decrease of pollution levels on the on the right side of reference line compared with it on the left of reference line on the whole.

$SO_2$ isn't main pollutant emissions of car exhaust, but it happened to appear a few high points before the policy implementation and then show a downward trend, this suggests that there are other policies implementing while the two policies is in implementation, this would affect other kinds of pollutants, so other pollutants' concentrations fall, we couldn't conduct this trend is results of the "license plate lottery" policy and upgraded the "peak hour driving restriction" policy.

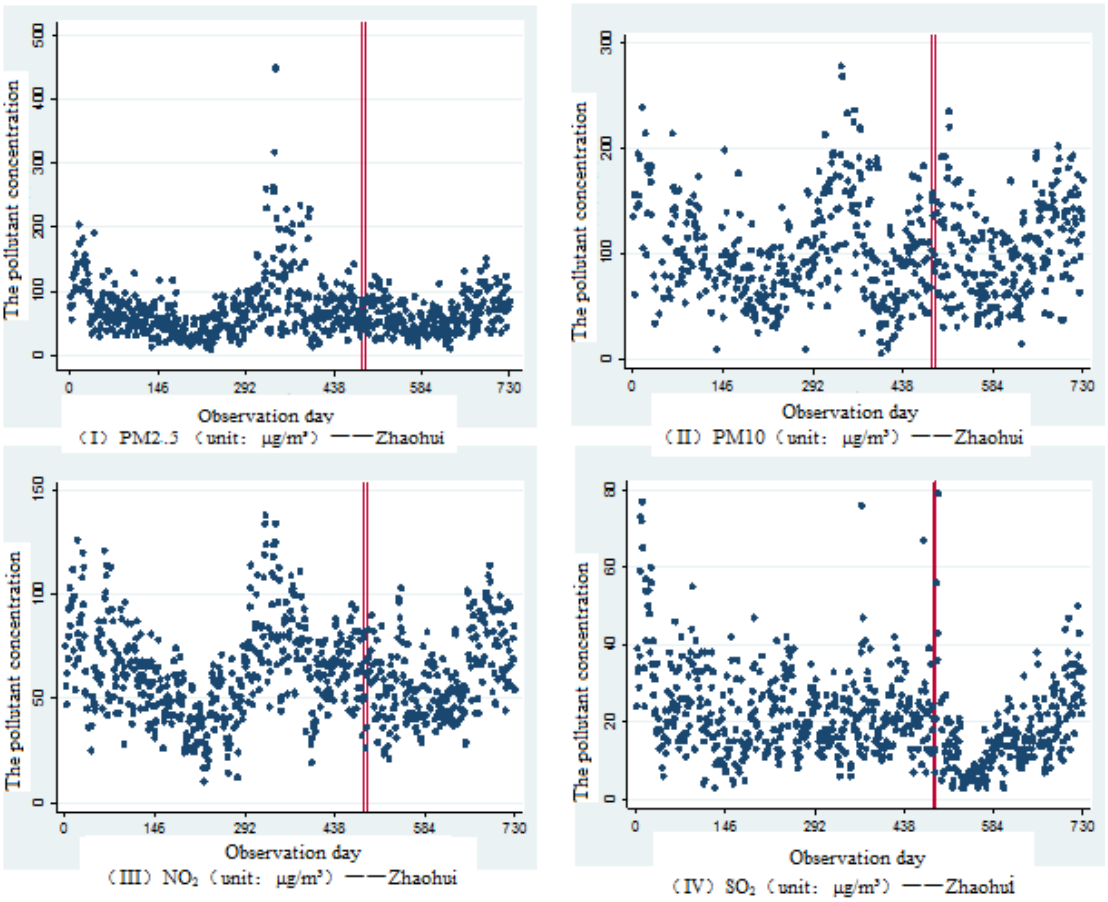


Figure 4.1 The concentration variation of four kinds of pollutants (Observation point: Zhaohui-fifth-area)

