Final report

IGC International Growth Centre

From clean fuel to clean air in India's metropolitan cities

Parikshit Ghosh
Rohini Somanathan

April 2017

When citing this paper, please use the title and the following reference number:
C-35135-INC-1

DIRECTED BY LSE UNIVERSITY OF OXFORD

FUNDED BY UKaid from the British people

From clean-fuel to clean air in India's metropolitan cities

IGC Project Final Report

Parikshit Ghosh and Rohini Somanathan

April 3, 2017

1 Introduction

Levels of ambient air pollution in many of the world's largest cities are alarming. According to the World Health Organization (WHO), 90% of the population living in cities in 2014 was exposed to concentrations of fine particulate matter ($PM_{2.5}$) exceeding WHO air quality guidelines.[1] Most Indian cities have noxious urban air quality for much of the year. Among the mega-cities of the world (those with more than 14 million inhabitants), Delhi has the highest level of suspended particulate matter (PM_{10}) and Kolkata has the fourth-highest.

In response to court mandates and public pressure, several Indian states have passed legislation to improve air quality through the use of cleaner fuels and an improved vehicle fleet. In addition, the city of Delhi, experimented with driving restrictions over two fortnights in 2016. During the course of this project we collated information on the regulatory environment in Indian metropolitan cities and evaluated two major policies that have been undertaken. The first of these is the move towards clean fuel and a newer public transport fleet in Kolkata in 2009. The second is the experiment with driving restrictions in Delhi.

Our objective was to study the regulatory environment and analyze air pollution data and legislation in five metropolitan cities in India (Delhi, Mumbai, Kolkata, Chennai, Hyderabad). We have been able to study regulatory changes in all of these cities, but air pollution data were not easily available in the public domain, although they were supposed to be. We have therefore focussed on the two most polluted cities of Delhi and Kolkata. Through repeated interactions with officials and scientists at the State and Central Pollution Control Board offices in these cities, we were able to obtain some data series on pollutants. We have restricted our analysis to the monitoring stations and the periods for which these data were mostly complete.

The next section summarizes major regulatory changes over the last two decades designed to improve urban air quality in India and puts them in cross-national perspective through comparisons with similar changes in major world cities. The following two sections focus on air pollution data for Delhi and Kolkata and contain an assessment of the policy changes in these two cities. We end with some survey data from public transport operators and citizens to capture attitudes towards policy changes.

[1] http://www.who.int/gho/phe/air_pollution_pm25_concentrations/en/.

2 The regulatory environment

Air quality regulations can directly target the producers of vehicles, transport operators or consumers. Norms on improved engines and fuel are in the first category, those on the vintage of the fleet, the restricted use of roads and the fuel used are in the second, and driving restrictions for private vehicle owners are in the last category.

Major regulations in Indian cities since 1998 are shown in Tables 1 and 2. Delhi led the way in both the use of unleaded fuel and the shift to compressed natural gas (CNG) in public transport vehicles. In spite of this, air-quality has been the worst in the world in recent years, because of an inability to control the total number of vehicles and other sources of air pollution. This motivated the two phases of driving restrictions which we study in greater detail below.

Regulations on producers of cars, such as the introduction of Bharat Stage IV standards, modeled on Euro IV standards, were implemented nationwide, but in a staggered fashion, starting first with 17 cities. Similarly regulations reducing the sulphur content of petroleum products were also universal. Guttikunda & Mohan (2014) emphasize the need to continuously raise these standards to offset the negative effect on air quality of the rising number of cars. Although total number of vehicles increased by 700% between 1990 and 2010, per capita ownership is still well below the middle-income countries and as incomes rise, air quality is likely to deteriorate.

Fuel changes for public transport are harder to implement on a large scale at a given point in time, partly because they rely on being passed by state legislatures and executive bodies and also because they rely on available infrastructure. For example, the use of CNG is only possible in areas with CNG pipelines. This why cities like Hyderabad and Kolkata had to transition to Liquefied Petroleum Gas (LPG) instead. Table 2 shows the progression of clean fuel in auto-rickshaws in Indian cities.

3 The monitoring of air pollution in India

Air pollution in India is monitored by the Central Pollution Control Board (CPCB) together with the State Pollution Control Boards (SPCBs) and the National Environmental Engineering Research Institute (NEERI) in Nagpur.[2] The National Air Quality Monitoring Programme (NAMP) was started in 1984 with 7 stations. As of 31st March 2015, the air quality network had 591 operating Air Quality Monitoring Stations covering 248 towns and cities in the country. Monitoring in the stations under NAMP is manual, and undertaken at 4-hourly intervals for gaseous pollutants and 8-hourly intervals for particulate matter. This is done for 24 hours about two days a week.

Given its low frequency, the NAMP data is not suitable for estimating the short-run effect of interventions such as the two fortnights of driving restrictions that were mandated in Delhi in 2016. For high frequency data, the CPCB has initiated a number of automatic ambient air quality monitoring analyzers in the larger cities such as Delhi and Kolkata. These are called the Continuous Ambient Air Quality Monitoring Stations (CAAQMS). They are closer to widely

[2] CPCB Annual Report 2014-15, Chapter 5.

Table 1: Air Quality Legislation in Indian cities

Cities	Year	Details
All major cities[a]	2010	Bharat Stage IV (equivalent to Euro IV standards) implemented for all categories of 4-wheelers
	2010	Content of sulphur reduced to 0.005% in gasoline and diesel
Delhi[acd]	1998	Phasing out of leaded petrol
	2000	Prohibition of the plying and idle parking of heavy goods, medium goods and light goods vehicles on certain roads and areas during specified timings
	2015	Temporary ban on registration of certain classes of diesel vehicles (lifted for private vehicles in August, 2016)
	2016	Driving restrictions for vehicles on alternate days. Implemented for two fortnights in January and April
	2015	Ban on firecrackers and diesel powered generators
	2016	Closure of polluting industries
Mumbai[e]	2016	Restriction on entry of heavy vehicles between 8am to 12pm and 4pm to 10pm. This was part of a 30-day trial plan, which began from July 13 2016.
Bangalore[a]	2003	Supply of 5% ethanol blended petrol in 27 districts
	2014	Ban on entry of trucks during between 6 am and 10 pm
Hyderabad[a]	2003	Multi Model Transport System (MMTS) to improve mass transportation system introduced
	2003	Restriction on plying of inter-state/intercity buses and restriction of entry to non-destined commercial vehicles in city
	2009	Phasing out of 15 year old commercial vehicles
Kolkata	2009	Phasing out of 15 year old commercial vehicles
Chennai[a]	2007	Ban on entry of trucks during between 6 am and 10 pm
Thiruvananthapuram, Kollam, Kochi, Thrissur, Kozhikode and Kannur[b]	2016	Ban on registration of diesel vehicles and use of diesel vehicles more than 10 years old

[a] See Central Pollution Control Board (2006)
[b] Indian Express, "Kerala HC Stays NGT Order Banning 10-Year-Old Diesel Vehicles", 10 June, 2016.
[c] See Government of Delhi (2016)
[d] Times of India, "DPCC orders closure of 146 polluting units", 26 October, 2016.
[e] Times of India, "No entry for heavy vehicles in city during peak hrs for 1 month", 15 July, 2016.

Table 2: Clean fuel in public transport for major Indian cities.

Cities	Year	Details
Delhi[g]	2000	Buses and autorickshaws to run on CNG
Bangalore[a]	2004	LPG kits mandated in all autorickshaws, stopped issuing permits to Non-LPG Rickshaws
Ahmedabad[b]	2005	Buses and auto-rickshaws to run on CNG
Hyderabad[b]	2005	All auto-rickshaws to run on LPG
Lucknow[c]	2007	All auto-rickshaws to run on CNG
Chennai[f]	2008	All auto-rickshaws to run on LPG
Chandigarh[e]	2009	All auto-rickshaws to run on LPG
Kolkata[d]	2010	All auto-rickshaws to LPG using only 4-stroke engines

[a] See Karnataka State Pollution Control Board (2004)
[b] See Central Pollution Control Board (2006)
[c] See Environment Pollution (Prevention & Control) Authority for the National Capital Region (n.d.)
[d] See Calcutta High Court Order - 'Howrah Ganatantrik Nagarik Samity & Ors vs Union Of India & Ors on 27 August, 2009'
[e] India Express, "Only LPG autos to ply on city roads", 18 May, 2008.
[f] See Tamil Nadu State Pollution Control Board (2008)
[g] See Delhi Department of Transport (n.d.)

accepted international norms. They produce hourly averages of pollutants but monitor a much smaller set of pollutants than the manual stations.

