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Assessing Driving Restrictions: Evidence from Delhi's Odd-Even Scheme

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Abstract: ***In this paper, we present the analysis of odd – even scheme implemented in Delhi. In a random fixed effects model, we use difference-in-differences (DD) and difference-in- difference-in-differences (DDD) research design that draw on temporal variation and spatial variation to identify the effects of the scheme. We use pollution levels as our outcome measure and define our treatment group to be the set of peak traffic hours in the restricted zone. We exploit temporal variation by using a DD strategy that compares the change in pollution during peak hours inside the restricted zone to the change in pollution during off- peak hours in the same zone. Spatial variation is exploited by using a DD strategy that compares the change in pollution during peak hours inside the restricted zone to the change in pollution during the same hours outside the restricted zone. Both types of variation are also exploited with a difference-in-difference-in-differences strategy. In the section 2, we present a review of the existing literature on driving restrictions. In section 3, we provide some more detail about Data sources, the odd-even program, along with background information about Delhi and its air quality. Our empirical strategy is described in section 4 and section 5 with Results.***

Keywords: Difference –in-Difference strategy, Odd Even Scheme, PM2.5

1. Introduction

Large cities across the developing world face problems of road traffic congestion and pollution. Driving restrictions or road space rationing measures are a popular set of policies that aim to directly reduce traffic congestion and urban air pollution. These policies consist of barring drivers of private cars to access public roads only on certain days, usually based on the digits of their license plate. The first round of Odd-Even rule was implemented in Delhi from 1st January 2016 to 15th January 2016 and second round was from 15th April to 30th April 2016. During this period only odd numbered passenger cars were allowed to ply on odd days and even numbered cars on even days between 08:00 and 20:00 hours. The rule did not apply on Saturdays and Sundays and the following vehicles were exempted: all taxis, passenger cars operating on CNG and electric power, cars with only women passengers, and all motorized two wheelers. All school were closed during first round of the policy.

This paper estimates the impact of the odd-even program on air quality. To do so, we use high frequency data from monitoring stations to compare fine particulate concentrations in Delhi (where the odd even policy was implemented) to that reported for the neighboring towns of Faridabad and Gurgaon (where the policy was not implemented). In contrast, Delhi's air did not show any quality gains relative to its neighboring cities during the April phase of the program. A likely cause is that the warmer month of April is marked by greater dispersion of particulates, a fact that is reflected in Delhi's lower particulate concentrations during summer relative to the winter. In contrast, the winter month of January is marked by thermal inversion, a phenomenon where a layer of hot air covers cold air near the ground. This, in turn, causes air pollution to be trapped near the ground.

Indian cities, however, routinely exceed these norms. Greenstone et al, (2015) estimated 660 million Indians (or 54.5 % of the population) live in regions exceeding the national standards and reducing the pollution levels just to meet standards could increase life expectancy by 3.1 years on average. In this paper we focus on air quality in Delhi and neighboring cities and below we provide some background on Delhi's air quality as a precursor to our quantitative analysis.

There is a debate on why the pollution is not reduced. A middle class family who possess one car for commuting daily is more worried about the outcome of the trials. In general, citizens of India and Delhi are keeping the hope of an official declaration of failure / success of the experiment and what would be the next step, either one more trial or implementing the rule permanently or close the pilot project permanently.

Several studies have examined the effectiveness of driving restrictions programs, focusing primarily on their ability to improve air quality. In the previous literature on the effects of license plate-based driving restrictions, Eskeland and Feyzioglu (1997) examine the effect of Hoy No Circula on gasoline demand and car ownership in Mexico City during the period 1984-1993. Davis (2008) measures the effect of Hoy No Circula on air quality during the period 1986-1993 by using a regression discontinuity design to control for possible confounding factors. These two studies find no evidence that Hoy No Circula improved air quality in Mexico City. Two more recent papers, find that restrictions are successful at reducing CO and PM-10 in Quito and Beijing, respectively, Carrillo et al 2015; Viard and Fu 2015.

2. Existing Literature

Air pollution and its health consequences are a major concern in Delhi, which was ranked second "most polluted city" in the world in 2016 for suspended particulates by World Health Organization. Particulate matter is linked to cardiopulmonary diseases, respiratory infections, and lung cancer (EPA, 2004), and increases infant mortality (Chay and Greenstone, 2003). Other air pollutants also have negative health effects linked to infant mortality (Currie and Neidell, 2005) and childhood asthma (Neidell, 2004).

Although driving restrictions have been in place for a long time and discussions are ongoing about whether to adopt similar restrictions in places around the world, there are not many studies, empirical or theoretical, of the effect of driving restrictions on air quality. Davis (2008) measures the effect of Hoy No Circula on air quality using hourly air pollution records from monitoring stations in Mexico City. Using a regression discontinuity (RD) design with pollution levels before the implementation of Hoy No Circula as a comparison group to control for seasonality, pollution levels of five major pollutants before and after the restrictions are compared. A regression discontinuity design (RDD) is a quasi-experimental pretest- posttest design that elicits the causal effects of interventions by assigning a cutoff or threshold above or below which an intervention is assigned. This study found no evidence that Hoy No Circula improved air quality in Mexico City.

Gallego, Montero, and Salas (2013) found that the Hoy No Circula (HNC) program in Mexico City, which banned most drivers from using their vehicles one weekday per week, was ineffective. HNC induced many households to buy additional cars (mainly old and highly polluting ones).

