Transboundary air pollution and health: evidence from East Asia *

Jaehyun Jung † Anna Choi ‡ Semee Yoon §

ONLINE APPENDIX

†Korea Institute of Public Finance, Sejong-si, Republic of Korea.

‡Department of Public Administration, Sejong University, Seoul, Republic of Korea.

§Underwood International College, Yonsei University, 85 Songdogwahak-ro, Yeonsu-gu, Incheon 21983, Republic of Korea. Corresponding author. Email: yoonsemee@yonsei.ac.kr

Appendix 1. Figures

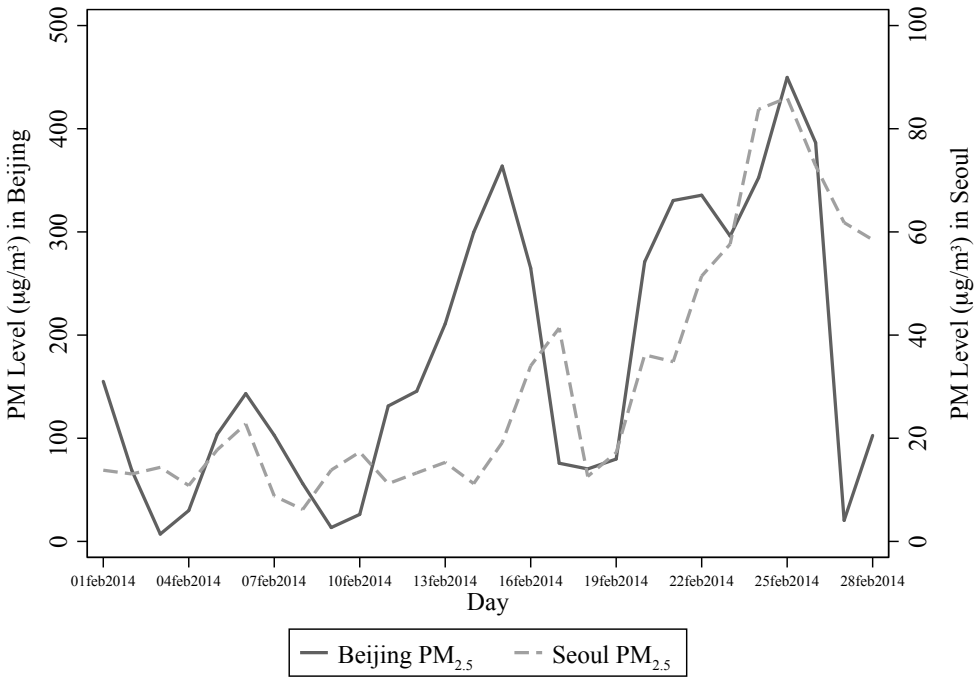


Figure A1. Daily $PM_{2.5}$ concentration in Beijing and Seoul in Feb. 2014

Notes: The figure plots the $PM_{2.5}$ concentration level in Beijing, China (solid line, left vertical axis) and in Seoul, South Korea (dotted line, right vertical axis) in February 2014.

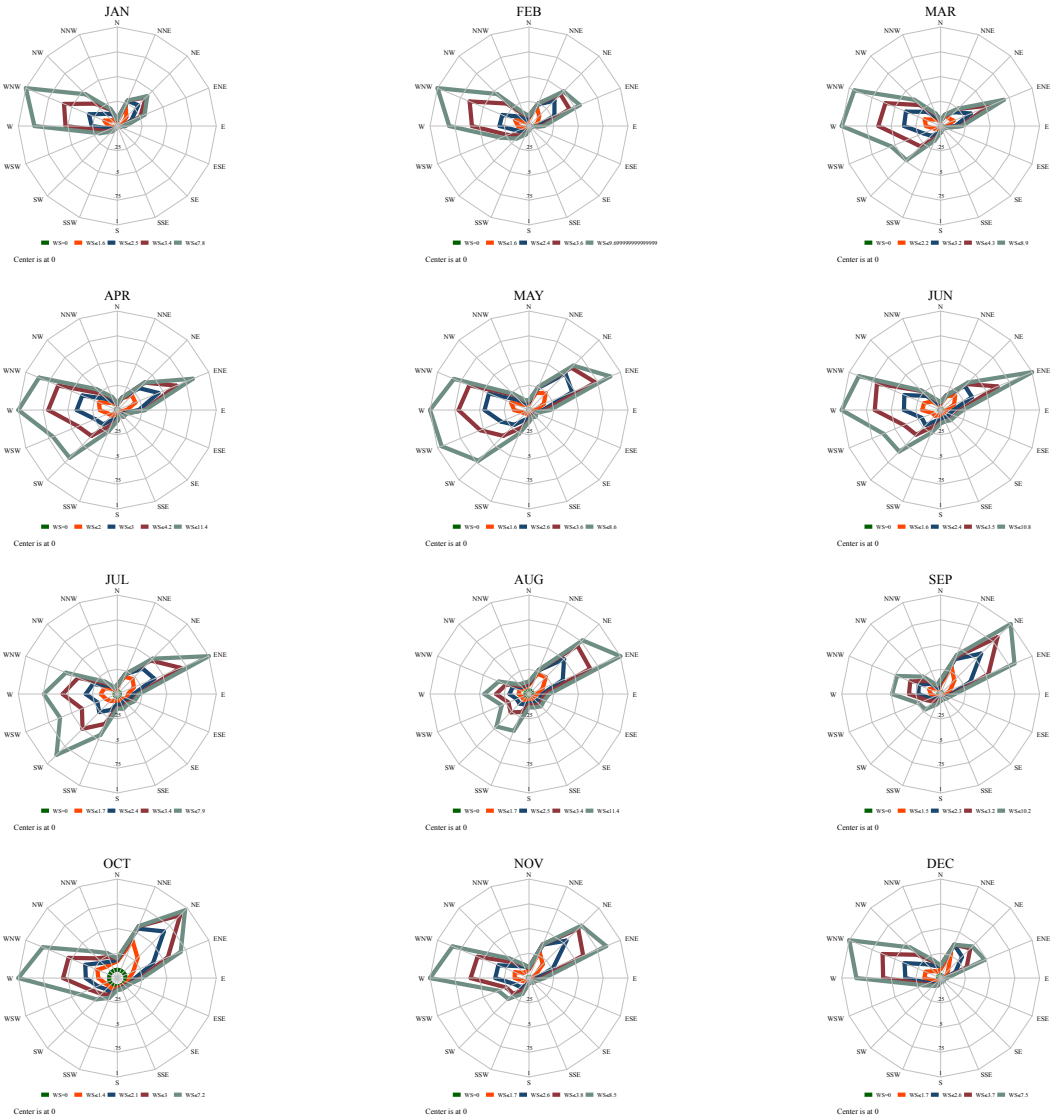


Figure A2. Daily wind patterns by month in Seoul, South Korea in 2010-2012

Notes: This figure plots the histogram of daily wind directions and speeds. Winds blow from the direction in which the shapes are pointing. For example, in January, winds mostly blow from WNW, and the wind is strongest among all seasons.