One difficulty with obtaining air pollution data in India is that some data sets are under the jurisdiction of the CPCB while others are with the SPCBs and the data online is very incomplete so data users have to deal with the bureaucracy of multiple institutions. We decided to restrict our attention to Kolkata and Delhi to get as complete data for these two cities as possible. The list of stations monitored by the CPCB and the Delhi Pollution Control Committee (DPCC) in Delhi is in Table 3.

Figures 1 and 2 are maps with the locations of all the sources in Delhi and Kolkata from which were were able to get some data.

Table 3: Automatic and Manual Stations in Delhi.

Automatic		Manual	
Station	Monitoring Agency	Station	Monitoring Agency
ITO	CPCB	Shahdhara	CPCB
Siri Fort	CPCB	Shahzada Bagh	CPCB
Shadipur	CPCB	Janakpuri	CPCB
Dwarka	CPCB	N.Y School	CPCB
IHBAS	CPCB	Nizamuddin	CPCB
East Arjun Nagar	CPCB	Pitampura	CPCB
DCE	CPCB	Siri Fort	CPCB
Mobile Van	CPCB	BSZ Marg	CPCB
Mandir Marg	DPCC	DCE	CPCB
IGI Airport	DPCC	Ashok Vihar	CPCB
Punjabi Bagh	DPCC	Town Hall	CPCB + NEERI
Civil Lines	DPCC	Sarojini Nagar	CPCB + NEERI
Anand Vihar	DPCC	Mayapuri	CPCB + NEERI
RK Puram	DPCC		

Figure 1: Pollution monitoring stations in Delhi.

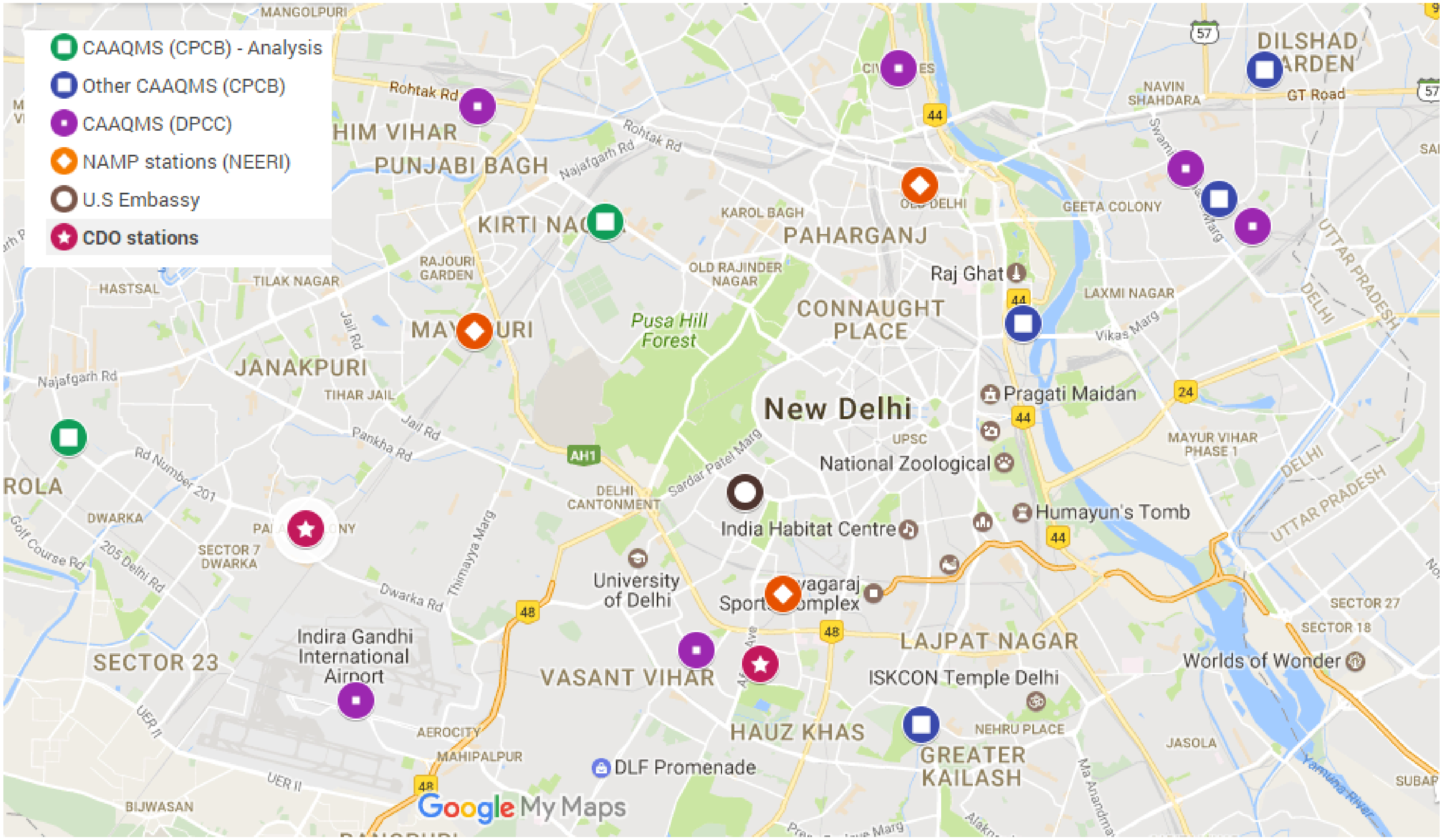
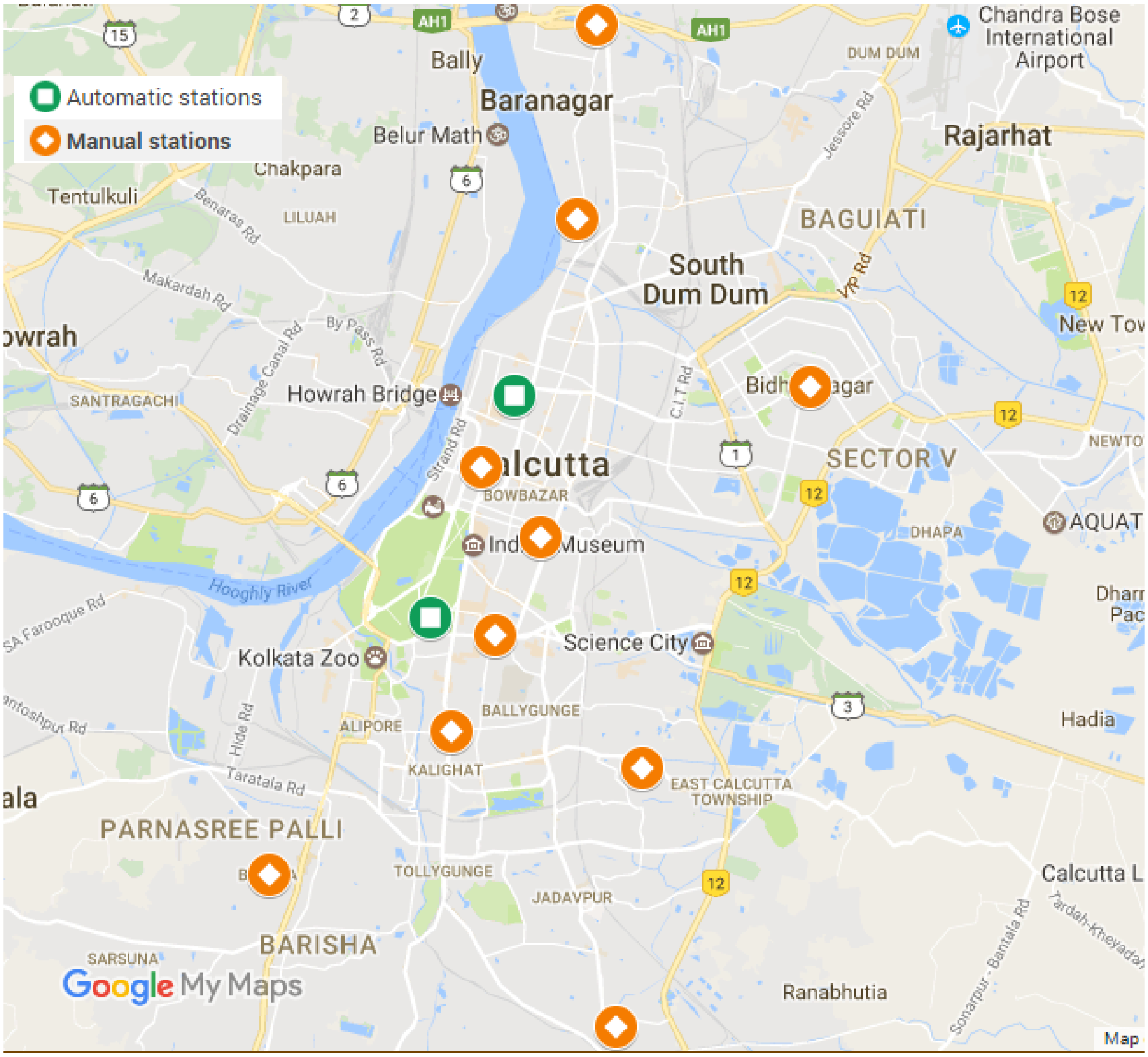


Figure 2: Pollution monitoring stations in Kolkata.



