Did Beijing's Vehicle Use Restriction Policy Reduce Smog in 2014? A Time Series Analysis Using Chinese Government and US Embassy Data

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Capstone Project

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Executive Summary

Objective:

The analysis in this paper is designed to find out whether the vehicle use restriction policy issued by Beijing Municipal Government contributed to a change of air quality in 2014. I analyze both Chinese data and data collected by the U.S. Embassy in Beijing in order to determine whether the type of data used makes a difference to the findings.

Method:

I conduct a regression analysis with time series data. The analysis unit is the day. The main independent variable is the holiday schedule during 2014 that determined whether the restriction policy was in place or not. There are two dependent variables. One is the air quality (PM 10) at 8:00 am each day in 2014. These data stem from the Chinese authorities. The other dependent variable is the air quality based on the PM 2.5 standard at 8:00 am each day. These data stem from the U.S. Embassy in Beijing. The reason I chose the data at 8:00 am is that traffic reaches its peak around 8:00 am in Beijing's urban areas.

Key finding:

There is no evidence that the vehicle use restriction policy affected air quality in Beijing urban areas during the morning rush hour in 2014. Coal burning in winter, precipitation also cannot affect air quality statistically. The only factor that can improve air quality is wind speed.

In addition, data from US Embassy indicate that air quality in Beijing urban areas was worse than the data report from Chinese government.

Key words:

Air Quality in Beijing, PM 2.5, PM 10, Vehicle Use Restriction, Local Weather

Background

Beijing, the capital and the biggest city of the People's Republic of China, has been suffering from among the most severe air pollution in the world in recent years. "Fog" and haze, as the city's severe smog is often called, caused serious cardiovascular and respiratory diseases among residents and paralyzed urban highway traffic. Sometimes, flights from Beijing are canceled due to "fog". Generally, the primary causes of Beijing's smog are the burning of coal, vehicle and industrial emissions, and dust. Vehicle ownership in Beijing has rapidly increased over the past two decades. Since the city is surrounded on three sides by mountains that block the air flow and since there is extensive industrial development around Beijing, vehicle emissions are but one factor causing the city's heavy smog. But one point can be affirmed: The large increase in vehicle ownership has led to more emissions, which are exacerbated by the heavy congestion of Beijing's roads, which increases the time that engines are running.

In 2008, in order to ease the traffic pressure and air pollution during the 29th Olympic Games, Beijing municipal authority issued a temporary regulation on vehicle use on the basis of license plate numbers: On some days, only vehicles with an odd license plate numbers were allowed to operate, whereas on the other days only vehicles with an even number could be operated. A similar system has been in use in Mexico City for a long time, which was considered the metropolis with the worst air before the title went to Beijing. Now Mexico City's air is much better. Air pollution from vehicle emissions also decreased in Beijing with the vehicle usage restrictions during the Olympics. Following this success, Beijing municipal authority turned the

temporary regulation into a permanent policy to restrict vehicle use. The permanent rule is "one day without a car per week".

From the year of 1986 until 2008, the number of vehicles in Beijing had increased from 0.6 million to 3.4 million before the Olympic Games on average with 21% growth per year. At the end of 2014, the number had soared to 5.37 million. In other words, more than 1 million more vehicles are traveling per day in Beijing right now. Actually, to address the rapid increase of vehicle ownership, originally in 2011, Beijing municipal authority released restrictions on the selection of qualified purchasers by drawing lots. No matter which policy the authority enacted, restriction of ownership or reducing the vehicle use, the important purpose of those is to reduce the air pollution from exhaust emissions, especially in urban area.

In the two years following 2011, in spite of the restrictions on car ownership and usage, Beijing's smog has not improved significantly. To avoid a false negative, I want to formally test whether there is a relationship between the vehicle use policy and the severity of the "fog and haze" weather, controlling for other factors. They include wind speed and precipitation, which could be alternative explanations for the persistence of smog. Transportation demand keeps rising based on the population growth and urban growth. The consequences of growth, traffic volume and trip distance have already played a key role in urban traffic congestion, air pollution, and gasoline consumption. The appropriateness of my data and model specification will determine the accuracy of my research outcomes.