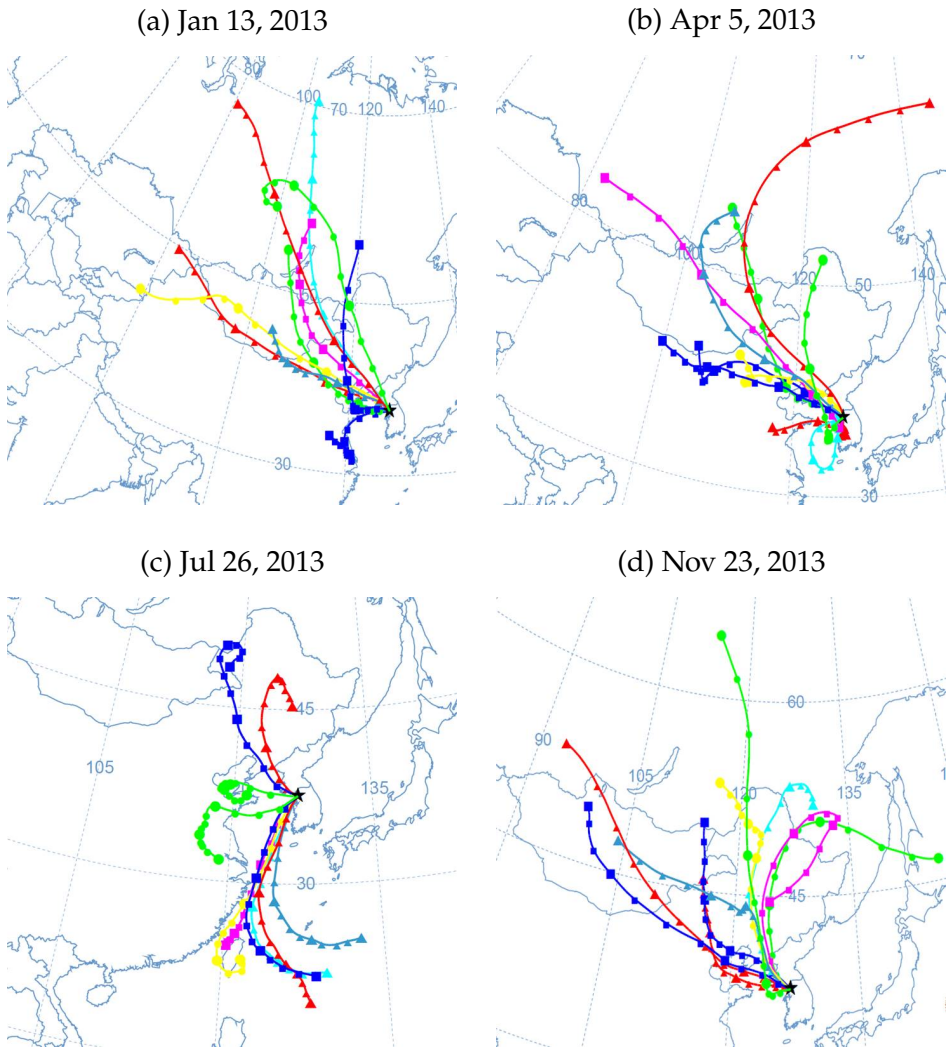


Figure A3. Backtrajectory analysis of high $PM_{2.5}$ days by season in 2013

Notes: Using the readings from one station in Seoul, South Korea, we choose the days with the highest readings of $PM_{2.5}$ for each season in 2013. Then, we calculate 72-hour back trajectories for every hour on that day to identify air mass pathways using NOAA HYSPLIT MODEL Backward trajectories. The arrival point at 00 UTC on each high-$PM_{2.5}$ episode is Seoul (37.57 N, 126.97 E), and 1000m above the surface is settled as the arrival height for given boundary layers. Each panel displays ten 72-hour back trajectories for every 24 hours, and each point represents a six-hour trajectory. The readings of $PM_{2.5}$ were 76.5$\mu g/m^3$, 71.9$\mu g/m^3$, 62.5$\mu g/m^3$ and 51.75$\mu g/m^3$ on Jan 13, Apr 5, Jul 26 and Nov 23, 2013, respectively.

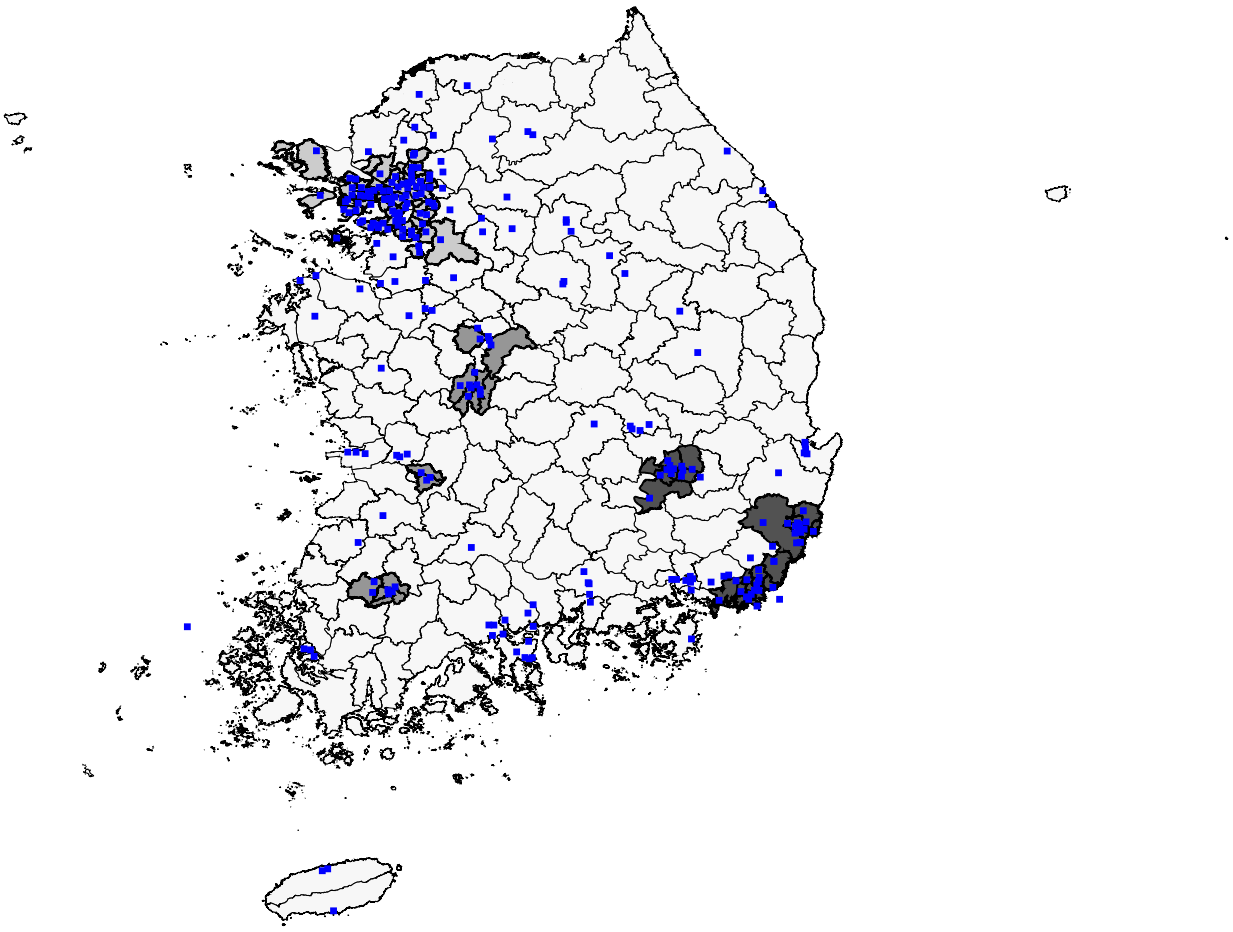
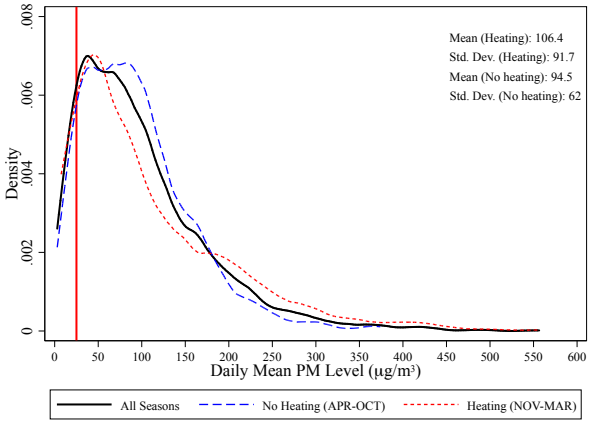


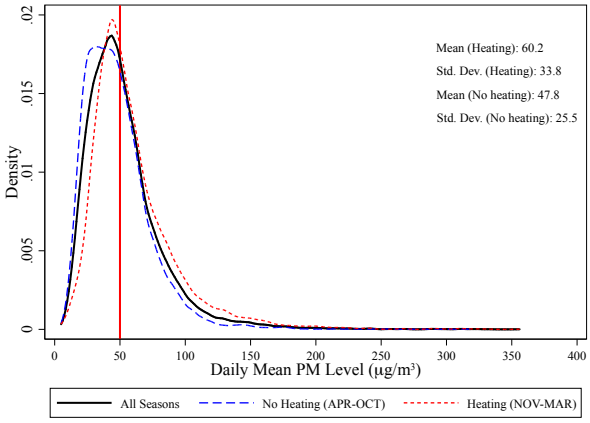
Figure A4. Cities and pollution monitors in South Korea

Notes: Blue squares denote the pollution monitors in residential areas. Region 1 (light gray) includes 14 cities. Region 2 (darker gray) includes the remaining 7 cities.