Within these cities, we attempt to document all data available but restrict our analysis of policy impact to a few automatic stations for which we were able to obtain the most complete data. Even for the automatic stations, data is often missing for several days at a stretch, possibly because of malfunctioning instruments in automatic stations. Tables 4 and 5 show the percentage of data points available for different pollutants from the three active CPCB stations in Delhi, and the two stations in Kolkata from which we could obtain some data.

We have fairly complete data on carbon monoxide, nitrogen oxides, PM 2.5, temperature and humidity from 2 automatic stations (Shadipur and NSIT-Dwarka), both monitored by CPCB. For Kolkata, all our data is from the West Bengal State Pollution Board. We use data from two automatic stations in Kolkata and the 2 stations of Haldia and Howrah that border the city. Hourly data on PM 10, sulphur dioxide, carbon monoxide and nitrogen dioxide is available for all these years.

For the selected automatic stations for which data is available, we find enormous variation across

Table 4: Data Availability in Automatic Delhi Stations

Station	Year	CO	NOx	PM 2.5	Relative Humidity	Temperature
Dwarka	2009	32	39	0	14	17
	2010	87	94	0	95	93
	2011	91	88	0	95	95
	2012	75	36	0	79	78
	2013	76	80	0	88	87
	2014	89	90	0	91	91
	2015	78	78	53	61	84
	2016	73	73	72	74	74
IHBAS	2009	20	64	0	24	6
	2010	70	65	0	55	79
	2011	87	73	0	92	69
	2012	78	58	87	89	78
	2013	88	90	94	93	93
	2014	91	89	92	91	91
	2015	47	48	48	48	35
	2016	60	62	62	62	0
Shadipur	2009	63	66	0	24	24
	2010	61	44	0	73	73
	2011	97	97	0	99	99
	2012	54	41	0	85	85
	2013	90	86	0	97	97
	2014	92	84	0	94	94
	2015	87	86	67	95	95
	2016	76	76	75	77	83

,

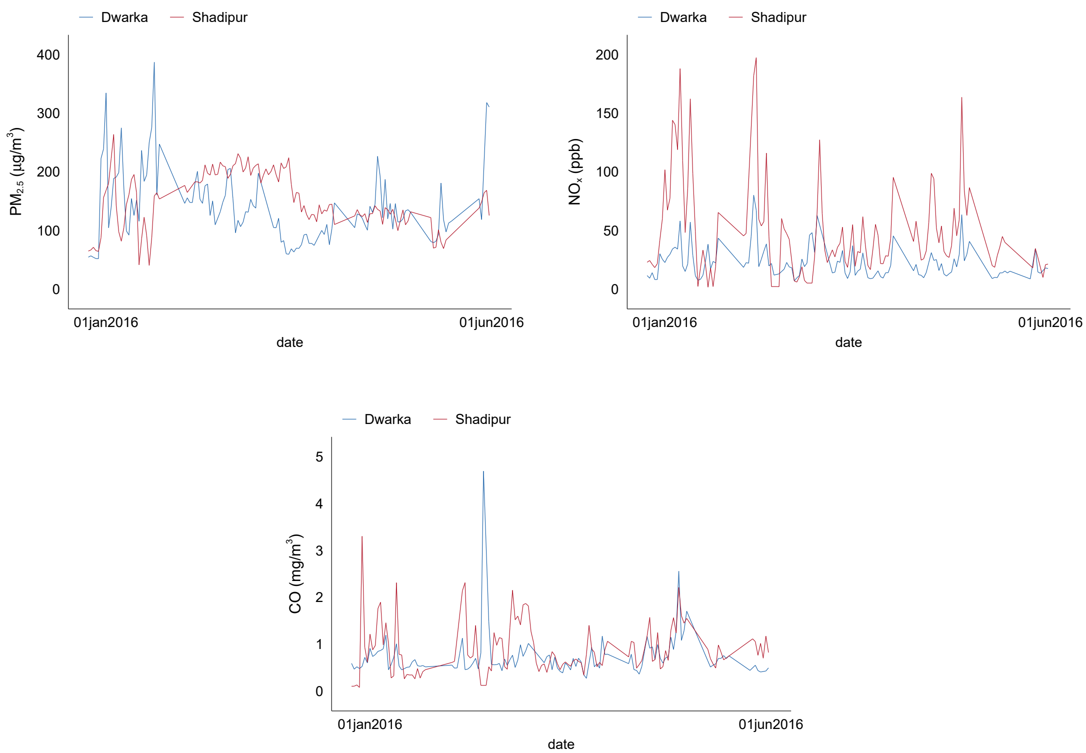
Table 5: Data Availability in Automatic Kolkata Stations.

Station	Year	CO	NO_2	PM_{10}
Rabindra Bharti	2003	79	72	58
	2005	86	32	89
	2006	97	68	96
	2007	94	89	97
	2008	76	89	97
	2009	95	87	94
	2010	71	90	98
Victoria Memorial	2003	84	63	73
	2005	88	86	81
	2006	95	78	77
	2007	92	85	94
	2008	91	81	96
	2009	99	90	97
	2010	95	87	94

,

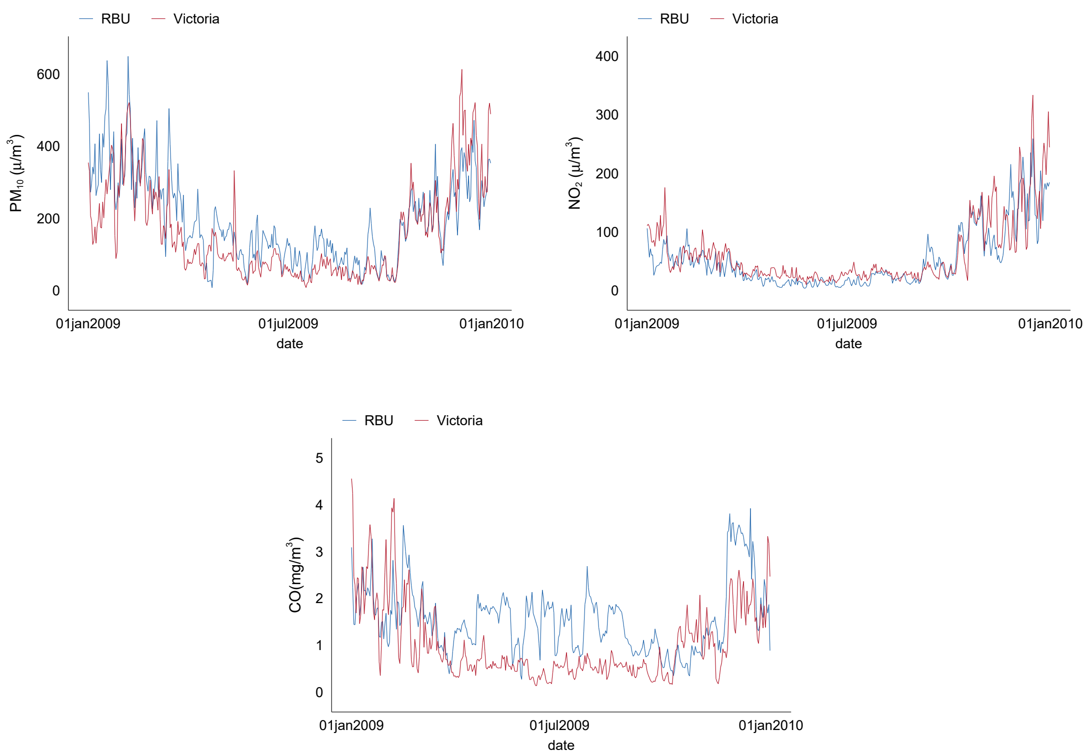
the year in levels of pollutants and even in the ranking of different stations within each city. This is illustrated in Figures 3 and 4.