Literature Review

There are two major types of research trying to test the effectiveness of the vehicle use restriction policy in improving air quality in Beijing. One consists of bivariate studies that focus on describing the relationship between policy implementation and air quality or frequency of fog and haze.

Among studies of this type, Chunyan Li (2008) found out that that "odd and even" vehicle use definitely cut down the average time of residents' commute daily. But, by monitoring the vehicle flow rate and speed in the most congested roads in the urban area, Dan Wu (2008) found out that the restriction policy did not achieve the anticipated effect. Using data from 2008, Gang Tian (2009) also mentioned that road dust emission decreased about 60%-70% and construction dust decreased about 30%-47% under vehicle use restriction.[1] This dramatic decrease was mainly based on restriction on construction activities in urban areas during Olympics. Beijing Transportation Research Center (BTRC) issued an annual report in 2009 that indicating the restriction policy achieved good results: 1) the index of traffic jam in urban area declined from "Moderate" before implementation to "Mild" after implementation, and 2) Vehicle exhaust emission reduced nearly 10 percent. But many academic researchers held divergent opinions. In reality, traffic jams became more and more serious than before. The most important reason was that residents preferred to purchase two or even three cars to commute to cope with the restriction policy. In fact, the number of vehicles was growing rapidly. So, Xuxuan Xie (2010)

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[1] Tian Gang, Li Gand, Qin Jianping, Nie Lei, "Vehicle Restriction Impact on Road and Construction Dust". Environmental Sciences, 2009, Vol 5, p1528-2532

indicated that results of annual report from BTRC failed to confirm that the improvement

resulted from the Vehicle Use Restriction. Xie insisted that construction of roads and subways,

industrial emissions, and commercial housing construction, and other activities, had negative

impacts on air quality. The annual report failed to take these factors into account.

The other major type of study uses multivariate statistical analysis to find out causal impact of

certain factors. Viard and Fu (2010) employed a fixed effect panel data model and found out the

current restriction policy significantly improved air quality. Specifically, the "odd and even"

policy cut down the index of air pollution nearly 19%, "license number grouping" policy cut

down the index about 8%. At the same time, this policy reduced the work time, leading to

economic loss. In 2011, Chen et al. discussed policies that were issued by Beijing municipal

authority to influence the air quality. They found that the air pollution index (API) [2]decreased

before the Beijing Olympics. Just a week after the Olympics, API rose again rapidly. Even

though they controlled for some national factors that would influence air quality trend, it was

hard to prove how much impact the Car Use Restriction had on air quality, because other policies

play an important role in improving air quality, such as policies affecting building construction

in urban areas and industrial emissions in suburban areas. Additionally, Beijing municipal

authority issued another policy to control the rapid growth of car ownership: 1) The Department

of Motor and Vehicle Management only issues about 10,000 private license plates per month; 2)

licenses are distributed by lottery. The limitations on traveling and car ownership aim to reduce

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[2] Air Pollution Index (API) is a generalized way to describe the air quality. It was formerly used in mainland China and Hong Kong. In mainland China the API was replaced by an updated Air Quality Index (AQI) in early 2012. The API level was based on the level of 5 atmospheric pollutants, namely sulfur dioxide (SO2), nitrogen dioxide (NO2), suspended particulates (PM10), carbon monoxide (CO), and ozone (O3).

traffic congestion and to improve air quality in urban area, but, in reality, from 2013 until now, Beijing's air quality has experienced the worst period of smog weather since 1949.

