Driving Restriction, Traffic Congestion, and Air Pollution: Evidence from Beijing

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Traffic Congestion and Air Pollution

Motivation

Traffic congestion is associated with significant economic, environmental, and health costs (Levy et al. 2010, Currie and Walker, 2011)

Contributions of vehicles to air pollution in Beijing

- $PM_{2.5}$: 33.1% (Beijing EPB, 2014)
- CO: 86%, NO_x: 57%, HC: 38% (Beijing EPB, 2013)

The empirical study of the impact of traffic speed on air pollution is very limited

- mean speed and air quality are simultaneously determined
- data limitation

Empirical Challenge

Pollution caused by speed

- vehicle speed $\longrightarrow$ per vehicle gasoline consumption $\longrightarrow$ air quality
- vehicle speed $\longrightarrow$ volume of traffic $\longrightarrow$ air quality

Speed caused by pollution

- air quality $\longrightarrow$ travel demand $\longrightarrow$ traffic density $\longrightarrow$ vehicle speed
- air quality $\longrightarrow$ visibility $\longrightarrow$ vehicle speed

This Paper

We exploit the potentially exogenous variation created by driving restriction to evaluate the effect of traffic congestion on air quality in Beijing

- Different from the previous studies focusing on the reduced-form effect of driving restriction on air pollution

Relevant literature

Mexico City (Davis, 2008), Mexico City and Santiago (Gallego, Montero and Salas, 2013), Beijing (Chen et al., 2013; Viard and Fu, 2013), Quito (Carrillo, Malik and Yoo, 2013), Milan (Gibson and Carnovale, 2013), Cities in China and Latin America (Lin, Zhang and Umanskaya, 2013), Beijing (Sun, Zheng, Wang, 2014)

One-Day-A-Week Driving Restriction

Time

- April 12, 2009 - present, weekdays only, 7am-8pm

Areas

- All areas within but not including the 5th Ring Road

Rule

- Once a week for each vehicle based on the last digit of license plate number
- Deterministic combinations: (1,6), (2,7), (3,8), (4,9), (5,0)
- Digit-weekday restriction assignment rotates every 13 weeks
- Exception: police cars, taxis, ambulances, postal vehicles, and embassy cars

Chinese Numerology

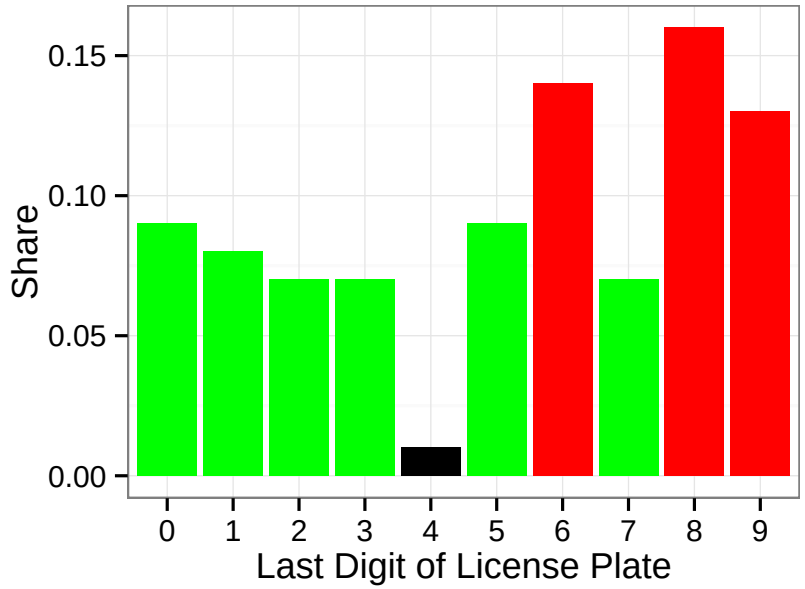
Unlucky number

- **4: death**

Lucky numbers

- **6: smooth**
- **8: wealth**
- **9: complete**

Empirical evidence: WTP for lucky numbers in floors, addresses, telephone numbers, and license plates (Shum et al., 2014)



Source: unofficial license data from Tianjian city

`http://club.autohome.com.cn/`

Rotation Induces Daily Variation in Traffic

Date	Last Digit of License Plate				
	M	Tu	W	Th	F
. . . . .	. . .	. . .	. . .	. . .	. . .
2012/01/08-2012/04/08	**4,9**	0,5	1,6	2,7	3,8
2012/04/09-2012/07/07	3,8	**4,9**	0,5	1,6	2,7
2012/07/08-2012/10/06	2,7	3,8	**4,9**	0,5	1,6
2012/10/07-2013/01/05	1,6	2,7	3,8	**4,9**	0,5
2013/01/06-2013/04/07	0,5	1,6	2,7	3,8	**4,9**
. . . . .	. . .	. . .	. . .	. . .	. . .