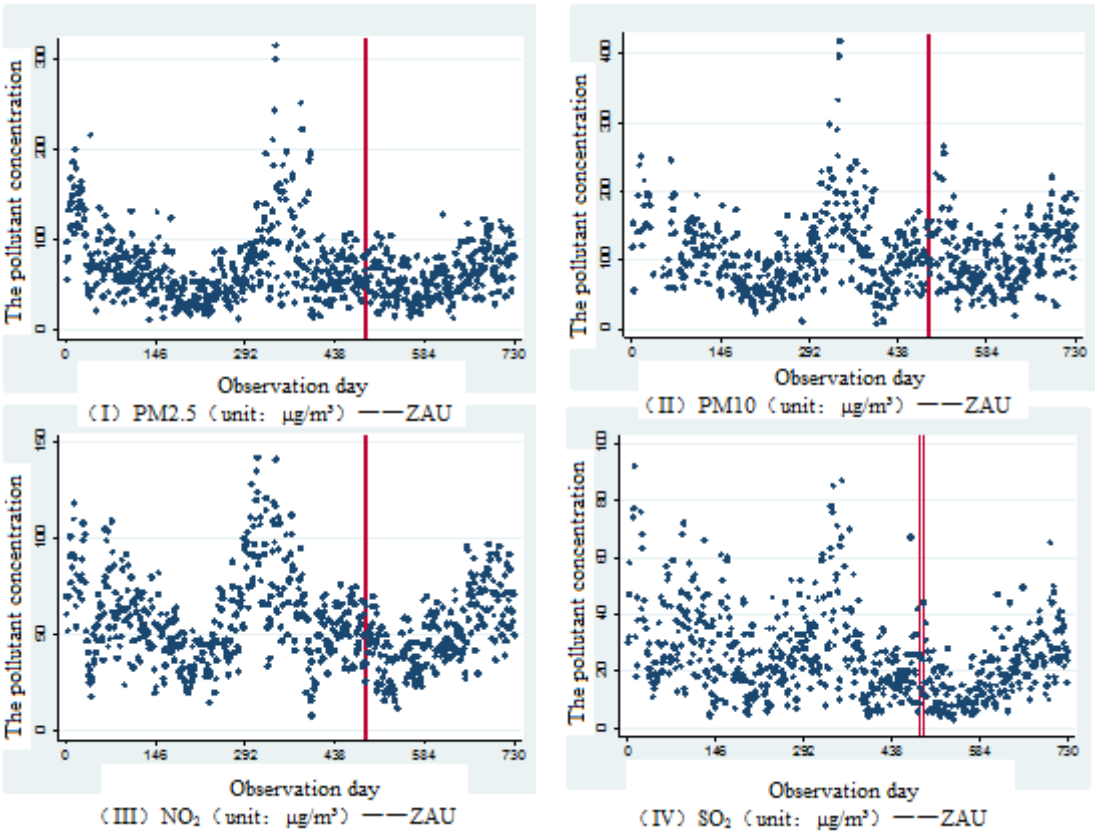


Figure 4.2 The concentration variation of four kinds of pollutants (Observation point:

Zhejiang Agricultural University)

In Figure 4.3, indexes of PM2.5 and PM10 fell after the operation of Metro Line No.2, the index of NO2 increased after decreased, but we can't avoid the effects of other factors such as seasonal fluctuations. The critical point is around by autumn and winter and there are small samples after the policy implement, so we can't estimate the long-term trend. The index of SO2 doesn't appear obvious fluctuation before and after policy implement.