Beijing is not the first metropolis to implement a vehicle use restriction policy. Mexico City Government implemented the "one day without a car per week" policy in order to improve urban air quality in 1989. But Eskeland and Feyzioglu (1997) found out that gas consumption and prices during policy implementation were higher than before implementation. The restriction policy certainly was not the only reason for the increase in gas price but then this policy led residents to purchase a second vehicle to cope with restriction policy. So they attributed this phenomenon to increased private vehicle ownership to guarantee residents they could drive on the road legally every workday. In 2008, by using a regression discontinuity design, Davis (2008) analyzed air pollution data (including CO, CO2, ozone, ox-Nitride, and sulfur dioxide) for Mexico City rush hours from 1986 to 2005. A dummy variable indicates whether the policy was implemented or not. The independent variable shows the relationship between air quality and pollution materials emission. Davis found that the Vehicle Use Restriction led people to own more than one vehicle to cope with the policy. At the same time, public transportation in Mexico City was not greatly improved, although it is worth noting that during this period, the government did open a high-capacity metro line and one light rail line, both in heavily populated parts of the city. There were no restrictions on vehicle ownership of the kind now in place in Beijing. Overall, the policy did not achieve the anticipated affect.

In 2014, Jing Cao, Xin Wang, and Xiaohan Zhong studied whether the restriction policy improved Beijing's air quality. They used the same research method Davis used to evaluate the Mexico City policy. They also delve into policy implications. This study included many factors to find out how this policy works. The data spanned from January, 1st, 2001 to December, 31st, 2011 and included the Air pollution Index, NO2, PM10, and SO2, weather index, production growth of three major pollution industries, and vacation schedule data. Besides, this study also adopted cost-benefit analysis to find out how restriction policy affected resident consumption behavior. They found out that Vehicle Use Restriction failed to have a significant impact to improve air quality in the area of Beijing. Increasing vehicle sales and unrestricted industrial emissions around Beijing urban area offset any positive influence of the restriction policy.

Having reviewed several pertinent studies, I conclude that previous regression analysis and statistical analysis tend to agree that the Vehicle use restriction has, at best, a very small positive effect on air quality in Beijing. While Beijing municipal authority tried to address the worsening air quality condition, it has never achieved the goals that governors and residents expected.

Research Design and Results

(1) Model

I developed a multiple regression model to study whether vehicle use restriction affects the air quality in Beijing during a whole year. Multiple regression can explain whether vehicle use restriction policy have an impact on smog under some control variables. The dependent variable

is the air quality index that indicates how clean or polluted air is, and what associated health effects might be a concern. In addition, I introduce weather conditions, especially maximum steady wind speed, precipitation and vacation, special events schedule data to control the absence of vehicle use restriction policy. I use two different measures for air quality (the dependent variable): The first stems from the Ministry of Environmental Protection of the People's Republic of China (MEP) and is based on the PM10 standard. The second stems from the Embassy of the United States in Beijing and is based on the PM 2.5 standard.[3]

(2) Data

The daily time series data set I built for the regression analysis covers all of 2014. The time period is limited by the availability of air quality data from MEP. The weather condition data come from I-Weather that provides Beijing weather monitoring data monthly[4], and national statutory holiday based on the holidays notification issued by General Office of the State Council. And AQI (PM2.5) is collected from Stateair website.[5] Beijing is also adopting the central-heating system in most of urban area by burning coal. So coal burning is very important polluting source in winter.

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[3] PM 2.5 refers to tiny particles or droplets in the air that are two and one half microns or less in width, which reduce visibility and cause the air to appear hazy when rose. Outdoor sources of PM 2.5 mainly come from car, truck, bus and off-road vehicle exhausts, burning fuels, heating oil and coals. Besides, fin particles are brought by wind from out-of-urban sources. PM 2.5 standard to measure air quality was established by the United States Environment Protection Agency (EPA) in 1997. Most of developed countries and regions adopted PM 2.5 to monitor air quality. PM 10 standard was employed in 1987 by EPA to replace previous standard. Just as its name implies, particles measured by PM 10 standard is larger than that by PM 2.5, which cannot reflect the fact accurately that how air quality affected by emission from fuel burning, especially gaseous pollutants (such as SO2 and NOx)
[4] Weather data resource: http://i-weather.com/weather/beijing/history/monthly-history/

5 Beijing PM2.5: http://www.stateair.net/web/post/1/1.html

There are two reasons to choose a multivariate data set. Because there are many studies showing vehicle use restriction policy is not useful to address the air quality issue due to the comprehensive factors that cause this problem. Data from a relatively short period would be eliminating the omitted variables bias when omitted variables are constant in their influence. In this way, regression has considered the variation within a steady state. For example, the construction and industrial pollution are all staying active or inactive.

