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New Evidence on the Environmental Impacts of Driving Restrictions and Other Government Policies

Zheng Liu
University of Connecticut - Storrs, zheng.liu.uconn@gmail.com

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Zheng Liu, PhD

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Studies using time-series regression discontinuity (RD) designs find no effect of Mexico City's driving restriction but an increase in car ownership after the restriction, while studies using difference-in-differences (DD) methods have shown the effectiveness of similar restrictions in other cities. Development literature has shown a wage shock for white-collar workers in Mexico during the same period, which may encourage initial car purchases among white-collars and confound the results from time-series RD. To control the wage shock, this study applies a DD method with unrestricted days and days after the restriction as a two-way control. It finds that Mexico City's program led to a 3 to 5 percent significant reduction in Carbon Monoxide (CO) concentrations for all hours of the day and an 11 to 18 percent reduction during rush hours four years after the program. Echoing the possible effect of the white-collar wage shock, it also provides evidence of an increase in initial car purchases during the same period from household microdata. This new finding reconciles conflicting signs in the driving restrictions literature.

A one-weekday-per-week driving restriction used to curb severe air pollution was implemented in Beijing right after the Olympic Games in October 2008. Macroeconomics studies have shown that previous Olympics have led to a boom in the local economy. To prepare for the Olympics, the Beijing government also introduced other programs such as closure of high-polluting plants, enforcement of new emission standards and extension of subway routes. Given that the Olympic shock may have added more pollution while other programs may have reduced pollution, it is essential to separate these effects when evaluating the driving restriction's effects. Previous study failed to account for these other factors have reported that driving restrictions led to a 21% decrease

in Beijing's air pollution. Using weekends as a control, this study finds a 3-5 percent significant reduction in air pollution. The magnitude of the effect is similar as the magnitude found in Mexico City's driving restriction.

In May 2013, President Xi Jinping launched an ambitious anti-corruption drive (ACD) in China that prohibits various forms of corruption among party officials. Given most forms of corruption such as bureaucratic banquets/visits involve use of motor vehicles, the ACD could indirectly reduce the use of motor vehicles and hence pollutants mainly emitted from them. This paper identifies the effect of the ACD through the exogenous variations in air quality generated by the ACD in metropolitan Beijing and suburb Beijing before and after the program. It finds a 6 percent significant reduction in PM2.5 concentrations due to the ACD, the magnitude of which is similar to imposing a driving ban in Beijing.

New Evidence on the Environmental Impacts of Driving Restrictions and Other Government Policies

Zheng Liu

B.A., Qingdao University of Science and Technology, **[2009]**

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New Evidence on the Environmental Impacts of Driving Restrictions and Other Government Policies

Presented by

Zheng Liu, B.A., M.A.

Major Advisor ____

Kathleen Segerson

Associate Advisor ____

Stephen L. Ross

Associate Advisor ____

Michele Baggio

University of Connecticut

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New Evidence on the Effect of Mexico City's Driving Restriction on Air Quality: A Difference-in-Differences Approach

ZHENG LIU, KATHLEEN SEGERSON, STEPHEN L. ROSS

Abstract

Studies using time-series regression discontinuity (RD) designs find no effect of Mexico City's driving restriction but an increase in car ownership after the restriction, while studies using difference-in-differences (DD) methods have shown the effectiveness of similar restrictions in other cities. Development literature has shown a wage shock for white-collar workers in Mexico during the same period, which may encourage initial car purchases among white-collars and confound the results from time-series RD. To control the wage shock, this study applies a DD method with unrestricted days and days after the restriction as a two-way control. It finds that Mexico City's program led to a 3 to 5 percent significant reduction in Carbon Monoxide (CO) concentrations for all hours of the day and an 11 to 18 percent reduction during rush hours four years after the program. Echoing the possible effect of the white-collar wage shock, it also provides evidence of an increase in initial car purchases during the same period from household microdata. This new finding reconciles conflicting signs in the driving restrictions literature.

Keywords: driving restriction; air pollution; difference-in-differences

I. Introduction

Beijing had experienced APEC blue[1] at the end of 2014 when it reapplied its every-other-day driving restriction, which had been shown effective during its 2008 Summer Olympic Games. Driving restrictions have been popularized recently by many key international cities. Followed by Rome and Milan's implementation at the end of 2015, New Delhi introduced a driving restriction on New Year's Day of 2016.[2] Given their popularity, several studies have sought to evaluate the effectiveness of driving restrictions (see literature review below). However, the results have been mixed. There have been studies showing that Mexico City's driving restriction had no effect at all, while other studies have shown similar restrictions to be effective in Beijing and Quito. Through revisiting Mexico City's program, this paper aims to find explanations for why driving restrictions have been found to be effective in some cities but not effective in Mexico City.

A comparison of previous literature shows that only Mexico City's program was examined using a time-series regression discontinuity (RD) design, which yields different findings with all other studies that employed a difference-in-differences (DD) method. In contrast to a cross-sectional RD that is free from time variant confounding factors, a time-series RD relies on additional assumptions in order to be causal. A key assumption for a time-series RD to have the same causal inference power as a cross-sectional RD is that there are no time variant confounding factors during the study period. Therefore, this paper starts by reviewing background information of Mexico City around the time when the restriction was implemented to investigate whether previous studies satisfy the key assumption needed to apply a time-series RD.

[1] "In 2014, Internet users coined the wry term 'APEC blue' for the capital's clear skies during the two-week gathering of world leaders during the APEC summit." (*CNN* Dec 15, 2016)

[2] *New York Times* Jan 4, 2016.

After the 1982 debt crisis, Mexico extensively restructured its economy to be manufacturing export oriented. Average annual growth of GDP per capita was still negative from 1981 to 1993. Wages in manufacturing for blue-collar and white-collar workers had dropped to 62% and 75% of their 1980 level respectively in 1989. In contrast to steady growth in wages for blue-collar workers, wages for white-collar workers experienced a sharp increase and recovered to be 6% higher than their 1980 level by 1994. The rising disparity of labor income between blue-collar and white-collar workers contributed mostly to the income inequality in Mexico from 1989 to 1992.[3] Since 1989, Mexico City has also experienced sharp car growth and a one-weekday-per-week driving ban was implemented to curb severe traffic congestion and air pollution.

Given the wage shock of white-collar workers during the same period, the key assumption to apply a time-series RD is violated as the wage shock could encourage more white-collar workers to purchase their initial cars. Therefore, this study first implements a robustness check of a previous study to illustrate that its time-series RD results are sensitive with respect to various factors because the key assumption is violated. Then, it provides additional evidence from a household car ownership survey, which suggests that the explanation of the increase in additional car purchases provided by previous studies is <u>not</u> true. Last, it offers an econometric explanation of why a DD with a valid control would solve the time variant confounding factor issue faced by a time-series RD.

In order to control for the white-collar wage shock, this study applied a DD method to reevaluate Mexico City's Hoy No Circula (HNC)[4] program. By choosing unrestricted days as a control for

[3] See table 1 of Alarcon and McKinley (1997).

[4] Hoy No Circula is the Spanish name of Mexico City's driving restriction implemented on November 20, 1989. It bans most cars running from 5am to 10pm one weekday per week based on the last digits of vehicles license plates. See the detailed introduction of the HNC in page 39 of Davis (2008).

the economy change, this study finds a 3 to 5 percent significant reduction in carbon monoxide (CO) concentrations - a major pollutant emitted by motor vehicles – for all hours of the day and an 11 to 18 percent reduction during rush hours four years after the HNC. The results are robust with respect to various specifications and pass both placebo tests as well as a valid control group test. This new finding reconciles conflicting signs in the driving restrictions' literature.

II. Prior Literature

The recent literature examining the effect of driving restrictions on air quality has frequently employed quasi-experimental methods to take advantage of the temporal and/or spatial variations generated by these programs (Davis 2008; Chen et al. 2013; Gallego et al. 2013; Viard and Fu 2015; Carrillo et al. 2016). Within these studies, there is no consensus on either the sign or the magnitude of the effect, not only in different countries but also in the same country. The dominant finding is that driving restrictions significantly reduced air pollution (Chen et al. 2013; Viard and Fu 2015; Carrillo et al. 2016). However, several studies find the restriction had no effect at all (Davis 2008; Gallego et al. 2013). Besides their different results, these studies also differ in the time windows, data structures, identification strategies, and the control groups they use.

TABLE 1— QUASI-EXPERIMENTAL STUDIES OF DRIVING RESTRICTIONS AND AIR QUALITY

Studies	Period	Data	Method	Control Group	Results
Panel A. Beijing					
Chen et al. (2013)	2000-09	Panel	FE	Unrestricted cities	- 6~19%
Viard and Fu (2015)	2007-09	Panel	RD & DD	Before period & far-away stations	-21%
Panel B. Quito					
Carrillo et al. (2016)	2008-12	Panel	DD	Unrestricted hours & unrestricted zone	- 9~11%
Panel C. Mexico City					
Davis (2008)	1986-93	Time-series	RD	Before period	0
Gallego et al. (2013)	1987-91	Time-series	RD	Before period	0

Note: "0" denotes no effect and "~" denotes the effect range.

Table 1 summarizes recent quasi-experimental studies of the effect of different countries' one-day-per-week driving restrictions on air quality by their key features. The panels are organized by countries and studies within countries are presented in chronological order. If we first look at the results presented in the last column, Beijing and Quito's driving restrictions are found to have had a negative and significant effect while Mexico City's restriction is found to have had no effect. Though it is reasonable to believe the effect of driving restrictions may vary across countries, other characteristics in the table may also provide insight into the different results. Moving to the middle column of Table 1 (Method) and comparing the methods with the results, it seems that the results could be sensitive to the methods since all studies using difference-in-differences (DD) methods, including fixed-effects (FE), got negative results while papers applying RD methods found no effect.

Davis and Gallego et al. both applied RD methods to examine the effect of Mexico City's driving restriction on air quality by constructing time-series data from hourly concentrations of major pollutants aggregated by monitoring stations. Applying RD with 7^{th}, 8^{th} and 9^{th} order polynomials and controlling for weather variables on four nested time windows from 8 years to 2 years centered at the date of the restriction, Davis found no discontinuity at the cutoff, suggesting the program had no effect on improving air quality following its immediate implementation but was instead associated with increased pollution afterward. He found that the results are robust to both subgroups such as restricted hours, unrestricted hours during restricted days, and unrestricted days as well as mean and extreme concentrations of CO and specifications including gasoline prices, excluding weather covariates and so on. Further, Davis found the program was associated with increased gasoline sales, new car sales and vehicle registration but decreases in subway ridership and public bus ridership. Therefore, he concluded that the restriction had no effect by claiming that the restriction stimulates drivers to buy additional cars without providing direct evidence on second car purchases.

Gallego et al. modified Davis' model by adding 12 monthly dummies after the policy, considering background pollution levels and replacing Davis' high order polynomials with lower orders from linear to cubic on a morning rush hour subsample. Though Gallego et al. found the policy had significant negative effect in the first two months, the effect became positive in less than a year. By looking at the effect of the restriction on different income groups, Gallego et al. found a strong positive effect in the middle income groups, claiming they are the group most likely to purchase additional cars since high income households already own second cars while low income households owning no cars are not affected by the policy.

One concern with Davis and Gallego et al.'s work is that they cannot disentangle the effect of the driving restriction and other confounding factors such as economic growth since the RD method can only be used for a very narrow time window in order for observations after the policy to be as nearly randomly assigned as observations before. Longer time windows will invalidate the random assignment assumption since other events may occur and confound the driving restriction's effect. For example, the 1990s economic expansion favoring the middle classes can also explain Davis' finding of increased car ownership and Gallego et al.'s finding of the increased car purchases by middle class households. As mentioned by Alarcon and McKinley (1997), the salaries of white-collar workers in manufacturing "dropped by about a quarter from 1980 to 1989" but "recovered to be 6% higher than their 1980 level by 1994". The change in wages for this special groups is very likely to contribute to changes in car purchasing behavior.

Besides these RD studies, the other DD studies seem to be less concerned with addressing other time-varying confounding factors. Chen et al. (2013) examines the effect of Olympics-related environmental policies on air quality in Beijing. By applying a fixed effect model on a panel dataset of a cohort of Chinese cities, they find that Beijing's one-day-per-week driving restriction improved PM10 pollution by 19% immediately after the policy but the effect faded to 6% within a year.

Using both RD in a very short time window within two months and DD with stations near a major road and stations far away from major roads as treatment and control groups, Viard and Fu (2015) found Beijing's one-day-per-week driving restriction significantly reduced PM10 pollution by 21% at the cutoff from both methods. Their finding is further strengthened by evidence of reduced labor supply measured by increased TV viewership among flexible time workers after the policy. However, the limitation of their paper is the lack of a longer period analysis, which is essential to see if the effect can be generalized in the long run.

Carrillo et al. (2016) claimed that Quito's one-day-per-week peak hours driving restriction reduced CO concentrations, a pollutant mainly emitted by motor vehicles, by 9 to 11% two years after the program. The variations of CO in both space and time generated by the policy in both unrestricted stations and unrestricted hours allows them to apply DD and difference-in-differences-in-differences (DDD) methods to identify the effect of the driving restriction. Consistent with the literature on Beijing's restriction, which also applied DD, they found that Quito's driving restriction was effective, though the magnitude was smaller than the effect found by Viard and Fu (2015).

All the DD literature consistently shows that the one-day-per-week driving restrictions have had a significant effect in reducing air pollution, though the effect varies from 6 percent to 21 percent. The only exceptions are the RD studies examining Mexico City's driving restriction that find no effect on improving air quality at all. The following sections will revisit the impact of Mexico City's program and present different findings.

III. Issues in Previous Studies

Besides the sensitivity of results with respect to methods in the driving restrictions' literature, there are internal issues that exist in the previous RD studies. One issue is the reliability of an author-selected polynomial time trend. Given the time trend under the counterfactual world in the absence of the HNC was unknown, a self-selected polynomial time trend may have either a false continuity or a false discontinuity issue.[5] Below I present a robustness check of Table 3 of Davis (2008) with respect to time windows, which illustrates this point. Second, previous RD studies attribute their findings of ineffectiveness to the possibility that the HNC may induce drivers to purchase additional cars. However, I present below evidence showing a lack of an increase in two-car and multiple car households three years after the HNC based on Mexico City's household income and expenditure surveys. In the last part, I also provide an econometric explanation to illustrate why a DD with a valid control is better than a time-series RD.

A. A Robustness Check of Davis (2008)

Davis (2008) evaluates the effect of Mexico City's driving restriction on air pollution using an RD method from 1986 to 1993. The coefficients of the HNC's effect on CO levels are reported in column 1 of Table 3 of Davis (2008) by different orders of polynomial time trends. To confirm whether his results are robust with respect to time windows, I narrow the eight-year window to a six-year, four-year and two-year windows.

The left column of Table 2 replicates the results from column 1 of Table 3 in Davis (2008). It shows that the coefficients of the HNC with all orders of polynomial time trends are positive and not significantly different from zero during 1986-93. It suggests no improvement in air quality

[5] See Angrist and Pischke (2008) page 254 Figure 6.1.1 C. for the false discontinuity issue. There could be false continuity issues as well.

during 1986-93 when estimated using RD with 7th to 9th order polynomial time trends. The right three columns of Table 2 report a robustness check of the HNC coefficients with respect to narrowed time windows. The coefficient of the HNC with the ninth-order polynomial time trend becomes negative and significant when the time window is restricted to 1987-92. When the time window is narrowed into 1988-91 and 1989-90, all the coefficients become negative, suggesting an improvement in air quality. Notably, the coefficient becomes negative and significant again with an eighth-order polynomial time trend for the 1989-90 time window, suggesting a significant improvement in air quality. The result that most coefficients change signs when estimated using narrowed time windows and even significances of the opposite sign suggests that the results of Davis (2008) are not robust and reliable.

TABLE 2—SENSITIVITY TESTS OF EFFECT OF HNC ON CO LEVELS BY TIME WINDOW: REGRESSION DISCONTINUITY

	Davis (2008)	A Robustness Check		
	1986-93	1987-92	1988-91	1989-90
Seventh-order polynomial time trend	0.048 (0.100)	0.035 (0.076)	-0.081 (0.072)	-0.068 (0.049)
Eighth-order polynomial time trend	0.049 (0.098)	0.057 (0.082)	-0.043 (0.079)	-0.123*** (0.029)
Ninth-order polynomial time trend	0.007 (0.092)	-0.127** (0.061)	-0.074 (0.067)	-0.053 (0.053)

Notes: The years used here are calendar years, same as in Davis (2008).