Figure 3: Station-wise variability in pollution levels in Delhi: Jan-June 2016



In addition to data from the pollution control boards, we downloaded hourly PM 2.5 data from a station monitored by the U.S Embassy in Chanakyapuri in Delhi. Once again, pollution levels at the Chanakyapuri station are quite different from those in the other two Delhi locations.

Figure 4: Station-wise variability in pollution levels in Kolkata during 2009



4 Policies and their Impact

4.1 The urgent need for policy

As already mentioned, Indian cities are among the most polluted in the world and levels of exposure are well above both WHO standards set in 2005 and the weaker national standards set by the Indian government in 2009. For example, the WHO standard for $PM_{2.5}$ is 10 micrograms per cubic meter ($\mu g/m^3$) for annual average concentrations and $25\mu g/m^3$ for daily concentrations and for PM_{10} it is 25 and 50 $\mu g/m^3$ respectively (WHO 2006). For nitrogen dioxide, the standards are 40 $\mu g/m^3$ for annual means and 200 $\mu g/m^3$ for one-hour means. The National Ambient Air Quality Standards announced by the Indian government are much less stringent. Annual and daily mean concentrations are 40 and 60 $\mu g/m^3$ for $PM_{2.5}$ and 60 and 100 $\mu g/m^3$ for PM_{10}. For nitrogen dioxide, the Indian standards are 40 and 80 $\mu g/m^3$ for annual and daily concentrations and for carbon monoxide, they are 2 mg/m^3 for 8-hourly averages and 4 mg/m^3 for hourly averages. (GOI 2009). Standards for particulates are grossly violated for most of urban India.

4.2 The Delhi Odd-Even Scheme

The Delhi government restricted the types private cars that were allowed to be on the road between 8 a.m. and 8 p.m during two fortnights in 2016: January 1 to January 15 and April 15 to April 30. During each of these periods, number plates ending in an odd number were allowed on the roads on odd-numbered days of the month, similarly with even number days. The government did announce fines for violators, but monitoring was done to a large extent by volunteers who had no enforcement capacity and relied on the cooperation and conscience of citizens.

We studied pollution levels before, after and during this period using the 2 automatic stations, Dwarka and Shadipur. We used hourly data on concentrations of PM 2.5, carbon monoxide, and nitrogen oxides for a 4-week period in each case, starting a week before each phase of the scheme and ending a week after. We also control for temperature and humidity which has important effects on the height to which pollutants rise. There was no rainfall during our period of analysis, hence it was excluded from our analysis. The sources of the data we used and descriptive statistics are summarized in Table 6.

Table 6: Delhi Pollution Levels in the Odd-Even Phases

		Dec 25-Jan 22, 2016		April 8 - May 7, 2016	
Description	Source	Mean	N	Mean	N
Carbon monoxide(mg/cubic metres)	CPCB (Shadipur and Dwarka)	0.81	1639	0.86	1908
PM 2.5(µg/cubic metres)	CPCB (Shadipur and Dwarka)	158.53	1633	122.53	1909
Humidity (%)	CPCB (Shadipur and Dwarka)	69.20	1642	20.55	1844
Oxides of nitrogen (ppb)	CPCB (Shadipur and Dwarka)	46.74	1671	38.64	1895
Temperature (degrees Celsius)	CPCB (Shadipur and Dwarka)	16.41	1334	31.86	1379

The levels of PM 2.5 were much higher in winter than in summer, but CO and NOx levels across the two phases are similar. Figure 5 shows that the intra-day variation was greater during both the Odd-Even periods as compared to the control periods, suggesting that the policy did have an effect.

For an estimate of policy impact, we estimate a linear model with controls for weather and station-fixed effects. Our identification strategy is based on the difference between the day and night levels during the operation of the scheme. We estimate

$$\begin{aligned} P_{ihj} &= \alpha + \beta_1 \text{ (Eight-to-Eight)}_h + \beta_2 \text{(Eight-to-Eight)}_h * \text{Odd-Even}_h \\ &+ \sum_k \gamma_k W_{hk} + \text{week}_h + \text{station}_j + \epsilon_{ihj} \end{aligned} \tag{1}$$

where P_{ihj} denotes the level of pollutant i, measured during hour h in station j. $\text{(Eight-to-Eight)}_h *$ Odd-Even_h indicates that the hour for which the pollutant was monitored was within the period when driving restrictions were operational. Thus β_2 is our coefficient of interest.

We used data from our 2 automatic stations to estimate (1) separately for each of the two phases and each of our three pollutants. We also fit a specification, which uses data for the entire eight week period and estimates separate treatment effects for each of the two phases. For $PM_{2.5}$ we have access to the U.S. Embassy data from the monitoring station in Chanakyapuri and estimate (1) separately for data from this monitoring station since the instruments used and the way in which data is recorded may be different from those used by the CPCB.

Our results are in Table 7. The CPCB data for the stations we are using suggests that the driving restrictions are estimated to have lowered levels of all pollutants (CO, NO_2 and $PM_{2.5}$). The effects are especially large for the first phase of the restrictions that were implemented in January. Controlling for weather and station and week fixed-effects and for Sundays, when there were no restrictions, $PM_{2.5}$ concentrations were about 50 $\mu g/m^3$ lower during the hours the restrictions were operative. This is about one-third of the average level of particulates in the 4- week period from December 25 to January 22, 2016. The relative effects for carbon monoxide and nitrogen oxides are even larger. The effects for the second phase in April are much smaller, but have the same sign as estimates for the first phase for the CPCB data. We also find no significant difference in the levels of $PM_{2.5}$ from the Chanakyapuri station for the period with the driving restrictions in January and find positive effects for the second phase.

There are many possible reasons for the differences between the first and second phase of the *Odd-Even* policy. The first phase was during the winter months when the levels of pollution are the highest. The differences in weather could also lead to varying lifespans of emissions in the air. It is also plausible that citizen responses to the policy varied over the two phases. Those buying new cars would have tried to get number plates that would allow them to use one of their cars on each day of the policy. There may also have been different levels of enforcement. The differences in the same pollutant $PM_{2.5}$ across the Chanakyapuri and CPCB stations is more puzzling. They suggest that pollution measures may be especially sensitive to neighborhoods and instruments used.

Finally, a caveat. We rely on the day-night variation in pollution levels during the period of driving restrictions relative to the period without them. To the extent that trips during the day are substituted by night time trips, our estimates would be upwardly biased.