Data

Air quality

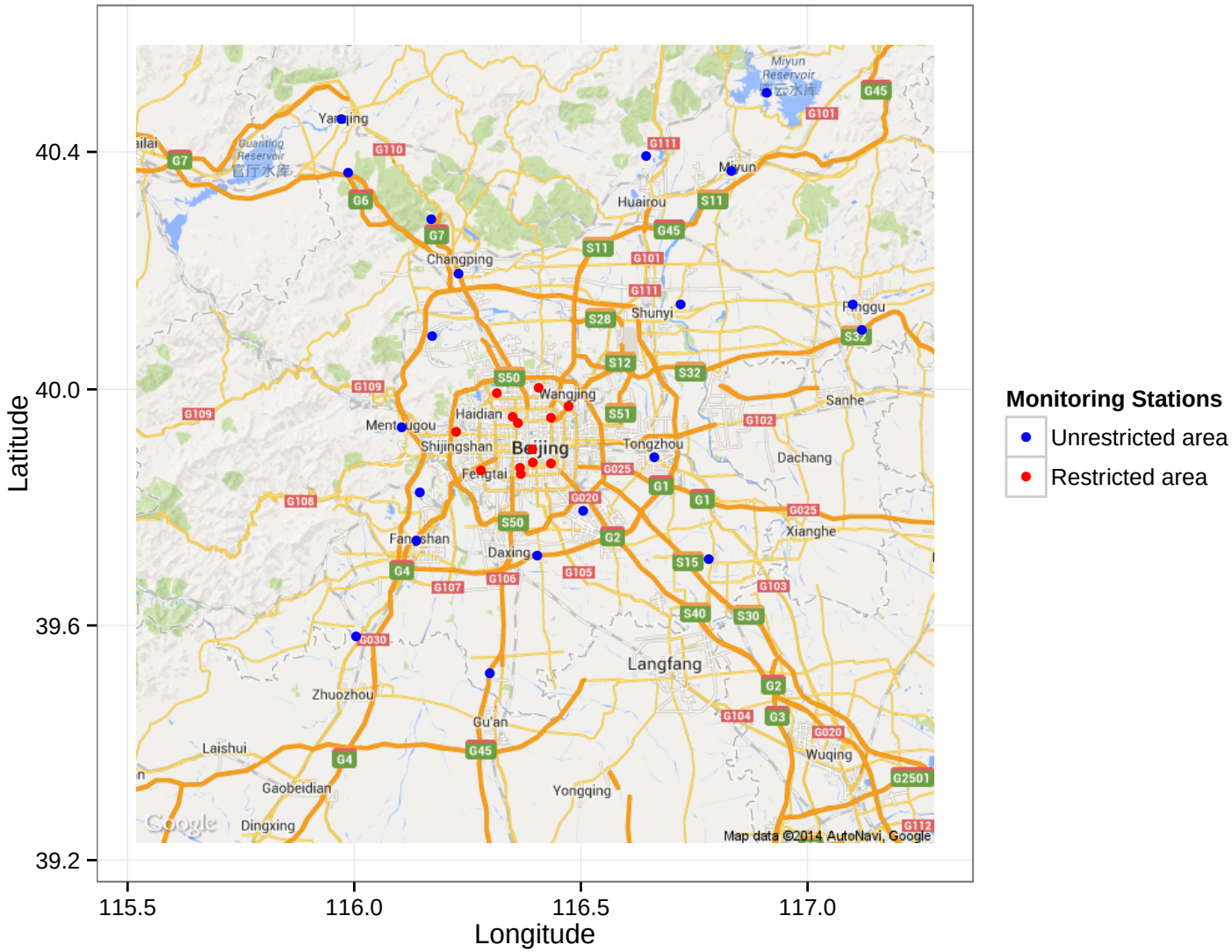
- Hourly criteria pollutant concentrations (SO_2, NO_2, CO, O_3, PM_{10}, $PM_{2.5}$): 2013-
- Hourly $PM_{2.5}$ concentrations from the US Embassy: 2012-2013