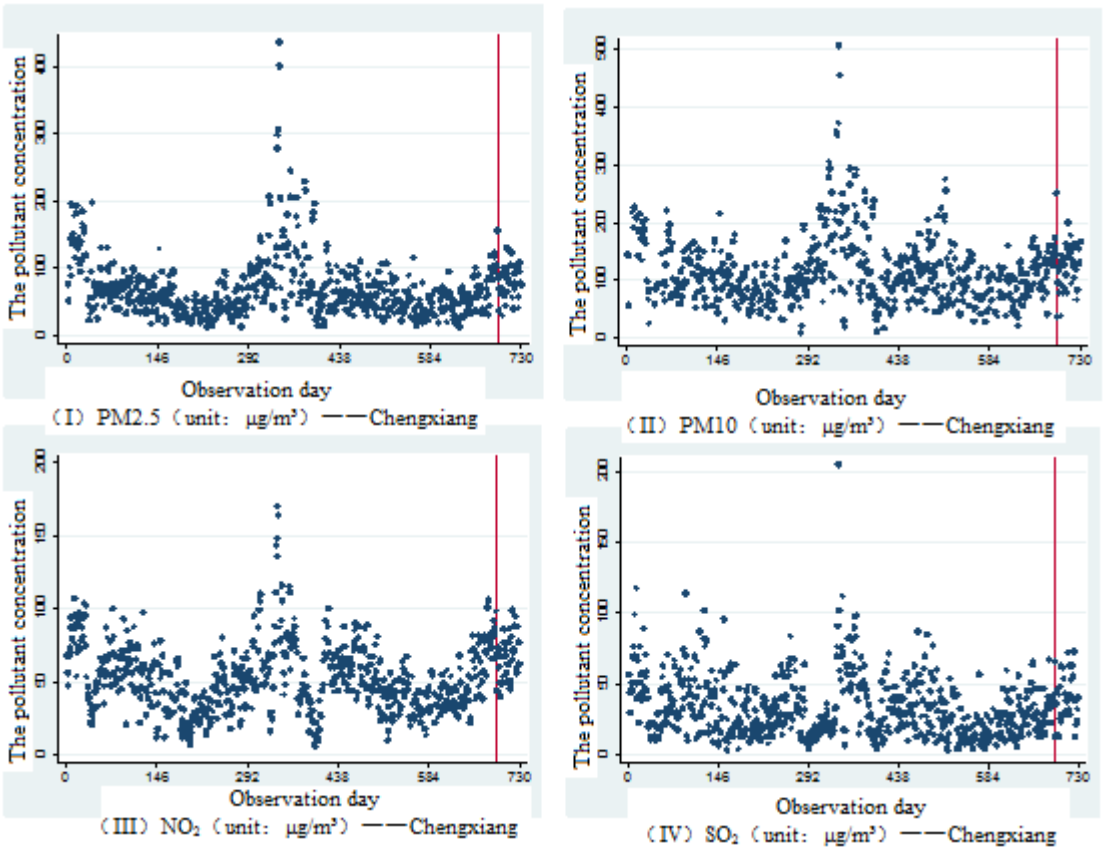


Figure 4.3 The concentration variation of four kinds of pollutants (Observation point: Chengxiang Town)

In general, the intuitive graphical description provides slight evidence for license plate lottery, peak hour driving restriction and developing rail transit, but the inner causation needs a further test by regression.

## 5 Regression result

### 5.1 General linear regression

First we analyze the influence of the three policies by general linear regression (OLS), respectively introduce three dummy variables-license plate lottery, peak hour driving restriction extension and metro line operation, get estimates of corresponding coefficient. Meanwhile, we control the weather variables, adjust season and joined the national holiday and paid leave day as dummy variables, the results is showed in Table5.1, Table5.2 and Table5.3.

In regard to the efficiency of 'license plate lottery' policy, there are a list of result in which PM2.5 joins different variables (due to the limit of space, the results of the combination of other air quality objectives and different variable are not listed). All coefficients are negative, and the significance decreases after control variables join them, and the data of Zhaohui observation point becomes non-significant. After control all variables, 'license plate lottery' policy make PM2.5 of ZAU decrease 5 percentage with 90% confidence level, which equal to 6% of the mean of all sample.

Strangely, the coefficient of PM10 is positive, and its significance level is higher than 5%, it means the implementation of 'license plate lottery' policy makes PM10 pollution more seriously. This may because we didn't take other factors into account, for example, we didn't consider the influence of industrial production, but actually it's an important source of pollution, the increase of PM10 concentration is caused by some factors like this. After control all variables, the regression result of ZAU observation point data show the coefficient of NO2 is negative and significant, the implementation of 'license plate lottery' policy leads 7 percentage decrease of concentration of $NO_2$, which equals to 6% of the mean of all sample. After take all the control variables into account, the coefficient of SO2 is negative and significant as the analysis in statistics section, it should leaded by the concentration of $SO_2$ suddenly rise and the fall around the implement of policy for some reasons.