Study by Troncoso et al. (2012) examines the effect of permanent driving restrictions that have been in place in Santiago since 1998 in autumn and winter on air pollution. It found that the temporary restrictions reduce daily average concentrations of a number of air pollutants on weekdays but not on weekends.

Bonilla (2013) conducts a detailed study of Bogota’s Pico y Placa program introduced in 1998 to reduce congestion. For the first 10 years, the program restricted vehicles only during morning and evening peak hours. In 2009, the restrictions were extended to cover 14 hours of the day. Using data on ambient CO (carbon monoxide) concentrations, Bonilla studies the program’s effectiveness using a regression discontinuity design that incorporates an autoregressive distributed lag model. He finds that the program reduced CO concentrations in the first few months after its introduction, but the reductions subsequently disappeared. Similarly, the increase in program stringency in 2009 reduced CO concentrations during off- peak hours, but these reductions were sustained for less than a year. He attributes this increase to household purchases of additional vehicles to circumvent the more stringent restrictions.

Chen et al. (2013) study the air quality effects of measures imposed before, during and after the Beijing Olympic Games. It supplements the API data with data on aerosol optical depth (AOD) which is an indirect measure of air pollution. They find that the stringent, temporary driving restrictions imposed during the Games were effective in reducing both API and AOD, but the less stringent, permanent restrictions imposed after the Games were not. Viard and Fu (2015) study the permanent post-Olympics restrictions using exclusively the API data. They find that the restrictions reduced particulate matter pollution by 7% to 19%.

Carrillo et al. (2016) analyse Pico Ya Placa program in Quito which went into effect in 2010. Using series of hourly pollution and meteorological data for the parts of the city, Carrillo studies difference-in-differences (DD) and difference-in-difference-in-differences (DDD) research designs to identify the effects of the program. He finds that the program significantly reduced ambient concentrations of carbon monoxide since its introduction. The estimated reductions for peak hours range from 9% to 11%. No significant evidence was found regarding the increase in concentration at other hours of the day or week, or at other locations.

In sum, existing studies indicate that driving restrictions have been successful in reducing air pollution or traffic congestion only to some extent.

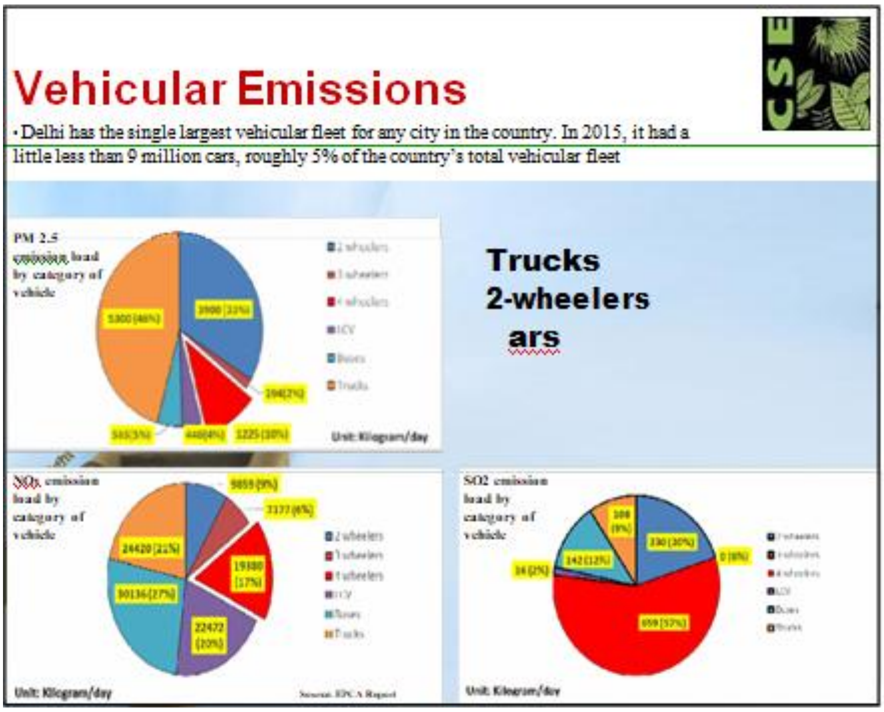
3. Data Sources and Variables

Delhi air quality data was collected from the Delhi Pollution Control Committee and Central Pollution Control Board websites which is publicly available (Secondary data) for the time period between from 15th December, 2015 to 15th January, 2016 and 1st April to 30th April, 2016 across all the stations for various parameters such as NO2, SO2 and PM2.5. The stations observed were Punjabi Bagh, Dwarka, R.K.Puram, Mandir Marg, Shadipur, IHBS and Anand Vihar as treated groups and Gurgaon, Faridabad were control groups. The data analysis for days preceding (period from 25th to 31st December, 2015) shows that during pre-odd-even scheme, the pollutants viz., PM2.5 (52-298 µg/m3); SO2 (4-31 µg/m3); NO2 (5-116 µg/m3) and CO (114 – 1244 µg/m3). The average PM2.5 concentration in Delhi’s air was 68.98 micrograms per cubic metre (µg/m^3) during the odd-even period, from April 15 to April 29, indicating “moderate” conditions, which increased from 56.17µg/m^3, indicating “average” air quality between April 1 and April 14. During the odd-even period, 7 am was the worst hour in Delhi, based on hourly averages between April 15 and April 29, with PM2.5 levels indicating “poor” air-quality levels of 124.3µg/m3, a 31% increase (94.67µg/m3) in the hourly average recorded at the same time Before the rule was implemented from April 1 to April 14.