Weather

- Temperature, precipitation, wind speed, wind direction, dew point

Traffic Performance Index (TPI)

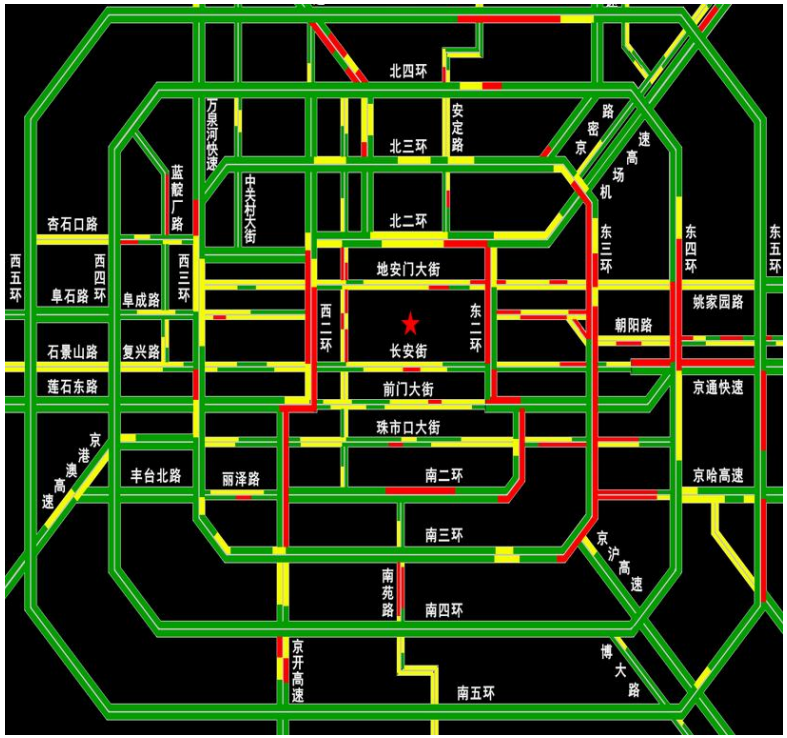
- Morning/evening rush hour, and daily average TPI


Latitude
40.4
40.0
39.6
39.2
115.5
116.0
116.5
117.0
Longitude
Monitoring Stations
Unrestricted area
Restricted area
Beijing
Changping
Huairou
Miyun
Shunyi
Tongzhou
Haidian
Wangjing
Fengtai
Shijingshan
Fangshan
Daxing
Mentougou
Dachang
Xianghe
Sanhe
Langfang
Zhuozhou
Gu'an
Laishui
Gaobeidian
Yongqing
Wuqing
Dingxing
Yanqing
Miyun Reservoir
Guanting Reservoir
Map data ©2014 AutoNavi, Google

Traffic Performance Index (TPI)

TPI: a normalized index measuring traffic congestion on a scale from 0 (free flow) to 10 (forced or breakdown flow)

TPI	Average Vehicle Travel Time
$[0, 2)$	1
$[2, 4)$	1.3-1.5
$[4, 6)$	1.5-1.8
$[6, 8)$	1.8-2
$[8, 10]$	2



Source: `http://eye.bjjtw.gov.cn/`

Specification

Traffic-pollution relationship

$$\log y_{it} = \beta_0 + \beta_1 \log \mathsf{TPI}_t + \beta_2{}' \log w_t + \mathsf{Station}_i + \mathsf{Year}_t + \mathsf{Month}_t + \mathsf{Weekday}_t + \varepsilon_{it}$$

Notations

- i: monitoring station
- t: day, morning/evening rush hour
- y: pollutant concentration for SO_2, NO_2, CO, O_3, PM_{10}, $PM_{2.5}$
- w: temperature, precipitation, wind speed/direction, dew point (proxy for humidity)
- Station: monitoring site fixed effect
- Year, Month, and Weekdays: time fixed effects