My analysis unit is daily readings of air pollution in 2014 and my calculation includes the variation between weather condition and variation of policy absence or not. I measure the vehicle restriction policy by a dummy variable covering the days for which it is not in effect, which are the "Holiday and weekend" days. It is in effect on all other days. In other words, my policy dummy variable covers the times when the policy is not in effect.

Table 1 Names and descriptions of variable in the model

Variable names	Description
Dependent variable	
AQI-PM 10 (MEP, China)	Index range from 0-500
AQI-PM 2.5 (Embassy, USA)	Index range from 0-500, beyond index (>500)
Independent varible	
Weather Index (Maximun steay wind)	rate from 0-117 Km/h, Cyclone >117 Km/h
Holiday and weekend	dummy variable (1= no restriction, 0=restriction)
Coal Burning for winter warming	coal Burning:Jan,1st-Mar,15th and Nov,15th-Dec,31st
Precipitation	total daily amount from (≥ 0 mm)

(3) Results

The data set includes 365 observations (from 01/01/2014 to 12/31/2014), 342 of them are valid sample to be calculated statistically, and other 13 days data are missing. I used robust standard errors. The results of the statistical analysis can be seen in Table 2

**Table 2 Stata Time Series Data results (PM 2.5 and PM 10)**

| PM 10	Coef.	t	P> |t|
Wind Speed	-0.983	-3.05	**0.002**
Policy	-2.794	-0.41	0.684
CoalBurning	12.788	1.01	0.315
Precipitation	0.487	0.9	0.371
PM 2.5	Coef.	t	P> |t|
Wind Speed	-0.205	-0.54	0.592
Policy	-4.912	-0.6	0.547
CoalBurning	12.331	1.02	0.308
Precipitation	0.725	1.11	0.266

*p＜0.05, **p ＜0.01, ***p＜0.001

(1) I measured the vehicle restriction policy with a dummy indicating the days when it is not in effect, that is, holiday and weekends. Looking first at the regression estimating PM10 pollution, the vehicle restriction policy has no statistically significant effects on daily air quality in Beijing (P=0.684). Therefore, there is no evidence that the vehicle restriction policy is related to the air quality index. Coal burning for heating in winter also has no statistically significant effect, either (p=0.315). Besides, daily precipitation in Beijing is not statistically significant either (p=0.371). Wind speed, however, has a positive effect on air quality. (p=0.002). When the wind speed increases, PM 10 values decrease.

(2) In the regression estimating PM2.5 pollution, none of the explanatory variables have a statistically significant effect.

Further analysis

I do not have direct measures of construction pollution and industrial emission around urban areas. They partly are absorbed in the error term and partly by the explanatory variables I do have. The one variable affecting pollution in my model is wind speed, and it also works on construction pollution and industrial emissions. I check the possibility whether windless weather condition can result in more severe air quality (PM 10) in Beijing. Usually, in spring and winter, it always windy in Beijing. Based on my hypothesis, the air quality in spring and winter should better than that in summer and autumn. I find that air quality (both PM 10 and PM 2.5) in February, March, October, November, and December are generally worse than rest of months.