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

B. Counter-Evidence from Household Surveys

The main explanation previous RD studies of Mexico's HNC program use to support their findings of its ineffectiveness is that drivers possibly purchased additional cars to circumvent the restriction.[6] In this case, we could expect to see an increase in the share of two-car households or multiple-car households in Mexico City. However, evidence from Mexico City's income and expenditure surveys rejects this claim.[7]

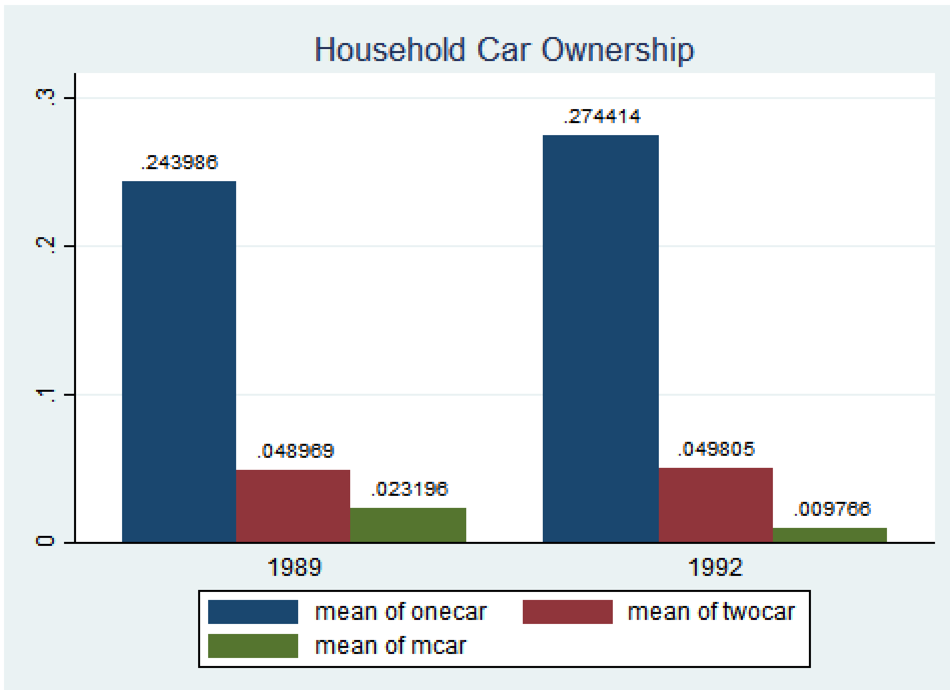

FIGURE 1. HOUSEHOLD CAR OWNERSHIP (1989, 1992). [USE COLOR IN PRINT]

Notes: The means are defined as the percentage of households belonging to a category with respect to all surveyed households.

Figure 1 plots the percentages of one-car households, two-car households and multiple-car households in Mexico City by year based on the survey. In 1989, surveyed right before the date of the HNC, the percentage of one-car households is 24.4 percent. In 1992, three years after the HNC,

[6] Davis (2008) also provide evidence of an increase in registered vehicles and sales of new automobiles, but he failed to provide evidence of cars per driver or per household.

[7] The National Income and Expenditure Survey (ENIGH) is formally raised by the National Institute of Statistics and Geography (INEGI) since 1984. It was previously surveyed in 1984, 1989, and 1992. It contains five boards, each of which is saved as a dbf file. The household car ownership data is obtained from the 1989 hogares.dbf file and 1992 hogares.dbf file, the content of which includes household characteristics, housing and the expansion factors. Only records of households located in Federal District (Mexico City narrowly defined) are kept. The sample contains 1164 households in 1989 and 1024 households in 1992. The data link is http://www.inegi.org.mx/est/contenidos/Proyectos/encuestas/hogares/regulares/enigh/.

this percentage is 27.4 percent, indicating a 3 percent age point increase in one-car households three years after the HNC. For two-car households, the percentage is 4.9 percent in 1989 and 4.98 percent in 1992, not a discernable increase. For multiple-car households, the percentage dropped from 2.3 percent to 0.98 percent, not even an increase.

Based on the results from the survey, it is true that there is an increase in the percent of total households with cars but that increase is mainly coming from the increase in the share of one-car households instead of two-car or multiple-car households. This increase in the share of one-car households cannot be attributed to the HNC since the driving ban decreased the marginal benefit of owning a car by restricting 1/7 of day time driving. Instead, the growth of the share of one-car households could possibly be driven by the white-collar wage shock from 1989 to 1994. Since white-collar workers experienced substantial wage shock compared to blue-collar workers, it is reasonable to believe that more white-collar households could be able to purchase their initial cars due to the shock.

C. Econometric Explanations

Previous studies (Davis and Gallego et al.) using RD have found that the discontinuity at the cutoff is sensitive to both the functional forms of time trends and the lengths of time windows. This sensitivity is driven by the unknown functional form of air quality time trend in the absence of the policy. As mentioned by Angrist and Pischke (2009, p.254), false discontinuity may be detected if the polynomial model is mistakenly chosen. Similarly, false continuity can also occur due to misspecifying the functional form of the time trend. This section explains why a DD method could solve the issue of the unobserved functional form of the time trend required by a RD.

Suppose the correct functional form of CO trend during the study period is specified by a smooth function $f(t)$, where t stands for time. The key assumption under DD is that the control group's

CO concentration shares a common trend with the treatment group's CO concentration, which implies $f(t)$ is common to both treatment and control. For each individual station i, the CO concentrations for both treatment and control at time t can be written as:

(1) $CO_{it} = \alpha_1 + \beta HNC_{it} + f(\mathrm{t}) + \varepsilon_{it}$, if t is in the treatment group

(2) $CO_{it} = \alpha_0 + f(\mathrm{t}) + \mu_{it}$, if t is in the control group

where HNC_{it} is a dummy variable for the driving restriction with value of 1 if t is in treatment group and 0 if t is in control group; α_0 and α_1 are constants for treatment and control respectively; ε_{it} and μ_{it} are random disturbance terms with mean zero. β measures the effect of the policy. When we take the first difference between treatment and control, we get:

(3) $\Delta CO_{it} = \alpha_1 - \alpha_0 + \beta HNC_{it} + \varepsilon_{it} - \mu_{it}$,

For periods before and after the driving restriction, the first difference becomes:

(4) $\Delta CO_{it} = \alpha_1 - \alpha_0 + \beta$, if t is after the restriction

(5) $\Delta CO_{it'} = \alpha_1 - \alpha_0$, if t' is before the restriction

where t' denotes periods before the restriction.

The treatment effect of the restriction is identified by taking time difference of group differences of treatment and control:

(6) $\Delta\Delta CO_{i,t-t'} = \beta$.

Therefore, the DD estimator correctly identifies the effect of the driving restriction on air quality without knowing the exact functional form of the air quality trend under the assumption that CO in the control group shares a common trend with CO in the treatment group. However, the RD method relies on correctly specifying the functional form of $f(\mathrm{t})$ in order to get the policy impact of the coefficient on HNC_{it} in equation (2), which is the basic regression equation Davis and Gallego et al. run with their self-picked polynomial in the $f(\mathrm{t})$.

IV. Data

Air quality data and weather data are obtained from Davis's homepage on the publication list of Davis (2008). However, while Davis uses six pollutants as the outcome variables, this paper only uses CO as the measure of air quality since it is the major pollutant emitted by motor vehicles (accounting for 99% of total CO concentrations). Weather variables including temperature, relative humidity and wind speed are used as control variables, as in Davis. The data period covers 1986 to 1993. To be consistent with Davis, this paper uses Davis' code to refine the data. That is, before running the main analysis, all non-positive readings are treated as missing; weather variables blatantly making no sense also are treated as missing; and the sample is restricted to stations reporting in 1986.

V. Methodology

Given the above two issues in previous RD studies and the sensitivity of results with respect to methods in the driving restrictions' literature, this section adapts a DD method to evaluate the effect of Mexico City's HNC on air pollution. It starts by identifying a suitable control group that was not contaminated by the policy. Then it introduces the DD method with various specifications, placebo tests and subgroup variation.

A. Choice of Control Group

Previous studies examining Mexico City's driving restrictions have applied the RD method because it is hard to find a control group for Mexico City. The extensive coverage of the restriction from 5am to 10 pm makes it impossible to choose other active unrestricted hours as a control. The widely covered area of the restriction not only for Mexico City but also for its surrounding states also makes it hard to choose a neighboring city as a control. The unusual geographic condition, unique transportation system and extremely large population also prevent using another city as a control. [8]

This study initially exploits both the temporal variation between restricted day and unrestricted days (i.e., weekdays versus weekends) as well as the temporal variation before and after Mexico City's restriction to identify the program impact. Though previous studies have suggested that there may be spillovers of driving from restricted days to unrestricted days, as shown below, I find no evidence of spillover, probably because weekdays and weekends are very different, making it hard to substitute driving.

Six regressions are run to show that there is no spillover of driving from weekdays to weekends. Using the same RD specification as Davis (2008) in three very short time windows (i.e., one week, two weeks and three weeks) before and after the HNC on two subgroups (i.e.: weekdays and weekends), it shows the policy's differentiated impacts on weekdays and weekends in the above three periods. The regression equation stated in Davis (2008) is:

$$(7) \qquad \log CO_t = \gamma_0 + \gamma_1 1(HNC_t) + \boldsymbol{\gamma_2 x_t} + \mu_t$$

[8] In footnote 11 of Davis (2008), he mentioned the reasons that it is unlikely to find any other city as a credible counterfactual.

where $logCO_t$ is the logarithm of average hourly CO concentrations aggregated by stations, which is categorized into weekday and weekend subgroups, $1(HNC_t)$ is a dummy variable with value 1 if time t is after the HNC's implementation, and $\boldsymbol{x}_t$ is a vector of control variables that are the same as the controls in Davis (2008). These include indicator variables for month of the year, day of the week, and hour of the day, interactions between weekends and hour of the day, as well as weather variables such as current and 1-hour lags of quartics in temperature, humidity, and wind speed. Then, 7th, 8th, and 9th orders of polynomial time trends are used, again the same as Davis.

TABLE 3— THE EFFECT OF THE HNC ON WEEKDAY AND WEEKEND CO LEVELS: REGRESSION DISCONTINUITY

	One week	Two weeks	Three weeks
Panel A. Weekday Subgroup			
7th order polynomial time trend	-0.969**	-1.520***	-0.613**
	(0.0563)	(0.00678)	(0.0149)
8th order polynomial time trend	-0.969**	-1.525**	-0.627
	(0.0563)	(0.0387)	(0.141)
9th order polynomial time trend	-0.969**	-1.576**	-0.836*
	(0.0563)	(0.0575)	(0.109)
Panel B. Weekend Subgroup			
7th order polynomial time trend	0.184	-0.308	0.129
	(0.126)	(0.549)	(0.845)
8th order polynomial time trend	0.184	-0.308	0.0572
	(0.126)	(0.549)	(0.294)
9th order polynomial time trend	0.184	-0.308	0.0572
	(0.126)	(0.549)	(0.294)

Notes: A week is defined as 7 days before the HNC and 7 days after the HNC. Robust standard errors in parentheses.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Table 3 reports the estimates of γ_1 by weekday and weekend subgroups for one week, two weeks and three weeks before and after the HNC. In Panel A, all the HNC coefficients are negative and most of them are significant during weekdays, suggesting a significant improvement on weekday air quality after the HNC. On the other hand, the coefficients of the HNC on weekend subgroup in

Panel B do not show any significant sign, suggesting the HNC does not seem to have any effect on weekends. The results are robust with respect to different orders of polynomial time trends. Given the HNC was only in effect during weekdays instead of weekends, these results suggest there was no spillover of driving from weekdays to weekends. Therefore, weekends' CO concentrations serve as a good control group for weekdays' CO concentrations.

B. Air Quality Trend

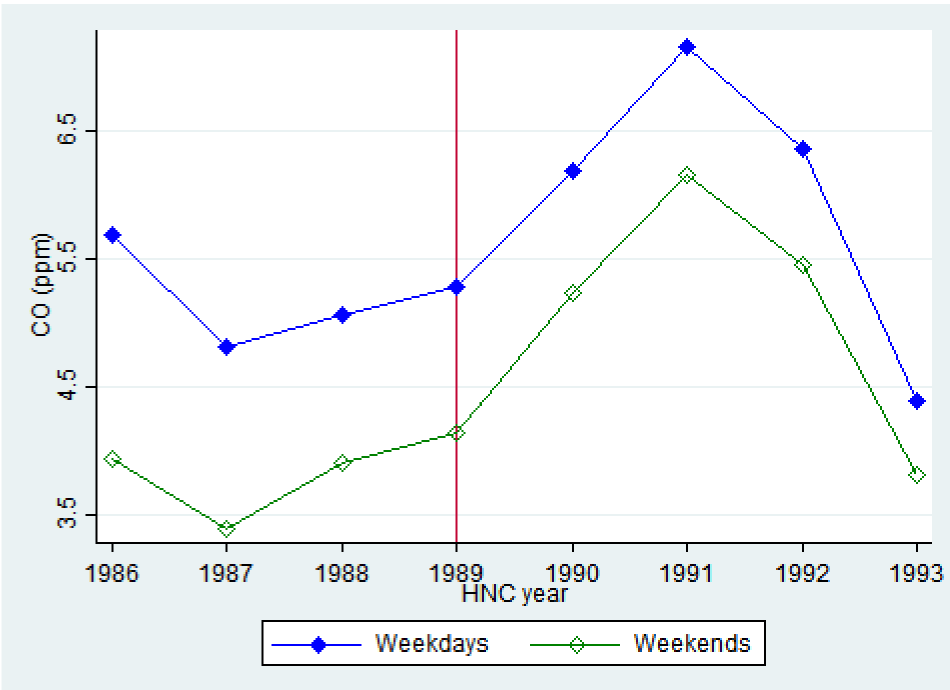

FIGURE 2. WEEKDAY AND WEEKEND CO TRENDS (1986-1993) [USE COLOR IN PRINT]

Notes: The years are defined by HNC calendar staring at Nov 20 and ends at Nov 19 next year.

Figure 2 plots annual weekday and weekend CO trends from 1986 to 1993 during daytime hours (5am to 10pm) in Mexico City. The years are defined by HNC calendar that starts at Nov 20 as the first day of a year and ends at Nov 19 as the last day of the year. The red vertical line denotes the date of the policy implemented on Nov 20, 1989. From the graph, we can see that weekday concentrations increased sharply in 1990 and 1991 but then decreased in 1992 after the policy. Just focusing on the weekday times-series, a naïve interpretation is that the policy induced more CO pollution. However, if we also look at the time-series for weekends, when are not subject to the restriction, we also find a similar trend, suggesting the upward weekday CO trend may not be due to the policy. Another observation from this graph is that the gaps between weekday and weekend CO concentrations are large before the program, but are discernably narrowed after the program. If the weekend CO trend successfully predicts the counterfactual trend of weekday CO in the absence of the policy, this narrowed gap suggests that the policy reduced weekday CO after the restriction compared to what CO would have been without the policy.

C. Difference-in-Differences Method

After confirming weekend as a valid control, a DD method considering both air quality differences between weekdays and weekends and air quality differences before and after the HNC is applied to identify the policy effect. The regression equation is stated as:

$$(8) \qquad \log CO_t = \beta_0 + \beta_1 Weekday_t + \beta_2 HNC_t + \beta_3 Weekday_t * HNC_t + \boldsymbol{\beta_4 x_t} + \varepsilon_t$$

where $logCO_t$ is the logarithm of average hourly CO concentration aggregated across the stations, $Weekday_t$ is a dummy variable with a value of 1 if the CO reading is on a weekday, HNC_t is the other dummy variable with value 1 if the CO reading is after the HNC's implementation, $Weekday_t * HNC_t$ is an interacted dummy with value 1 if the CO reading is both on a weekday and after the HNC, $\boldsymbol{x}_t$ is a vector of control variables, which are the same as the controls in equation (7). β_3 is the coefficient of interest, which measures the effect of the HNC on CO concentrations.

Five specifications are used here to perform the main analysis: (1) the standard DD method with no controls; (2) the DD specification with weather controls and fixed effects; (3) Specification (2) with a 7^{th} order polynomial time trend; (4) Specification (2) with an 8^{th} order polynomial time trend; and (5) Specification (2) with a 9^{th} order polynomial time trend. The 7^{th}, 8^{th}, and 9^{th} order polynomial time trends were chosen to be consistent with Davis (2008).

Four nested time windows are examined for each of the five specifications: 1986-93, 1987-92, 1988-91, and 1989-90. Reporting the results for four nested time windows aims to show whether the policy impact exists for different periods.

In order to confirm that the main results from the DD analysis are causal, several placebo tests are also performed to examine whether weekday and weekend air quality share a similar trend in years when there was no policy in place. Six placebo events are created, one for each year before the HNC and each year after the HNC: 1986, 1987, 1988, 1990, 1991, and 1992.