Empirical Strategy

Driving restriction as an instrument for TPI

Relevance

- Driving restriction affects traffic speed by limiting traffic volume

Exogeneity

- Predetermined schedule of rotation for restricted vehicles
- The distribution of last digit of license plate number is determined by culture

Exclusion restriction

- The only channel that driving restrictions affect air quality is through traffic

Intuition: Average TPI by Restrictions

Restriction	Morning Peak	Evening Peak	Daily Average
No	3.498	4.445	3.968
	(1.423)	(1.964)	(1.544)
1&6	4.212	5.009	4.611
	(1.526)	(1.604)	(1.37)
2&7	4.378	5.471	4.903
	(1.661)	(1.716)	(1.395)
3&8	4.208	4.937	4.566
	(1.429)	(1.591)	(1.245)
4&9	4.798	6.268	5.503
	(1.556)	(2.01)	(1.637)
5&0	4.260	5.267	4.745
	(1.293)	(1.896)	(1.328)

Notes: Standard errors in parentheses.

Threat to Identification

Buying a second car

- Beijing Auto-license lottery since 2011: about 20,000 new passenger vehicles/month
- Year and month dummies to control for total stock of vehicles

Substitution of drivings

- Inter-temporal substitution: daily vs rush hours
- Spatial substitution: restricted vs unrestricted zones

Driving preference independent from ending digit numbers

- Assuming the license holders with ending digit 4&9 are equally likely to substitute driving or violate restriction as those with other ending digits do

First Stage: The Effect of Driving Restrictions on Traffic

VARIABLES	Daily TPI	Morning TPI	Evening TPI
Non-4&9 restricted	-0.124**	-0.105**	-0.155***
	(0.049)	(0.048)	(0.057)
Observations	323	322	321
R-squared	0.328	0.461	0.276
rmse	0.343	0.336	0.397

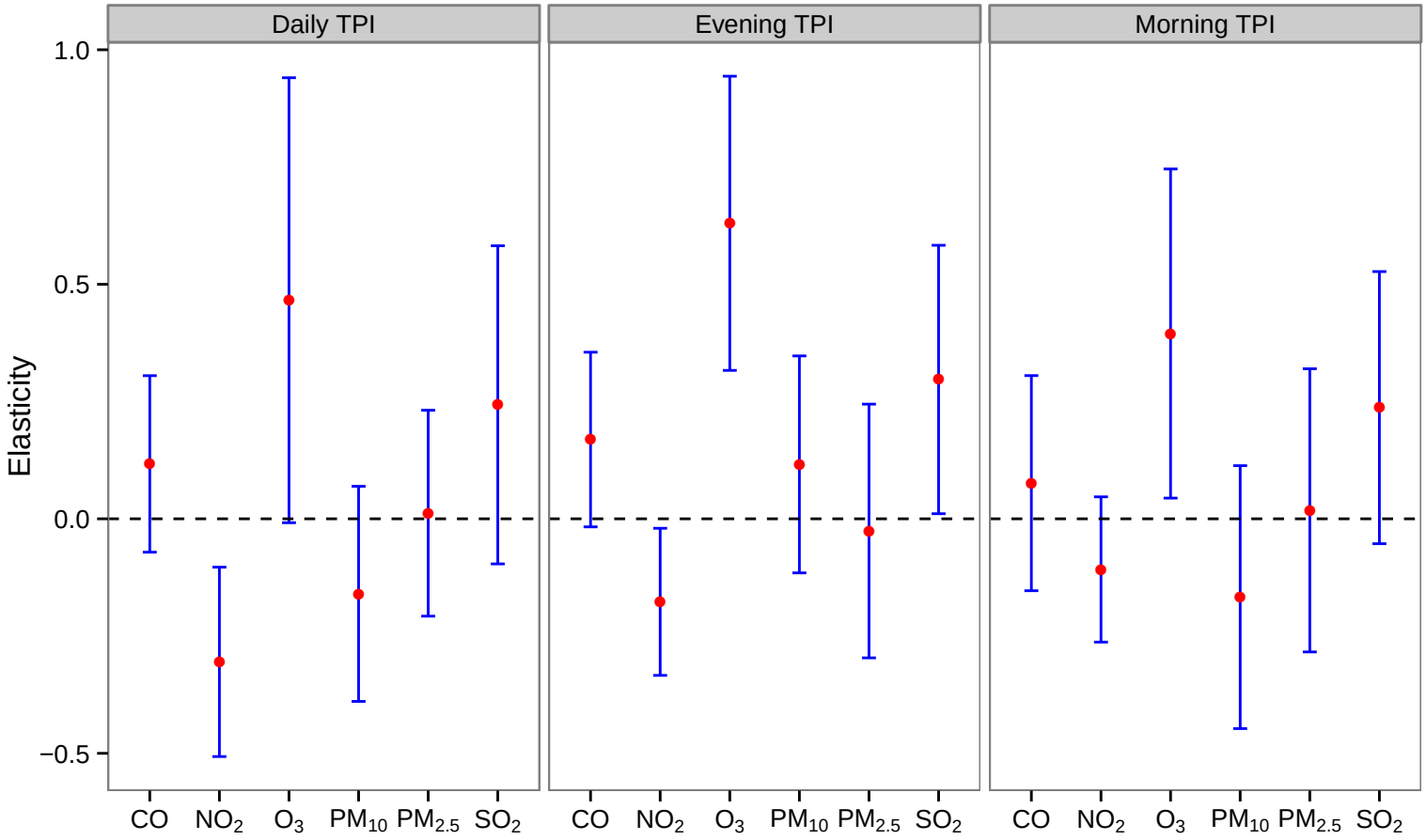
Notes: Other exogenous variables in the first-stage regression include all weather variables and year/month/weekday fixed effects. Weak identification statistics Cragg-Donald (N-L)*minEval/L2 F-stat: 15.50. Standard errors in parentheses: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