Figure 5: Hourly variation in pollutants

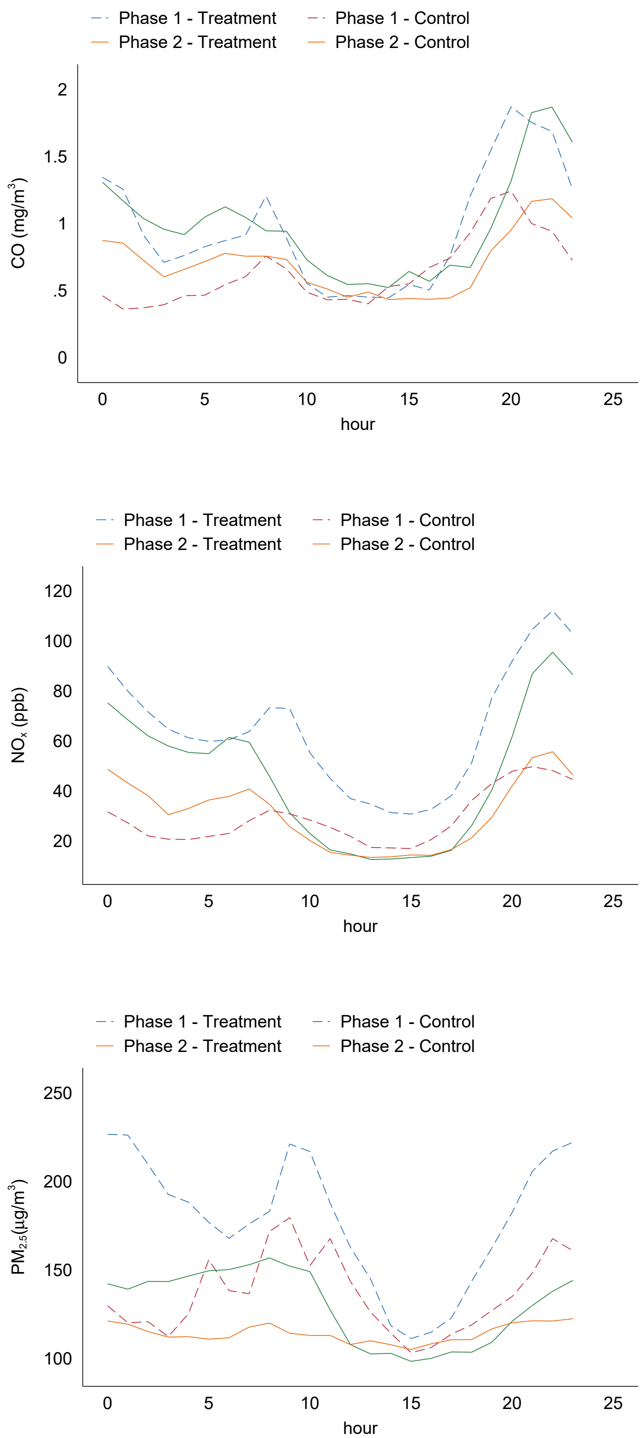


Table 7: The Impact of Delhi Driving Restrictions on Pollution

PM 2.5 (U.S Embassy)	**Phase 1**	**Phase 2**	**Combined**
8 AM - 8 PM	11.14	2.115	5.655
	(1.07)	(0.20)	(0.73)
Jan 1-15 × 8 AM - 8 PM	-3.162		-9.335
	(-0.23)		(-0.78)
Apr 15-30 × 8 AM - 8 PM		32.13***	17.72
		(2.66)	(1.44)
Constant	-642.8***	-31.20	-204.4***
	(-6.36)	(-0.14)	(-3.20)
Observations	666	629	1295
PM 2.5 (CPCB)	**Phase 1**	**Phase 2**	**Combined**
8 AM - 8 PM	22.01**	12.71***	18.09***
	(2.16)	(3.04)	(3.32)
Jan 1-15 × 8 AM - 8 PM	-49.11***		-42.56***
	(-3.98)		(-5.17)
Apr 15-30 × 8 AM - 8 PM		-16.00***	-21.58**
		(-3.32)	(-2.57)
Constant	232.6***	127.1**	316.4***
	(4.70)	(2.04)	(12.58)
Observations	1290	1301	2591
CO	**Phase 1**	**Phase 2**	**Combined**
8 AM - 8 PM	0.0277	-0.398***	-0.184***
	(0.35)	(-5.44)	(-3.44)
Jan 1-15 × 8 AM - 8 PM	-0.370***		-0.192**
	(-3.87)		(-2.37)
Apr 15-30 × 8 AM - 8 PM		-0.229***	-0.443***
		(-2.71)	(-5.34)
Constant	-1.149***	-3.309***	-0.203
	(-3.05)	(-3.04)	(-0.83)
Observations	1318	1300	2618
Nitrogen oxides	**Phase 1**	**Phase 2**	**Combined**
8 AM - 8 PM	7.284*	-23.18***	-8.927***
	(1.77)	(-6.32)	(-3.21)
Jan 1-15 × 8 AM - 8 PM	-34.90***		-20.16***
	(-6.97)		(-4.80)
Apr 15-30 × 8 AM - 8 PM		-19.08***	-33.94***
		(-4.50)	(-7.85)
Constant	-108.7***	-156.3***	-37.94***
	(-5.51)	(-2.86)	(-2.96)
Observations	1327	1293	2620

t statistics in parentheses
Source: Hourly data from 2 CPCB stations (Shadipur and Dwarka). PM 2.5 data also obtained from the U.S Embassy station in Chanakyapuri. The control period is one week before and after the restrictions were put into place. A day-night comparison is estimated taking into account that the restrictions were in place only during the day
Weekly and station fixed effects included. Controls for temperature, humidity, and their squares have been included. A control for Sundays has also been included.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

4.3 Kolkata clean-air legislation

The Kolkata high court, under pressure from the Supreme Court, ordered the state government to implement legislation that would control air pollution in the city. Starting in July 2009, all auto-rickshaws were required to have 4-stroke engines and use LPG. In addition, buses older than 15 years were ordered off city roads. There was considerable resistance to this by private players, who eventually had to comply. We used data from automatic stations monitored by the CPCB in Kolkata for the years 2008-2010 to examine the impact of the new law.

We use all available data for a three-year period, 2008-2010 for the two automatic stations within the city of Kolkata and Howrah and Haldia outside it. We therefore have an 18-month period before the change and 18 months after it. We estimate the effect of the law on the three pollutants- carbon monoxide, nitrogen dioxide and PM 10. Average pollution levels for these two groups of stations and for the two periods (before and after the legislation) are seen in Table 8.

Table 8: Pollution levels in automatic stations in and around Kolkata.

		Jan, 2008 - June, 2009		July, 2009 - Dec, 2010	
Source	Pollutant	Mean	N	Mean	N
RBU and Victoria Memorial	Carbon Monoxide (mg/cubic metres)	1.22	29842	1.10	16270
	Nitrogen dioxide (μg/cubic metres)	49.70	32821	79.80	17144
	PM 10 (μg/cubic metres)	157.03	33402	134.76	17152
Howrah and Haldia	Carbon Monoxide (mg/cubic metres)	1.09	30640	1.21	16392
	Nitrogen dioxide (μg/cubic metres)	38.30	30009	48.23	16330
	PM 10 (μg/cubic metres)	165.24	29566	166.84	16328

For each pollutant, we estimate three models. Our dependent variable in all of these is the hourly recording of the pollutant. In our first specification, we estimate the average effect of the legislation using data from the entire three-year period. In the second, we break up the 18-month period after the legislation and estimate separate treatment effects for each of the six quarters following the introduction of the clean-air policy. Our hypothesis is that lags in implementation result in an increasing effect of treatment over time. Our last model is the same as the second one, but uses data only for six quarters in our data set that are in the post-treatment period. In all specifications we include fixed-effects for each hour since there is systematic variation in emissions over the course of the day. We also include quarter fixed effects to adjust for seasonality and station fixed-effects for the first two models that use data for the entire 2008-2010 period. Our first and second specifications are therefore:

$$P_{ihjq} = \alpha + \beta T + quarter_h + station_j + hour_h + \epsilon_{ihjq} \tag{2}$$

$$P_{ihjq} = \alpha + \sum \beta_k T * quarter_h + quarter_h + station_j + hour_h + \epsilon_{ihjq} \tag{3}$$

where P_{ihjq} measures the concentration of a pollutant i at hour h in station j for quarter q. T indicates treatment and takes the value 1 for all Kolkata recordings after July 1, 2009. Quarters are numbered starting in January and q_h indicates that the quarter in which the hourly recording occurs.

This strategy implies that our identification of treatment effects is based on a comparison of both temporal and spatial differences in pollution levels. Our controls for the first two specifications are Kolkata stations before July 2009 and the Howrah and Haldia stations throughout the period. For the third model, since we use data only post 2009, our controls are only spatial, namely Howrah and Haldia.

Our results are in Table 9. We find that carbon monoxide and PM 10 levels declined across all 3 specifications and, on average, these effects increase over time. Nitrogen oxide levels rise during the treatment period and the changes are less systematic during the post-treatment period.