(a) $PM_{2.5}$ in Beijing



(b) PM_{10} in Region 1, Korea



(c) PM_{10} in Region 2, Korea

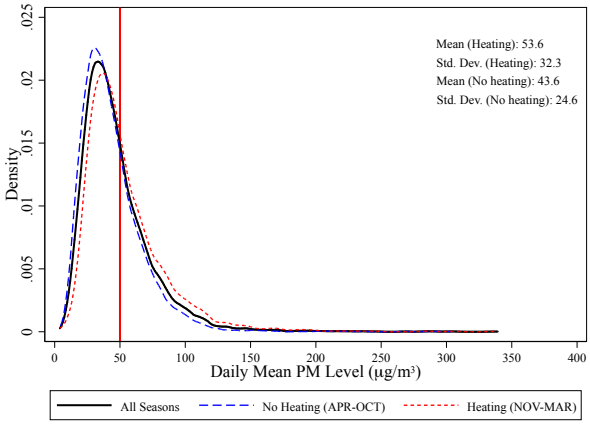


Figure A5. Distributions of daily mean PM level in Beijing and in Korea

Notes: Figures plot the kernel density estimation on the distributions of daily mean PM levels by season in Beijing and in Korea. Red solid lines denote the WHO guidelines for daily exposure to $PM_{2.5}$ ($25\mu g/m^3$) and PM_{10} ($50\mu g/m^3$), respectively.

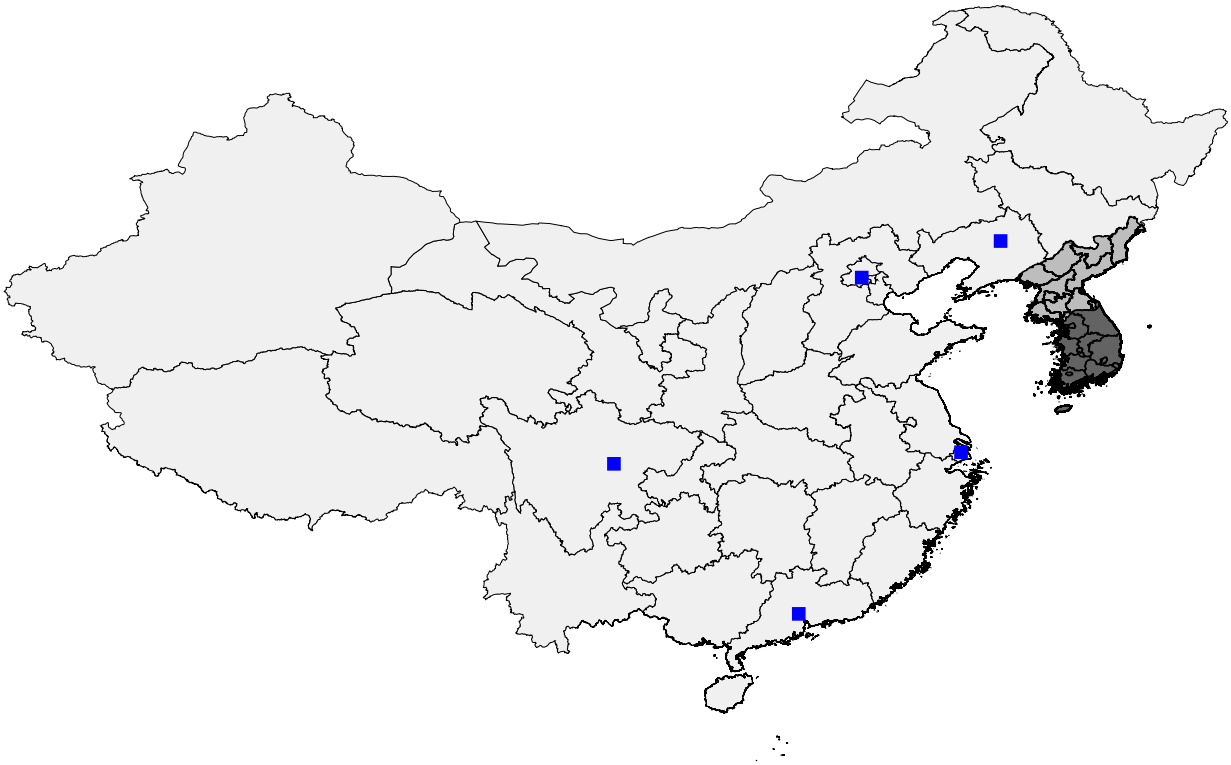


Figure A6. Locations of pollution monitors in China

Notes: The blue dot at 12 o'clock represents the monitor located at the U.S. embassy in Beijing. Shenyang is at 1 o'clock, Shanghai at 5, Guangzhou is at 7, and Chengdu is at 8, respectively.

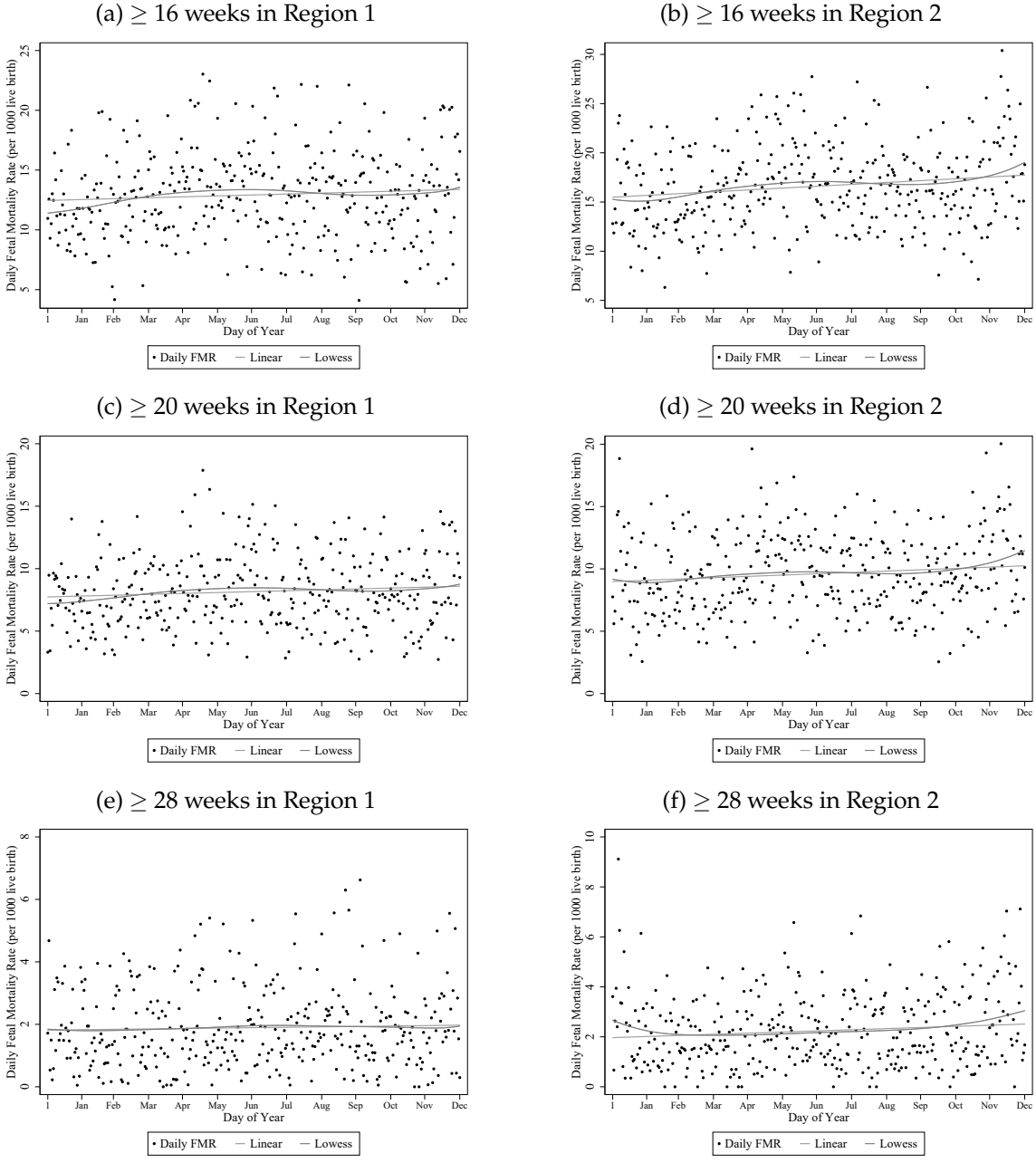


Figure A7. Seasonality of daily fetal mortality rates by region in South Korea

Notes: Linear fits and Lowess are overlaid to detect possible trends and seasonalities over the scatter plots of daily fetal mortality rates.