Since the HNC was effective from 5 am in the morning to 10 pm at night, looking at the variations of the policy effect by hour subgroup would be interesting. Looking at the HNC 's impact on restricted hours and unrestricted hours near the threshold indicates if there exists intertemporal substitution of driving. Focusing on the HNC's impact on different restricted hours shows the HNC's heterogeneous effect by hour. Therefore, the last part of the analysis examines subgroup variation of the HNC by hour.

VI. Empirical Results

A. Main Results

TABLE 4—MAIN RESULTS OF ESTIMATES OF THE MAJOR COEFFICIENTS (1986-93): DIFF-IN-DIFF

	(1)	(2)	(3)	(4)	(5)
HNC	0.315***	0.340***	0.0778	0.0781	0.0367
	(0.0601)	(0.0493)	(0.0997)	(0.0980)	(0.0914)

Weekday	0.125*** (0.0112)	0.151*** (0.0197)	0.150*** (0.0190)	0.150*** (0.0189)	0.150*** (0.0190)
HNC_weekday	-0.039*** (0.015)	-0.041*** (0.014)	-0.041*** (0.013)	-0.041*** (0.013)	-0.041*** (0.013)
Weather controls & fixed effects	No	Yes	Yes	Yes	Yes
7th order polynomial	No	No	Yes	No	No
8th order polynomial	No	No	No	Yes	No
9th order polynomial	No	No	No	No	Yes
Observations	63,542	60,595	60,595	60,595	60,595
R-squared	0.089	0.499	0.659	0.659	0.660

Notes: (1)-(5) denotes specification (1) to (5) as discussed in the paper.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Table 4 reports the estimated coefficients for the HNC dummy, the weekday dummy, and the interacted HNC and weekday dummy across five specifications defined above in the 1986-93 time window. In specifications (1) and (2) without assigning any time trend, the coefficients of the HNC dummy are positive and significant, suggesting a significant increase in CO concentrations after the HNC. When a 7^{th}, 8^{th}, or 9^{th} order polynomial time trend is considered in specifications (3) to (5), this coefficient becomes insignificant, indicating that CO concentrations did not change significantly after the HNC when a high order time trend is introduced. Looking at the coefficients on the weekday dummy, all of them are positive and significant, suggesting significantly higher CO concentrations during weekdays versus weekends. For the HNC_weekday dummy, the coefficients of are negative and significant on all five specifications, implying a significant improvement in CO concentrations during weekdays relative to weekends after the HNC. Therefore, the main results from the DD analysis suggest that the HNC significantly improved air quality measured by CO concentrations during weekdays (when it was in effect) relative to weekends (when it was not in effect). In addition, the magnitude of the effect ranges from -0.039

in specification (1) to -0.041 in specification (5), suggesting the HNC reduced CO concentrations by 3.9 percent to 4.1 percent during weekdays.

TABLE 5—THE EFFECT OF THE HNC ON CO CONCENTRATIONS WITH RESPECT TO TIME WINDOWS: DIFF-IN-DIFF

	1986-93	1987-92	1988-91	1989-90
(1) No control	-0.039***	-0.049***	-0.042***	-0.029
	(0.015)	(0.014)	(0.014)	(0.018)
(2) No time trend	-0.041***	-0.046***	-0.039***	-0.038**
	(0.014)	(0.013)	(0.012)	(0.015)
(3) 7^{th} order polynomial time trend	-0.041***	-0.044***	-0.038***	-0.029*
	(0.013)	(0.013)	(0.012)	(0.014)
(4) 8^{th} order polynomial time trend	-0.041***	-0.044***	-0.037***	-0.029**
	(0.013)	(0.013)	(0.012)	(0.014)
(5) 9^{th} order polynomial time trend	-0.041***	-0.045***	-0.036***	-0.029**
	(0.013)	(0.013)	(0.011)	(0.014)

Notes: This table only reports estimates of the coefficient of the interacted dummy β_3. These (1) to (5) specifications are the same as the five specifications in Table 4, except for they are arranged by row instead by column.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Table 5 reports only the coefficients on the interacted HNC and weekday dummy by time window and across the same five specifications. Across all specifications, the DD estimators are negative and highly significant for the 1986-93, 1987-92 and 1988-92 time windows, suggesting that the HNC significantly improved air quality two years, three years and four years after the program. As for the percentage change, the results imply that the HNC significantly reduced CO concentrations by 3.6 to 4.9 percent during a four-year, six-year, and eight-year period. For the 1989-90 time window, the DD estimators are negative across all specifications and significant for most specifications. The only one that is not significant in the 1989-90 time window is the DD specification with no controls. However, the magnitude of the DD estimator is -0.029, which is the same as the magnitude with a 7^{th} order, an 8^{th} order or a 9^{th} order polynomial time trends. This lack of significance may be driven by the large standard error in the absence of other control variables. Therefore, the results from Table 5 suggest that the HNC's impact on CO concentrations is robust to different time windows.

B. Placebo Tests

TABLE 6—THE EFFECT OF PLACEBOS ON CO CONCENTRATIONS: DIFF-IN-DIFF

	1986/1987	1988/1989	1991/1992	1992/1993
(1) No controls	0.019	-0.025	0.006	-0.020
	(0.046)	(0.018)	(0.025)	(0.034)
(2) No time trend	-0.0175	-0.002	-0.010	0.011
	(0.040)	(0.015)	(0.021)	(0.031)
(3) 7th order polynomial time trend	-0.023	-0.002	-0.011	0.011
	(0.041)	(0.015)	(0.020)	(0.030)
(4) 8th order polynomial time trend	-0.023	-0.002	-0.011	0.011
	(0.041)	(0.015)	(0.020)	(0.030)
(5) 9th order polynomial time trend	-0.024	-0.002	-0.011	0.013
	(0.041)	(0.0145)	(0.020)	(0.030)

Notes: The / denotes comparing. This table only reports estimates of the coefficient of the interacted dummy of the fake events. These (1) to (5) specifications are the same as the five specifications in Table 4, except for they are arranged by row instead by column.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

To confirm that the main results from Table 5 are causal, several placebo tests could be performed from subsamples of the main analysis. The subsample could be drawn from either years before the HNC or years after the HNC given that those years do not have other events. Table 6 reports the coefficients of the DD estimates on four placebos. Based on a one-year radius, the results are summarized across the five specifications from Table 5. Based on 1 year before and 1 year after the placebo event, the coefficients of the DD estimators on all four placebos are insignificant and not different from zero, suggesting no difference in CO trends between weekdays and weekends for all four paired years 1986/1987, 1988/1989, 1991/1992 and 1992/1993.[9]

The result that weekday and weekend air quality share a parallel trend for all placebo years provides strong evidence that the improved air quality presented in Table 5 are caused by the HNC. Therefore, we are confident to say that the HNC caused a 3 percent to 5 percent significant reduction in CO concentrations from a one-year to a four-year period.

C. Subgroup Variation

Table 7 presents the coefficients of the HNC_weekday dummy by hour subgroups. From 7 am to 9 pm, the coefficients of the DD estimators are all negative and significant, suggesting improved air quality for all hours between 7 am and 9 pm. This improvement makes sense since 7 am to 9 pm are active hours of a day that workers commute and the HNC was in effect. Although the HNC was in effect between 5am and 7am, these are not active hours that workers commute. From 12 am to 5 am, the coefficients of the DD estimators are positive and significant, suggesting weekday late night CO concentrations were worse than weekend late night CO concentrations after the HNC. For 6 am, 10 pm, and 11 pm, the coefficients are insignificant and not different from zero.

TABLE 7—THE EFFECT OF THE HNC ON CO CONCENTRATIONS BY HOUR DISAGGREGATION: DIFF-IN-DIFF

1am	2am	3am	4am	5am	6am
0.069** (0.032)	0.085** (0.032)	0.105*** (0.035)	0.096** (0.037)	0.079** (0.033)	0.006 (0.026)

[9] There are two pairs that cannot be used as placebos such as the 1987/1988 pair and 1990/1991 pair as other events had been going on during these two paired years. In 1988, the first comprehensive environmental law, known as the General Ecology Law or LGEEPA (1988), was implemented. "It addresses a broad range of environmental matters including water, air and ground pollution, resource conservation, and environmental enforcement. This law closely resembles the U.S. statutes: the Clean Air Act, Clean Water Act, and Resource Conservation and Recovery Act. However, the Mexican law seemed to encompass many issues that came with the growing industrialization of the country—unlike American acts, which were individually formed in response to specific instances." "In addition, from 1991 onwards all new cars were required to have catalytic converters" (Gleeson Hanna and Garcia 2008, Page 1).

7am	8am	9am	10am	11am	12pm
-0.076***	-0.183***	-0.154***	-0.114***	-0.090***	-0.077***
(0.022)	(0.024)	(0.022)	(0.021)	(0.021)	(0.019)
1pm	**2pm**	**3pm**	**4pm**	**5pm**	**6pm**
-0.072***	-0.074***	-0.090***	-0.118***	-0.131***	-0.115***
(0.016)	(0.017)	(0.017)	(0.018)	(0.018)	(0.016)
7pm	**8pm**	**9pm**	**10pm**	**11pm**	**12am**
-0.105***	-0.068***	-0.037*	-0.010	0.014	0.045*
(0.018)	(0.019)	(0.020)	(0.021)	(0.023)	(0.025)

Notes: This table only reports estimates of the coefficient of the interacted dummy. Only Specification (3) is used, which is the one with a 7th order polynomial time trend. The time window is 1986-93.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

As for the magnitude of the effect of the HNC on different hours, the effect is largest during 8 am to 10 am and 4 pm to 6pm, ranging from 11 percent to 18 percent and 11 percent to 13 percent, respectively. The magnitude of the effect with respect to hours makes sense because 8 am to 10 am are morning peak hours and 4 pm to 6 pm are afternoon peak hours when workers were expected to commute during these hours. It suggests that the HNC significantly improved air quality by 11 to 18 percent during peak hours, which is a reasonable amount since the HNC banned roughly 20% of motor vehicles every weekday.

VII. Conclusion

Due to the wage shock of white-collar workers, which happened around the same time with the HNC, studies using time-series RD to examine the impact of Mexico City's driving restriction suffers from this confounder. To control for this wage shock and other time variant confounding factors, this study applies a DD method with unrestricted days as a control to examine the HNC's effect. It finds a 3 to 5 percent significant reduction in CO concentrations for all hours of the day and an 11 to 18 percent reduction during rush hours four years after the program. Using RD on weekday and weekend subgroups in a very short time window near the date of the HNC shows that there does not exist spillovers of driving from weekdays to weekends. Further, placebo tests from subsamples of the main analysis certify that the effect found by the main analysis is not caused by any time differences in CO trends between weekdays and weekends. This new finding reconciles conflicting signs in the driving restrictions' literature.

In addition to the new finding, this study also provides a replication and a robustness check of a previous time-series RD study (Davis 2008). It finds that the coefficient in the main specification provided by Davis is sensitive with respect to both time windows and orders of polynomial time trends. Besides, it provides the econometric explanation for why a DD with a valid control solves the confounding factor issue (the white-collar wage shock) faced by a time-series RD. It also presents evidence generated from household survey microdata that households with one-car increased after the HNC but households with two or more cars did not witness any increase, which further confirms the effect of the white-collar wage shock.

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Chapter 2
New Observations on the Effect of Beijing's Driving Restriction on Air Pollution

ZHENG LIU, KATHLEEN SEGERSON AND STEPHEN ROSS

Abstract

A one-weekday-per-week driving restriction used to curb severe air pollution was implemented in Beijing right after the Olympic Games in October 2008. This restriction was found to have reduced air pollution by 21 percent through a temporal regression discontinuity design and a spatial difference-in-differences (DD) method. However, previous Olympics were found to have boomed local economies and the Beijing government had introduced other programs such as closure of high-polluting plants, enforcement of new emission standards and extension of subway routes to prepare for the Olympics. It is essential to control for the effect of both the Olympics and other environmental programs when evaluating the driving restriction's impact. Using both a spatial DD and a temporal DD, this study find that Beijing’s driving restriction together with other environmental programs have reduced air pollution by 12 to 18 percent but the driving restriction itself have reduced air pollution by 3 to 5 percent.

Keywords: driving restriction; air pollution; difference-in-differences

I. Introduction

Among all the cities in China, Beijing is the most developed in both economy and technology, but has the poorest air quality. Blue sky days rarely appear in Beijing and people usually wear masks when they are outside. Schools have been forced to cancel outdoor activities, and health experts recommend children, the elderly and people with respiratory ailments stay indoors. Inhalable Particulate Matters (IPMs or PM10) have ranked first as the primary air pollutant since 2000. In 2007, 89% of the days had PM10 as its primary air pollutant and the average concentrations of PM10 exceeded health-based national air quality standard[10] by 22%, which was the only pollutant that did not meet the national standard.[11]

Major concerns for human health from exposure to PM10 include effects on breathing and respiratory systems, damage to lung tissue, cancer, and premature death. The elderly, children and people with chronic lung disease, influenza, or asthma are especially sensitive to the effects of particulate matter. The social cost of PM10 has been researched by Kan and Chen (2004) and Quah and Boon (2003). Kan and Chen (2004) claimed that the total economic cost of health impacts caused by particulate air pollution was around 625.40 million US dollars in Shanghai in 2001, which was 1.03% of Shanghai's GDP. Quah and Boon (2003) found that the total economic cost of PM10 in Singapore was 3.362 billion US dollars, which was 4.31% of Singapore's GDP in 1999. From an economic cost perspective, therefore, it is important to reduce PM10 pollution.

Among all sources that contribute to PM10 in Beijing, car emissions are the major source and account for 22% of total PM10 concentration. Other sources are emissions from burning coal,

[10] Beijing's health-based national air quality standard for PM10 is 100 µg/m3, which is two times higher than World Health Organization (WHO)'s 2005 standard (50 µg/m3).

[11] Source: Beijing's Municipal Environmental Protection Bureau (EPB).

construction dusts and industrial emissions, which contribute 16.7%, 16.3% and 15.7% of total PM10 pollution, respectively.[12]

As the host city for the 2008 Summer Olympic Games, the Beijing government had introduced a driving restriction to reduce severe air pollution and traffic congestion. It was known as the Odd-Even number Limit (OEL) implemented before and during the Olympics (i.e., from July 1 to September 20). Using the tail numbers on license plates, the OEL bans odd tail number cars from running on odd days and even tail number cars from running on even days. Statistics from Beijing's EPB show that air quality had improved by 42.47% during the Olympics, compared to the air quality three months before the OEL.

The reported success of the OEL had led the Beijing government to announce a continued driving restriction for a half-year. This continued driving restriction was a modified version of the OEL and has banned most drivers from using their vehicles one weekday per week instead of every other days. It is called One-Weekday per week Limit (OWL), enforced from October 11, 2008 to April 10, 2009. Instead of banning five odd or even digits per day by the OEL, the OWL banned two digits per weekday based on the same license number screening.[13] The OWL was effective on every road within the Fifth Ring region from 6:00am to 9:00pm every weekday excluding holidays.[14] It applied to most motor vehicles excluding police cars, fire trucks, ambulances, project rescue vehicles, buses, taxis and postal vehicles. Violators were fined 100 RMB (roughly 17 US

[12] Source: Beijing's EPB 2014.

[13] The digits are divided into five groups (i.e., \{1, 6\}, \{2, 7\}, \{3, 8\}, \{4, 9\}, \{5, 0\}) and each group is bundled with a weekday (i.e., \{1, 6\} is bundled with Monday, \{2, 7\} Tuesday and so on). If the tail number of a motor vehicle falls into any group, that car cannot be driven on the day bundled with the group. For example, if the license plate ends with 6, which falls into group \{1, 6\}, that car cannot be driven on Monday, the day bundled with \{1, 6\}.