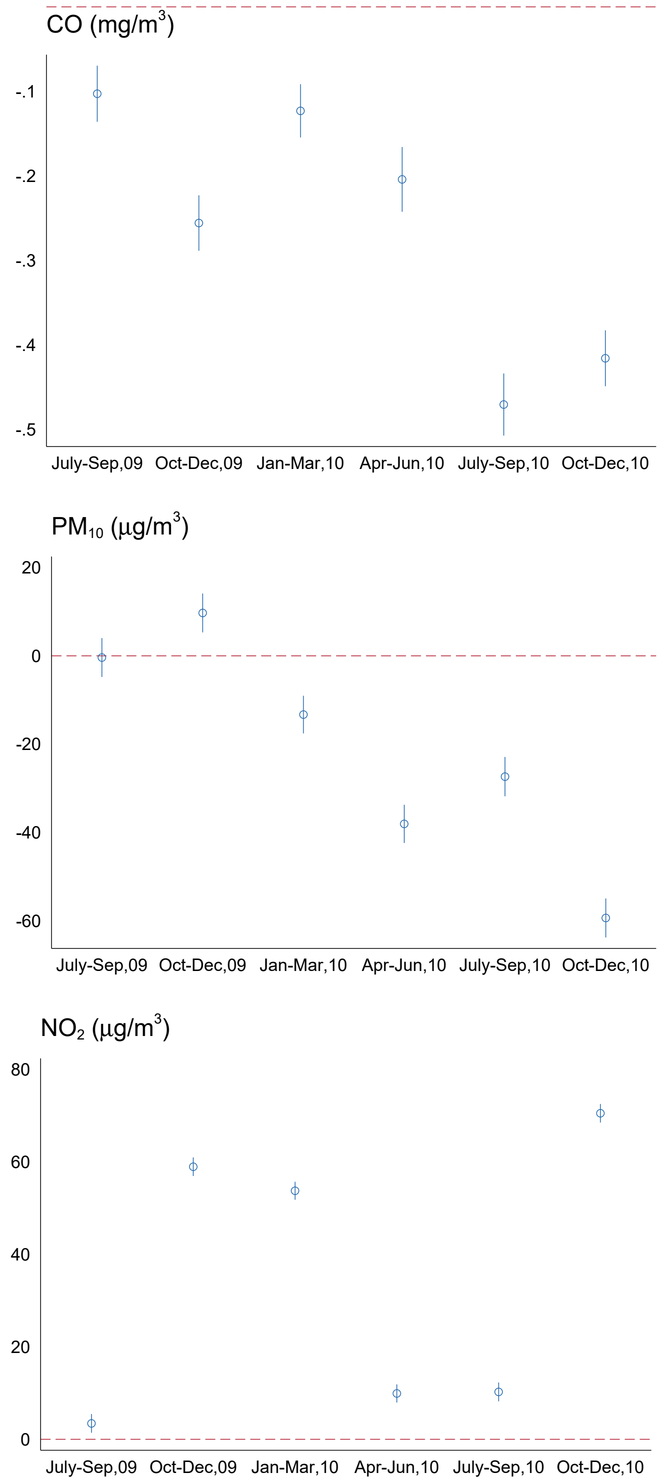
Table 9: Estimated Impacts of Clean fuel legislation in Kolkata

	CO (mg/m^3)			PM10 ($\mu g/m^3$)			NO2 ($\mu g/m^3$)		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
July,09-Dec,10 x Kolkata	-0.243***			-21.80***			34.50***		
	(-27.15)			(-19.08)			(64.80)		
quarter=1	0.730***	0	0	149.2***	0	0	41.59***	0	0
	(85.02)	(.)	(.)	(129.90)	(.)	(.)	(79.04)	(.)	(.)
quarter=2	0	-0.714***	-0.991***	0	-144.8***	-160.7***	0	-33.93***	-51.34***
	(.)	(-77.10)	(-42.68)	(.)	(-114.84)	(-49.19)	(.)	(-59.81)	(-27.72)
quarter=3	0.162***	-0.541***	-0.737***	-19.11***	-169.7***	-172.7***	-4.657***	-32.75***	-57.94***
	(17.92)	(-53.78)	(-40.31)	(-16.39)	(-127.27)	(-67.44)	(-8.56)	(-53.34)	(-39.76)
quarter=4	0.891***	0.214***	-0.0919***	143.9***	-2.815**	6.903***	54.58***	5.961***	-8.196***
	(100.90)	(21.89)	(-5.04)	(124.53)	(-2.14)	(2.71)	(102.55)	(10.06)	(-5.65)
Jul - Sep 2009 x Kolkata		-0.103***	0.0271		-0.389	-5.913**		3.436***	5.295***
		(-6.07)	(1.53)		(-0.17)	(-2.39)		(3.32)	(3.74)
Oct - Dec 09 x Kolkata		-0.256***	-0.0157		9.710***	-8.481***		58.94***	49.77***
		(-15.29)	(-0.88)		(4.33)	(-3.44)		(57.71)	(35.33)
Jan - Mar 2010 x Kolkata		-0.123***	-0.189***		-13.30***	-21.92***		53.75***	30.40***
		(-7.66)	(-9.06)		(-6.12)	(-7.53)		(54.10)	(18.27)
Apr - Jun 2010 x Kolkata		-0.204***	-0.0261		-38.06***	-30.04***		9.918***	4.006**
		(-10.44)	(-1.03)		(-17.25)	(-9.29)		(9.93)	(2.19)
July - Sep 2010 x Kolkata		-0.471***	-0.359***		-27.36***	-32.25***		10.25***	12.09***
		(-25.09)	(-18.30)		(-12.05)	(-12.91)		(9.87)	(8.51)
Oct - Dec 2010 x Kolkata		-0.416***	-0.174***		-59.36***	-77.36***		70.51***	61.30***
		(-24.64)	(-9.76)		(-26.36)	(-31.28)		(68.75)	(43.35)
Constant	0.742***	1.449***	1.988***	72.32***	220.3***	297.7***	14.57***	53.13***	108.5***
	(44.59)	(87.42)	(77.21)	(32.69)	(99.46)	(84.33)	(14.22)	(52.79)	(54.03)
Observations	93144	93144	46449	96448	96448	48503	96304	96304	48566

t-statistics in parentheses
Notes: All models use data from four CPCB automatic stations: Victoria Memorial and Rabindra Bharti University in Kolkata, and the neighboring stations of Howrah and Haldia. Model (3) uses data post July 2009, while the other two models use data for the entire three year period, 2008-2010. Station-effects are included in Models (1) and (2).
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 6 illustrates the quarter-wise treatment effects that we see in Table 9, together with 95% confidence intervals.

Figure 6: Estimates and confidence intervals for quarter-wise treatment effects in Kolkata



Estimates and confidence intervals from are Model (2) in Table 9.

5 Attitudes and Compliance

5.1 The Delhi Odd-Even rule

During the second Odd-Even phase in the last week of April, we conducted brief interviews with 155 citizens to gauge their response to the policy. We interviewed public transport users at bus stands and metro stations and those using private cars at petrol pumps. For compliance rates, we observed vehicles for short periods at several traffic signals across Delhi. We also obtained figures on e-auctions for number plates of choice that are held by the Delhi Transport Authority and examine whether the demand for these number plates went up in response to the policy.

Our sample for citizen interviews consisted of 81 public transport users and 74 private car owners. The locations of these interviews are shown in Table 10.

Table 10: Sample for citizen interviews conducted during April 15-10, 2016

Area	Location	Region	N
Vehicle owner survey			
Anand Vihar	Petrol pump	East	20
Green Park	Petrol pump	South	22
Vishwavidyala	Petrol pump	North	10
Malkagunj	Petrol pump	North	10
Rajouri Garden Mall	Parking lot	West	9
Shivaji Enclave	Petrol pump	West	3
Total			74
Public transport user survey			
Anand Vihar	Bus stop	East	10
Anand Vihar	Metro station	East	10
AIIMS	Metro station	South	4
Green Park	Metro station	South	6
Satya Niketan	Bus stop	South	11
Civil lines	Bus stop	North	10
GTB nagar	Metro station	North	10
Rajouri Garden	Metro station	West	10
Rajouri Garden	Bus stop	West	10
Total			81

We asked both types of respondents about the most important advantage and disadvantage of the policy and also whether or not they would support it if it were permanent. A summary of responses in is Table 11. We also asked car owners about their alternative means of transport on days on which the restrictions were binding for them. Figure 7 shows the percentage using various alternatives. The largest fraction continued to use cars or their private two-wheelers that were not restricted. About one third of the car drivers switched to public transport, but less than half of these used the metro and no one switched to buses. The others used taxis and auto-rickshaws. About half of private car users and one-fifth of public transport users opposed a permanent switch to the policy, and both groups reported lower traffic and less pollution, although to varying degrees.

Table 11: Citizen responses to the Odd-Even rule.