- Evening 5 PM2.5was the best hour for Delhi during the odd-even phase, with PM2.5 levels at 21µg/m3, indicating “good” air quality.
- Data on meteorological variables Relative Humidity and Temperature, wind speed, wind direction were taken from India Meteorological Department, Ministry of Earth Science, Govt. of India

4. Background

Typical winter conditions -- cold temperature, lower mixing height of air, calm and no- wind conditions trap air and pollution. As a result, pollution builds up very quickly and peaks. This is why winter months require tougher emergency action to reduce pollution. Weather is an important constraint in pollution management. The winter months of November and December 2015 show higher number of days in severe category- four times the safe standard – which is the worst category according to the National Air Quality Index. November 2015 had 73% of days in severe category against 53% in November, 2014. December 2015 has 67% of days in severe category as against 65% in December 2014. December 2014 at least had 3% of days in good and satisfactory category but December 2015 has none.



Vehicular Emissions

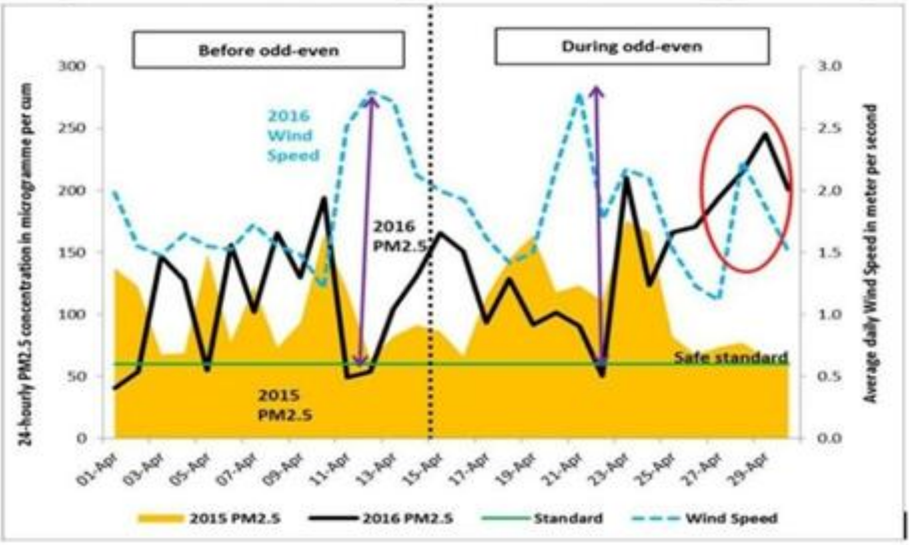
- Delhi has the single largest vehicular fleet for any city in the country. In 2015, it had a little less than 9 million cars, roughly 5% of the country's total vehicular fleet

Trucks
2-wheelers
ars

Source CSE

It is to be noted that the average concentrations of the pollutants are lower in summers, hence the phase 2 was implemented in April to seek the effectiveness of the scheme in summer season. CSE analysis of odd-and-even scheme shows air pollution dropped during first 10 days of the scheme but suddenly increased April 23 onwards. The sudden spike in pollution after April 23 had to have a reason. CSE therefore investigated based on NASA satellite imagery (NASA web fire mapper) and found that before the odd-and-even scheme and during the first few days, there was virtually no crop fire in Punjab and Haryana. But April 21 onwards, there was a sudden spurt in crop fires that became widespread and intense from April 23 onwards. April 26 was particularly bad. During the spike, the pollution levels increased despite the increase in wind speed.

Graph 1: PM 2.5 levels before and during second odd and even scheme (April 1 –30, 2016)



Air pollution

First, *Particulate Matter* which is a complex mixture of both organic and inorganic substances suspended in air, affects the health of the people more than any other pollutant. The major components are sulphate, sodium, chloride, nitrates, ammonia, mineral dust, black carbon, and water. Particulates less than or equal to diameter of 10 microns are most health damaging which have the capability to penetrate and lodge deep into the lungs and can even cause cardiovascular and respiratory diseases as well as lung cancer.

Sulphur Dioxide (SO2), a colorless gas with a sharp odour, is produced from the burning of sulphur containing fossil fuels like coal & oil, smelting mineral ore containing sulphur, power generation and motor vehicles. SO2 in combination with water causes sulphuric acid which is the main constituent of acid rain and the main cause of deforestation. This gas can affect the respiratory system and functions of lungs, irritation in eyes, mucus secretion, inflammation of the respiratory tract, aggravation of asthma and chronic diseases.

Nitrogen Dioxide (NO2) is a toxic gas which causes significant inflammation in the airways, is the main source of nitrate aerosols, which forms an important fraction of PM2.5 and in the presence of the ultraviolet light of the ozone. The main sources of the emission of NO2 are heating, power generation and engines in vehicles. There has been sufficient evidence that long-term exposure of NO2 leads to symptoms of bronchitis in asthmatic children.

Carbon monoxide (CO) is an odourless, colourless, tasteless gas produced by the incomplete burning of organic matter, such as fossil fuels (petroleum), waste and wood. In the atmosphere, it transforms into carbon dioxide (CO2), a major greenhouse gas. In urban areas, CO readings are highest during peak rush hour traffic periods, near expressways and other major urban arteries. It reduces oxygen intake to organs and tissues.