Table 5.1The impact of 'license plate lottery' policy on air quality: OLS Regression

| | PM2.5 | | | PM10 | $NO_2$ | $SO_2$ |
|---|---|---|---|---|---|---|
| | （1） | （2） | （3） | （4） | （5） | （6） |
| Zhaohui-fifth -area | -12.68*** | -3.56* | -4.49 | 10.64** | 2.22 | -4.39*** |
| | （3.54） | （3.39） | （3.23） | （3.44） | （1,36） | （0.88） |
| Adjust specific date | - | join | join | join | join | join |
| Seasonal adjustment | - | join | join | join | join | join |
| Weather | - | - | join | join | join | join |
| Sample number | 719 | 719 | 719 | 625 | 717 | 705 |

| | | | | | | |
|---|---|---|---|---|---|---|
| ZAU | -12.39*** | -3.56 | -4.38* | 11.27** | -7.54*** | -6.93*** |
| | （3.02） | （2.84） | （2.63） | （3.73） | （1.49） | （1.14） |
| Adjust specific date | - | join | join | join | join | join |
| Seasonal adjustment | - | join | join | join | join | join |
| Weather | - | - | join | join | join | join |
| Sample number | 720 | 720 | 720 | 636 | 698 | 690 |

The effect of peak hour driving restriction extension is completely similar to the regression result of license plate lottery. This is because the implementation date of both policies is too close, respectively on May 5, 2014 and 2014 on May 1, that we couldn't distinguish their effect in time sequence. The later analysis conclusion is basically consistent of former, it means extending peak hour driving restriction makes the concentrate of PM2.5 drop four percentage, but we can't throw the influence of "license plate lottery" policy. So the former conclusion should be complemented that implementation of both 'license plate lottery' policy and upgraded the 'peak hour driving restriction extension' policy together makes the concentrate of PM2.5 drop four percentage and $NO_2$ drop 7 percentage.

Table 5.2The impact of 'peak hour driving restriction extension' policy on air quality: OLS Regression

| | PM2.5 | | | PM10 | $NO_2$ | $SO_2$ |
|---|---|---|---|---|---|---|
| | （1） | （2） | （3） | （4） | （5） | （6） |
| Zhaohui-fifth | -12.66*** | -3.61 | -4.62 | 9.84** | 2.32* | -4.2*** |
| -area | （3.55） | （3.42） | （3.26） | （3.47） | （1,37） | （0.89） |
| | - | join | join | join | join | join |
| Adjust specific date | - | join | join | join | join | join |
| Seasonal adjustment | - | - | join | join | join | join |
| Weather | 719 | 719 | 719 | 625 | 717 | 705 |
| ZAU | -12.46*** | -3.68 | -4.54* | 10.91** | -7.56*** | -6.79*** |
| | （3.02） | （2.86） | （2.65） | （3.77） | （1.5） | （1.15） |
| Adjust specific date | - | join | join | join | join | join |
| Seasonal adjustment | - | join | join | join | join | join |
| Weather | - | - | join | join | join | join |
| Sample number | 720 | 720 | 720 | 636 | 698 | 690 |

In regard to the influence of the operation of Metro Line No.2, the data of PM2.5 and PM10 is negative while using Chengxiang Town's (observation spot) data and OLS regression model, and its significance level is higher than 5%. This indicates

the operation of metro line makes the concentrate of PM2.5 and PM10 drop 19%, which respectively equal to 27% and 16% of the mean of all sample. The coefficient of NO2 is significantly positive, and as well as the analysis of the former two policies, this is because we didn't take other factors into account. The coefficient of SO2 is negative and non-significant; it indicates the operation of metro doesn't have a significant influence on SO2, which is consistent with the common sense.

Table 5.3 The impact of metro line operation on air quality: OLS Regression

| | PM2.5 | | | PM10 | $NO_2$ | $SO_2$ |
|---|---|---|---|---|---|---|
| | （1） | （2） | （3） | （4） | （5） | （6） |
| Chengxiang Town | 11.71 | -19.66*** | -19.87*** | -19.19** | 6.88** | -2.74 |
| | （7.41） | （6.82） | （6.41） | （8.74） | （3.34） | （3.39） |
| Adjust specific date | - | join | join | join | join | join |
| Seasonal adjustment | - | join | join | join | join | join |
| Weather | - | - | join | join | join | join |
| Sample number | 697 | 697 | 697 | 643 | 705 | 712 |

However, OLS regression results are not necessarily reliable, because we don't distinguish the influence of other policies or measures, for example, the "license plate lottery" policy and upgraded the "peak hour driving restriction" policy are temporal overlap with Hangzhou's pollution industrial adjustment and popularization of the natural gas. But the implementation of long-term policies has no specific time point, so we couldn't observe it directly. In order to solve endogenous problems of ignored variables, it's necessary to run a regression discontinuity.