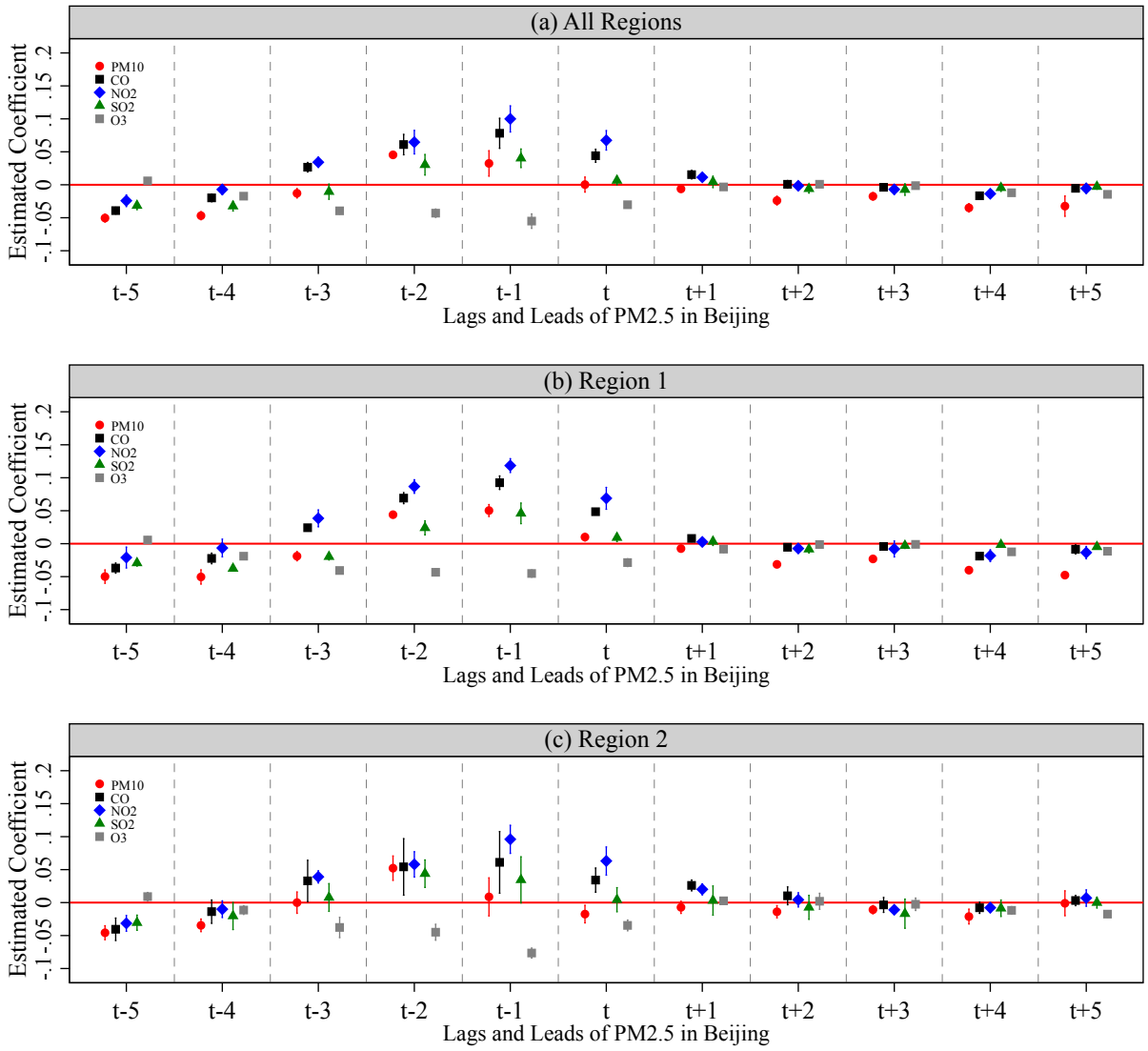
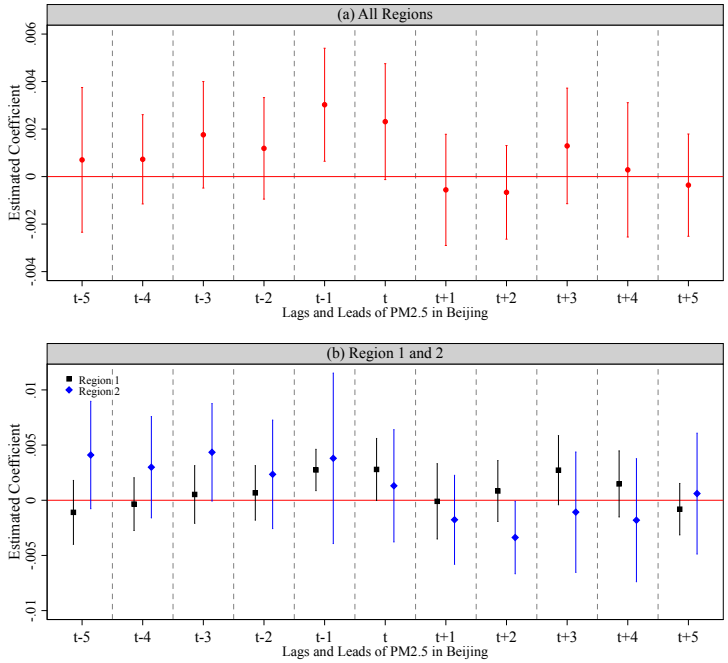


Figure A8. Effects of Beijing's $PM_{2.5}$ level on local pollution levels in South Korea by region

Notes: : Each panel provides the standardized point estimates and the corresponding 95% confidence intervals from linear regressions of the daily mean of five major pollutant levels in cities in South Korea on lags and leads of Beijing $PM_{2.5}$ level from $t-5$ to $t+5$, respectively.

(a) Daily Fetal Mortality Rate (≥20 weeks)



(b) Daily Fetal Mortality Rate (≥28 weeks)

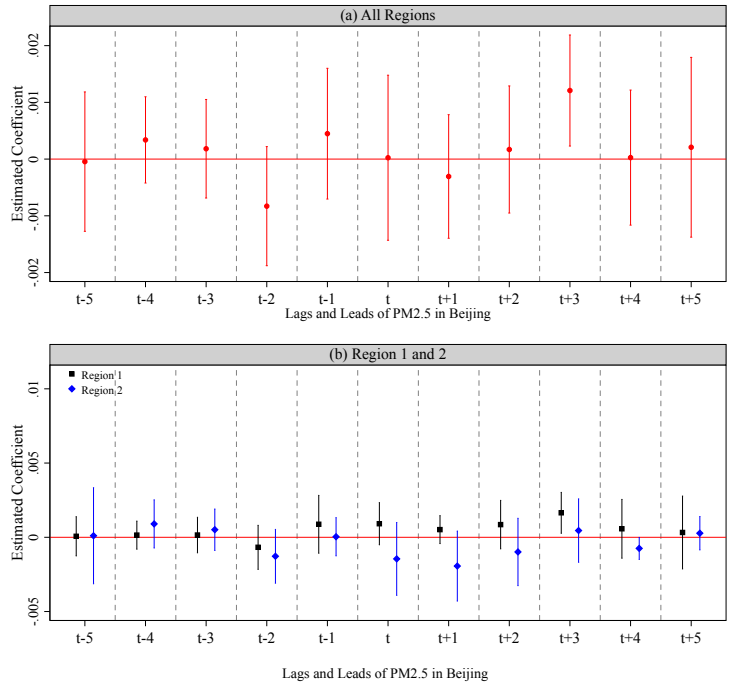


Figure A9. Effects of Beijing's $PM_{2.5}$ (from $t-5$ to $t+5$) on daily fetal mortality rates (≥20 and ≥28 weeks) in South Korea

Notes: Each panel provides the point estimates and the corresponding 95 percent confidence intervals from linear regressions of daily fetal mortality rates (≥20 weeks in Panel (a) and ≥28 weeks in Panel (b)) in South Korea on lags and leads of Beijing $PM_{2.5}$ level from $t-5$ to $t+5$ using equation (2).