As pressure builds over an area, *Winds Speed* becomes lighter. Light winds or absence of wind- allow pollutants that create ozone and particle pollution to build up, and provide a more favorable environment for the chemical reactions necessary to create particle pollution to take place. During odd-even programme, day time even with lower wind speed has shown faster drop in pollution.

It is clearly evident from the air pollution data that despite the lower wind speed in some days during odd and even scheme, pollution had fallen during those hours. In fact, it is notable that during days before the programme was started pollution levels had increased when wind speed was low. This brings out the clear impact of the odd and even scheme on the pollution levels. Even when wind was not there to blow it away, the scheme succeeded in arresting the upward trend. Both the real time pollution and wind data are from the Delhi Pollution Control monitoring stations.

Wind Direction is responsible for transport and travel of Pollutants. Air quality can worsen in the community if the wind is blowing from a region that contains numerous sources of pollution. If the winds are coming from areas with little or no pollution, they can make air quality better. Very light winds or no wind, such as those in a strong high pressure system, can be a problem for urban areas, because all the pollution that a city creates stays in one place.

Relative Humidity refers to the amount of moisture in the air. Moisture helps clouds form by causing air to rise and cool. When air is dry, it does not move as much, and pollutants build up. For example, on days when ozone is high, the relative humidity is often very low.

Humidity adds water to the atmosphere, and this moisture is absorbed by particles, causing them to swell and impair visibility even more. Therefore, poor visibility on humid days is the result of particle pollution.

Temperature impacts pollution levels significantly. As the temperature rises particulate matter content decreases.

Due to substantial changes in meteorological parameters, daily variations in traffic, and interference through background and other sources like wood burning on 13th January (Lohri festival), the delineation of impact of the odd-even scheme on air pollutant concentrations is difficult.

Odd Even rule in Delhi

- Odd-Even policy was a 15 day scheme implemented by the government of Delhi to get analysis of its impact on pollution index of Delhi. On even dates, only cars with license plates ending with an even number were be permitted and on odd dates, cars with license plates ending with an odd number were allowed.
- Odd-Even rule was applicable only on private-owned four wheelers.
- Odd-even rule violation led to a levy of a fine of Rs .2, 000 in accordance with the provisions of sub-section (1) of section 194 of Motor Vehicles Act, 1988.
- The Odd-even rule was effective between Monday-Saturday between 8 AM to 8 PM. School children in uniform were exempted from the ‘Odd-even rule’ in the second phase. Women were exempted from the odd-even rule in its first phase and second phase.
- Odd-even rule was not be applicable on emergency vehicles like PCR vans, fire tenders and ambulances, and on public transports like CNG-driven buses, taxis and auto-rickshaws.
- Emergency cases were obviously exempted from the rule

4) Empirical strategy

The identifying assumption underlying DD strategies is that of a common trend for the treatment and control groups in the absence of treatment. In our setting, the dependent variables are Carbon Monoxide (CO), Particulate Matter (PM), Sulphur-Di-Oxide (SO2) and Nitrogen-Di- Oxide (NO2) in their log forms. For logCO as the dependent variable, the assumption implies that the percentage change in CO concentrations over time is the same for the two groups. To the extent that CO concentrations track vehicle flows, this is equivalent to assuming that the percentage change in vehicle flows is the same for the two groups. The treatment group in our DD strategies is policy hours (8a.m. and 8p.m.) on working days inside the restricted zone, i.e., the set of hours during which Odd-Even is in effect. The plausible candidate for control group is same-hours pollution at stations outside the restricted zone.

We nonetheless consider a DD strategy that uses same-hours pollution at stations outside the restricted zone as the control group. It is susceptible to possible spillover effects from Odd-Even Scheme. However, the negative spillovers we detect would result in the effect of Odd-Even being underestimated.

To control for differences in trends across stations as well as differences in trends between policy and off-policy hours, we also employ a Difference-in-Difference in-Differences (DDD) strategy. We describe this strategy, as well as our two DD strategies, in greater detail below. With all three strategies, we focus attention on all days, i.e., including working days and holidays so as to get the effect of policy on the period as a whole. We also examine pollution on non-working days.

Difference-in-differences strategy with off-policy hours as controls:

For our primary DD strategy, which relies on same-station off-peak-hours pollution as the control, we start with the simplest DD specification:

$$\text{Log COidh} = \alpha 0i + \alpha 1ipolicyh*phased + \alpha 2iT + \alpha 3iR + \Theta iWidh + \text{€}I \qquad (1)$$

Where logCOdh is the log of CO concentration at hour *h* of day *d* in month m at station *i*, phase is an indicator variable that takes on a value of 1 for the start of Odd-Even scheme ie, 1st -15th January and 16th-30th April.

The specification in eq. (1) is extended incrementally to incorporate a set of season-specific effects:

$$\text{Log COi dh} = \alpha 0i + \alpha 1ipolicyh*phased + \alpha 2iT + \alpha 3iR + \alpha 4iS + \Theta iWidh + \text{€}I \qquad (2)$$

To test the validity of this DD strategy, we conduct a pre-treatment test. In addition, we estimate the above models for all days and for stations outside the restricted zone. Subject to the possibility of spillovers mentioned above, the coefficient of interest should not have a negative sign for these regressions.

Difference-in-difference-in-differences strategy:
To control for factors other than Odd-Even that might affect the relationship between policy and off-policy hours CO concentrations over time, we make use of a difference-in-difference-in-differences (DDD) strategy. Conceptually, the strategy computes two pooled DD estimates.

