

Environment, Public Policy and Human Capital

The Health Effect of Fine Particulate Matter: Evidence from Power Plant Opening and Closing in Taiwan

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Outline

- Purpose: Identify the causal effect of PM_{2.5} exposure on health outcomes.
- Outcomes: mortality, cardiovascular diseases, lung and respiratory diseases, heart diseases (e.g., myocardial ischemia, heart attack, heart failure, stroke, arrhythmia), neurological disorders (autistic disorders, ADHD, and neurodegenerative disease)
- Heterogeneity: By age, sex & income.

Previous Studies

- Many correlational studies:
 - e.g., Janssen *et al.*, 2013, Manuel *et al.*, 2013, Mathilde *et al.*, 2014, Dabass *et al.*, 2016, Tsai *et al.*, 2014, Feng *et al.*, 2016, Cox and Popken, 2015.
 - Exploit time-series or cross-sectional variation in PM \Rightarrow *association*.
- Causal analysis among recent studies:
 - Chay and Greenstone (2003) - changes in air pollution induced by the 1980-1982 recession in the U.S. to identify its effect on infant mortality.
 - Chen *et al.* (2013) - China's north/south difference in coal-based heating provision to identify impact on mortality.
 - He, Fan, and Zhou (2016) - 2018 Beijing Olympic Games to evaluate impact on mortality.
 - Barreca *et al.* (2017) - U.S. Acid Rain Program to estimate effect on mortality.

Identification Strategy

- Why causality is important?
 - Self-selection - health conscious individuals will migrate from high pollution areas.
 - Pollution level may correlate with other regional socio-economic characteristics, e.g, job characteristics, level of economic development, and health behavior, etc.
 - Variation in $PM_{2.5}$ may be associated with economic variations - high $PM_{2.5}$ may imply high economic activity levels \Rightarrow stress, smoking, alcoholic consumption.
- Variation in $PM_{2.5}$ induced by opening & closing of power plants
- Greenstone and Gayer (2009): *quasi-experimental* is an effective way of evaluating the causal effect in environmental economics.

Empirical model

- Model of interest:

$$y_{cti} = p_{ct}\theta + X_{cti}\beta + u_c + v_t + \epsilon_{cti} \quad (1)$$

- Self-selection/unobserved heterogeneity - $\text{corr}(p_{ct}, \epsilon_{cti}) \neq 0$
 - $p_{ct} = \text{PM}_{2.5}$
 - ϵ_{cti} = ability to migrate, economic activity levels, regional characteristics, etc.
- Use plant opening/closing to generate an exogenous variable in $\text{PM}_{2.5}$:

$$\hat{\theta} = \frac{\Delta y_{cti}}{\Delta p_{ct}}$$

Δy_{cti} = change in health/economic outcome before and after plant closing/opening

Δp_{ct} = change in $\text{PM}_{2.5}$ before and after plant closing/opening

Empirical model

Implementation

■ Difference-in-Difference I:

- Look at a fixed set of township ($\#C_g$) surrounding (e.g., within 10KM or 15KM) a power plant g :

$$p_{ct} = D_{ct}\alpha_p + e_c + T_c\delta_{p1} + D_{ct} \times T_c\delta_{p2} + \bar{X}_{ct}\delta_{p0} + \xi_{pc} + \eta_{pct}, \quad c \in \#C_g \quad (2)$$

$$y_{cti} = D_t\alpha_y + e_c + T_{ci}\delta_{y1} + D_t \times T_c\delta_{p2} + \bar{X}_{cti}\delta_{y0} + \xi_{yi} + \eta_{ycti}, \quad c \in \#C_g \quad (3)$$

p_{ct} = annual pollutant level one year before/after closing.

y_{ct} = annual annual level one year before/after closing.

$T_{ci} = 0/1$ - Control/treatment group; i.e., cohort aged 0-2 on Sept. 30, 2007 ($T = 0$) on Sept. 30 2008 ($T = 1$).

$D_{cti} = 0/1$ - Aged 1-3.

ξ_{pc}, ξ_{yi} = township/individual fixed effects.

- Estimate:

$$\hat{\theta} = \frac{\hat{\delta}_{y2}}{\hat{\delta}_{p2}} \quad (4)$$

Empirical model

Implementation

■ Difference-in-Difference II:

- Look at two set of townships (a) within 10KM surrounding a power plant g , and (b) far away from the power power plant:

$$p_{ct} = D_{ct}\alpha_p + e_c + T_c\delta_{p1} + D_{ct} \times T_c\delta_{p2} + \bar{X}_{ct}\delta_{p0} + \xi_{pc} + \eta_{pct}, \quad c \in \#C_g \quad (5)$$

$$y_{cti} = D_{ct}\alpha_y + e_c + T_{ci}\delta_{y1} + D_{ct} \times T_c\delta_{p2} + \bar{X}_{cti}\delta_{y0} + \xi_{yi} + \eta_{ycti}, \quad c \in \#C_g \quad (6)$$

p_{ct} = annual pollutant level one year before/after closing.

y_{ct} = annual annual level one year before/after closing.