## 5.2 Regression Discontinuity

This section analyzed the effect of the three policies with regression discontinuity (RD). It chose 1 bandwidth to get estimated values for corresponding coefficients, using three policy dummy variables respectively (license restriction, limitation time extension, subway opening). At the same time, weather variable was controlled and adjusted seasonally. Statutory holiday and exchanging holiday were also considered as dummy variables. The results are listed in Table 5.4, Table 5.5 and Table 5.6.

As for the effect of license restriction policy, the regression result significantly improved after using RD. As reported in Table 5.4, it was found to be negatively related to PM2.5 and level of significance was higher than 5percentage points given that all control variables were added, which is true for both Chaohui and Zhengjiang A&F University. It means that the implementation of the license

restriction made PM2.5 declined by 4percentage points which accounted for 6percentage points of the total sample average. For PM10, there is no difference between results of RD and OLS. Regression results of the two observation points are significantly positive, because PM10 raised by other factors. Regression results of Zhejiang A&F University data showed that the coefficient of NO2 was significantly negative, indicating that the implementation of license restriction made NO2 decreased by 8percentage points which accounted for 7percentage points of the total sample average. Whereas the coefficient of NO2 in Chaohui was positive, because NO2 was caused by increase of other factors. As previously analyzed, the two policies were too close to exclude the influence brought by limitation time extension. After considering all the variables, the coefficient of SO2 came out from RD regression remained significantly negative, it should be other factors that lead to decrease in SO2.

Table 5.4 the effect of license restriction on air quality: RD

| | PM2.5 | | | PM10 | $NO_2$ | $SO_2$ |
|---|---|---|---|---|---|---|
| | （1） | （2） | （3） | （4） | （5） | （6） |
| Chaohui five areas | -12.67*** | -3.88* | -4.58** | 10.99*** | 2.15* | -4.15*** |
| | （2.94） | （2.26） | （2.15） | （3.31） | （1.23） | （0.89） |
| Specific days adjustment | no | yes | yes | yes | yes | yes |
| Seasonal adjustment | no | yes | yes | yes | yes | yes |
| weather | no | no | yes | yes | yes | yes |
| observations | 719 | 719 | 719 | 625 | 717 | 705 |
| Zhejiang A&F University | -12.39*** | -3.88* | -4.58** | 11.56*** | -8.34*** | -6.79*** |
| | （2.56） | （2.26） | （2.15） | （3.57） | （1.45） | （0.95） |
| Specific days adjustment | no | yes | yes | yes | yes | yes |
| Seasonal adjustment | no | yes | yes | yes | yes | yes |
| weather | no | no | yes | yes | yes | yes |
| observations | 720 | 720 | 720 | 636 | 698 | 690 |

As for the effect of limitation time extension policy, the regression result significantly improved after using RD. As reported in Table 5.5, the coefficients of PM2.5 and NO2 were significantly negative and levels of significance were higher than 5percentage points after considering weather variables and adjusting season and specific days. It means limitation time extension could decrease 4-5 percentage points of PM2.5 in downtown (accounted for 5-7percentage points of the total sample average) and decrease 7 percentage points of NO2 in Zhejiang

A&F University (accounted for 5-7percentage points of the total sample average). Similarly, the above-mentioned findings could not rule out from the effect of license restriction policy.

Table 5.5 the effect of limitation time extension on air quality: RD

| | | PM2.5 | | PM10 | $NO_2$ | $SO_2$ |
|---|---|---|---|---|---|---|
| | （1） | （2） | （3） | （4） | （5） | （6） |
| Chaohui five areas | -12.66*** | -3.92 | -5.71** | 10.17** | 2.25* | -3.95*** |
| | （2.95） | （2.71） | （2.76） | （3.39） | （1.25） | （0.92） |
| Specific days adjustment | no | yes | yes | yes | yes | yes |
| Seasonal adjustment | no | yes | yes | yes | yes | yes |
| weather | no | no | yes | yes | yes | yes |
| observations | 719 | 719 | 719 | 625 | 717 | 705 |
| | （1） | （2） | （3） | （4） | （5） | （6） |
| Zhejiang A&F University | -12.46*** | -4.02* | -4.76** | 11.22** | -7.32*** | -6.65*** |
| | （2.57） | （2.3） | （2.19） | （3.68） | （1.36） | （0.97） |
| Specific days adjustment | no | yes | yes | yes | yes | yes |
| Seasonal adjustment | no | yes | yes | yes | yes | yes |
| weather | no | no | yes | yes | yes | yes |
| observations | 720 | 720 | 720 | 636 | 698 | 690 |