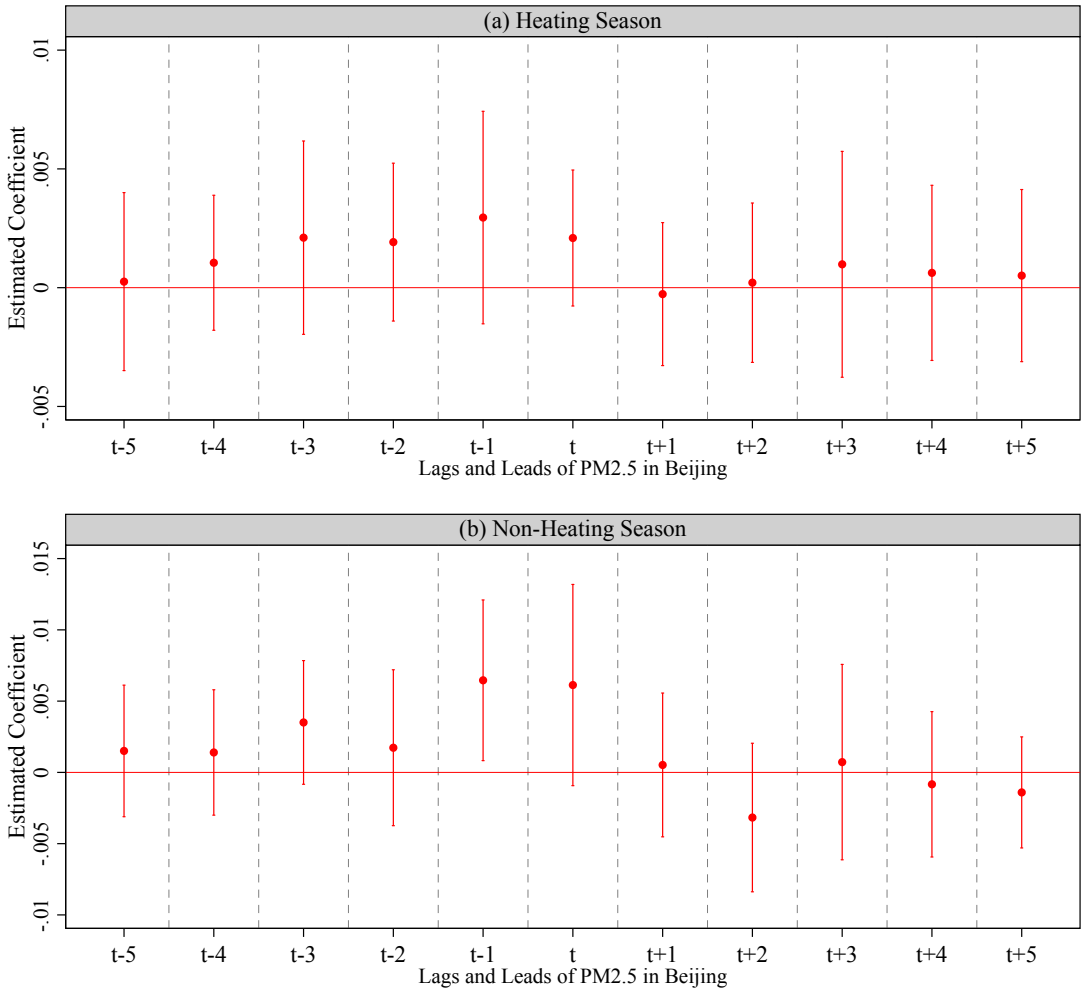


Figure A10. Effects of Beijing's $PM_{2.5}$ on daily fetal mortality rate ($\geq$16 weeks) in South Korea by heating seasons in China

Notes: Each panel provides the point estimates and the corresponding 95% confidence intervals from linear regressions of daily fetal mortality rate ($\geq$16 weeks) in South Korea on lags and leads of Beijing $PM_{2.5}$ level from $t-5$ to $t+5$ by public heating seasons in Beijing, China. Panel (a) shows the effects during the heating season and Panel (b) shows the effects during non-heating season in China.

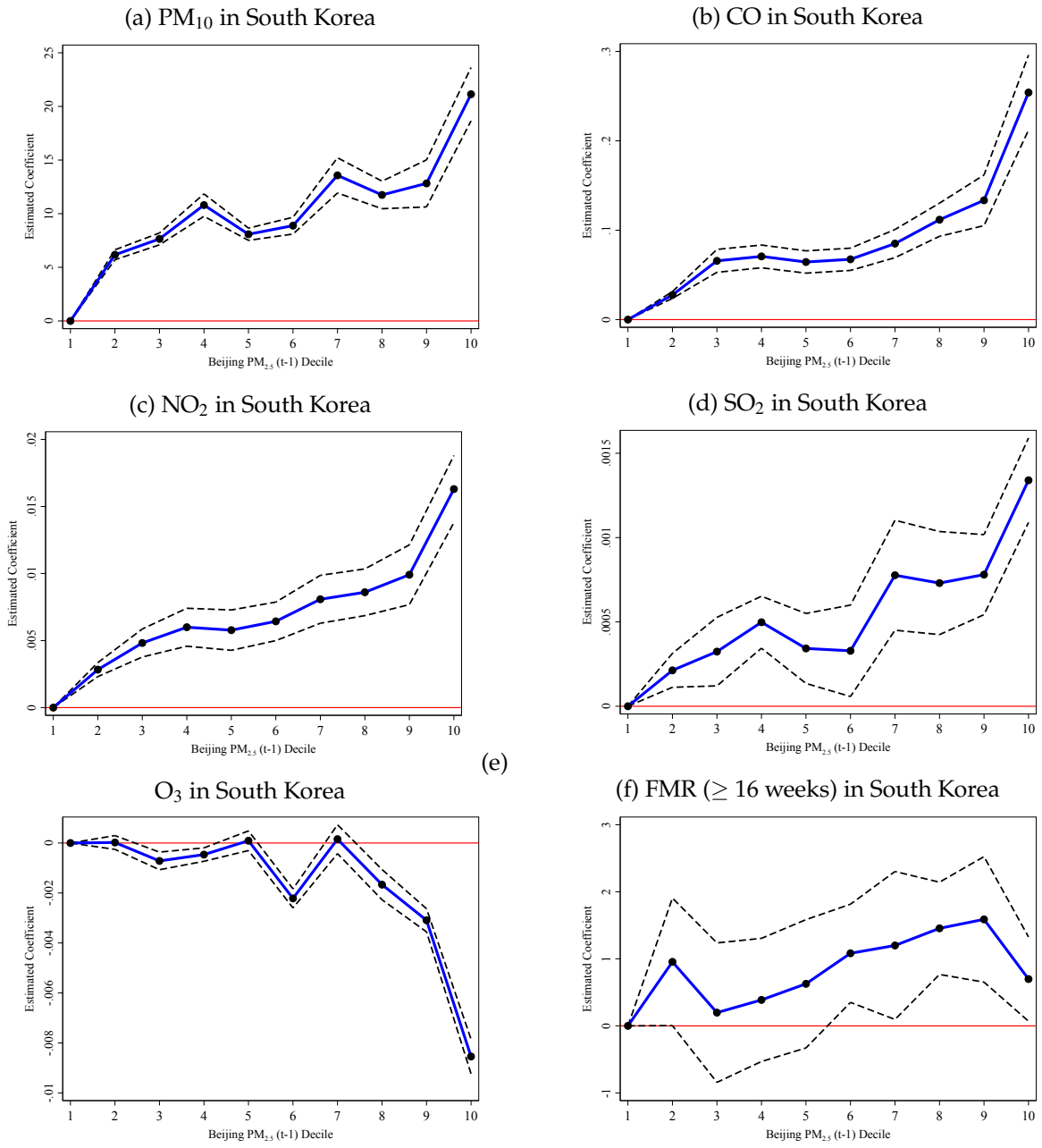


Figure A11. Effects of Beijing's $PM_{2.5}$ $(t-1)$ deciles on levels of major pollutants and daily fetal mortality rate ($\geq$16 weeks) in South Korea

Notes: The figure plots the estimated coefficients and the 95% confidence intervals from regressions of five major air pollution levels and fetal mortality rates on the dummies for each 10th percentile (decile) of Beijing's $PM_{2.5}$ $(t-1)$ distribution in 2009-2013. The omitted category is the 1st decile.