Table 3, Trends of PM 10 and PM 2.5 in 2014

PM25 concentration over a year
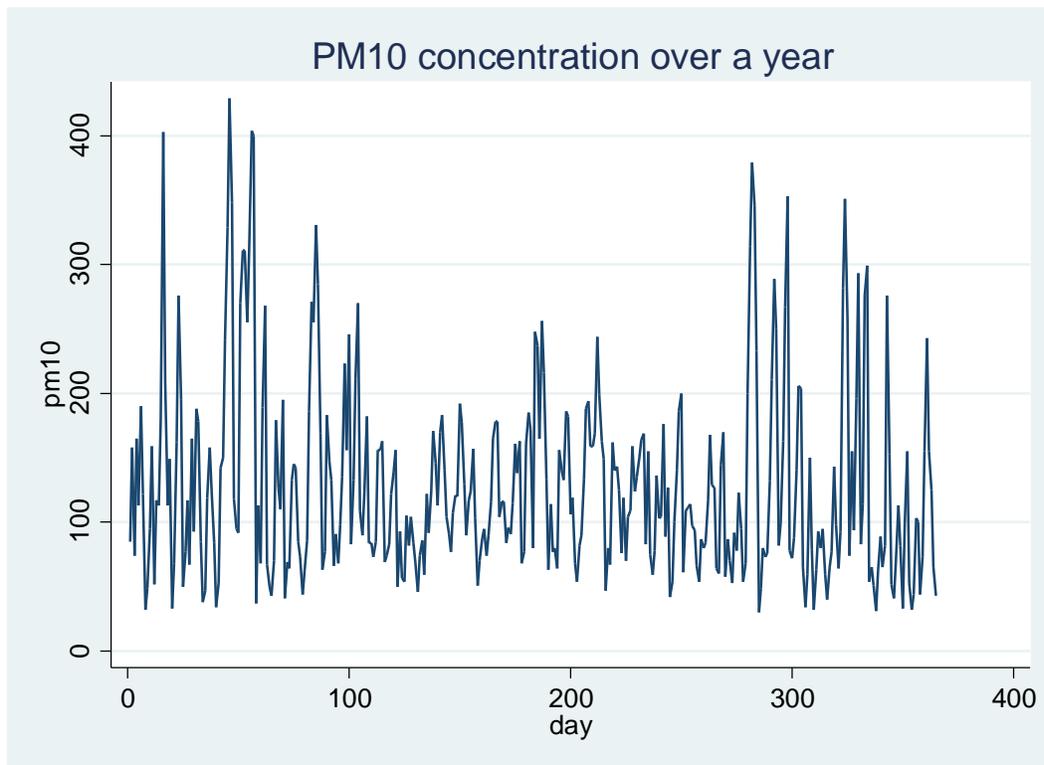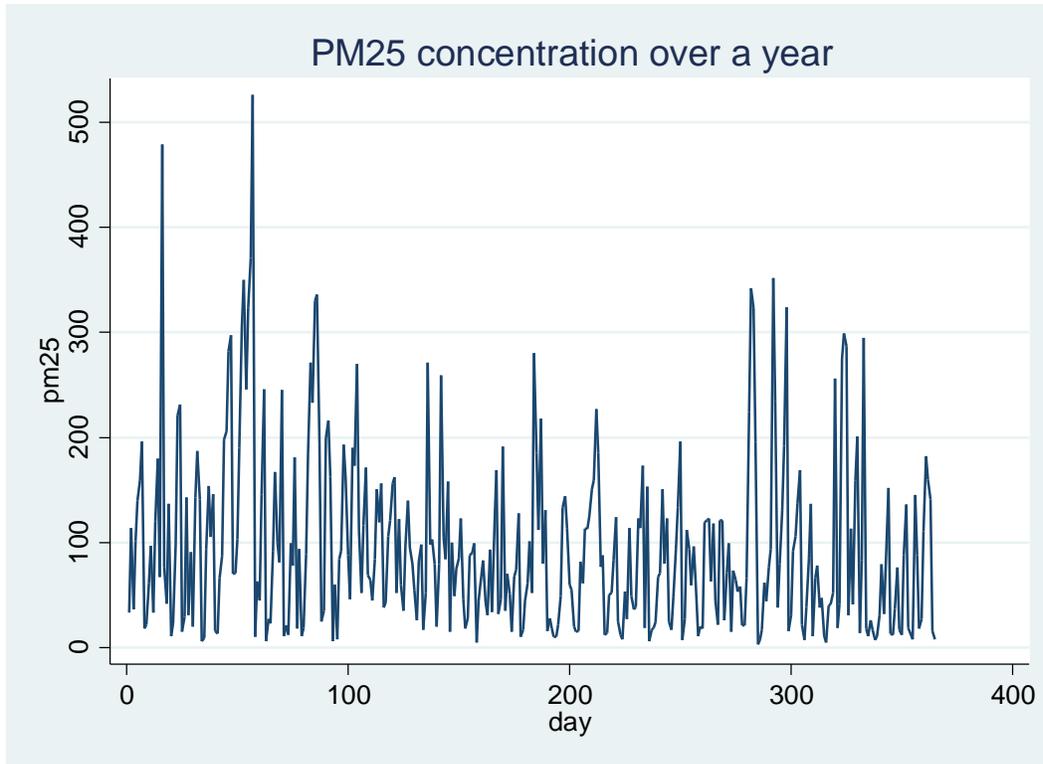
One possible reason is that while Beijing's weather is always dry, there is even less precipitation during spring and winter and during these months, the wind is always from northern region and bring with it sand and dust from Inner Mongolia desert. Sand storm are very common during Beijing's spring weather that cause the air quality get worse. And another reason is the setting off of fireworks during Spring Festival and Lantern Festival. Fireworks produce a massive amount of PM 2.5, sulfur dioxide and carbon dioxide that would lead to smog weather, especially, in windless weather.