	Vehicle owners (%)	Public transport users (%)
What are the advantages and disadvantages of the policy?		
Advantages		
Less Traffic	39	21
Less Pollution	4	31
Less Traffic and Less Pollution	12	23
None	32	6
Others	8	5
No response	4	14
Disadvantages		
Not an appropriate solution	19	5
Distributionally unfair	12	9
Insufficient public transport	8	14
General inconvenience	26	9
Non compliance	3	4
None	22	47
No response	11	14
N	74	81
If the policy was implemented on a permanent basis, would you support or oppose it?		
Support	43	69
Oppose	51	21
Neutral	6	10
N	72	77

Figure 7: Alternative means of transport used by private vehicle owners on restricted days

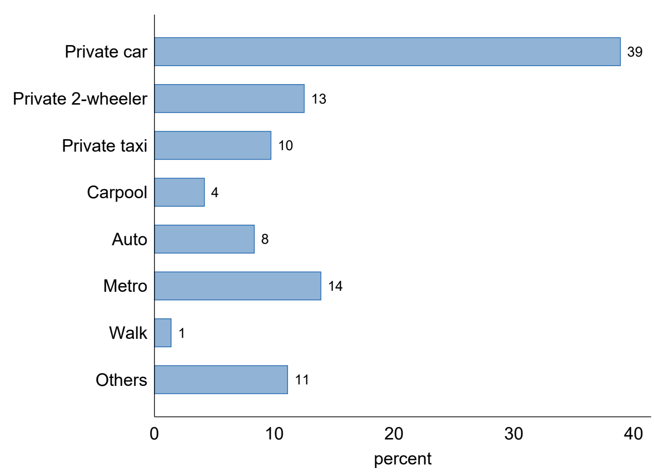


Table 12: Compliance rates observed at traffic signals (26th-30th Apr, 2016)

Date	Time	Signal	Region	Total # of cars	Compliance rate (%)
25/4/2016	11:26	GTB Nagar	North Delhi	35	85.71
25/4/2016	5:41	Ramjas College	North Delhi	24	95.83
25/4/2016	10:38	Patel Chest Hospital	North Delhi	19	94.74
25/4/2016	11:10	Hudson Lines	North Delhi	9	88.89
25/4/2016	10:49	Patel Chest Hospital(Opp. side)	North Delhi	64	89.06
27/4/2016	11:43	Hari Nagar Chowk	West Delhi	38	76.32
27/4/2016	11:10	Ansal Tower - Rajouri Garden	West Delhi	34	76.47
27/4/2016	1:46	Gulab Bagh	West Delhi	48	95.83
27/4/2016	10:43	Metro Station - Rajouri Garden	West Delhi	73	95.89
27/4/2016	12:40	Press Colony, Mayapuri	West Delhi	82	96.34
29/4/2016	12:27	Mangalam Marg	East Delhi	53	90.57
29/4/2016	3:05	Balco Market Mayur Vihar	East Delhi	61	90.16
29/4/2016	2:30	Khichirpur Road - Kondli Colony	East Delhi	89	92.13
29/4/2016	12:56	Laxmi Nagar Mother Dairy	East Delhi	52	90.38
29/4/2016	1:52	Mayur Vihar Metro Station	East Delhi	39	82.05
30/4/2016	6:15	Malviya Nagar Metro Station	South Delhi	78	94.87
30/4/2016	7:30	Saket District Court	South Delhi	39	79.49
		Total		**837**	**90.20**

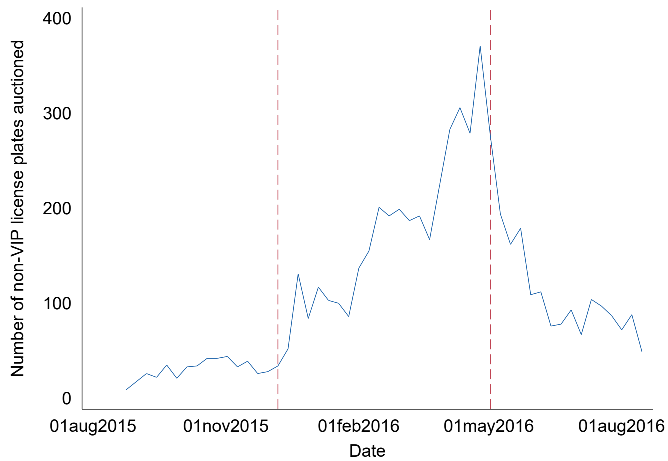
To obtain a sample to estimate compliance rates in Delhi, we observed vehicles at 17 major cross roads across the city for about 10 minutes at each traffic light and counted the number of cars and the number of violators. These data are summarized in Table 12. Of the 837 cars we observed, only 10 per cent were in violation of the rule.

Rationing schemes can also create perverse incentives in cities with insufficient public transport. In Mexico, driving restrictions were found to increase the number of cars (Eskeland & Feyzioglu 1997, Davis 2008). In our survey of car-users described above, 6.75% of our respondents using cars stated that they had purchased a new vehicle between the two phases of the scheme. We also find that families paid more for license number plates of choice. From September 2014, the Delhi Transport Authority started selling license plate numbers of choice to owners of 4-wheelers through an e-auction process. These e-auctions are conducted about once a week and the minimum reserve price for registration numbers is Rs. 20,000. We obtained e-auction data for the 50 auctions that were conducted between August 2015 and August 2016. Figure 8 shows the dramatic increase in plates sold through these auctions between the two phases of the Odd-Even rule.

5.2 Clean fuel in Kolkata auto-rickshaws

We conducted three surveys of drivers of auto-rickshaws (colloquially called *autos*) in Kolkata and its surrounding areas over the period 2010-2013. The first round was conducted in June 2010 at the 12 LPG filling stations in the city just under a year after the official start of the policy of 4-stroke LPG autos. We surveyed 100 auto-rickshaw drivers on their revenues and expenses, their perceptions of health benefits and their support for the policy. We realized after

Figure 8: License Plate Auctions, 2015-2016.



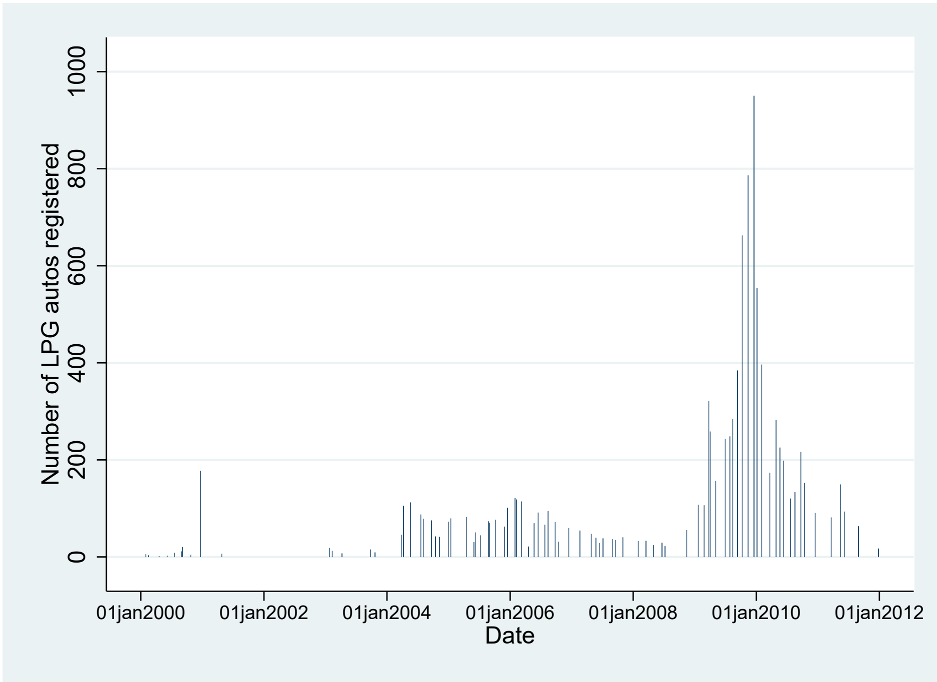
this survey that compliance was far from complete and these drivers were therefore a select sample. We decided to do additional surveys based on the geographical sampling of auto stands rather than filling stations.