[14] The Fifth Ring region is the metropolitan area of Beijing. It consists of five nested rings from the highest radius to the smallest radius, named as Fifth Ring, Forth Ring, Third Ring, Second Ring and First Ring, respectively.

dollars and 1/40 of Beijing citizens' average month salary) and forced off the road. Since April 11, 2009, the OWL has been extended for four times with small modifications.[15]

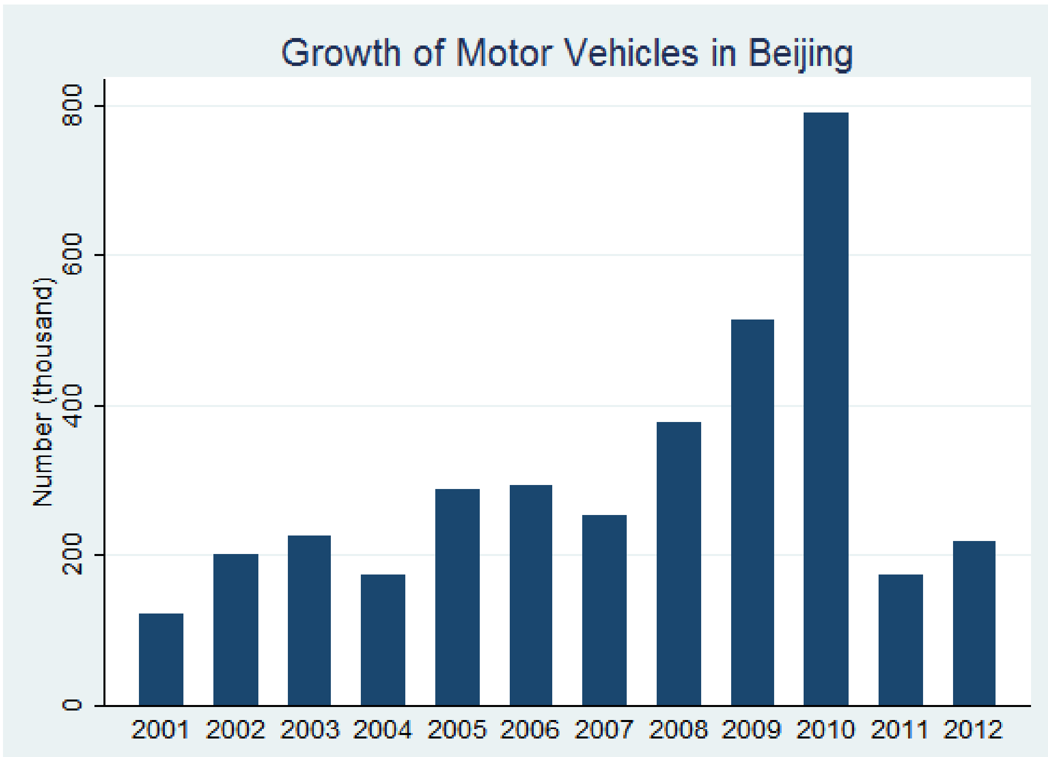


FIGURE 1. GROWTH OF MOTOR VEHICLES IN BEIJING

Notes: Car Purchasing Lottery (CPL) took place at the end of 2010.

Despite the OWL, the number of motor vehicles had increased significantly after Olympics in Beijing. Figure 1 shows annual growth of the number of motor vehicles in Beijing since 2000.[16] The growth of motor vehicles was very stable from 2002 to 2007 with roughly 200 thousand cars per year. But the number had increased significant since 2008 with 376 thousand, 515 thousand and 790 thousand in 2008, 2009 and 2010 respectively. Though the growth in 2010 can be partially

[15] These modifications include the restricted time had been shortened to 7:00am to 8:00pm and the Fifth Ring had been excluded from the enforced region.

[16] Data source: Beijing Transportation Bureau (BTB). http://www.bjjtgl.gov.cn/publish/portal0/tab118/.

explained by the Car Purchasing Lottery (CPL)[17], three year's consistent growth since 2008 was still overwhelming. Two reasons could account for this growth. One reason could be an economic boom triggered by the 2008 Summer Olympics.[18] The other reason could be an internal cause induced by the OWL, where people may react by buying a second car to circumvent the restriction. In order to evaluate the effect of the OWL, one must control for the possible confounding impact of the Olympics.

Besides the Olympic shock that may add more pollution to the economy, other programs designed to alleviate air pollution were also implemented in Beijing. These programs include plant closures, introduction of new emission standards, and subway extensions, which were enforced both before and after the Olympics and the OWL. Table 1 summarizes these programs in chronological order since 2003. As we can see from the chart, China has adopted an extensive plant relocation/closure plan to curb air pollution since 2003. It also introduced a new emission standard based on the European standard and updated it on a yearly basis. Starting in 2007, the Beijing government also began to extend its subway system on a yearly base to fill the needs of an increased population. During 2008, the year of the Olympics, vehicle control was put into place to alleviate the severe traffic congestion and air pollution.

This study identifies the OWL's impact by sequentially controlling for both the impact of the Olympic Games and the impact of other environmental policies. Using Tainjin - an Olympic cohosting city as a spatial control for the Olympic Games, this study finds that all environmental programs implemented in Beijing only including the OWL have contributed to 14 percent

[17] The CPL is another vehicle control policy that had begun on Dec 23, 2010. This policy assigns quotas for purchasing cars, which may have contributed to the sharp reduction in the growth of motor vehicles after 2010. However, it may also contribute to the significant car growth in 2010 as people were rushed to purchase cars before the policy was announced.

[18] See \cite{hotchkiss2003impact}, \cite{madden1998estimating} and \cite{kasimati2009assessing. These three papers talked about the economic impact of Olympic Games in the 1996 Georgia Olympics, the 2000 Sydney Olympics and the 2004 Greek Olympics using a macroeconomic model.

reduction of total air pollution. While using weekends when the OWL was not effective as a control for both the Olympics and other environmental programs enforced on weekends as well, this study finds that the OWL has led to a 3 to 5 percent reduction in air pollution. This new magnitude is far more less than the magnitude found in previous study of a 21 percent significant reduction in air pollution due to the OWL and it is consistent with the new findings of the impact of the Mexico City's driving restriction in the previous chapter.

Table 1: TIMELINE OF OTHER ENVIRONMENTAL PROGRAMS.

Time	Events	Status
Plant Relocation		
2003-2004	Beijing reduced its industrial use of coal by 10 million tons, desulfurized air pollutants from the YanShan Petrochemical Company, shut down coal-fired generators at the Capital Steel Company and Beijing Coking Plant	Done
2005	The largest plant Capital Steel Company was relocated.	Start
2005	The Capital Steel's largest production unit was permanently closed.	Done
2005-2006	China constructed desulfurization, dust removal, and denitrification facilities at the Beijing Thermal Power Plant and the power plant of Capital Steel.	Done
2006.7.23	Beijing Coking Plant was closed.	Done
2006.10.31	Beijing renovated 100% of the furnaces for clean fuel in five districts, and 50% in the three other districts.	Done
2007.12.31	The Second Beijing Chemical Plant completed its production closure.	Done
2008.6.30	Beijing required that all coal-fired power plants install and operate de-nitrification equipment after installing desulphurization and high-efficient dust elimination equipment.	Done
2008.12.30	Beijing required that 40 high polluting and high energy-consuming enterprises shut down.	Done
2010.12.31	The Capital Steel completely stopped all its production.	Done
Emission Standard		
2004.7.1	China applied European II emission standard.	
2005.12.30	Beijing applied European III emission standard. Vehicles passed III standard before can install OBD after one year.	
2006.12.1	New cars without OBD were prohibited to sell in Beijing.	
2007.7.1	Other parts of China applied European III emission standard.	
2008.3.1	Beijing began to apply European IV emission standard applied to new vehicles.	
Subway Expansion		
2007.10.7	Line 5 was opened.	
2008.7.19	Line 8, Line 10 and Airport Express were opened.	
2009.9.28	Line 4 was opened.	
2010.12.30	Five suburban lines (Line 15, Changping Line, Daxing Line, Fangshan Line, Yizhuang Line) were opened.	
Subway Fare Change		
2007	Subway fare was changed from 3 yuan (US$0.5) per ticket to 2 yuan (US$ 0.3).	
Vehicle Control		
2008.10.11	One-day-per-week Driving Restriction (i.e. OWL)	
2010.12.23	Car Purchasing Lottery (CPL) was put into place.	

II. Previous Literature

In contrast to the literature examining the effect of Mexico City's driving restriction, which found no evidence of improved air quality, both of the studies evaluate Beijing's driving restriction found that the OWL significantly reduced Beijing's air pollution. However, the magnitudes of the effect reported are somewhat different. Chen et al. (2013) reported an average treatment effect (ATE) of 19 percent one year after the Games due to all involved policies, but a reduced marginal effect of 5.1 to 5.9 percent ten months after the Games mostly due to the OWL. Viard and Fu (2015) found an ATE of 21 percent one year and a half after the Games.

Using both a time-series regression discontinuity (RD) method and a difference-in-differences (DD) method with stations far away from major roads as a control for stations nearby major roads before and after the OWL (i.e.: 2007 to 2009), Viard and Fu (2015) found that the OWL significantly improved Beijing's air quality by 21 percent. Though they controlled for the events of the Olympics and subway extensions, plant closure/relocations and introduction of new emission standards were not considered in their paper. These environmental programs affected both far away stations and nearby stations. For instance, the introduction of new emission standards will have a bigger impact on stations nearby major roads than stations far away from major roads since it influences the emission from cars. Therefore, their estimates tend to overestimate the real effect of the OWL due to failing to control for other environmental policies.

Besides the failure to control for several other environmental programs, Viard and Fu (2015) also has a contradiction in their findings concerning the magnitudes of the effect of the OEL and the OWL. As introduced above, the OEL banned roughly 50 percent of cars and the OWL banned roughly 20 percent of cars. Given that the OEL was implemented just a couple of months ahead of the OWL, we anticipate the OEL has a 2.5 times bigger effect than the OWL. However, Viard and Fu (2015) found that the OEL reduced PM by 18 percent while the OWL reduced PM by 21 percent, the effect of which is even bigger than the effect of the OEL. This conflicting estimate also suggests that the effect of the OWL may be overestimated.

In contrast to Viard and Fu (2015), which only evaluates the ATE of the driving restrictions, Chen et al. (2013) examines both the ATE and the marginal effect of all policies involved for the Olympics. Applying a fixed effect (FE) model with cohorts of Olympic co-hosting cities and Beijing's neighboring cities as controls, Chen et al. (2013) show that Beijing's policies such as the OEL, the OWL, and plant closure/relocation in preparation for the 2008 Olympic Games improved Beijing's air quality during and a little after the Olympics, but a significant portion of the effect faded away in one year. Specifically, they found that the ATE of all policies implemented after the Olympics is 19 percent during a one year time frame while the marginal effect became 5.1 to 5.9 percent, which were mostly contributed by the OWL. However, using all Olympic co-hosting cities as a control may underestimate the post-Olympic shock in Beijing since several Olympic co-hosting cities such as Qinhuangdao are very small and are expected to experience very little post-Olympic shock. In addition, the lack of information on other environmental programs implemented in those Olympic co-hosting cities may also have weakened the results of their FE model.

In addition to studies examining Beijing's driving restriction, a recent paper evaluating Quito, Ecuador's similar restriction also found evidence of improved air quality. Carrillo et al. (2016) claims that Quito's three-year-old driving restriction has reduced ambient concentrations of carbon monoxide (CO), a pollutant primarily emitted by motor vehicles, by 9-11% during peak traffic hours and by approximately 6% during an extended daytime period. They applied two DID methods with off peak hours within restricted regions and peak hours within unrestricted regions as the controls. Then, they applied a DDD method with both of the above two controls. Given that ambient concentrations of CO generally track the spatial and temporal distributions of traffic, these reductions in pollution suggest similar reductions in vehicle flows.

Contrary to the results of these panel findings are time-series studies examining the effect of Mexico City's Hoy No Circula (HNC) driving restriction. Using a time-series RD on days before and days after the HNC, Davis (2008) and Gallego et al. (2013) both find no evidence of improved air quality but evidence of increased car ownership in Mexico City. In contrast to cross-sectional RD, time-series RD suffers from the issue of time variant confounding factors. Since both studies look at the HNC's impact on time windows longer than a year, it is very likely that the lack of improved air quality was caused by other events such as an economic boom roughly at the same time as the HNC. These other events can also explain their additional findings of increased car ownership.

The overwhelming finding in the driving restrictions' literature is evidence of improved air quality due to the restriction except for two time-series RD papers. However, the lack of full consideration of all macroeconomic factors weakened the credibility of these analyses. Therefore, it is necessary to reevaluate and provide a more accurate estimate of the effect of Beijing's OWL.

III. Measuring Air Quality in China

Air quality in China was measured according to the ambient air quality standard (namely GB3095-1996) enforced on Dec 6, 1996. This standard set rules for categories, averaging times and concentration limits of different air pollutants in different area. For example, Beijing, denoted as a metropolitan area, applied Grade II standard for PM10 concentration, which was 100 $\mu g/m^3$ of yearly average and 150 $\mu g/m^3$ of daily average. The concentration of each pollutant should not exceed its limit for health concerns. Concentrations of different pollutants were monitored by multiple air monitoring stations distributed throughout a city. They were averaged across day or hour depending on the natures of the pollutants. Daily or hourly concentration of each pollutant in a city was computed by simply averaging the concentrations from different air monitoring stations in that city. This averaged concentration will be transformed into an Air Pollution Index (API) through a transformation function.[19] The pollutant with the highest API was denoted as the major pollutant on that day. For Beijing, PM10 was the primary pollutant for most days of a year during the study period.