Discussion

(1) Based on my analysis, there is no evidence that Beijing' vehicle use restriction policy improves smog weather in the urban area during the morning. Surprisingly, the wind can

improve air quality effectively based on the PM 10 monitoring system that is employed by

the Chinese government. At the same time, PM 2.5 data from US Embassy indicate a

different result: wind speed cannot improve smog weather effectively.

(2) One possible reason for the lack of a policy effect is that the number of vehicle is still

increasing at a rate of more than 10,000 per month. It is reasonable under this circumstance

the restriction cannot affect the air quality positively and also cannot address the traffic jam

during rush hour in urban area. Additionally, because vehicles are not restricted by the policy

on weekends, the number of vehicles on the road is increasing compared with the number of

vehicles during weekdays, regardless of how many vehicles are owned by residents in total.

I also found out a special case that indicated how effective the government executive order is

to improve the air quality during Asia-Pacific Economic Cooperation (APEC) in 2014.

During the summit, from November 5th to November 13th, the air quality was the best of the

whole year. During APEC, to guarantee "blue skies", government issued a holiday order for

a whole week, so residents did not commute, and then some of them chose traveling for

relaxing. Construction projects in the urban area and industrial activities around the urban

areas were also ordered to suspend their business to improve air quality. Administrative

orders have positive effect to address the air pollution, but the cost of this policy is extremely

too high to be a long-term method for local government.

(3) The absence of no statistical relationship between the vehicle use policy and air quality is

that public service vehicles, government vehicles, buses, and taxis are not affected by the

vehicle policy. These vehicles make up a large proportion of total vehicles in Beijing.

Considering the fast increase in the number of new vehicle and slow rate of elimination of

old vehicles, total emissions from vehicles continue to rise. Further, vehicles from the suburban area and other cities are not limited during weekends and holiday, which could explain the absence of a statistical difference in air quality between weekdays and weekends.

(4) The coal burning during winter has no relationship with the air quality index. One possible reason is that central heating systems are generally located in the suburban area and also at downwind direction. And, active cold airflows during winter have helped particulate matter to disperse, which can reduce the impact from coal burning pollution. But air pollution is obviously serious during Chinese Spring Festival at the beginning of February. The main reason of this occurrence is that residents celebrate the festival by setting off fireworks that release a large number of unhealthy and polluting gases and dust, such as carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen oxides, which fill the air, and such air makes people suffocate. Besides, I also found out that air quality is generally worse during spring. The possible reason is that sand-dust storm is common during Beijing spring. Strong wind and dry weather in spring is a seedbed of sand-dust storm weather. So weather and special events are the most important reason to produce air pollution during spring and winter.

(5) China still uses PM 10 as the official standard to monitor and report the air quality condition. T

(6) The range to define air quality differs between the two standards (see table 4). Heavy air pollution under PM 2.5 is just moderate pollution under PM10. This might provide an

explanation for why the Chinese government still uses the out-of-date standard to measure air quality.