Eq. (1) we allow all but the coefficient of interest to vary across stations. This pooled DD estimate, which we label αIN captures the average effect of Odd-Even on policy-hours on pollution inside the restricted zone with off-policy hours pollution inside the zone as the control. The second pooled DD estimate, αOUT is obtained in the same manner but using pooled data for the two stations outside the restricted zone. The DDD estimate is given by the difference αi –αi Formally, our first DDD estimate is obtained using the simplest DDD specification:

$$\text{log}COidh = \beta i0 + \beta i1 Insidei*Policyh*phased + \beta i2T + \beta i3R + \Upsilon iWidh + \text{€}I \qquad (3)$$

where Inside^{i} is an indicator variable that takes on the value of 1 for stations inside the restricted zone. The coefficient of interest, β1.

The coefficient of interest in the above model is α3 measures the change after introduction of Odd-Even in the policy hours. Its sign will be negative if Odd-Even has reduced policy-hours pollution relative to off-policy hour's pollution.

Wi is a vector of wind speed interacted with wind direction which has been divided into eight sub- groups of its directions: north, north-east, south-east, south, south-west, west, north-west.

T and R are temperature and relative humidity respectively.

The specification in eq. (3) is extended incrementally to incorporate a full set of season-specific fixed effects:

$$\text{logCOidh} = \beta i0 + \beta i1 Insidei*Policyh*phased + \beta i2T + \beta i3R + \beta i4S + \Upsilon iWidh + \text{€}i \qquad (4)$$

Here, S is an indicator variable which takes the value 1 for winter period and 0 for summer period. It indicates the average effect of pollutant CO in winter season relative to summer season. We estimate eq. (5) by pooling data for all stations. An alternative approach would be to estimate the equation using data for a single station inside the restricted zone and a single station outside it, and repeating this for each pair of stations. We choose to pool the data for all stations because it allows us to incorporate a common set of fixed effects in the extended specification. Among other things, these fixed effects correct for seasonal factors that influence CO concentrations.

To assess the effect of Odd-Even on policy-hours pollution, we estimate the above models using data for the set of policy hours defined earlier.

We estimate all of the above models using ordinary least squares. Serial correlations as well as contemporaneous correlation in pollution across stations are accounted for by clustering (robust) standard errors at the quarter level, with all stations in the same cluster

5. Results

The highest concentration of PM2.5 is in the form of air pollution in Delhi which is supposed to be a very serious matter and can lead to respiratory diseases and other health problems like lung cancer.

Carbon monoxide (CO), a dangerous gas emission, is around 6, 000 microgram per cubic metre in Delhi, which is much above the safe level of 2, 000 microgram per cubic metre.

The level of nitrogen dioxide (NO2) and sulphur-di-oxide (SO2) has also been increasing. In addition to these direct (i.e. primary) emissions of particles, PM2.5 can also be formed from the chemical reactions of gases such as sulphur dioxide (SO2) and nitrogen oxides; these are called secondary particles.

- We first present the results obtained using our primary DD strategy, which makes use of same- station off-policy hours pollution as the control. Each column is estimated by using the simplest DD specification in eq. (1) .

Independent Variables	Log CO	Log PM	Log SO2	Log NO2
WS 1	.1037737***	-.484998***	-.312398***	-.3460929***
WS 2	-.0348756	-.3821681***	-.2913985***	-.3899845***
WS 3	-.7713168***	-.3403188***	-.0398122	-.3576026***
WS 4	-.6247299***	-.2306823***	-.2479304***	-.5174952***
WS 5	-.5975623***	-.2808171***	-.2675553***	-.4800599***
WS 6	-.4613415***	-.38174***	-.1928557***	-.4386708***
WS 7	-.4980751***	-.3715658***	-.2008838***	-.2545286***
WS 8	-.3827622***	-.3863059***	-.035869	-.6012002***
Temperature	-.0013294	-.0002569	-.0016526	.000937
Relative Humidity	.0048736***	.005692***	-.0053328***	-.001005**
Season	-.2651737***	.2706298***	-.1063393***	.0414098*
Policyphase	-.0615557**	.0596311***	-.2175865***	.0581181***
Constant	-.354275	4.947106	3.721738	4.879727
r square	0.35	0.41	0.32	0.64

- Table 1 estimates a 9% reduction in CO but not in PM2.5as it is positive during policy period.
- The coefficient of interaction between policy hours and phase is negative for carbon monoxide and sulphur-di-oxide which implies that odd even scheme has reduced effect of their concentrations in the atmosphere. And PM2.5 in positive means during odd even it has not reduced significantly, which can be also due to the following reasons:
- Particulate Matter 2.5 concentrations are also affected by weather conditions: low temperatures and low wind speeds typically result in higher concentrations of PM2.5 other sources (industrial, commercial and domestic emissions) of PM2.5 emission has not been taken into consideration under this study. Moreover, NO2 increased during the policy phase which implies that it augmented PM2.5 levels as NO2 is a major component of PM2.5.
- Note: Season wise results are shown in the appendix.
- We now present the results obtained using our primary DDD strategy, which makes use of same-station off-policy hours pollution as the control.