As for the effect of subway opening on air quality, the coefficients of PM2.5 and PM10 were significantly negative and level of significance was lower than 5% when all control variables were considered, which means the operation of subway line 2, which made PM2.5 and PM10 along the line 2 declined by 19 percentage points (account for 27 and 16 percentage points respectively). The result of RD was correspond with that of OLS, illustrating that there was no other policy at the same time in Chengxiang town area, further supporting the causal relationship between the operation of subway and the improvement of air quality.

Table 5.6 the effect of subway line 2 on air quality: RD

| | PM2.5 | | | PM10 | $NO_2$ | $SO_2$ |
|---|---|---|---|---|---|---|
| | （1） | （2） | （3） | （4） | （5） | （6） |
| Chengxiang town | 11.71*** | -19.54*** | -19.72*** | -19.33** | 6.41** | -2.71 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | （4.38） | （6.12） | （5.9） | （7.85） | （2.99） | （2.78） |
| Specific days adjustment | no | yes | yes | yes | yes | yes |
| Seasonal adjustment | no | yes | yes | yes | yes | yes |
| weather | no | No | yes | yes | yes | yes |
| observations | 697 | 697 | 697 | 643 | 705 | 712 |

Overall, the results of RD indicates that PM2.5 concentration indeed decreased in downtown and NO2 concentration declined in some areas in downtown. Above evidences demonstrated that the implementation of two policies eased the traffic pressure to some extent, thereby improving air quality. The opening of subway line 2 made PM2.5 and PM10 along the line significantly decreased by as much as 27%. It was correspond with our prediction that subway opening effectively changed people's transportation, thus easing the traffic pressure and improving the air quality.

### 5.3 Robust Test

When the results of RD are robust test, we need to test if other control variables jump at the critical value and choose different estimated values. What's more, consideration must be given to both situations with control variables or not. Also, we have to consider results got from different observation window widths.

The previous part is based on results under default one bandwidth. Actually, this paper also tested that of half bandwidth and two bandwidths. The results showed that changing bandwidth may effected estimated value, but properties of positive and negative and significance weren't affected. So in this experiment, the estimated values is not dependent much on the bandwidth.

In this paper, control variables include weather, specific days and seasonal factors, etc. In the experiment, we tried different cases with control variables (all, some, none), but they are not presented because of limited space. In general, results with control variables are more reasonable.

Taking PM2.5 as an example, estimated values were negative for both situations in tests to check the effect of license restrictions and limitation time extension. What's more, level of significance became much higher. When it comes to subway opening, estimated values were positive without control variables, which is not consistent with common sense. Estimated values became negative after taking control variables into consideration, which means the model was more reasonable with control variables. Theoretically, adding control variables is to rule out the influence of other factors, thus producing more accurate results.

To test whether other control variables jump at the critical value, we output the covariates conditional function at the breakpoint in Stata. It indicated that in addition to specific days dummy jumped at license restriction policy

implementation (May Day) and subway line 2 opening (Monday) and specific weather dummy jumped at the breakpoint of license restriction and limitation time extension, conditional density function of the other covariates were continuous at the breakpoint.

Judging from the time window of data this paper used, the period before the two policies was longer than after and the period before subway line 2 opening was obviously longer than after, leading to big differences between policies before and after. In order to eliminate differences brought by sample asymmetry and run RD again, we limited samples after September 2013 to test the effect of license restriction and limitation time extension and limited samples after October 18, 2014 to test the effect of subway opening on air quality. As Table 5.7 and Table 5.8 demonstrated, after adjusting the observation window width, the regression results still support the conclusions get before the adjustment, at least not violated.