Table 4 Air Quality Guide for PM 10 and PM 2.5

AQI (PM 2.5)	Level of Air Quality 1	AQI (PM 10)	Level of Air Quality 2
0-50	Excellent	0-50	Excellent
51-100	Good	50-100	Good
101-150	Slight Pollution	100-200	Slight Pollution
151-200	Moderate Pollution	200-300	Moderate Pollution
201-300	Heavy Pollution	300-400	Heavy Pollution
301-500	Hazardous Pollution	400-500	Hazardous Pollution
>500 (Beyond Index)	Extremely High Levels of PM 2.5		
Source: www.stateair.net/web/post/1/1.html			

Figure 1 shows that more days are classified as having heavy pollution under the PM2.5 standard than under the PM10 standard. More precisely, based on the PM2.5 standard, there were 80 with heavy pollution in 2014. Under the official Chinese standard, there were only 47 days with heavy pollution in the same year.

Figure 1, Days of API level in 2014 (PM 2.5 and PM 10)
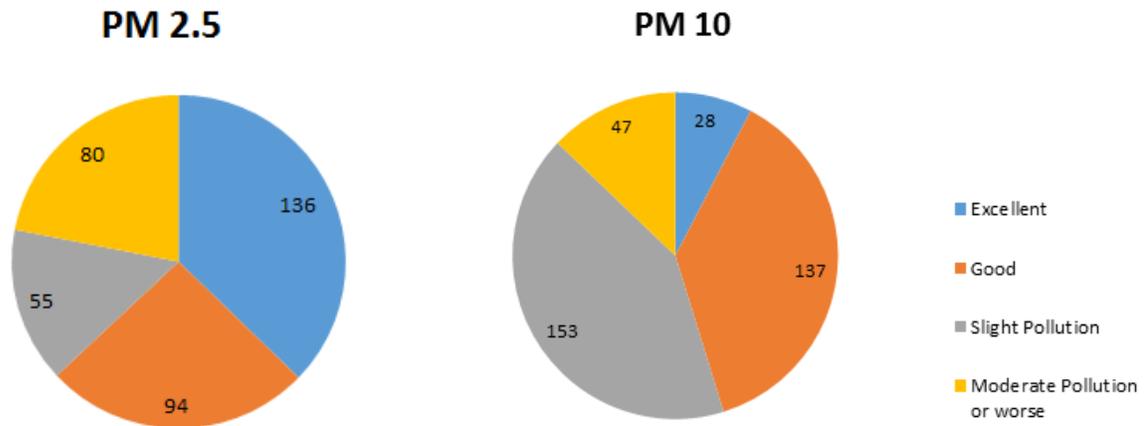
Limitation

(1) I lack data on other causes of pollution, such as road construction, industrial emissions, and

   sand-dust storms. The main reason is that I could not obtain these data on a daily basis.

(2) I only chose one whole year to measure effect of vehicle restriction policy on AQI. A more

   thorough analysis would have a substantial time span both before and after a change in

   vehicle restrictions.

(3) I used the Air Quality Index at 8:00 am each day. I found out that it is not the highest value

   on all days for a number of reasons, such as weather change (raining or snowing). So it

   would not fully reflect the reality of air quality on certain days.

Conclusion and Recommendations

(1) Conclusion

Overall, based on my research results, I found out that Beijing's vehicle use restriction policy was inefficient to reduce smog in 2014. Through the vehicle use restriction reduced the number of vehicle on the road on weekdays, there were still several factors to lead air pollution.

(2) Recommendations

First, central government should transform and upgrade industrial types in North China (from heavy industry to high-technology industry) in the long term, which would address the air pollution in a whole area, especially reduce the air pollution resources around Beijing

Second, in the short term, Beijing municipal authority should issue more restricted policy on pollution emission in urban area and suburban area of Beijing.

Third, local government and agencies should increase gas price and parting rate in urban area to control vehicle use.

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