$T_{ci} = 0/1$ - Control/treatment group; i.e., 10KM within ($T = 0$); far away ($T = 1$).

$D_{cti} = 0/1$ - Before/after closing.

ξ_{pc}, ξ_{yi} = township/individual fixed effects.

Health Outcomes

- Mortality: 0-2, 50+, 60+, 65+
- Lung and respiratory diseases: 0-2, 50+, 60+, 65+
- Heart diseases: 50+, 60+, 65+
- ADHD and Autistic disorders: 0-16
- Dementia/Alzheimer's diseases/Parkinson's diseases: 60+
- Socioeconomic and birth outcomes: in utero exposure on childhood/adulthood health and income

Changes in Power Plant Operation

Plant	Capacity	Operator	Event	Date	Feul	Location
Mailiao	3.29 million kW	FPG	Unit 1 started	1999	Coal	Mailiao (Yunlin)
			(0.6 Million kW)	(6/1)		
			Unit 2 started	1999	Coal	
			(0.6 Million kW)	(8/24)		
			Unit 3 started	2000	Coal	
			(0.6 Million kW)	(9/23)		
Hoping	1.32 million kW	HPPC	Started operation	2002	Coal	Xiulin
				(6/1 & 9/6)		(Hualien)
Shenao	0.4 million kW	TPC	Stopped operation	2007	Coal & Oil	Rueifang
				(9/30)		(New Taipei)

Map

Townships affected

Shenao (深澳) - Treatment group

- Wind direction: N
- Townships within 10KM:
 - Population: 274,968
 - Townships: Zhongshan (Keelung) Zhongzheng (Keelung)
 Renai (Keelung) Xinyi (Keelung)
 Nuannuan (Keelung) Ruifang (New Taipei)
- Townships within 11-15KM:
 - Population: 149,966
 - Townships: Qidu (Keelung) Pingxi (New Taipei)
 Shuangxi (New Taipei) Anle (Keelung)

[Map](#)

Townships affected

Heping (和平) - Treatment group

- Wind direction: NNW
- Townships within 10KM:
 - Population: 21,821
 - Townships: Nanaon (Yilan) Xiulin (Yilan)

[Map](#)

Townships in control group

Xincheng (新城) - Control group

- Wind direction: NE

- Townships within 10KM:
 - Population: 140,072

 - Townships: Xincheng (Hualien) Xiulin (Hualien)
 Hualien (Hualien)

- Townships within 11-15KM:
 - Population: 83,711

 - Township: Jian (Hualien)

[Map](#)

Townships in control group

Taitung (台東) - Control group

- Wind direction: NNW
- Townships within 10KM:
 - Population: 114,317
 - Townships: Donghe (Taitung) Taitung (Taitung)
- Townships within 11-15KM:
 - Population: 17,398
 - Township: Beinan (Taitung)

[Map](#)

Townships in control group

Nantou (南投) - Control group

- Wind direction: NNE

- Townships within 10KM:
 - Population: 238,345

 - Townships: Zhongliao (Nantou) Nantou (Nantou)
 Mingjian (Nantou) Tianzhong (Changhua)
 Shetou (Changhua)

- Townships within 11-15KM:
 - Population: 309,353

 - Townships: Caotun (Nantou) Jiji (Nantou)
 Ershui (Changhua) Yuanlin (Changhua)
 Yongjing (Changhua) Tianzhong (Changhua)

[Map](#)

Townships in control group

Houlong (後龍) - Control group

- Wind direction: SW
- Townships within 10KM:
 - Population: 156,258
 - Townships: Houlong (Miaoli) Miaoli (Miaoli)
 Xihu (Miaoli) Zaoqiao (Miaoli)
 Touwu (Miaoli)
- Townships within 11-15KM:
 - Population: 229,089
 - Townships: Sanwan (Miaoli) Gongguan (Miaoli)
 Zhunan (Miaoli) Toufen (Miaoli)

[Map](#)

Main Results

Children aged 0-2

Table: Medical care utilization

	Inpatient		Emergency room		Inpatient-days		Outpatient services		Inpatient services	
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
Effect	-0.0966 (0.0739)	0.0225 (0.0766)	-0.1590 (0.1889)	-0.0192 (0.1872)	-0.1527 (0.1136)	0.0170 (0.1163)	-43.7349*** (9.8645)	-32.9989*** (9.3110)	-0.9085 (0.6844)	0.1851 (0.7036)
R^2	0.0092	0.0087	0.0106	0.0121	0.0101	0.0085	0.0693	0.0798	0.0095	0.0087

Main Results

Children aged 0-2

Table: Respiratory 1

	Respiratory		Lung diseases		Common cold	
	[1]	[2]	[3]	[4]	[5]	[6]
	Men	Women	Men	Women	Men	Women
Effect	-5.8002*** (1.3275)	-4.5450*** (1.2698)	-4.9568*** (0.8791)	-3.3184*** (0.8412)	-6.1882*** (1.2545)	-4.6373*** (1.1992)
R ²	0.0398	0.0419	0.0802	0.0820	0.0569	0.0601