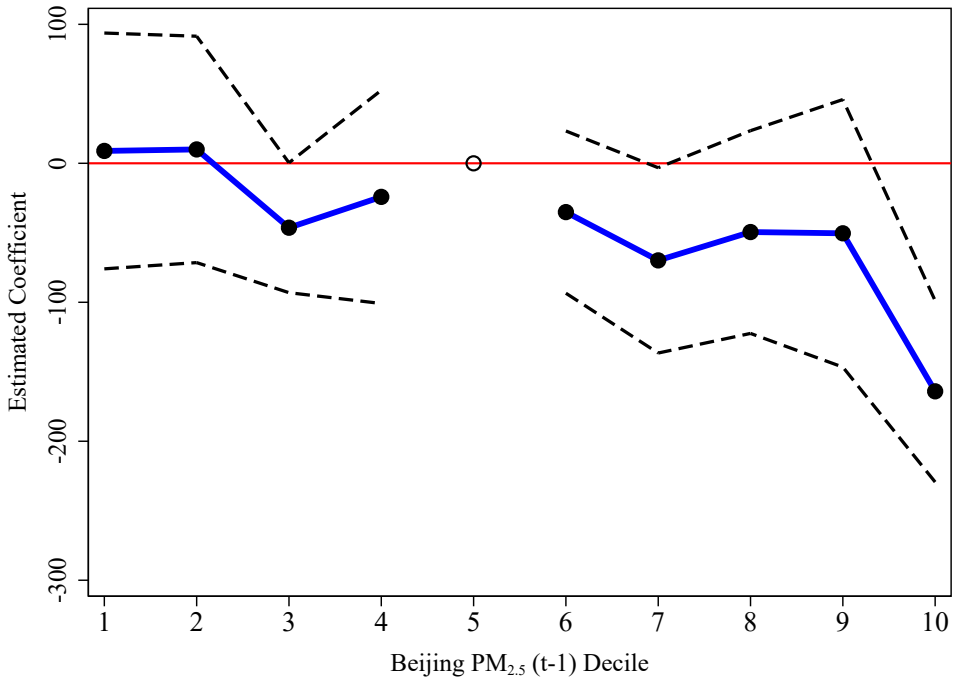


Figure A12. Effects of Beijing's $PM_{2.5}$ $(t-1)$ deciles on meteorological optical ranges in three cities in Region 1 of South Korea

Notes: The figure plots the estimated coefficients and 95% confidence intervals from a regression of meteorological optical ranges in three cities in Region 1 of South Korea on the dummies for each 10th percentile (decile) of Beijing's $PM_{2.5}$ $(t-1)$ distribution. The omitted category is the 5th decile.

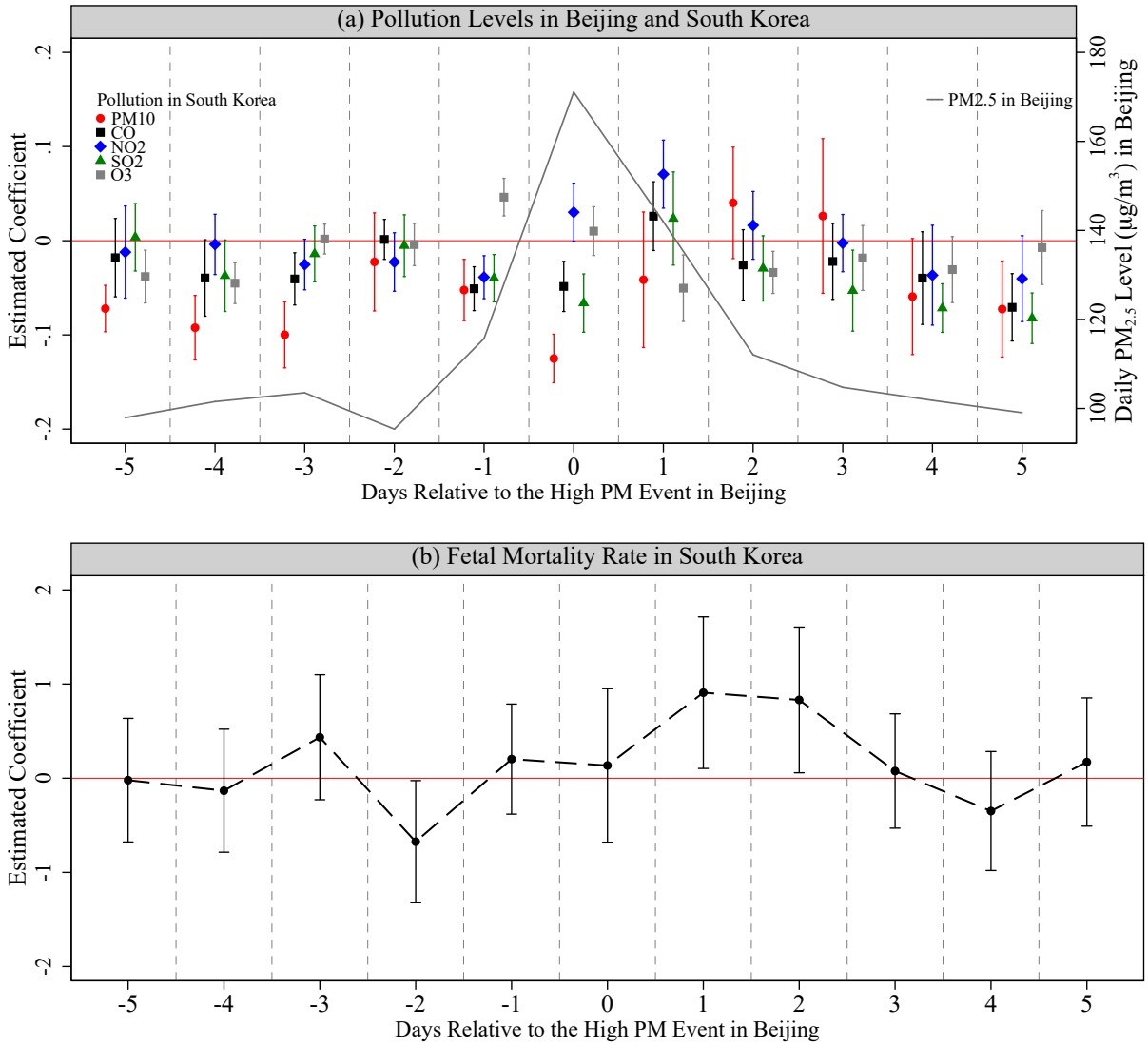


Figure A13. Effects of high PM events on pollutant levels and fetal mortality rates in South Korea

Notes: This figure plots the coefficients on the indicators for n days away from high $PM_{2.5}$ episodes occurring at $n = 0$ in the regression estimating the effect on local pollution levels (Panel (a)) and daily fetal mortality rates (Panel(b)) in South Korea. The vertical bars refer to the 95% confidence intervals. Panel (a) provides the standardized point estimates, and the gray line denotes daily average $PM_{2.5}$ concentration levels in Beijing from 5 days before and after the 9th-decile event.