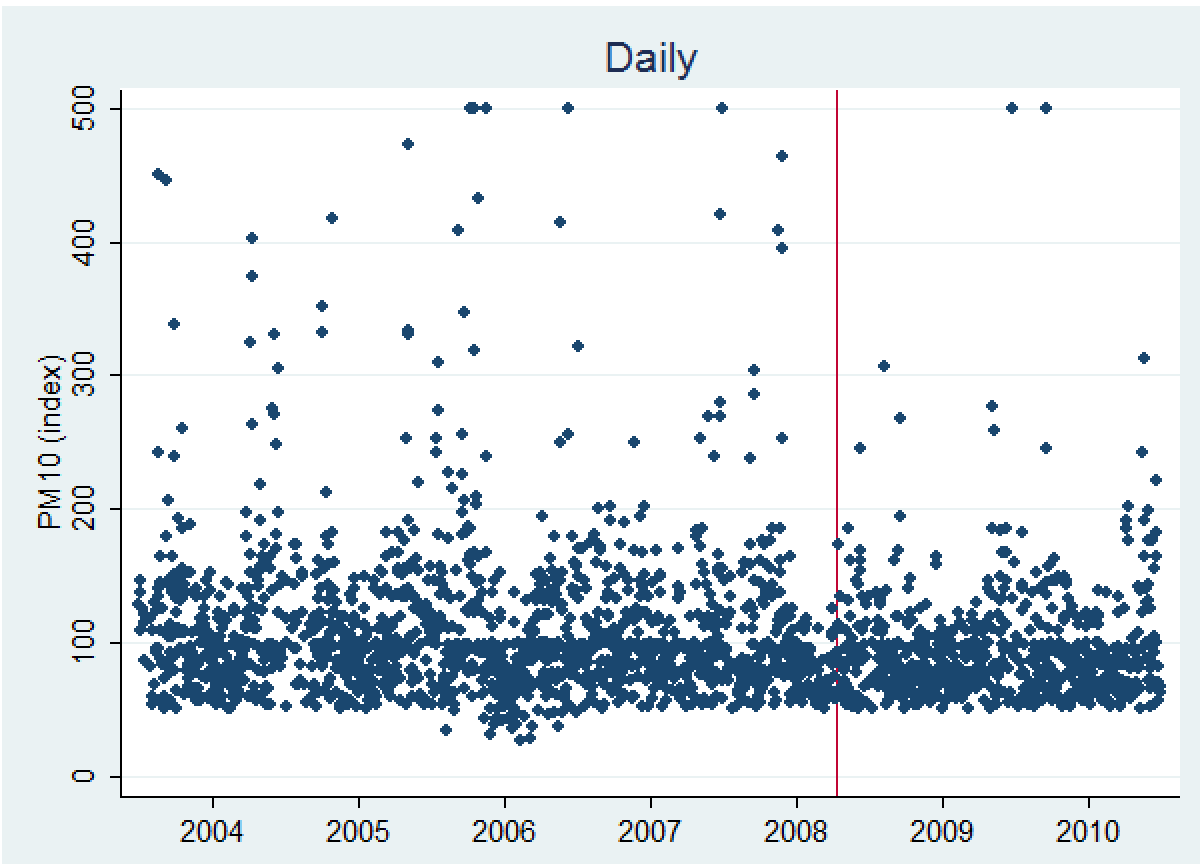


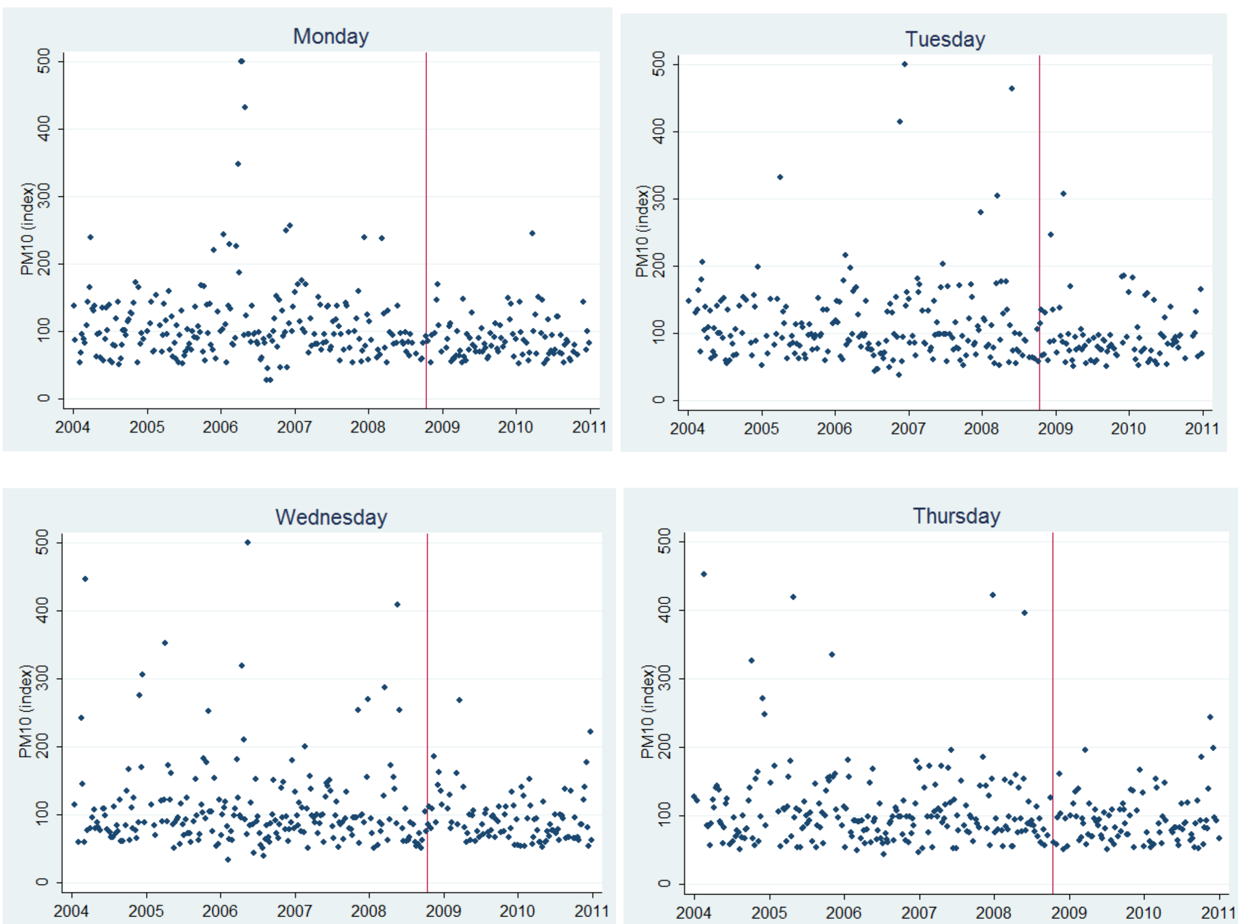
FIGURE 1. AVERAGE DAILY API OF PM 10 IN BEIJING

Since 2000, daily APIs in major cities has been reported by the Ministry of Environmental Protection (MEP) of the People's Republic of China online.[20] By manually collecting the data

[19] The specific transformation procedure is shown on EPB's website: http://www.bjmemc.com.cn/g327/s968/t1261.aspx.

[20] Detailed air quality daily report data is available on MEP's website: http://datacenter.mep.gov.cn/report/air_daily/air_dairy.jsp.

online, this paper was able to conduct the following analysis. Figure 1 plots average daily API of PM10 in Beijing from 2004 to 2010. The red line denotes the date that the OWL was implemented (Oct 11, 2008). It can be seen that the daily API of PM10 in Beijing was clustered and no clear time trend was found on the plot. Further, the average daily API was sorted by day of week and was plotted on Figure 2. Still, the shapes with sorting do not show any visible difference with the shape without sorting. The lack of time trend may disable the use of regression discontinuity design as a valid identification strategy.



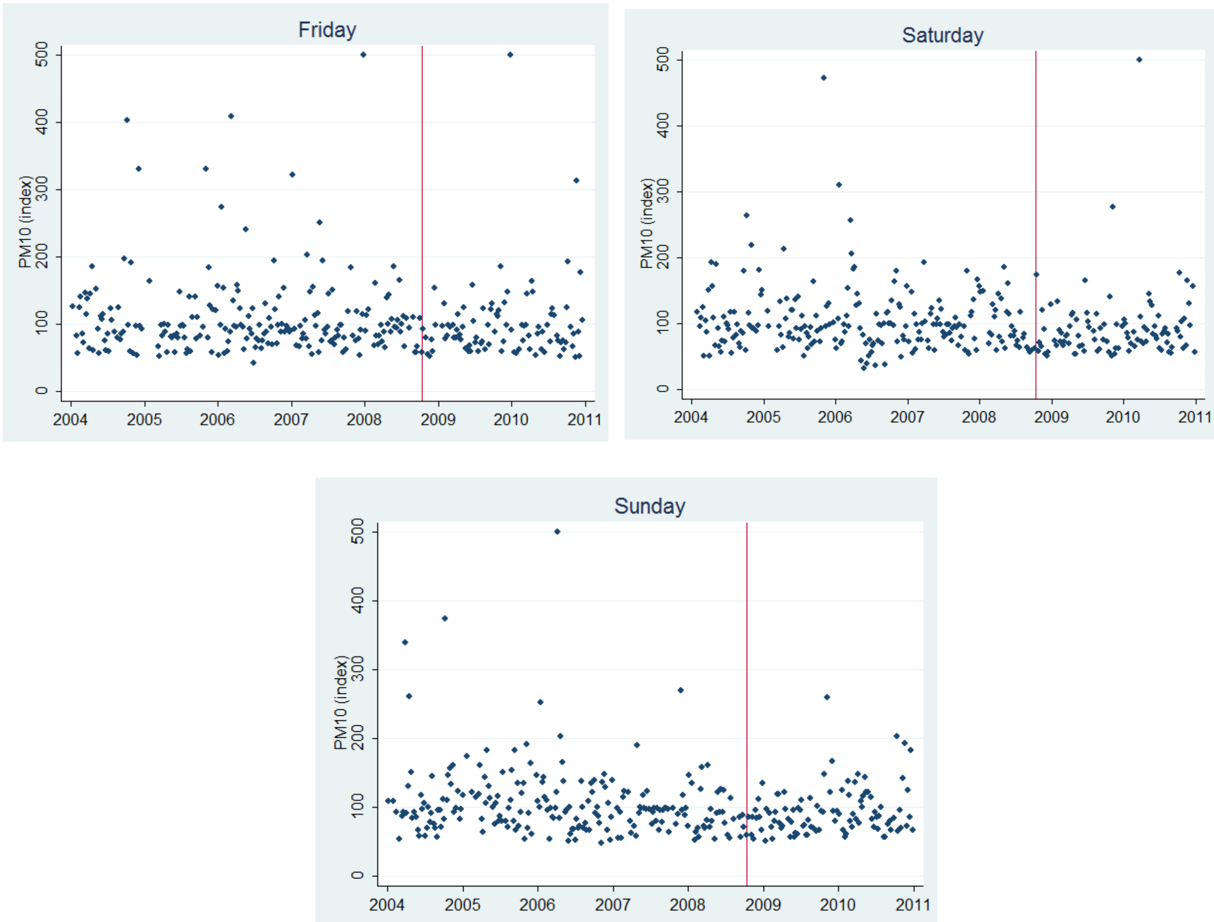


FIGURE 2. AVERAGE DAILY API OF PM 10 BY DAY OF WEEK

Summary statistics of daily API of PM10 in Beijing has been described in Table 2. It shows that the means and standard deviations are very similar on each day of week with Tuesday and Friday relatively higher and weekends relatively lower. This information is reasonable because people usually do not work on weekends but perform extra activities on Tuesdays and Fridays. People usually take social activities such as banquets or parties after work on Fridays right before weekends come. And people often perform extra activities on Tuesday afternoons as they have been the time that most TVs were on vacation.[21]

[21] Most Chinese TV programs were on vacation every Tuesday afternoon. http://news.ifeng.com/gundong/detail_2011_05/14/6388470_0.shtml.

Table 2

Air Quality for PM_{10} in Beijing 2004-2010: Summary Statistics

API for PM_{10}	Observations	Mean	Std. Dev.	Min	Max
Daily	2199	103.68	54.72	27	500
Monday	317	103.71	55.71	27	500
Tuesday	305	106.65	56.62	37	500
Wednesday	321	103.72	57.94	34	500
Thursday	316	103.78	54.63	44	451
Friday	308	105.68	59.76	42	500
Saturday	321	100.56	50.30	32	500
Sunday	311	101.80	47.46	48	500

Since PM10 is a pollutant highly correlated with weather conditions, this study also uses meteorological data to control for weather conditions. China Meteorological Administration (CMA) collects major city's daily meteorological data and files them in a yearly basis. Upon applying, I got Beijing and Tianjin's meteorological data during the study period. There are seven key meteorological variables in the data file including average barometric pressure, average temperature, average water vapor pressure, average relative humidity, total rainfall, average wind speed and sunshine hours. All these key variables are used as a weather vector controls in the empirical analysis.

IV. Empirical Strategy

A. Choice of Control Groups

The control group should have similar air quality trend of PM10 pollution as Beijing does before the OWL was implemented. Determinants of the air quality trend of PM10 include both economic characteristics as well as weather characteristics. The economic characteristics of Beijing that was a well developed municipality and has hosted the 2008 Summer Olympic Games allow us to choose a well developed Olympic cohosting municipality as a control. The weather characteristics of Beijing that are in a high latitude and far away from the coast enable us to choose a city that is in the similar geographic location as Beijing does as a control.

FIGURE 2. GDP

In order to have similar economic conditions with Beijing, the control city needs to have both similar economic development level and a similar Olympic shock as Beijing did. For similar economic development level, China's central government provides a good selection. The central government selects four cities (Beijing, Tianjin, Shanghai and Chongqing) as its direct-controlled municipalities, which have the same rank as provinces and are large economy bodies. Figure 2 plots the GDPs in China's four municipalities since 2004.[22] The GDP of Beijing was ranked second in these four municipalities with the GDP of Shanghai one third above it and the GDP of Tianjin

[22] Data source: National Bureau of Statistics of China. http://data.stats.gov.cn/workspace/index;jsessionid=1F5592527FC41D21F23E9510E0210C26?m=fsnd

one third below it. The GDP of Chongqing has increased slowly relative to Tianjin since 2004. Among these four municipalities, three have been selected as the 2008 Summer Olympic Games hosting cities. Besides Beijing as the major hosting city, Shanghai and Tianjin also co-hosted football matches.[23] Chongqing is the only municipality that has not been selected to co-host the Game, which is therefore deleted from the control candidates.

FIGURE 3. THE LOCATION OF OLYMPIC COHOSTING CITIES

For similar weather, a reasonable control group should be at a similar latitude as Beijing and in the interior instead of near the coast since Beijing is an interior land and not near the coast. Otherwise, air quality might be influenced by temperature, precipitation, seasonality, etc. Tianjin is supposed to be a better control group than Shanghai would be since it is at a similar latitude as Beijing is, while Shanghai is at a different latitude and near the coast. Figure 3 shows the location of these municipalities. Figure 4 display monthly weather conditions such as mean max temperature, mean min temperature and amount of rainfall from 1961 to 1990 in these

[23] See 2008 Beijing Olympics' official website: http://web.archive.org/web/20081012084504/http:/en.beijing2008.cn/index.shtml

municipalities.[24] It can be easily seen that the shape of all three weather conditions are nearly overlapped for Beijing and Tianjin, while Shanghai has a different shape.

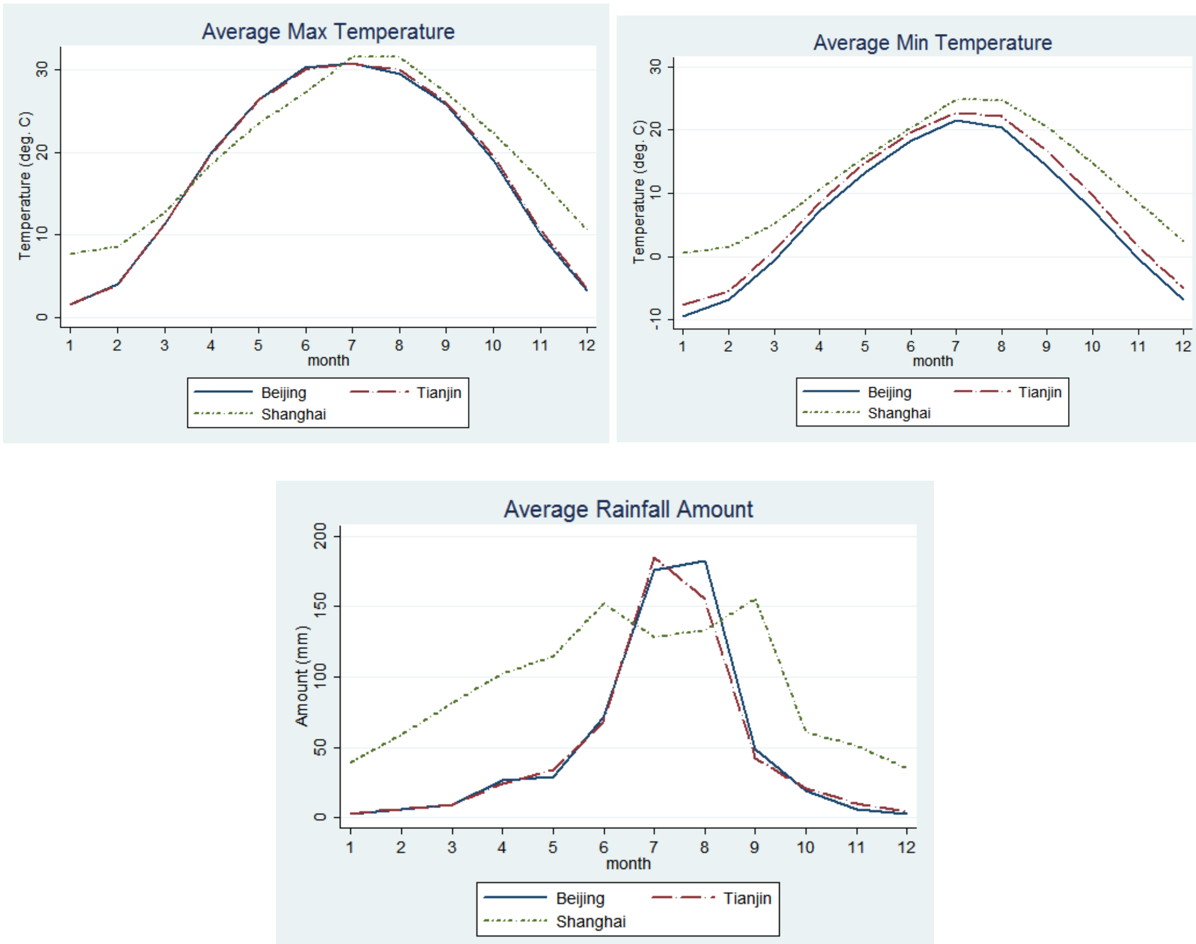


FIGURE 4. WEATHER CONDITIONS IN CHINA'S MAJOR MUNICIPALITIES

In terms of other environmental policies, both Beijing and Tianjin worked to reduce air pollution. For instance, Beijing and Tianjin both extended public transportation like subway trains and buses

24 Data source: Hong Kong Observatory, the Government of the Hong Kong Special Administrative Region.\url{http://www.hko.gov.hk/wxinfo/climat/world/eng/asia/china/china_e.htm

and introduced a stricter car emission standard (GB 18352.3—2005[25]) on July 1, 2007 before the Olympics. Both cities applied a temporary OEL driving restriction during the Olympics.[26]

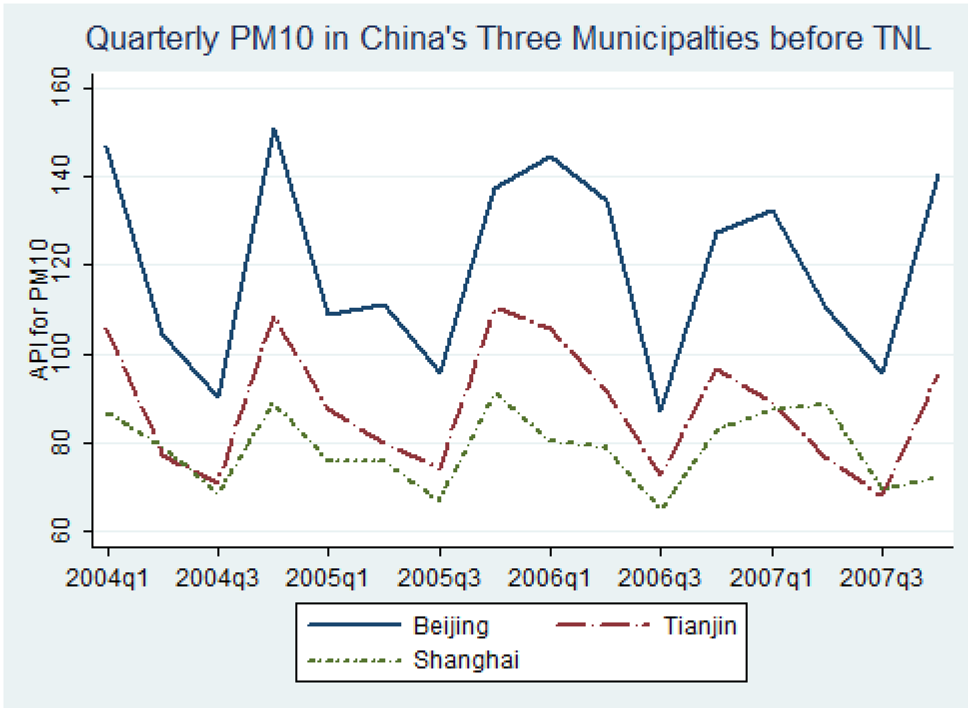


FIGURE 5. QUARTERLY PM 10 TREND

Historical data of API for PM 10 concentration in these municipalities also supports the use of Tianjin as a control group. Figure 5 shows the trend for PM 10 pollution in Beijing, Shanghai and Tianjin before the OWL (from 2004 to 2007) was implemented. Quarterly averaging data of the API for PM 10 in each city has been used to compare the trend. It can be seen that all three municipalities have seasonality over the course of year with a high PM 10 level in the first quarter, a decreased PM 10 level in the second and third quarter, and then an increased level in the fourth quarter. However, the PM 10 trend in Beijing is most unstable, while the trend for Shanghai is

[25] The emission standard of GB 18352.3—2005 is similar to the European III emission standard.