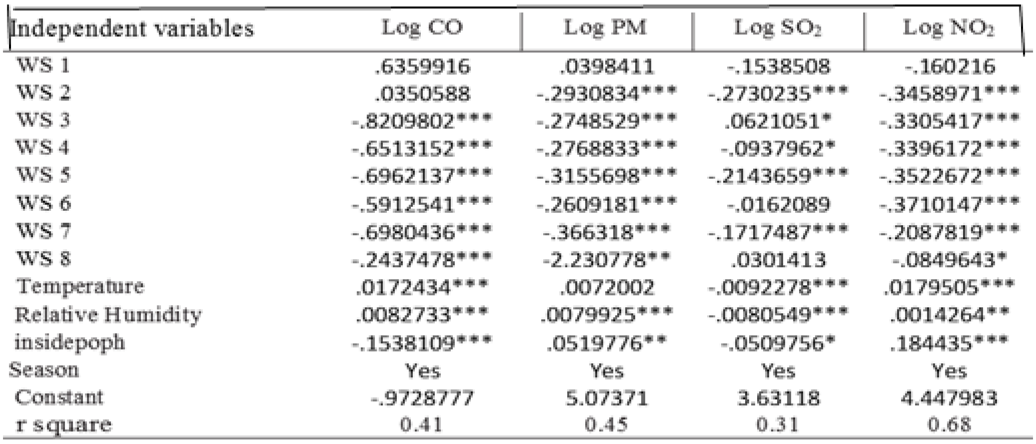
The triple difference variable is therefore the interaction term between Delhi region that is inside, policy hours (8 am to 8pm) and phase; and forms an alternative way to measure the program impact. Therefore, poor visibility on humid days is the result of particle pollution and moisture interactions.

Each column is estimated by using the simplest DDD which includes treated stations in winter season.

Table 2 estimates a decrease of 13% of CO in winter.

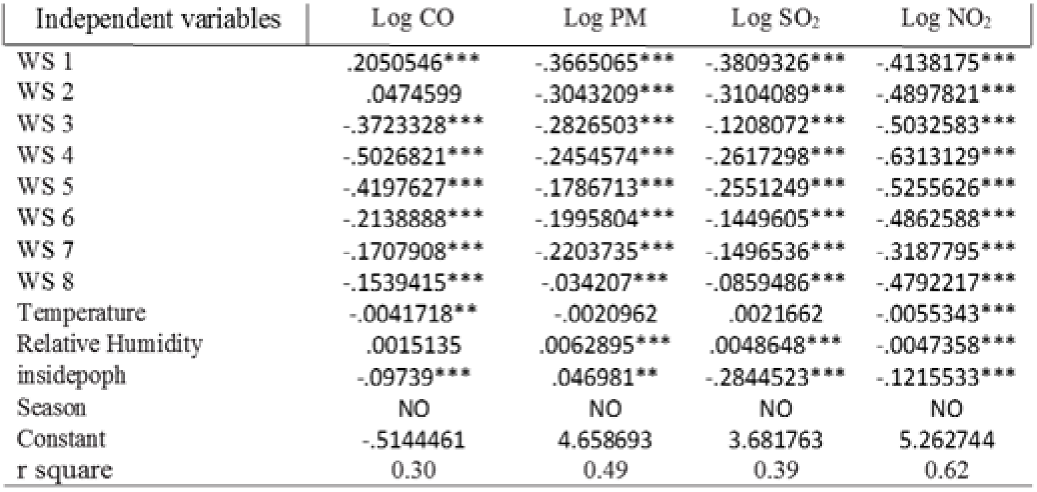
- In the winter season, the coefficient of interaction between inside policy hours and phase is negative for carbon monoxide which implies that odd even scheme has reduced effect of their concentrations in the atmosphere.
- The coefficients of temperature in positive higher temperatures promote chemical reactions.

Relative humidity coefficient is positive and significant. As in winter air in quite dry and when air is dry, it does not move as much, and pollutants build up.



Independent variables	Log CO	Log PM	Log SO_2	Log NO_2
WS 1	.6359916	.0398411	-.1538508	-.160216
WS 2	.0350588	-.2930834***	-.2730235***	-.3458971***
WS 3	-.8209802***	-.2748529***	.0621051*	-.3305417***
WS 4	-.6513152***	-.2768833***	-.0937962*	-.3396172***
WS 5	-.6962137***	-.3155698***	-.2143659***	-.3522672***
WS 6	-.5912541***	-.2609181***	-.0162089	-.3710147***
WS 7	-.6980436***	-.366318***	-.1717487***	-.2087819***
WS 8	-.2437478***	-2.230778**	.0301413	-.0849643*
Temperature	.0172434***	.0072002	-.0092278***	.0179505***
Relative Humidity	.0082733***	.0079925***	-.0080549***	.0014264**
insidepoph	-.1538109***	.0519776**	-.0509756*	.184435***
Season	Yes	Yes	Yes	Yes
Constant	-.9728777	5.07371	3.63118	4.447983
r square	0.41	0.45	0.31	0.68

But PM2.5is positive and sign. at 5% means it has not reduced because in winter people do more burning activities which increase residual dust and ashes in the atmosphere. Particulate Matter concentrations are also affected by weather conditions: low temperatures and low wind speeds typically result in higher concentrations.