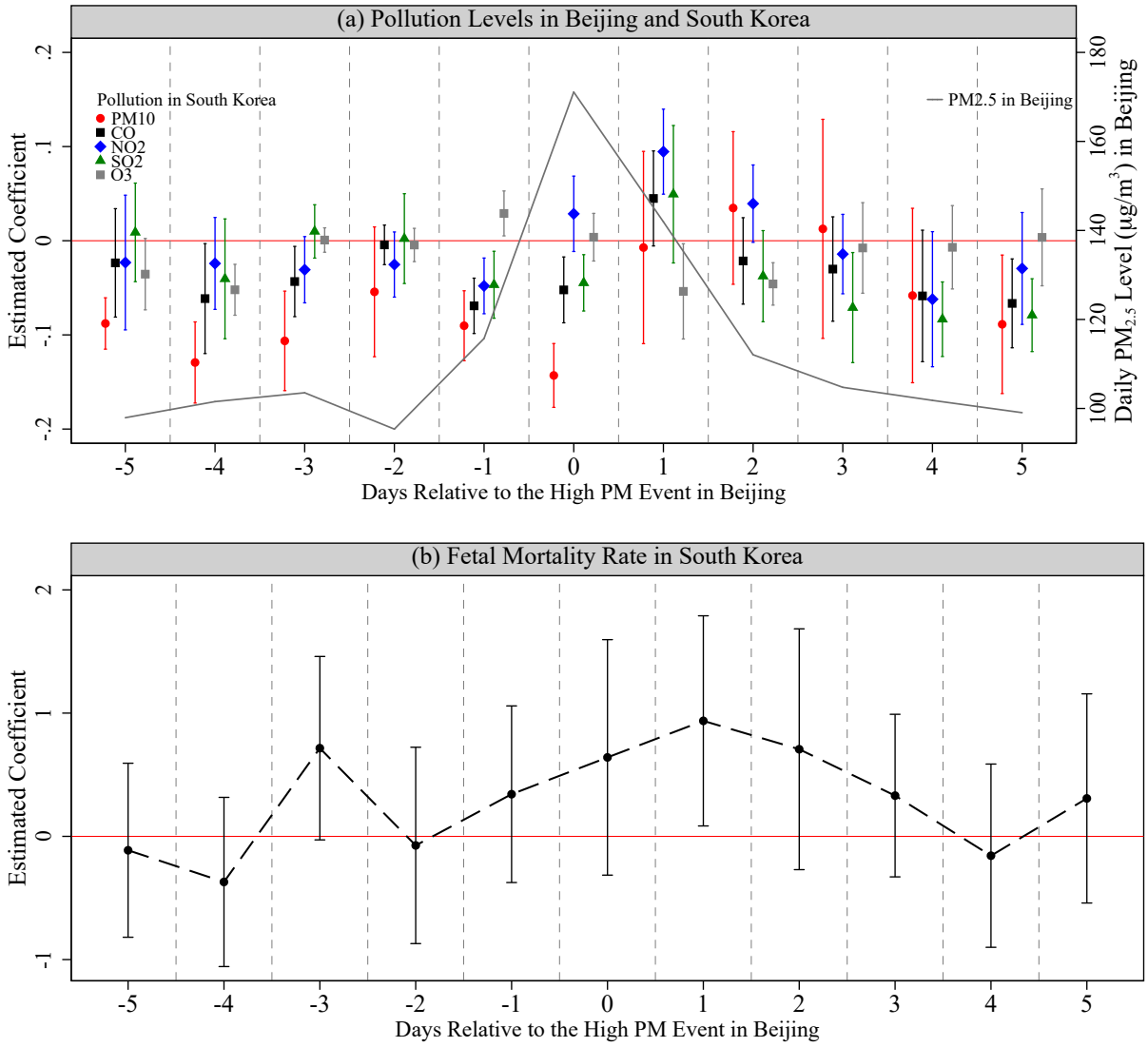


Figure A14. Effects of high PM events on pollutant levels and fetal mortality rates in Region 1, South Korea

Notes: This figure plots the coefficients on the indicators for n days away from high $PM_{2.5}$ episodes occurring at $n = 0$ in the regression estimating the effect on local pollution levels (Panel (a)) and daily fetal mortality rates (Panel(b)) in Region 1, South Korea. The vertical bars refer to the 95% confidence intervals. Panel (a) provides the standardized point estimates, and the gray line denotes daily average $PM_{2.5}$ concentration levels in Beijing from 5 days before and after the 9th-decile event.

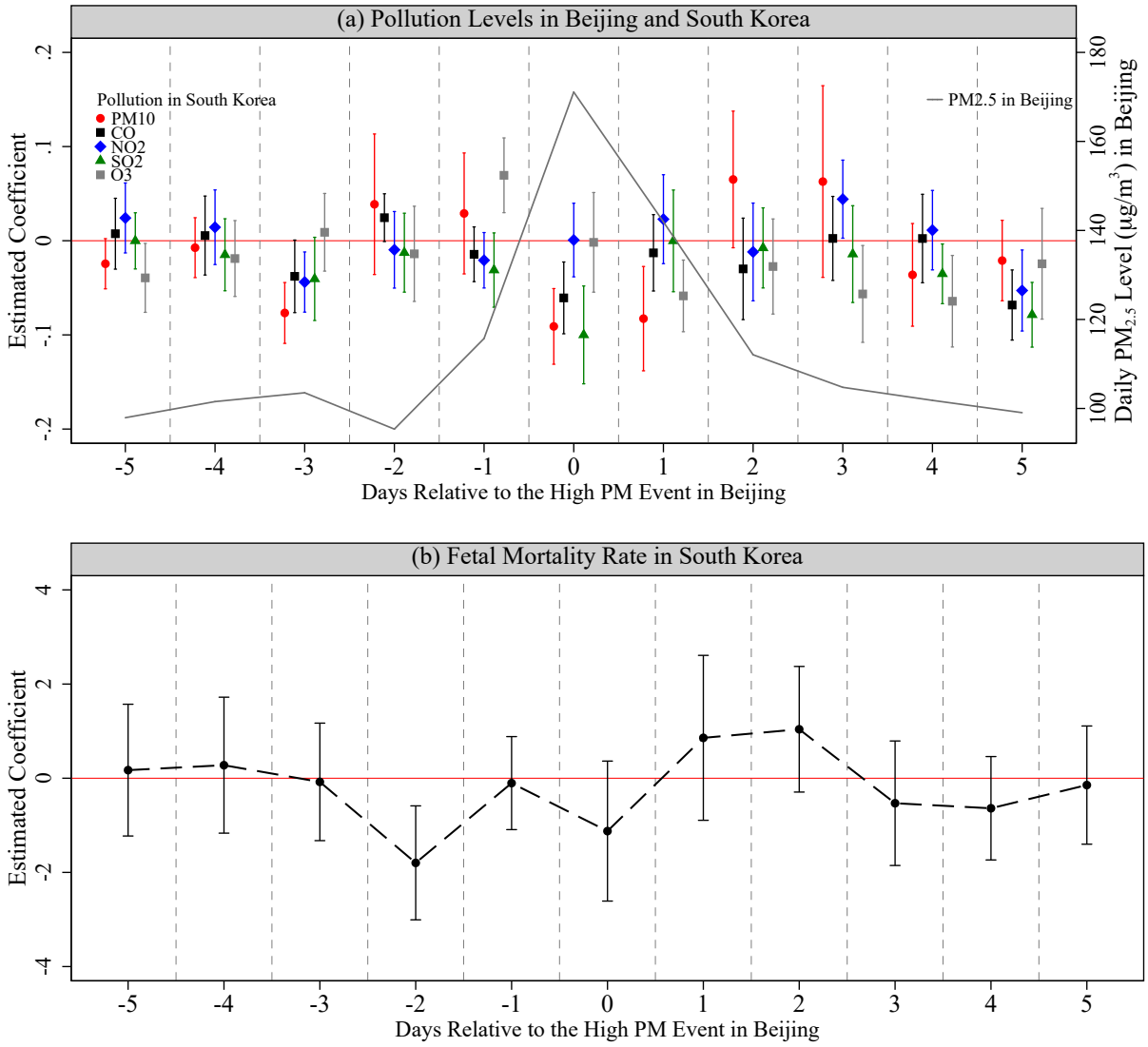


Figure A15. Effects of high PM events on pollutant levels and fetal mortality rates in Region 2, South Korea

Notes: This figure plots the coefficients on the indicators for n days away from high $PM_{2.5}$ episodes occurring at $n = 0$ in the regression estimating the effect on local pollution levels (Panel (a)) and daily fetal mortality rates (Panel(b)) in Region 2, South Korea. The vertical bars refer to the 95% confidence intervals. Panel (a) provides the standardized point estimates, and the gray line denotes daily average $PM_{2.5}$ concentration levels in Beijing from 5 days before and after the 9th-decile event.