[26] Beijing applied it from July 1 to September 20, 2008 and Tianjin applied it from August 6 to 15, 2008 during the co-hosting of the Olympic soccer games.

most stable. Tianjin's PM 10 level behaves almost parallel to Beijing's PM 10 level, while Shanghai's PM 10 level is not parallel to either PM 10 levels. Therefore, Tianjin serves as the best spatial control based on the graphical common trend.

However, Beijing, as China's capital city, had adapted more stringent programs to curb air pollution as presented in Table 1. Therefore, using Tianjin as a spatial control would only offer us the information on the impact of Beijing's various environmental programs on air quality. In order to control for Beijing's other stringent environmental programs, we have to introduce another control group that had both the Olympics Games and these other policies. The nature of the OWL that only affect weekdays instead of weekends provide us a good selection criterion. Since both the Olympics and other programs affect both weekdays and weekends, the impact of the OWL can be identified by using weekends as a control.

B. Choice of Study Period

After choosing the control group, a reasonable time period needs to be chosen in order to separate other car restrictions and/or other environmental policies besides the OWL. Since the OWL was implemented right after the Olympics and there are other policies like forced shut down of highly polluted industries and OEL during and/or before the Olympics, 2008 (the year of the Olympics) is deleted from our dataset. In addition, China introduced the worldwide measures of air quality in 2013, denoted as air quality index instead of air pollution index. To be consistent in measures of air quality, years after 2013 will not be considered. Therefore, there are four years data available after the OWL to conduct this analysis. To be symmetric, four years before the OWL will also be chosen as the sample period. The study period is from 2004 to 2012 (excluding 2008), an eight-year time window.

C. A Spatial Analysis

Given that Tianjin is the best available spatial control for Beijing in terms of endogenous determinants of PM 10 pollution, comparing changes in Tianjin's air pollution with changes in Beijing's air pollution would provide us the impact of all exogenous environmental programs including the OWL on air pollution in Beijing. A standard DD method with both Tianjin and pre-periods of the OWL as controls has been applied to estimate the impact. The estimation equation is shown as follows:

$$API_{it} = \gamma_0 + \gamma_1 After_t + \gamma_2 Beijing_i + \gamma_3 After_t * Beijing_i + \tau_{it}, (1)$$

where $Beijing_i$ is the city dummy with value 1 if the API is monitored in Beijing and with value 0 if the API is monitored in Tianjin, $After_t$ denotes the time dummy with value 1 if the API is monitored after the OWL and with value 0 if the API is monitored after the OWL, $After_t * Beijing_i$ is an interacted dummy with value 1 if the API is monitored both in Beijing and after the OWL and with value 0 in all other cases, τ_{it} is an error term. γ_3 is the DD estimator we are interested in, which measures the impact of all environmental policies on air pollution in Beijing.

Since weather characteristics and seasonality are also determinants of PM 10 pollution, equation (1) is also estimated by adding weather controls, city fixed effect, month fixed effect as well as day of week fixed effect, denoted as specifications (2), (3), (4) and (5) respectively.

The results on the effect of all the environmental policies on air quality in Beijing are presented in Table 3 with an eight-year time window (from 2004 to 2012). The coefficients on the DD estimator are negative and significant, suggesting that all the environmental programs implemented in Beijing together had significantly reduced air pollution. In addition, the magnitudes of the DD coefficients are similar across all five specifications, suggesting that the impact is robust with respect to specifications.

TABLE 3—THE EFFECT OF ALL ENVIRONMENTAL POLICIES ON AIR POLLUTION IN BEIJING (2004-12)

	(1)	(2)	(3)	(4)	(5)
After	-1.364	-2.285*	-2.285*	-1.321	-1.317
	(1.351)	(1.305)	(1.305)	(1.267)	(1.268)
Beijing	26.38***	22.55***	22.55***	24.06***	24.10***
	(1.936)	(1.808)	(1.808)	(1.748)	(1.750)
After_Beijing	-16.33***	-16.24***	-16.24***	-15.39***	-15.38***
	(2.486)	(2.365)	(2.365)	(2.289)	(2.289)
Weather controls	No	Yes	Yes	Yes	Yes
City fixed effect	No	No	Yes	Yes	Yes
Month fixed effect	No	No	No	Yes	Yes
Day of week fixed effect	No	No	No	No	Yes
Constant	84.70***	1,330***	1,330***	1,184***	1,184***
	(0.960)	(133.0)	(133.0)	(152.7)	(152.7)
Observations	4,571	4,571	4,571	4,571	4,571
R-squared	0.063	0.173	0.173	0.248	0.248

Notes: (1)-(5) denotes specification (1) to (5) as discussed in the empirical strategy section. The time window of 2004-12 does not include the year of 2008. Robust standard errors are in parenthesis.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Table 4 presents the major coefficients of the DD estimators on narrowed time windows. When the time window has been narrowed from an eight-year to a six-year, a four-year and a two-year, the DD coefficients are negative and significant with barely changes in magnitudes, suggesting that the impact is robust with respect to time windows. The magnitude of the DD estimates across all time windows and specifications is in the range of 14 to 21, suggesting that all environmental programs implemented in Beijing together significantly reduced the API of PM 10 by 14 to 21 levels compared to Tianjin. This is equivalent to a 12 to 18 percent reduction in API of PM10 pollution.

TABLE 4— THE EFFECT OF ALL ENVIRONMENTAL POLICIES ON AIR POLLUTION IN BEIJING BY TIME WINDOW

	(1)	(2)	(3)	(4)	(5)
2007-09	-18.76***	-20.84***	-20.84***	-18.75***	-18.49***

	(4.460)	(4.246)	(4.246)	(3.960)	(3.960)
2006-10	-17.01***	-18.43***	-18.43***	-16.40***	-16.46***
	(3.507)	(3.344)	(3.344)	(3.246)	(3.260)
2005-11	-14.94***	-15.16***	-15.16***	-13.75***	-13.78***
	(2.847)	(2.713)	(2.713)	(2.629)	(2.628)
2004-12	-16.33***	-16.24***	-16.24***	-15.39***	-15.38***
	(2.486)	(2.365)	(2.365)	(2.289)	(2.289)

Notes: The specification is the same as the previous table. All time windows excludes the year of 2008. Robust standard errors are in parenthesis.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Table 5 presents fake DD estimates based on various placebo tests. These placebos are generated by treating each year before the OWL or each year after the OWL as a fake event year. Substituting post-periods with fake event years, the fake DD estimates are generated by estimating the same equations as before. These placebos are treated as counterfactuals of the real analysis in absent of all the environmental policies implemented in Beijing. Across all five specifications, the fake DD estimates are never negative and significant, suggesting that in a counterfactual world without all the environmental policies there would be no change in air quality trends. Therefore, the DD estimates from the real analysis are causal.

TABLE 5— FALSIFICATION TEST OF THE EFFECT OF ALL ENVIRONMENTAL POLICIES ON AIR POLLUTION IN BEIJING

	(1)	(2)	(3)	(4)	(5)
04vs05	-2.283	-5.681	-5.681	-6.016	-6.003
	(5.348)	(4.964)	(4.964)	(4.413)	(4.426)
05vs06	3.732	4.595	4.595	5.857	6.089
	(5.792)	(5.308)	(5.308)	(5.055)	(5.094)
06vs07	0.00660	0.363	0.363	-0.309	-0.397
	(5.526)	(5.130)	(5.130)	(4.985)	(4.989)
0405vs0607	2.324	1.980	1.980	1.961	1.988
	(3.862)	(3.556)	(3.556)	(3.397)	(3.413)
09vs10	2.947	4.230	4.230	6.741*	6.795*
	(4.269)	(4.191)	(4.191)	(3.956)	(3.989)
10vs11	1.520	1.547	1.547	-0.594	-0.346
	(4.332)	(4.111)	(4.111)	(4.042)	(4.062)
0910vs1112	-0.903	0.621	0.621	-0.591	-0.487

	(3.120)	(2.943)	(2.943)	(2.861)	(2.874)

Notes: This table only reports estimates of the DD coefficient of the fake events. The specification is the same as reported in the main results table. Robust standard errors are in parenthesis.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

D. A Temporal Analysis

To evaluate the sole effect of the OWL, a control group need to pick up the sole impact of the OWL instead of other environmental programs implemented in Beijing. The nature of the OWL that only affect weekdays instead of weekends enable us to use weekends as a temporal control. Since all other changes such as the Olympic shock and other environmental policies are common to both weekdays and weekends, variations in weekday-weekend air quality before and after the OWL will identify the impact of OWL.

Two possible samples could be used in the temporal analysis: one is to use Beijing sample only; the other is to use Jing-Jin Bay sample which includes samples of both Beijing and Tianjin. The benefit of using Beijing's data only is that the impact may be more accurately reflected since the sample location is narrowed, though Beijing's data also contains air monitoring stations that are not enforced with the OWL. The advantage of using Jing-Jin Bay sample is that it may incorporate much information about the impact of the OWL since 30 percent of PM 10 pollution in Beijing comes from regional transmission according to EPB (2014). Therefore, the impact of the OWL in Beijing is very likely to spillover to Tianjin if regional transmission compose as an essential part of PM 10 pollution.

This subsection considers both cases in a DD setting similar as the previous analysis except for that the spatial variations between Beijing and Tianjin are substitute to weekday and weekend temporal variations. The temporal DD is run on two cases: Beijing's data only and the Bay area data containing both Beijing and Tianjin. The estimation equation of a basic DD method is shown as follows:

$$API_{it} = \beta_0 + \beta_1 After_t + \beta_2 Weekday_t + \beta_3 After_t * Weekday_t + \varepsilon_{it}, (1')$$

where API_{it} is the outcome variable of air pollution index of PM10 for city i at time t, $After_t$ denotes a dummy variable with value 1 if t is the date after the OWL, $Weekday_t$ is another dummy variable with value 1 if date t is a weekday, $After_t * Weekday_t$ is an interacted dummy with value 1 if date t is both a weekday and after the OWL, ε_{it} is a random noise term. β_3 is the coefficient we are interested in, which measures the effect of the OWL on air pollution based on variations in air pollution between weekdays and weekends after the OWL.

In addition to the main specification, alternative specifications including weather controls, city fixed effect, month fixed effect, and day of week fixed effect are also estimated similar to the spatial analysis. However, the specification with city fixed effect in Beijing sample is not valid since there is only one city available.

The main results from the temporal DD analysis using Beijing sample are presented in Table 6A and results using Jing-Jin Bay sample are presented in Table 6B. Across all specifications, the DD estimates are negative but not significant in the Beijing sample, but are negative and significant in the Bay sample. The lack of significance but similarity of magnitude in Table 6A suggest that using only Beijing's data may not be able to tell enough information about significance levels because of fewer observations in Beijing's analysis compared to the Bay's analysis. However, the estimates from the Bay analysis will only underestimate the impact if spillovers is not significant from Beijing to Tianjin.

TABLE 6A— THE EFFECT OF THE OWL ON AIR POLLUTION (2004-12): BEIJING SAMPLE

	(1')	(2')	(3')	(4')	(5')
After	-12.42***	-13.91***	-13.91***	-11.79***	-11.77***

	(3.905)	(3.728)	(3.728)	(3.577)	(3.576)
Weekday	4.148	3.421	3.421	3.206	1.596
	(3.451)	(3.222)	(3.222)	(3.032)	(4.438)
After_weekday	-7.359	-6.138	-6.138	-6.305	-6.308
	(4.620)	(4.332)	(4.332)	(4.137)	(4.137)
Weather controls	No	Yes	Yes	Yes	Yes
City fixed effect	No	No	No	Yes	Yes
Month fixed effect	No	No	No	Yes	Yes
Day of week fixed effect	No	No	No	No	Yes
Observations	2,436	2,436	2,436	2,436	2,436
R-squared	0.029	0.158	0.158	0.241	0.242

Notes: (1)-(5) denotes specification (1) to (5) as discussed in the empirical strategy section. The time window of 2004-12 does not include the year of 2008. Robust standard errors are in parenthesis.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

TABLE 6B— THE EFFECT OF THE OWL ON AIR POLLUTION (2004-12):: JING-JIN BAY SAMPLE

	(1')	(2')	(3')	(4')	(5')
After	-5.471**	-7.318***	-7.318***	-5.702***	-5.708***
	(2.431)	(2.292)	(2.292)	(2.189)	(2.190)
Weekday	3.274	2.441	2.441	2.138	1.214
	(2.012)	(1.893)	(1.893)	(1.808)	(2.524)
After_weekday	-6.403**	-5.074*	-5.074*	-5.339**	-5.325**
	(2.871)	(2.702)	(2.702)	(2.579)	(2.580)
Weather controls	No	Yes	Yes	Yes	Yes
City fixed effect	No	No	Yes	Yes	Yes
Month fixed effect	No	No	No	Yes	Yes
Day of week fixed effect	No	No	No	No	Yes
Observations	4,571	4,571	4,571	4,571	4,571
R-squared	0.056	0.165	0.165	0.242	0.242

Notes: (1)-(5) denotes specification (1) to (5) as discussed in the empirical strategy section. The time window of 2004-12 does not include the year of 2008. Standard errors are clustered at the city level and are presented in parenthesis.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Similarly, Table 7A and 7B presents the temporal DD analysis in both Beijing and Bay's sample with respect to time windows and specifications. Still, most of the DD estimates from the Beijing analysis are overwhelmingly negative but not significant, but most of the DD estimates from the Bay analysis are negative and significant, suggesting a significant reduction on air pollution in the Bay analysis. The magnitudes of the level estimates range from 5.1 to 7.6, which is roughly a 3 to 5 percent.