IV vs OLS: $PM_{2.5}$ in Restricted Zones

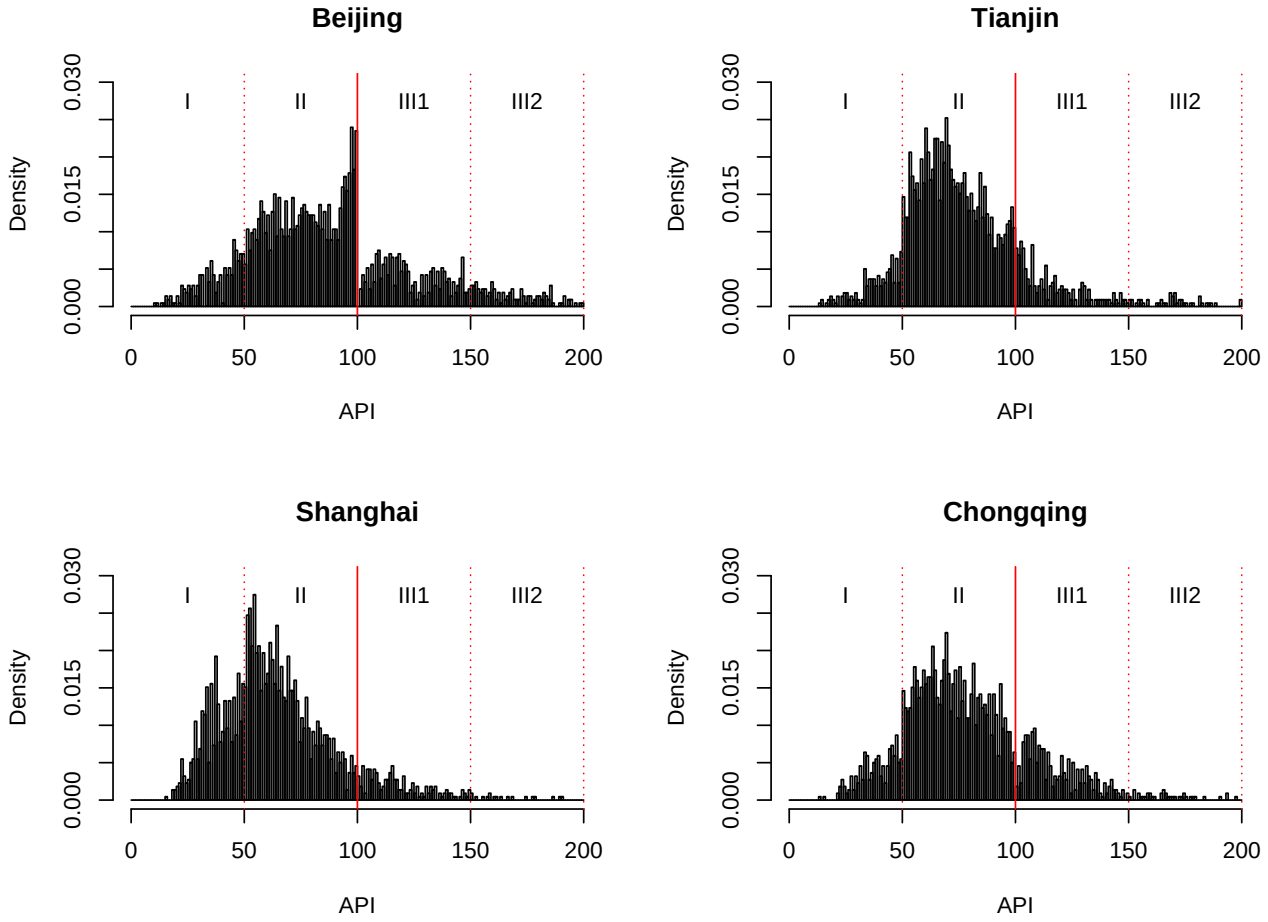
	IV			OLS		
VARIABLES	Daily $PM_{2.5}$	Morning $PM_{2.5}$	Evening $PM_{2.5}$	Daily $PM_{2.5}$	Morning $PM_{2.5}$	Evening $PM_{2.5}$
Daily TPI	0.012			-0.049*		
	(0.112)			(0.028)		
Morning TPI		0.018			-0.149***	
		(0.154)			(0.034)	
Evening TPI			-0.026			-0.084***
			(0.138)			(0.029)
Observations	3,049	3,098	3,098	3,049	3,098	3,098
R-squared	0.782	0.738	0.739	0.782	0.740	0.739