Independent variables	Log CO	Log PM	Log SO_2	Log NO_2
WS 1	.2050546***	-.3665065***	-.3809326***	-.4138175***
WS 2	.0474599	-.3043209***	-.3104089***	-.4897821***
WS 3	-.3723328***	-.2826503***	-.1208072***	-.5032583***
WS 4	-.5026821***	-.2454574***	-.2617298***	-.6313129***
WS 5	-.4197627***	-.1786713***	-.2551249***	-.5255626***
WS 6	-.2138888***	-.1995804***	-.1449605***	-.4862588***
WS 7	-.1707908***	-.2203735***	-.1496536***	-.3187795***
WS 8	-.1539415***	-.034207***	-.0859486***	-.4792217***
Temperature	-.0041718**	-.0020962	.0021662	-.0055343***
Relative Humidity	.0015135	.0062895***	.0048648***	-.0047358***
insidepoph	-.09739***	.046981**	-.2844523***	-.1215533***
Season	NO	NO	NO	NO
Constant	-.5144461	4.658693	3.681763	5.262744
r square	0.30	0.49	0.39	0.62

- Table 3 estimates a decrease in CO concentrations by 15% in summer season.
- In the summer season, the coefficient of insidepoph is negative and significant for CO, SO2 and NO2.
- For PM2.5, the coefficient is positive and significant which is implied by the fact that farm fires in the nearby regions (Haryana and Punjab) would have caused increase in the concentration of particulate matter in Delhi, given the wind circumstances.
- For PM2.5, the coefficient is positive and significant which is implied by the fact that farm fires in the nearby regions (Haryana and Punjab) would have caused increase in the concentration of particulate matter in Delhi, given the wind circumstances.
- Almost all the coefficient of interaction between wind speed and wind direction are negative and significant, which means that winds were able to rapidly transport pollutants.
- Air quality can worsen in an area if the wind is blowing from a region that contains numerous sources of pollution.
- The coefficient of Temperature is negative and significant for CO and NO2. The coefficient of Temperature is not significant for PM2.5.

6. Conclusion

We conclude that the odd-even pilot did have some impact in reducing hourly particulate air pollution concentrations during policy hours. CO levels reduced by 13% -15%. The odd-even program reduces pollution in two ways: Fewer cars on the road—thereby, directly removing some of the polluting sources. Reduced congestion would reduce slow moving traffic across the city, thereby reducing pollution for everybody. But absolute reduction in PM2.5 concentration is ambiguous, where as other pollutants concentration has reduced in the atmosphere during the policy and this resulted in reducing the air pollution level during the odd even scheme. There was no reduction in PM2.5levels due to meteorological factors. Also due to the fact that nitrogen oxide increased in the policy phase which is a major component of PM2.5. Moreover, vehicle load of PM2.5 comes majorly from trucks which commute in and out of Delhi in the early hours of morning when the policy was not active. There is sufficient evidence to show that odd-even scheme was not able to reduce PM2.5 levels due to effect of farm fires in summer and domestic heating activities in winter, given meteorological conditions but CO levels fell significantly which is a major source of pollution from vehicles.

Extension to the Paper

- One possible extension is to include peak hours that will alter the difference-in-difference (DD) and difference-in-difference-in-difference (DDD) strategies in the empirical analysis.
- An alternative approach would be to estimate the equation using data for a single station inside the restricted zone and a single station outside it, and repeating this for each pair of stations.
- More pollutants (dependent variables) such as PM10, Benzene, O3 can be tested upon.
- Weekends and holidays can be excluded from empirical analysis to possibly give a more viable result.
- The effect of night time pollution inside the restricted zone before and after odd-even can also be included in the analysis. Lastly, more treatment stations can be included in the analysis.

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References

[1] Bonilla, J. A. (2013) “Effects of the increased stringency of driving restrictions on air quality and car use in Bogota, ” University of Gothenburg Department of Economics

[2] Carrillo, P., Malik, A. & Yoo, Y. Driving Restrictions that Work? Quito’s Picoy Placa Program. *Canadian Journal of Economics*

[3] Chen, Y., Jin, G., Kumar, N. & Shi, G. The Promise of Beijing: Evaluating the Impact of the 2008 Olympic Games on Air Quality. *Journal of Environmental Economics and Management*, 424–443 (2013)

[4] Davis, L. W. (2008) “The effect of driving restrictions on air quality in Mexico City, ” Journal of Political Economy 116(11), 38–81

[5] Gallego, F., J. Montero, and C. Salas (2011). “The Effect of Transport Policies on Car Use: Theory and Evidence from Latin American Cities, ” Institute of Economics, Pontifical Catholic University of Chile working paper

[6] Jiang, X. (2006). “23% of PM10 in Beijing Comes From Vehicular Emissions, ”

[7] Road Traffic and Safety, 1, 45 (in Chinese)

[8] Viard, V. B., and S. Fu (2015) “The effect of Beijing’s driving restrictions on pollution and economic activity, ” Journal of Public Economics 125, 98–115

Appendix

Other Results Regarding DD strategy:

In this table we are taking inside Delhi location only in the winter phase

Independent variables	Log CO	Log PM	Log SO2	Log NO2
WS 1	.6294077	.0398411	-.1411743	-.1639262
WS 2	.0321642	-.2930834***	-.2676928***	-.3474242***
WS 3	-.824409***	-.2748529***	.0678172*	-.3319335***
WS 4	-.6549118***	-.2768833***	-.0869244*	-.3412698***
WS 5	-.7005129***	-.3155698***	-.2068592***	-.3542864***
WS 6	-.5930556***	-.2609181***	-.0107983	-.3718556***
WS 7	-.6959311***	-.366318***	-.1701088***	-.2088671***
WS 8	.014872***	-2.230778***	-.5604585***	.6672659***
Temperature	.0196265	.0072002	-.0135649	.019483
Relative Humidity	.0085488***	.0079925***	-.0086005***	.001615***
Policyphase	-.1624726***	.0519776***	-.0356845***	.1783664***
Constant	-1.014952	5.07371	3.710583	4.419897
r square	0.41		0.45	

Here also we are looking at the inside Delhi location only but in Summer phase.