Specifically, with regard to the effect of license restriction and limitation time extension on air quality, taking all control variables into consideration, the coefficient of PM2.5 remained significantly negative and the absolute value was bigger than that before adjustment. The two policies caused PM2.5 concentration to decrease by as much as 14 percentage points. For data from Zhengjiang A&F University, the coefficient of NO2 remained significantly negative and level of significance was higher than that before adjustment. Narrowing the time window further amplified the effect of these two policies. Although the regression results of PM10 and SO2 were not significant, it didn't disturb the conclusions established before adjustment.

Table 5.7 the effect of license restriction and limitation time extension on air quality: samples after September 2013

| | PM2.5 | | | PM10 | $NO_2$ | $SO_2$ |
|---|---|---|---|---|---|---|
| | （1） | （2） | （3） | （4） | （5） | （6） |
| Chaohui five areas license restriction | -24.1*** | -12.27*** | -14.36*** | 7.04 | 0.12 | 0.14 |
| | （4.31） | （4.01） | （4.1） | （4.57） | （1.76） | （0.98） |
| limitation time extension | -23.83*** | -12.34*** | -14.31*** | 7.59* | 0.28 | 0.41 |
| | （4.26） | （4.06） | （4.15） | （4.43） | （1.64） | （1.14） |
| Specific days adjustment | no | yes | yes | yes | Yes | yes |
| Seasonal adjustment | no | yes | yes | yes | Yes | yes |
| weather | no | no | yes | yes | Yes | yes |
| Observations | 719 | 719 | 719 | 625 | 717 | 705 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Zhejiang A&F University license restriction | -17.03*** | -5.67** | -6.98** | 6.05 | -7.91*** | -7.97*** |
| | （3.51） | （3.31） | （3.22） | （4.79） | （1.89） | （1.9） |
| limitation time extension | -16.97*** | -6.02* | -7.16** | 0.05 | -7.99*** | -8.06*** |
| | （3.48） | （3.34） | （3.25） | （5.49） | （1.64） | （1.91） |
| Specific days adjustment | no | yes | yes | yes | Yes | yes |
| Seasonal adjustment | no | yes | yes | yes | Yes | yes |
| weather | no | no | yes | yes | Yes | yes |
| observations | 720 | 720 | 720 | 636 | 698 | 690 |

As for the effect of subway opening on air quality, coefficients of PM2.5 and PM10 after adjustment remained significantly negative just as before adjustment when considering all control variables. It can still explain subway opening produced negative effect on PM2.5 and PM10. Regression results of NO2 and SO2 were not significant, which didn't disturb the conclusions.

Table 5.8 the effect of subway line 2 opening on air quality: samples after October 18, 2014

| | PM2.5 | | | PM10 | $NO_2$ | $SO_2$ |
|---|---|---|---|---|---|---|
| | （1） | （2） | （3） | （4） | （5） | （6） |
| Chengxiang town | 5.11 | -11.66* | -6.36* | -28.69* | -7.06 | -6.65 |
| | （6.51） | （9.73） | （11.42） | （15.95） | （4.9） | （5.42） |
| Specific days adjustment | no | Yes | yes | yes | Yes | yes |
| Seasonal adjustment | no | Yes | yes | yes | Yes | yes |
| weather | no | No | yes | yes | Yes | yes |
| observations | 697 | 697 | 697 | 643 | 705 | 712 |

Through tests, the results of RD still showed that license restriction, limitation time extension and subway opening negatively affected pollution index.

## 6 Conclusion

From the regression results, we find that the "lottery license plate", "rush hour traffic quota", and "subway system expansion" all policies improved air quality in Hangzhou. "lottery license plate", "rush hour traffic quota", both policies have

showed a significant negative impact on PM2.5 concentrations; the opening of Metro Line 2 decreased the PM2.5 and PM10 index.

The effectiveness of the "rush hour traffic quota" policy will be determined by accompanying policy. Davis (2008) 's paper on Mexico City and Cao Jing (2014) empirical research on the Beijing have shown that "rush hour traffic quota" policy could greatly encourage the wealthy families to buy a second car. In Mexico City people will purchase second hand cars from United States which will have higher pollution emissions. Besides the introduction of "rush hour traffic quota" policy, Hangzhou also implemented the "lottery license plate" policy, which strictly limit the issuance of motor vehicle license plate.

**Reference**

Omitted