Main Results

Children aged 0-2

Table: Respiratory 2

	Asthma		COPD		Pneumonia	
	[1]	[2]	[3]	[4]	[5]	[6]
	Men	Women	Men	Women	Men	Women
Effect	-4.1562*** (0.8830)	-2.6189*** (0.8305)	-4.4967*** (0.8410)	-2.8740*** (0.7957)	-0.4601*** (0.1677)	-0.4444*** (0.1873)
R ²	0.0507	0.0561	0.0793	0.0821	0.0067	0.0088

Main Results

Children aged 0-2

Table: Eyes diseases

	Eyes diseases		Conjunctivitis	
	[1]	[2]	[3]	[4]
	Men	Women	Men	Women
Effect	0.0109 (0.1314)	-0.1014 (0.1445)	0.0547 (0.1225)	-0.1046 (0.1298)
R^2	0.0049	0.0031	0.0028	0.0022

Main Results

Elderly aged 65 and above

Table: Medical care utilization

	Inpatient		Emergency room		Inpatient-days		Outpatient-services		Inpatient-services	
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
Effect	0.0198 (0.0565)	-0.0388 (0.0518)	-0.0904 (0.0890)	-0.1078 (0.0946)	0.0762 (0.1203)	-0.0674 (0.1122)	-40.2367*** (6.9381)	-47.7448*** (6.9168)	0.2660 (0.5867)	-0.4710 (0.5388)
R ²	0.0017	0.0013	0.0021	0.0016	0.0020	0.0015	0.0064	0.0124	0.0018	0.0013

Main Results

Elderly aged 65 and above

Table: Respiratory 1

	Respiratory		Lung diseases		Common cold	
	[1]	[2]	[3]	[4]	[5]	[6]
	Men	Women	Men	Women	Men	Women
Effect	-1.0767*** (0.3386)	-1.2011*** (0.3176)	-0.6017*** (0.2398)	-0.9455*** (0.2379)	-0.8268*** (0.2555)	-0.9541*** (0.2753)
R^2	0.0035	0.0037	0.0022	0.0043	0.0027	0.0029

Main Results

Elderly aged 65 and above

Table: Respiratory 2

	Asthma		COPD		Pneumonia	
	[1]	[2]	[3]	[4]	[5]	[6]
	Men	Women	Men	Women	Men	Women
Effect	-0.3371 (0.2512)	-0.8716*** (0.2484)	-0.3243 (0.2319)	-0.7111*** (0.2324)	-0.2773*** (0.0496)	-0.2344*** (0.0435)
R^2	0.0005	0.0023	0.0005	0.0020	0.0166	0.0235

Main Results

Elderly aged 65 and above

Table: Eyes diseases

	Eyes diseases		Conjunctivitis	
	[1]	[2]	[3]	[4]
	Men	Women	Men	Women
Effect	-0.6105*** (0.1982)	-0.9664*** (0.2159)	-0.3028** (0.1434)	-0.5227*** (0.1576)
R^2	0.0071	0.0125	0.0036	0.0077

Main Results

Elderly aged 65 and above

Table: Cardiovascular diseases

	HBP		Heart diseases		Cardiovasculars diseases		AMI		Stroke	
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
Effect	-0.2786** (0.1286)	-0.5248*** (0.1381)	-0.8732*** (0.2712)	-1.4112*** (0.2720)	-1.2826*** (0.3308)	-1.3962*** (0.3163)	-0.0049 (0.0353)	-0.0103 (0.0265)	-0.1642 (0.1013)	-0.0220 (0.0908)
R ²	0.0031	0.0044	0.0034	0.0058	0.0040	0.0058	0.0012	0.0003	0.0009	0.0006

Main Results

Elderly aged 65 and above

Table: Organic mental diseases

	All		Dementia		Alzheimer disease		Parkinson diseases	
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
	Men	Women	Men	Women	Men	Women	Men	Women
Effect	0.0210 (0.0646)	-0.0133 (0.0850)	0.0725 (0.0587)	-0.0308 (0.0821)	0.0096 (0.0139)	0.0137 (0.0189)	-0.0377 (0.0685)	0.0422 (0.0554)
R^2	0.0020	0.0006	0.0020	0.0006	0.0002	0.0000	0.0003	0.0008

Main Results

Elderly aged 65 and above

Table: Psychological disorders

	All		Depression-Psychosis		Anxiety		Depression		Behavior disorder	
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
	Men	Women	Men	Women	Men	Women	Men	Women	Men	Women
Effect	-0.1051 (0.0944)	-0.0866 (0.1086)	-0.0531 (0.0454)	-0.0653 (0.0458)	-0.0368 (0.0623)	0.0355 (0.0806)	0.0145 (0.0201)	0.0025 (0.0236)	-0.0041 (0.0520)	-0.0508 (0.0506)
R ²	0.0005	0.0006	0.0008	0.0018	0.0002	0.0003	0.0004	0.0003	0.0003	0.0005