TABLE 7A— THE EFFECT OF THE OWL ON AIR POLLUTION BY TIME WINDOW: BEIJING SAMPLE

	(1')	(2')	(3')	(4')	(5')
2007-09	-9.017 (7.046)	-6.605 (6.412)	-6.605 (6.412)	-10.36* (6.230)	-10.26 (6.279)
2006-10	-9.954 (6.226)	-7.790 (5.785)	-7.790 (5.785)	-9.257 (5.628)	-9.221 (5.637)
2005-11	-8.100 (5.278)	-6.290 (4.897)	-6.290 (4.897)	-7.497 (4.692)	-7.491 (4.695)
2004-12	-7.359 (4.620)	-6.138 (4.332)	-6.138 (4.332)	-6.305 (4.137)	-6.308 (4.137)

Notes: The specification is the same as reported in the main results table. All time windows excludes the year of 2008. Robust standard errors are in parenthesis. The number of observations for each time window are 634, 1271, 1852, 2436, respectively. R-squared from (1) to (5) for each time window are 0.033, 0.157, 0.157, 0.254, 0.260; 0.030, 0.163, 0.163, 0.224, 0.227; 0.027, 0.164, 0.164, 0.234, 0.235; 0.029, 0.158, 0.158, 0.241, 0.242.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

TABLE 7B— THE EFFECT OF THE OWL ON AIR POLLUTION BY TIME WINDOW: JING-JIN BAY SAMPLE

	(1')	(2')	(3')	(4')	(5')
2007-09	-6.235 (5.222)	-2.812 (4.947)	-2.812 (4.947)	-6.636 (4.718)	-6.764 (4.720)
2006-10	-7.420* (4.099)	-5.067 (3.862)	-5.067 (3.862)	-6.429* (3.736)	-6.354* (3.735)
2005-11	-7.346** (3.307)	-5.223* (3.105)	-5.223* (3.105)	-6.370** (2.986)	-6.354** (2.986)
2004-12	-6.403** (2.871)	-5.074* (2.702)	-5.074* (2.702)	-5.339** (2.579)	-5.325** (2.580)

Notes: The specification is the same as reported in the main results table. All time windows excludes the year of 2008. Standard errors are clustered at the city level and presented in parenthesis.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Table 8 reports placebo effects of estimates of the DD coefficient of all available fake events. Across all specifications, the estimates of the fake DD coefficient are not significant, suggesting there does not exist any significant change on air pollution between weekdays and weekends in the Bay sample. This lack of significance in the fake events also verifies that the estimates we get from the Bay's real analysis are causal.

TABLE 8—FALSIFICATION TEST OF THE EFFECT OF OWL ON AIR POLLUTION: JING-JIN BAY SAMPLE

	(1')	(2')	(3')	(4')	(5')
04vs05	-2.600	-5.208	-5.982	-3.621	-3.638
	(6.201)	(5.756)	(5.584)	(4.991)	(4.997)
05vs06	4.344	5.805	6.122	6.817	7.088
	(6.576)	(6.084)	(6.005)	(5.630)	(5.618)
06vs07	7.214	3.136	2.789	3.262	3.252
	(5.975)	(5.496)	(5.412)	(5.274)	(5.272)
0405vs0607	6.418	4.233	4.063	5.479	5.531
	(4.352)	(4.033)	(3.939)	(3.728)	(3.733)
10vs11	-2.838	-3.650	-3.465	-4.068	-4.021
	(5.892)	(5.495)	(5.476)	(5.361)	(5.250)
11vs12	6.872	5.997	6.149	6.694	6.751
	(6.315)	(6.100)	(6.098)	(5.849)	(5.843)
0910vs1112	-3.949	-4.738	-4.637	-3.684	-3.637
	(4.090)	(3.945)	(3.944)	(3.867)	(3.826)

Notes: This table only reports estimates of the DD coefficient of the fake events. The specification is the same as reported in the main results table. Robust standard errors are in parenthesis.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

V. Conclusion

Beijing's OWL was accompanied by both an economic boom such as an Olympic Games shock as well as other environmental policies such as plant relocations, subway extensions, and introduction of new emission standards. This paper applies both a spatial DD analysis and a temporal DD analysis to sequentially control for the Olympic Games and other environmental policies. It finds that Beijing's environmental programs as whole contribute to 14 to 21 percent significant reduction in the API of PM 10 pollution. However, the OWL only contribute to a 3 to 5 percent reduction of the API of PM 10 pollution. This new estimates are consistent with new estimates of the impact of Mexico City's driving restriction presented in the previous chapter. But they are far small than the estimates obtained from previous studies of a 21 percent reduction on air pollution. This new finding suggest that the impact of driving restrictions may be generalized across both time and country.

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Chapter 3
The Air Speaks: Evaluating the Effect of China's Anti-Corruption Drive from An Air Quality Perspective

ZHENG LIU

Abstract

In May 2013, Chinese President Xi Jinping launched an ambitious anti-corruption drive (ACD) that prohibits various forms of corruption among party officials. Given most forms of corruption such as bureaucratic banquets/visits involve the use of motor vehicles, the ACD could indirectly reduce the use of motor vehicles and hence pollutants mainly emitted from them. This paper identifies the effect of the ACD through the exogenous variations in air quality generated by the ACD in metropolitan Beijing and suburb Beijing before and after the program. It finds that the ACD has significantly reduced PM2.5 by at least 4.7 percent, the magnitude of which is similar as imposing a one weekday per week driving ban.

Keywords: anti-corruption; air pollution; difference-in-differences

I. Introduction

Corruption has been a severe problem in China. According to the 2016 Corruption Perceptions Index (CPI) reported by Transparency International, China was ranked 79 out of 175 among least corrupted nations. Due to China's one party sole charge system, corruption has become extensively severe among communist party officials. The most common forms of corruption among party officials include misuse of official cars, bureaucratic visits and banquets, which are essential components of Chinese culture. By 2012, nationwide annual public expenditure on eating and drinking had reached a total of RMB 300 billion (roughly 50 billion US dollars) among government officials.[27] Based on a government proposal from the Revolutionary Committee of the Chinese Nationalist Party, the total number of government vehicles is around 2 million and the cost to maintain these vehicles per year is roughly 150 to 200 billion yuan (roughly 25 to 33 billion US dollars).

As both driving and dining involve the extensive use of motor vehicles, corruption on wheels has been popularized in China. Officials with any rank worked towards getting an official car and maintain it using government bill. An official car usually bundled with a driver whose salary is paid by government bill as well as gasoline and maintenance cost. The free riding benefits of official cars has encouraged both officials and drivers to extensively use the cars for their private needs. Official cars were commonly seen as tools for picking up kids, shopping, traveling, dining, etc. Three usages of official cars have been summarized by Internet rumors: the official usage of the official car, the private usage of the car official, and the private usage of the car driver.

[27] Source: http://theasiadialogue.com/2017/01/09/eating-and-drinking-in-chinese-officialdom/

Since Xi Jinping became China's new president in 2012, he has dedicated to fix China's severe corruption issues. At a meeting of the Politiburo of the Communist Party of China on December 2012, President Xi has stipulated an Eight point Regulation that controlled for officials corrupted behaviors. To further enforce this regulation, Xi launched an anti-corruption drive (ACD) by sending out ten inspection teams in May 2013 to physically monitor and punish party officials' corrupted behaviors. Behaviors such as misusing and misprocessing of government vehicles, bureaucratic banquets and visits are highly monitored. Once officials have been caught, immediate punishment will be enforced ranging from position dismissing to jails. The strict enforcement of the ACD had threatened party officials. Since its immediate start, restaurants sales were decreased by 30 percent, luxury car sales were dropped down and the exchange of Macau's casinos market was also reduced sharply.[28] All of these market shocks have revealed that the enforcement of the ACD is strict and have overwhelming effect than previous anti-corruption events.

Since the worldwide measures of corruption - CPI are computed based on perceived amount in the public sectors, the unperceived amount and corruption in private sectors are still unknown and interesting to researchers. Up to date, there is still no measure of the exact amount in terms of both perceived and unperceived corruptions. Therefore, this paper tries to solve the research gap of missing exact corruption measures by identifying new measures of corruption based on China's corruption culture.

Given that the major pollutant from motor vehicles is particulate matter (PM), the impact of the ACD can be identified by variations in PMs. As China's capital, Beijing has the largest number of party officials and hence possibly the largest number of official cars. Though it has been reported

[28] New York Times.

that there were 62,026 official cars by the end of 2010 in Beijing[29], the exact amount was still a mystery. It has been widely spread on the Internet that the real amount was indeed 700,000, which is 10 times higher than the public reported amount.[30] In addition, official cars compose a considerable fraction across all motor vehicles in Beijing (i.e., the total number of motor vehicles in Beijing at 2013 was roughly 4 million). Beijing is therefore an ideal city to examine the ACD's impact. Using PMs as the measure of corruption in this paper is initial and novel in corruption's literature, which often use the perceived corruption such as the official caught rate as their measures.

This study applies a difference-in-differences (DD) to examine the ACD's impact by comparing variations in PMs. Given that most party officials as well as luxury restaurants and recreation zones are located in metropolitan Beijing, air quality in suburb Beijing has been chosen as a spatial control. Months before the ACD are used as the temporal control for months after the ACD. Daily air pollution indexes (API) of PM2.5 concentrations across air monitoring stations in both metropolitan and suburb Beijing are used as the measure of air quality. This paper finally finds that the ACD has led to a 4.7 percent significant reduction in air quality, the magnitude of which is similar as imposing a one-weekday-per-week driving ban in Beijing.

II. Literature Review

Table 1 summarizes recent literature on the impact of the ACD or literature examining the environmental impact of anti-corruptions by fields, research topics, and results. Most literature have evaluated the ACD's impact on macroeconomic conditions such as economic growth (Wang

[29] Beijing's Municipal Public Finance Bureau reports.

[30] See https://www.rfa.org/mandarin/yataibaodao/che-04062011092850.html

2016), firm's behaviors (Dang and Yang 2016, Xu and Yang 2017, Kong et al. 2017, Liu et al. 2016, Pan and Tian 2017, Wang et al. 2018), and credit risks (Qian 2018). Only two literature have investigated the impact of anti-corruption on the environment, though not directly related to the recent ACD.

TABLE 1—RECENT LITERATURE RELATED TO THE ACD OR THE ENVIRONMENT

Fields		Topics	Results
	Panel A. Macroeconomics		
Economic Growth	Wang (2016)		-0.1%
Firm's Behaviors	Dang and Yang (2016)	Firm innovation in R&D	+
	Xu and Yano (2017)	Firm innovation in R&D acquired	+
	Pan & Tian (2017)	Event Firm's investment	- expenditure + efficiency
	Kong et al. (2017)	Firm performance	+ SOEs - non SOES
	Wang et al. (2018)	Firm value	- 2%
Credit Risks	Qian (2018)	Local financing vehicles	-
	Panel B. Environmental Economics		
Air Pollution	Li et al. (2018)	SO_2 emissions	-
	Liao et al. (2017)	CO_2 emissions	- western China

Notes: + denotes a positive effect and – denotes a negative effect.

Source: Author summarized.

Applying a panel data method within Chinese 29 provinces from 1999 to 2012, Liao et al. (2017) claimed that an increase in the number of anti-corruption cases improved SO2 emissions. Their explanation is that bribes from firms to governments with the intention of lowering firms' environment standards would deteriorates pollutions. Using similar provincial level data from 1995 to 2011, Li et al. (2018) found that anti-corruption campaigns significantly improved CO2 emissions in western China but not in eastern and central China. They have suggested customizing anti-corruption policies by different regions in China.

In contrast to these two literature, this study initially evaluates the impact of China's most recent ACD, which designed directly on corruption behaviors in official's daily lives. Instead of restricting bribes on firms, restricting officials' corrupted behaviors among their daily lives would directly reduce emissions when perform those corruptions. Besides, my study applies a DD approach between metropolitan Beijing and suburb Beijing, which also differs from previous literature that utilized a panel provincial level approach.

Besides the literature examining the relation of anti-corruption and the environment, most literature focused on evaluating the ACD's impact on firm's behaviors. The ACD was found to affect firm's behaviors in several ways: firms' innovation, firms' investment, and firms' performance. First, the ACD was found to have encouraged firms' innovation by increasing research and development (R&D) investments as it discouraged political connections, both of which are found to be two mutual exclusive major channels for firms' growths. (Dang and Yang 2016) The ACD was found to have made firms more likely acquire long-term debt, which have also been used into R&D innovations and patent generations. (Xu and Yano 2017) Second, the ACD was found to have decreased event firms' investment expenditure relative to non-event firms, especially for non-State Owned Enterprises (SOEs); it was found to have improved event firms' but have declined non-event firms' investment efficiency compared to their non SOEs counterpart. (Pan and Tian 2017) Third, the ACD was found to have increased performance of SOEs but decreased performance of non-SOEs measured by returns on equity and returns on sales. (Kong et al. 2017) It was also found to have decreased private firms' equity value by 2 percent. (Wang et al. 2018)

In addition to the main body of the ACD's impact on firm's behaviors, there are also one literature examining the ACD's impact on economic growth and one literature evaluating the impact on local financing vehicles. The ACD was found to have curbed economic growth by roughly one percent measured by quarterly GDP when there was one more official ranking higher than vice department of provincial level. (Wang et al. 2016) It was also found to have decreased earnings of local financing vehicles (LFVs) and therefore increased the credit risk of LFVs. (Qian 2018)

III. Measure of Corruption

According to EPB 2014, both local emissions and regional transmissions contribute to total PM 2.5 pollution in Beijing, where local emissions account for 64 to 72 percent of total PM 2.5 pollution and regional transmissions account for 28 to 36 percent of total PM 2.5 pollution. Based on source analysis of local emissions, motor vehicles' emissions are the major source and account for 31 percent. Other sources of local emissions are from burning coals, industrial production, road dusts and several others, which account for 22 percent, 18 percent, 14 percent and 14 percent respectively. Therefore, emissions from motor vehicles are still the major source of total PM 2.5 pollution in Beijing and variations in motor vehicle emissions are a determinant factor in total PM 2.5 variations. If official cars account for 17 percent of total cars as widely spread on the internet, the elimination of corruption may have triggered significant changes in PM 2.5 pollution in Beijing. As the major pollutant emitted by motor vehicles,[31] PM 2.5 has been used as measure of air quality in this chapter.

Since 2013, China introduced internationally recognized measures of air quality, denoted as air quality indexes (AQI). Similar as the reporting criterions of the previous air pollution indexes (API), only pollutant with the highest concentrations will be recorded as AQI. There are two official recognized agencies report Beijing's AQI but they have different reporting structures. In

[31] See Beijing EPB (2014). http://www.bjepb.gov.cn/bjhrb/xxgk/jgzn/jgsz/jjgjgszjzz/xcjyc/xwfb/607219/index.html

contrast to the hourly city level AQI reported by Ministry of Environmental Protection (MEP) in People's Republic of China, Beijing's Municipal Environmental Protection Bureau (EPB) report daily stationary AQI. PM 2.5 was the most frequent pollutant appeared on stations in both metropolitan Beijing and suburban Beijing. After deleting invalid reporting and AQI of non PM2.5, there were 28 air monitoring stations left with valid readings of PM2.5. Across these 28 air monitoring stations, 13 stations are located in suburb Beijing and the other 15 stations are located in metropolitan Beijing.

IV. Empirical Strategy

A. Choice of A Control Group

In order to get the effect of the ACD, the control area should have less corruption but similar air pollution trend with the treated area. Since both weather and economic growth are major determinations of variations in air pollution, the control group needs to be located at the similar geographic area as Beijing. This condition restricted our control candidates to be locations nearby Beijing. However, since every city exhibits a sufficient number of party officials, the control group cannot be chosen from single cities in order to have less corruption. This leads us to think the possibility of using partial area as a control. Given that most luxury restaurants and government officials are located in the metropolitan area of Beijing (i.e. within the Fifth Ring), the suburb area of Beijing (i.e. outside the Fifth Ring) may serve as a good control group. To further confirm suburb Beijing is indeed a good control, the same air quality trend assumption needs to be satisfied. This assumption has been tested in the results section.

Since officials need transportation from their work places to bureaucratic visits and banquets, dine in luxury restaurants and visit recreation sites that are largely located in metropolitan Beijing, there expected to be sharp reduction in car emissions when these behaviors were prohibited compared to a counterfactual world when the ACD was not in effect. Therefore, given suburb Beijing as the counterfactual world, there expected to be sharp reduction in air pollution after the ACD in metropolitan Beijing compared to suburb Beijing.

B. Study Period

Because of the nature of corruption that is hard to monitor, the impact of ACD really depends on the caught rate of corrupted officials. The reported caught rate has only been realized after the inspection team was sent out and finished the caught. Therefore, there exists a transitional period from the announcement of the ACD to the performance end date of the inspection team. The starting date of the ACD (May 1, 2013) through the most violation caught month (Sep, 2013) is defined as the transitional period in this paper. The treatment period is defined as the date after most violations were caught.

For the real analysis, I first compare each cumulative months before the ACD (i.e.: first 1 month, first 2 months …) in 2013 with the same cumulative months after the ACD in 2014, which will provide clean DD estimates of the ACD. Then, I compare each cumulative months before the end of the transitional period (i.e.: first 5 months, first 6 months …) in 2013 with the same cumulative months after the end of the transitional period in 2014, which yield contaminated but downward biased DD estimates of the ACD. The dataset after the transitional period (i.e. after September) will serve as counterfactuals. For robustness checks, I basically compare the reverse cumulative months after the ACD (last 1 month, last 2 months …) in 2013 with the same reverse cumulative months after the ACD in 2014.