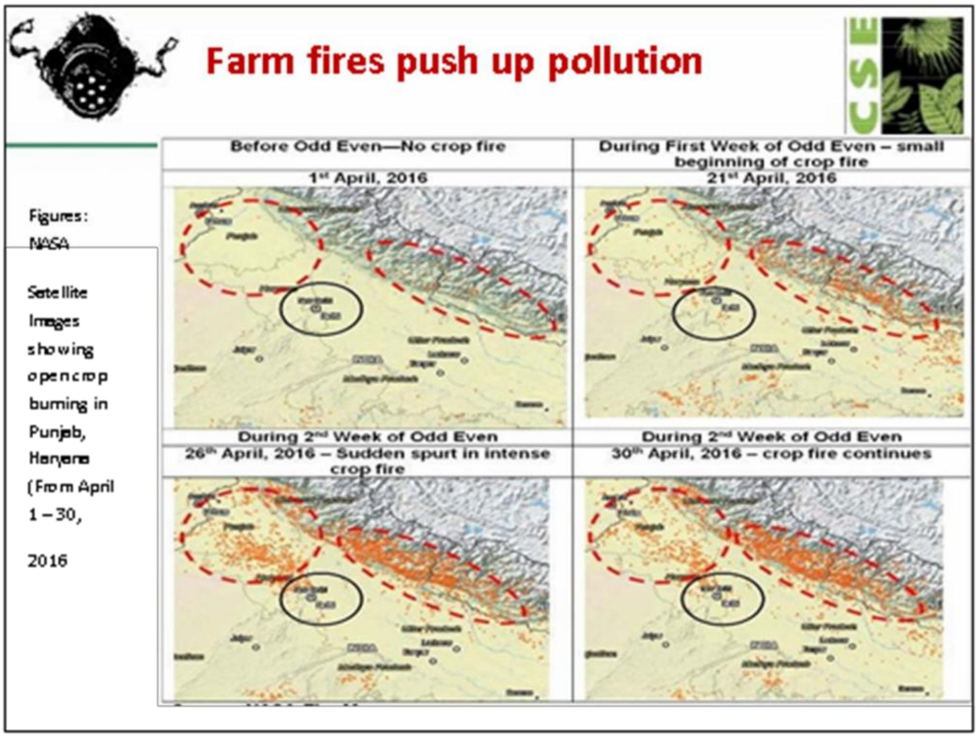
Independent variable	Log CO	Log PM	Log SO2	Log NO2
WS 1	.1853378***	-.3555176***	-.380442***	-.3991304***
WS 2	.0202729	-.2866396***	-.3178878***	-.4639751***
WS 3	-.4556899***	-.2849795***	-.2158611***	-.466655***
WS 4	-.6111684***	-.2431136***	-.4061618***	-.6006966***
WS 5	-.538765***	-.195609***	-.3889523***	-.5211986***
WS 6	-.4329451***	-.2736086***	-.3605929***	-.4338218***
WS 7	-.3215525***	-.2889708***	-.3025495***	-.263545***
WS 8	-.3224444	-.1295518***	-.2605777	-.6902616***
Temperature	-.0024492	.0019618	.0126124***	-.0048109***
Relative Humidity	.0043997***	.0128856***	.0056515***	-.0019087**
Policyphase	-.0480723	.1191978***	-.2892764***	-.0993818***
Inside	Yes	Yes	Yes	Yes
Season	NO	NO	NO	NO

Constant	-.5733452	4.412135	3.511467	5.151528
r square	0.30	0.57	0.32	0.68

This table shows DDD strategy result on over all odd even policy

Independent variables	Log CO	Log PM	Log SO2	Log NO2
WS 1	.1411138***	-.4756911***	-.3076423***	-.3590575***
WS 2	.0069183	-.3679101***	-.2616311***	-.397236***
WS 3	-.6708654***	-.3094247***	.008945	-.377717***
WS 4	-.5227755***	-.2030318***	-.1814729***	-.5523539***
WS 5	-.4764581***	-.2311501***	-.2173574***	-.4940404***
WS 6	-.2518204***	-.2668464***	-.1072662***	-.4793739***
WS 7	-.2298403***	-.2887389***	-.1261283***	-.3020176***
WS 8	-.1634869***	-.0351752***	-.0349672***	-.3505225***
Temperature	-.0028698	-.0027802***	-.0022521	.0048001***
Relative Humidity	.0041769***	.0046984***	-.0017417***	.0012055***
Season	-.2268666***	.3027556***	-.2981231***	-.0811194***
Insidepoph	-.0774625***	.0492187***	-.1916245***	.0668789***
Constant	-.3861374	4.991067	3.640333	4.81065
r square	0.34	0.38	0.31	0.61

Figure with reference to table 3 results



Farm fires push up pollution

Figures: NASA

Satellite Images showing open crop burning in Punjab, Haryana (From April 1 – 30, 2016

Before Odd Even—No crop fire
1st April, 2016

During First Week of Odd Even – small beginning of crop fire
21st April, 2016

During 2nd Week of Odd Even
26th April, 2016 – Sudden spurt in intense crop fire

During 2nd Week of Odd Even
30th April, 2016 – crop fire continues

Figure with reference to conclusion