Our second survey was in March 2012. We selected a sample of 40 routes from 126 registered auto-routes in the city of Kolkata. Unlike most other cities, all autos in Kolkata run on predetermined routes and each route has a cap on the number of permits that can be issued. Autos therefore function much more like buses than taxis. Since the number of autos per route varies, we selected routes using probability proportional to size weights and interviewed 6 auto drivers per stand. These were randomly chosen from those at the stand when we arrived. This survey was nearly three years after the mandated conversion to LPG and we found all the 240 city autos we surveyed at these stations to be using LPG. We observed non-LPG autos in the outskirts of the city and based on leads given to us by drivers, we located 44 such autos and interviewed their drivers as well. Our total sample therefore consists of 284 auto-rickshaw drivers.

In 2013, we looked at the entire Kolkata Metropolitan Development Area. We surveyed autos at all the railways stations in the region which had auto stands. Most train stations had two or three stands and we chose 10 autos spread across these. Apart from official licensed routes, we found a number of informal stands. We did not therefore adhere to the official route list for sampling in this round.

We also obtained registrations for LPG autos between 2000 and 2011. There are separate transport authorities for Kolkata city and for each of its bordering districts. We have this data only for the city so do not have a good estimate of compliance in the outskirts. Figure 9 shows the number of LPG autos that were registered for each month during these eleven years. We see that registrations peak about six months after the new law came into force. There was no change in the legal stock of autos over this period. If we consider the total stock of these registrations at the end of 2011 and examine the rate at which they were registered, we find only 49 percent were registered by the end of July 2009, 83% by January 2010 and 96% by January 2011. Perhaps these lags were due to bureaucratic delays or constraints in finding finance for the purchase of the new autos. It may also be that owners waited until enforcement picked up and may have also wanted to be sure that the order would not be withdrawn. These figures may also overstate total conversions since there were reportedly a large number of illegal autos on the roads. The fact that we were able to interview 71 petrol auto-drivers even in 2013 suggests high rates of non-compliance in the outskirts of Kolkata.

Figure 9:



In addition to the uncertainty surrounding the court order, one reason for the delayed implementation of the legislation could be the presence of supply bottlenecks, especially the scarcity of LPG stations in Kolkata. In fact, 43.2% of our respondents in 2010 stated that gas refilling was the primary disadvantage associated with the switch. However, this fell to 5.4% in 2013, indicating that these problems were overcome over time. Our surveys of autodrivers also reveal that waiting times for LPG at filling stations fell considerably over the three rounds.

One would expect that the transition to LPG would make auto owners worse off as compared to renters, since they would have to either purchase new autos. However, our survey data indicate that drivers who rented autos bore the brunt of the switch. In our previous report we found renters used cheap, adulterated fuel (katatel) more than owners. The switch to LPG would have more limited fuel savings for drivers who used katatel before the switch. Our data in 2013 reaffirms this to some extent; fuel savings as the primary advantage of the switch was stated by 40.5% of the renters and 51.4% of the owners in our sample.

When the legislation came into effect, buyers of new autos had to make a down-payment of 10,000 rupees. In addition, the State offered a subsidy on the purchase of new autos, and the state banks offered 60 month loans on the purchase of these autos. Monthly installments of about 2200 rupees had to be paid on these loans. In our survey, we found that median rents increased from 150 rupees per day on petrol autos before the switch to 300 rupees a day on the new LPG autos. The fuel savings of owner-drivers would compensate them at least partially for the monthly installments on the new vehicle. For those renting their auto 25 days a month, the increase in monthly rent was greater than the monthly installment.

The greatest losers from a policy are likely to be its strongest opponents. Although most auto drivers in Kolkata acknowledged that there had been improvements in their health post the legislation, the proportion supporting the switch was low. Table 13 compares incomes and the support for the new legislation by renter and owner drivers in Kolkata from our three surveys. Renter incomes were distinctly lower in the LPG phase and fewer renters supported the change even though their perceived health benefits were greater.

Table 13: Renters vs. owner drivers in Kolkata

	2010		2012		2013	
	Owner	Renter	Owner	Renter	Owner	Renter
Mean Monthly Household Income (Rs.)	9,023	7,238	12,842	10,461	13,244	10,775
Health Benefit(%)	41	62	50	54	54	46
Support(%)	34	31	8.1	3.1	35	29

A survey among the citizens of Kolkata revealed that 67% of our respondents supported the ban on 2-stroke autos and 84% of our respondents believed that pollution affects their family. However, when asked how much they were willing to contribute if there was a fund to improve air quality, about 41.5% of our respondents said that they would contribute nothing.

The Kolkata auto driver surveys revealed the importance of maintaining livelihoods in bringing about clean air legislation.

6 Policy lessons

This report summarizes our findings on the effects of air-quality legislation on air pollution in India's two most polluted metropolitan cities: Delhi and Kolkata. It also summarizes results from surveys of those affected by legislation. In Delhi, we find that driving restrictions did improve air quality and reduce traffic in their first phase, but these effects were much smaller in the second phase. Levels of air pollution recorded vary considerably by season and daily variations in weather conditions, so the smaller effects in the second phase could result from these extraneous factors. Our citizen surveys do however show that driving restrictions did not result in much of a switch to public transport. Auction data also shows and increase in demand for specific number plates that would allow individuals to continue to drive. Our findings suggest that driving restrictions are not likely to bring about major changes in behavior unless they are complemented by high quality public transport which can induce citizens to switch modes of transport. This corroborates findings in other world citiesGoh (2002).

In Kolkata too, the introduction of LPG and the phasing out of old vehicles systematically improved all the three measures of air quality that we are able to track. The effects of the legislation increase over each of the six quarters after June 2009, when the new law came into force, suggesting that there were considerable lags in its implementation. One important lesson from the Kolkata auto-rickshaw changes is that insufficient attention to the distributive changes that accompany environmental legislation can limit its political support. In both Delhi and Kolkata, the legislation put an undue burden on some sections of the population and our work suggests that a more integrated approach to urban air and transport may be necessary to achieve sustained benefits. A small increase in the cost of new registrations would have been sufficient to compensated the auto-drivers in Kolkata for the switch towards clean fuel. Had this been done, the path from clean-fuel to clean air could have been much smoother.

References

Central Pollution Control Board (2006), 'Air quality trends and action plan for control of air pollution from seventeen cities'.

Davis, L. W. (2008), 'The effect of driving restrictions on air quality in mexico city', *Journal of Political Economy* **116**(1), 38–81.

Delhi Department of Transport (n.d.), 'Pollution control'.
URL: *http://delhigovt.nic.in/newdelhi/dept/transport/tr2.asp*

Environment Pollution (Prevention & Control) Authority for the National Capital Region (n.d.), 'Epca report no: 13, 2nd final report on particulate pollution reduction strategy in seven critically polluted cities'.
URL: *http://delhigovt.nic.in/newdelhi/dept/transport/tr2.asp*

Eskeland, G. S. & Feyzioglu, T. (1997), 'Rationing can backfire: the "day without a car" in mexico city', *The World Bank Economic Review* **11**(3), 383–408.

Goh, M. (2002), 'Congestion management and electronic road pricing in singapore', *Journal of Transport Geography* **10**(1), 29–38.

GOI (2009), *National Ambient Air Quality Standards: Central Pollution Control Board Notification, Gazzette of India.*

Government of Delhi (2016), *Notification issued by Transport Department, NCT of Delhi dated 11 April,2016.*
URL: *https://goo.gl/0fG7Cm*

Guttikunda, S. K. & Mohan, D. (2014), 'Re-fueling road transport for better air quality in india', *Energy Policy* **68**, 556–561.

Karnataka State Pollution Control Board (2004), 'Karnataka state pollution control board : Annual report 2003-04'.

Tamil Nadu State Pollution Control Board (2008), *Motor Vehicles- coversion of existing petrol driven Auto Rickshaws into Liquefied Petroleum Gas mode-Enhancement of subsidy.*

WHO (2006), *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide.*

The International Growth Centre (IGC) aims to promote sustainable growth in developing countries by providing demand-led policy advice based on frontier research.

Find out more about
our work on our website
www.theigc.org

For media or communications
enquiries, please contact
mail@theigc.org

Subscribe to our newsletter
and topic updates
www.theigc.org/newsletter

Follow us on Twitter
@the_igc

Contact us
International Growth Centre,
London School of Economic
and Political Science,
Houghton Street,
London WC2A 2AE

IGC
International
Growth Centre

DIRECTED BY
LSE
UNIVERSITY OF OXFORD

FUNDED BY
UKaid
from the British people

Designed by soapbox.co.uk