C. Air Quality Trends

Figure 1A and Figure 1B plots yearly AQI in Beijing by air monitoring stations in 2013 and 2014. The orange colored spots denote treated stations, which are stations located in metropolitan Beijing. The blue colored spots denote control stations, which are stations located in suburb Beijing. The plots show that the AQI in metropolitan stations is higher than the AQI in suburb stations for both years. In addition, both metropolitan and suburb stations experienced an increase in AQI for both years. However, suburb stations experienced more growth than metropolitan stations.

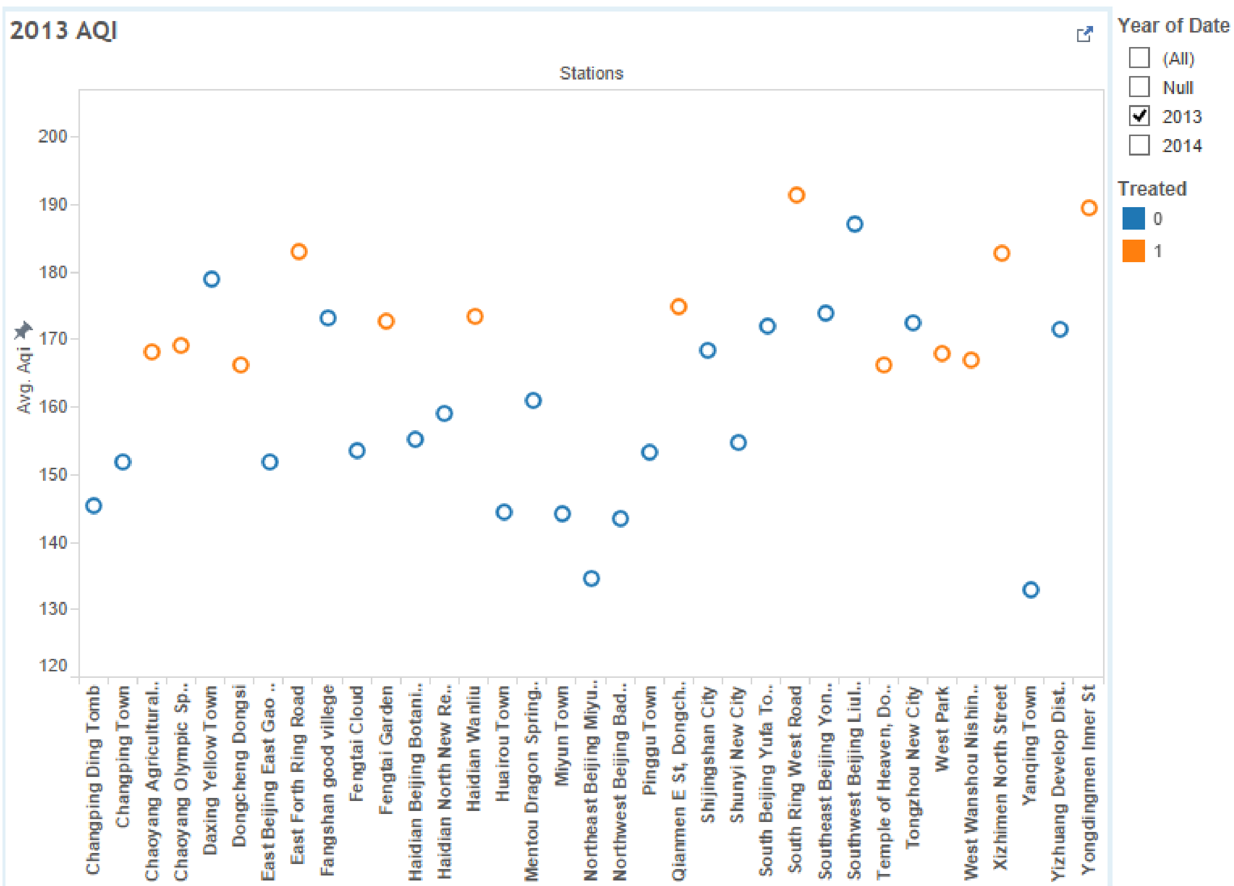

FIGURE 1A. AQI IN BEIJING BY STATION (2013)

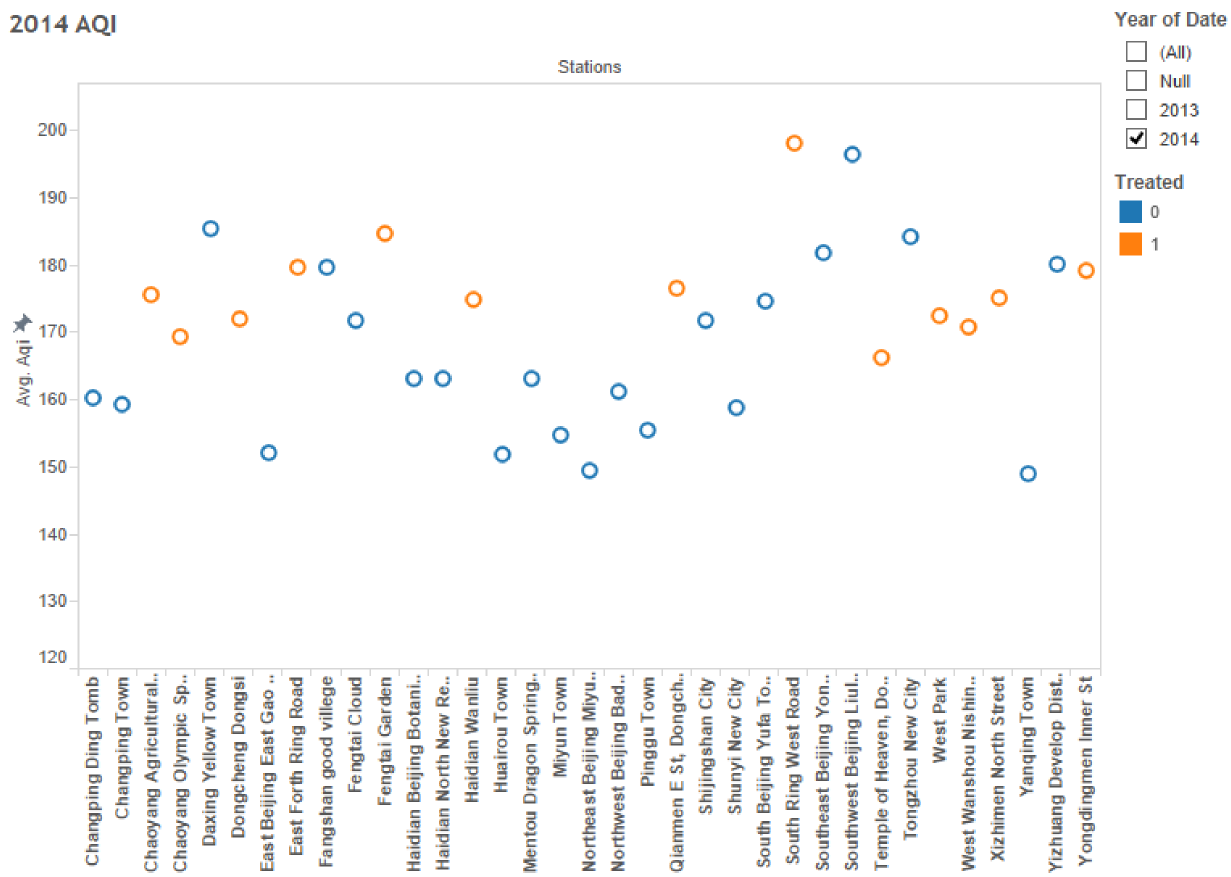

FIGURE 1B. AQI IN BEIJING BY STATION (2014)

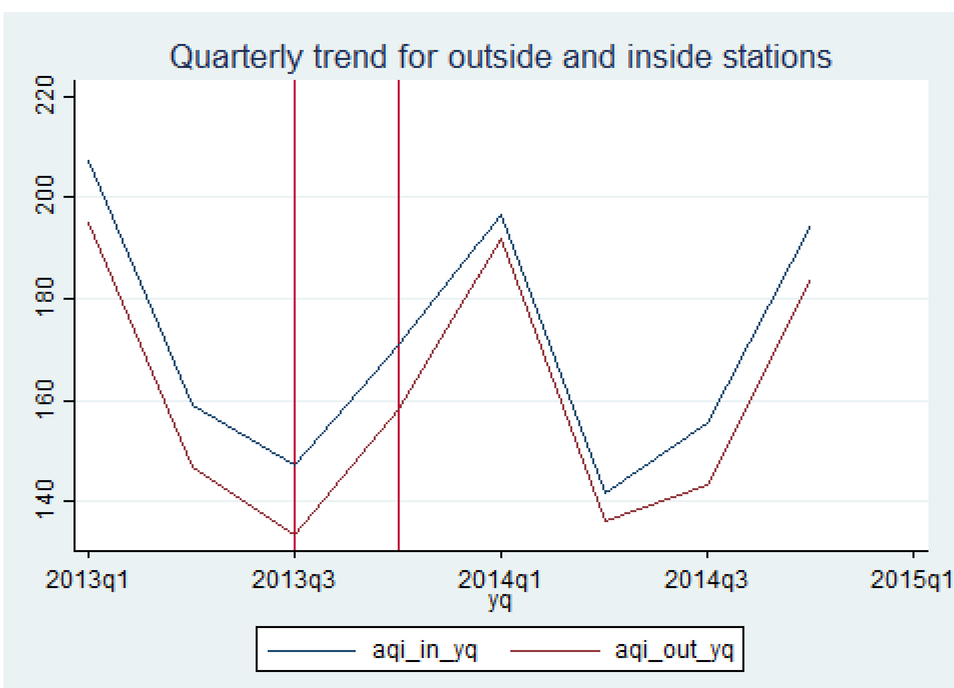

FIGURE 2 AIR QUALITY TRENDS IN METROPOLITAN AND SUBURB BEIJING

Figure 2 plots quarterly air quality trends in stations aggregated across metropolitan Beijing and stations aggregated across suburb Beijing from 2013 to 2014. It can be seen that there exists a parallel trend between metropolitan Beijing and suburb Beijing before the year of 2014. However, the air quality gap narrowed from the fourth quarter of 2013 to the first quarter of 2014. After that, air quality maintain a parallel trend and have a phase widening while go back to the parallel trend again until the end of 2014. The narrowed air quality gap from the end of 2013 to the beginning of 2014 is the period I am interested in since it is shortly after the ACD was put into place.

D. The Effect of ACD on Air Quality

Given suburb Beijing as the spatial control for metropolitan Beijing and the months in 2014 as the temporal controls for months in 2013 before the ACD, I employ a standard DD method to identify the impact of the ACD. The estimation equation is as follows:

$$PM2.5_{it} = \beta_0 + \beta_1 * Metropolitan_i + \beta_2 * After_t + \beta_3 Metropolitan_i * After_t + \varepsilon_{it}$$

where $PM2.5_{it}$_it denotes the AQI of PM2.5 in station i at time t, $Metropolitan_i$ denotes the dummy variable that takes the value of 1 if station i is located in the metropolitan area, $After_t$ is another dummy variable that equals 1 if t is after the date of the ACD (Sep 30, 2013), $Metropolitan_i * After_t$ is an interacted dummy denoting the treatment area with value 1 if both station i is located in the metropolitan area and the time t is after the date of the ACD, and ε_{it} is an error term. β_3 is the coefficient of our primary interest, which denotes the average treatment effect of the ACD.

TABLE 2—THE EFFECT OF THE ACD ON PM 2.5 CONCENTRATIONS: DIFF-IN-DIFF

	Month 1	Month 1-2	Month 1-3	Month 1-4	
AQI	-11.348	-12.741*	-8.944	-6.933	
	(10.119)	(7.739)	(6.107)	(5.227)	
	[1657]	[3189]	[4569]	[5664]	
Log AQI	-0.033	-0.068*	-0.047	-0.036	
	(0.050)	(0.040)	(0.033)	(0.028)	

	Month 1-5	Month 1-6	Month 1-7	Month 1-8	Month 1-9
AQI	-6.278	-8.710**	-8.517**	-8.225**	-6.916**
	(4.715)	(4.291)	(3.888)	(3.658)	(3.387)
	[6500]	[7388]	[8352]	[9027]	[10105]
Log AQI	-0.032	-0.045*	-0.047**	-0.045**	-0.036*
	(0.026)	(0.024)	(0.022)	(0.021)	(0.019)

	Month 1-10	Month 1-11	Month 1-12		
AQI	-7.476**	-6.868**	-7.966***		
	(3.253)	(3.117)	(2.991)		
	[11554]	[12791]	[13994]		
Log AQI	-0.041**	-0.038**	-0.042**		
	(0.019)	(0.018)	(0.017)		

Notes: This table only reports estimates of the coefficient of the interacted dummy. For each month combinations, the left panel reports the results on AQI and the right panel reports results on log AQI. Standard errors are in parentheses. The last row of the left panel are number of observations.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Table 2 reports the DD estimates of the effect of the ACD on the API of PM 2.5 concentrations by nested month combinations. As introduced in the previous section, the results are divided into three groups presented by each row. The first group is by comparing the first month up to the first four months in 2013 versus 2014, which are clean results. It can be seen that the coefficients are negative but not significant for most of the month combinations. The non-significant sign for most combinations is not surprising as the number of observations is small for the first group.

The second group reports the DD estimates of the ACD's impact on the transitional period. It can be seen that most of the estimates are negative and significant, suggesting that the ACD caused a significant reduction on PM 2.5 pollutions during the transitional period. The magnitude of the effect first increase and then decrease, suggesting that the ACD began to have its impact in the middle month between May and September. As we are not sure since which month the ACD starts to have effect, the results got from the second group can only provide an underestimate of the real effect of the ACD. The largest impact we got are from the first seventh months, which is a 4.7 percent significant reduction on PM 2.5 pollution. As the results are contaminated downwardly, we could say that the real effect of the ACD is at least 4.7 percent measured by the API of PM 2.5 concentrations.

Moving to the third group, it reports the estimates of contaminated results from the first ten months up to the whole year. As it includes both months affected by the ACD in 2013 as well as in 2014, the results are contaminated and expected to be smaller than the impact we found in the second group. The overall negative and significant estimates verify that the impact of the ACD we found in the second group are true. The magnitude of the impact in the third group is smaller than the largest effect we found in the second group, which also verifies that the month of which the ACD starts to have impact was in the transitional period.

E. Placebo Tests

TABLE 3—THE EFFECT OF PLACEBOS ON PM 2.5 CONCENTRATIONS: DIFF-IN-DIFF

	Month 12	Month 11-12	Month 10-12		
AQI	0.947	1.811	-1.668		
	(10.680)	(7.558)	(6.160)		
	1203	2440	3889		
	Month 9-12	Month 8-12	Month 7-12	Month 6-12	Month 5-12
AQI	-1.214	-1.738	-2.729	-5.178	-5.064
	(5.169)	(4.640)	(4.079)	(3.754)	(3.482)
	4967	5642	6606	7494	8330

Notes: This table only reports estimates of the coefficient of the interacted dummy. The last row of each panel records the number of observations.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

To further verify that the impact we found are causal, this subsection performs a placebo tests. The placebos are chosen from months that are fully experienced the ACD and months that are partially experienced the ACD (i.e.: during the transitional period). The first group of Table 3 reports clean results for months fully experienced the ACD. All estimates are not significantly different from zero, suggesting that there was no significant difference in air quality change between metropolitan Beijing and suburb Beijing in absence of the ACD.

Moving to the second group, which reports the estimates of the impact of the possibly contaminated placebos, all the estimates are still not significant. The results suggest that even for placebos that are possibly contaminated by the ACD, there was still no significant difference in air quality trends between metropolitan Beijing and suburb Beijing. The results from these placebos further confirm that the effect we found in the real analysis is causal.

V. Conclusion

Given that Beijing has most party officials, most common forms of corruption involve the use of motor vehicles, and emissions from motor vehicle are the major source of PM 2.5 pollution, this study initially uses air pollution of PM 2.5 as a novel measure of corruption. Taking the advantage of the fact that most luxury restaurants and recreation sites are located in metropolitan Beijing, this study uses suburb Beijing as spatial control. It finds that the impact of China's recent ACD was at least 4.7 percent measured by reduction in air pollution.

It has been widely spread on the internet that Beijing's official cars were indeed 10 times more than the officially reported number 62,026 by 2010. Based on the PM 2.5 source analysis reported by EPB (2014), motor vehicle emissions accounted for roughly 21 percent of total PM 2.5

pollution, and Beijing has roughly 5 million motor vehicles in the year of 2014. A back of the envelop calculation may support the rumor that Beijing indeed has 700,000 official cars in 2010.

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