Appendix 2. Tables

Table A1. Effects of Beijing $PM_{2.5}$ (t − 1) on daily fetal mortality rates in South Korea (hourly observations ≥ 20 per day)

Dependent variables	Daily Fetal Mortality Rate					
	≥ 16 weeks		≥ 20 weeks		≥ 28 weeks	
	(1)	(2)	(3)	(4)	(5)	(6)
Beijing $PM_{2.5}$ $(t-1)$	0.0021*	0.0021	-0.0005	-0.0005		
	(0.0012)	(0.0013)	(0.0006)	(0.0006)		
Observations	36,020	36,020	36,020	36,020		
R-squared	0.039	0.039	0.020	0.021		
Mean of Dep. Var.	9.649	9.649	2.731	2.731		
Controls						
City FE	Yes	Yes	Yes	Yes		
Temporal Controls	Yes	Yes	Yes	Yes		
Weather Controls	Yes	Yes	Yes	Yes		
Linear time trend		Yes		Yes		
Quadratic time trend		Yes		Yes		

Notes: This table contains results from equation (2). Regressions are weighted by the number of live births in a city. Robust standard errors are shown in parentheses and clustered at the city level. * Significant at the 10% level.

Table A2. Effects of Beijing's $PM_{2.5}$ level in $_{t-1}$ on local $PM_{2.5}$ level in t in South Korea

	$PM_{2.5}$ Concentration in South Korea ($\mu m/m^3$)				
	(1)	(2)	(3)	(4)	(5)
Panel (a): All Regions					
Beijing $PM_{2.5}$ $(t-1)$	0.0433***	0.0413***	0.0121***	0.0119***	0.0101***
	(0.0055)	(0.0039)	(0.0029)	(0.0030)	(0.0027)
Observations	2,780	2,780	2,780	2,780	2,780
R-squared	0.063	0.171	0.424	0.425	0.428
Mean of Dep. Var.	25.006	25.006	25.006	25.006	25.006
Panel (b): Seoul in Region 1					
Beijing $PM_{2.5}$ $(t-1)$	0.0492***	0.0465***	0.0166***	0.0164***	0.0143***
	(0.0058)	(0.0031)	(0.0013)	(0.0015)	(0.0015)
Observations	1,420	1,420	1,420	1,420	1,420
R-squared	0.077	0.194	0.463	0.464	0.467
Mean of Dep. Var.	24.180	24.180	24.180	24.180	24.180
Panel (c): Busan in Region 2					
Beijing $PM_{2.5}$ $(t-1)$	0.0235***	0.0243***	-0.0007	-0.0008	-0.0019
	(0.0033)	(0.0035)	(0.0025)	(0.0029)	(0.0028)
Observations	1,360	1,360	1,360	1,360	1,360
R-squared	0.023	0.084	0.420	0.421	0.423
Mean of Dep. Var.	25.868	25.868	25.868	25.868	25.868
Panel (d): Seoul in Region 1 excluding Jul.-Sep.					
Beijing $PM_{2.5}$ $(t-1)$	0.0509***	0.0517***	0.0194***	0.0191***	0.0165***
	(0.0067)	(0.0058)	(0.0031)	(0.0032)	(0.0024)
Observations	1,071	1,071	1,071	1,071	1,071
R-squared	0.088	0.150	0.477	0.478	0.483
Mean of Dep. Var.	26.367	26.367	26.367	26.367	26.367
Controls					
City FE	Yes	Yes	Yes	Yes	Yes
Temporal Controls		Yes	Yes	Yes	Yes
Weather Controls			Yes	Yes	Yes
Linear time trend				Yes	Yes
Quadratic time trend					Yes

Notes: This table contains results of regressions of the local $PM_{2.5}$ level in South Korea on one-day lagged $PM_{2.5}$ level in Beijing. Panel (a) presents results from the entire sample, while panel (b) uses a sample of Seoul in Region 1, and panel (c) for Busan in Region 2. Panel (d) uses a select sample of Seoul for non-summer days. Robust standard errors are shown in parentheses and clustered at the city level. *** Significant at the 1% level.

Table A3. Effects of Beijing $PM_{2.5\,t-1}$ on daily perinatal mortality rates in South Korea

Dependent variables	Daily Perinatal Mortality Rate			
	Perinatal mortality rate 1		Perinatal mortality rate 2	
	(1)	(2)	(3)	(4)
Beijing $PM_{2.5}$ $(t-1)$	0.0021*	0.0021	-0.0006	-0.0006
	(0.0010)	(0.0010)	(0.0005)	(0.0005)
Observations	35,934	35,934	35,934	35,934
R-squared	0.039	0.040	0.020	0.021
Mean of Dep. Var.	9.649	9.649	2.731	2.731
Controls				
City FE	Yes	Yes	Yes	Yes
Temporal Controls	Yes	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes	Yes
Local PM_{10} Levels	Yes	Yes	Yes	Yes
Linear time trend		Yes		Yes
Quadratic time trend		Yes		Yes

Notes: This table contains results from equation (2). Perinatal mortality rate 1 uses the fetal deaths at gestational age at 20 weeks or more and the infant deaths within 28 days after birth. Perinatal mortality rate 2 uses the fetal deaths at gestational age at 28 weeks or more and the infant deaths within 7 days after birth. Regressions are weighted by the number of live births in a city. Robust standard errors are shown in parentheses and clustered at the city level. *Significant at the 10% level.

Table A4. Effects of local PM_{10} on daily fetal mortality rates in South Korea using Beijing's $PM_{2.5\,t-1}$ level as instrument

Dependent variables	Daily Fetal Mortality Rate					
	$\geq$ 16 weeks		$\geq$ 20 weeks		$\geq$ 28 weeks	
	(1)	(2)	(3)	(4)	(5)	(6)
Local PM_{10} (t)	0.2249**	0.3107*	0.1884***	0.2455**	0.0235	0.0391
	(0.1117)	(0.1663)	(0.0720)	(0.1119)	(0.0316)	(0.0434)
Observations	36,007	36,007	36,007	36,007	36,007	36,007
R-squared	-0.008	-0.065	-0.032	-0.081	0.010	0.001
Mean of Dep. Var.	14.150	14.150	8.636	8.636	1.982	1.982
Controls						
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Temporal Controls	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes	Yes	Yes	Yes
Linear time trend		Yes		Yes		Yes
Quadratic time trend		Yes		Yes		Yes

Notes: This table contains results from equation (2). Regressions are weighted by the number of live births in a city. Robust standard errors are shown in parentheses and clustered at the city level.
*** Significant at the 1% level. ** Significant at the 5% level. * Significant at the 10% level.

Table A5. Effects of Beijing $PM_{2.5\,t-1}$ on daily fetal mortality rates in South Korea using wind directions

Dependent variables	Daily Fetal Mortality Rate					
	$\geq$ 16 weeks		$\geq$ 20 weeks		$\geq$ 28 weeks	
	(1)	(2)	(3)	(4)	(5)	(6)
Beijing $PM_{2.5}$ $(t-1)$	0.0025*	0.0028*	0.0025**	0.0025**	0.0006	0.0007
	(0.0013)	(0.0014)	(0.0011)	(0.0012)	(0.0006)	(0.0006)
Beijing $PM_{2.5}$ $(t-1)$ $\times$ Wind (180-270 degrees)	0.0049**	0.0049**	0.0024*	0.0024*	-0.0010	-0.0010
	(0.0018)	(0.0018)	(0.0012)	(0.0012)	(0.0007)	(0.0007)
Observations	36,020	36,020	36,020	36,020	36,020	36,020
R-squared	0.058	0.058	0.042	0.043	0.016	0.016
Mean of Dep. Var.	0.5499	0.5499	0.3373	0.3373	0.0759	0.0759
Controls						
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Temporal Controls	Yes	Yes	Yes	Yes	Yes	Yes
Weather Controls	Yes	Yes	Yes	Yes	Yes	Yes
Linear time trend		Yes		Yes		Yes
Quadratic time trend		Yes		Yes		Yes

Notes: This table contains results from equation (2). Regressions are weighted by the number of live births in a city. Robust standard errors are shown in parentheses and clustered at the city level. ** Significant at the 5% level. * Significant at the 10% level.