Notes: TPI is instrumented by driving restrictions in the IV results. Other exogenous variables in the first-stage regression include all weather variables and year/month/weekday fixed effects. Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Effects of Traffic on Air Quality in Restricted Zones

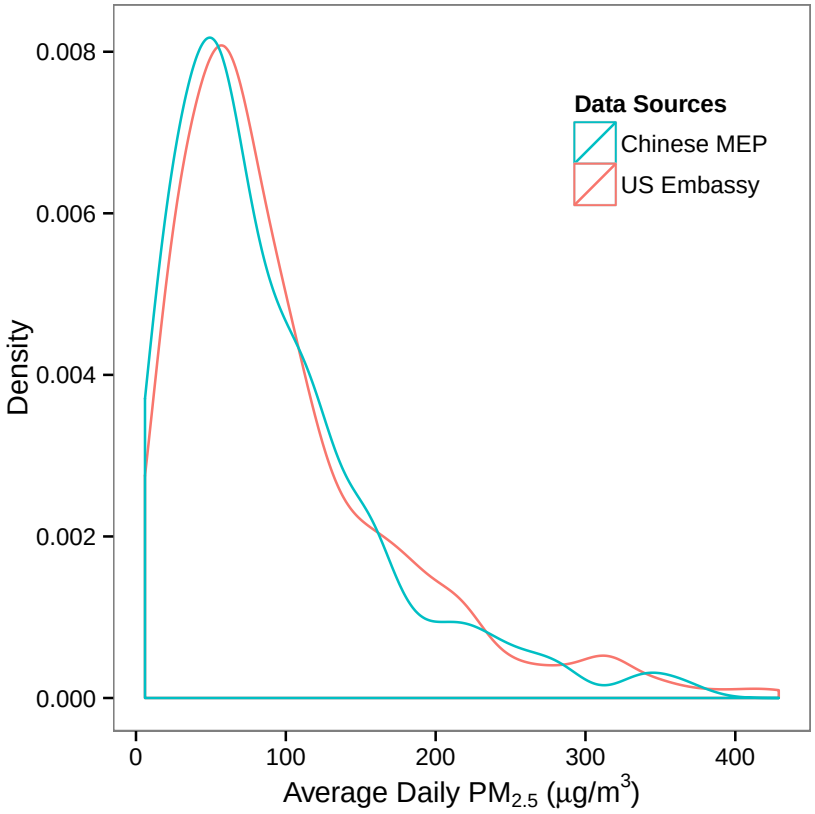


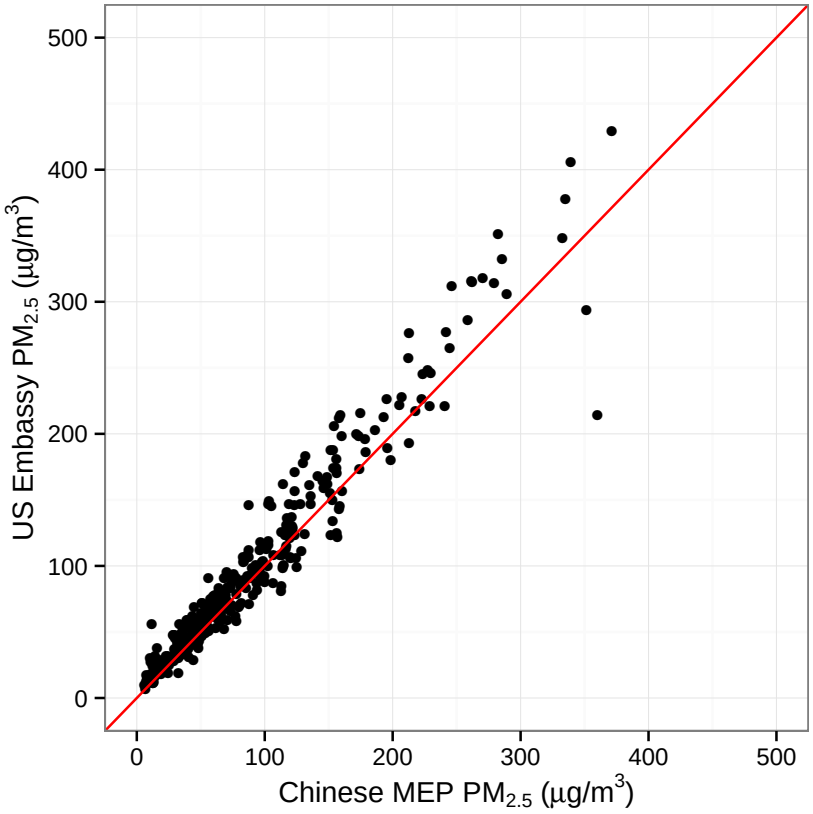
Concern of Air Pollution Data Manipulation (2001-2010)



Source: Ghanem and Zhang, 2014

Chinese MEP vs US Embassy (2013)





Traffic-Pollution Relationship: The US Embassy Data

VARIABLES	Daily $PM_{2.5}$	Morning $PM_{2.5}$	Evening $PM_{2.5}$
Daily TPI	0.753		
	(0.459)		
Morning TPI		-0.803	
		(0.815)	
Evening TPI			-0.517
			(0.503)
Observations	317	308	315
R-squared	0.804	0.680	0.744

Notes: TPI is instrumented by driving restrictions in the IV results. Other exogenous variables in the first-stage regression include all weather variables and year/month/weekday fixed effects. Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Concluding Remarks

Main results

- Driving restriction contributes to the ease of traffic congestion
- Heterogeneous effects of traffic speed on air quality

Caveats

- Binary restriction dummy as IV may not provide sufficient variation to identify the effect of traffic speed on air quality
- IV reduces precision of estimates

Appendix

IV vs OLS: $PM_{2.5}$ in the Unrestricted Zones

	IV			OLS		
VARIABLES	Daily $PM_{2.5}$	Morning $PM_{2.5}$	Evening $PM_{2.5}$	Daily $PM_{2.5}$	Morning $PM_{2.5}$	Evening $PM_{2.5}$
Daily TPI	0.155			-0.065**		
	(0.133)			(0.031)		
Morning TPI		-0.020			-0.194***	
		(0.134)			(0.028)	
Evening TPI			-0.059			-0.117***
			(0.130)			(0.025)
Observations	4,483	4,518	4,518	4,483	4,518	4,518
R-squared	0.668	0.742	0.728	0.672	0.744	0.728

Notes: TPI is instrumented by driving restrictions in the IV results. Other exogenous variables in the first-stage regression include all weather variables and year/month/weekday fixed effects. Standard errors in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Effects of Traffic on Air Quality: Unrestricted Zones