The winter choke: Coal-Fired heating, air pollution,and mortality in China

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- The impact of air pollution on mortality
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Introduction

What's the topic? & Why to research?

- What's the topic?
  - This paper assesses the impact of winter heating on airpollution and health utilizing regression discontinuity (RD)designs based on the turning-on dates of the heating sys-tems in northern Chinese cities.
  - The Chinese winter heat-ing program provides a compelling natural experiment toestimate the causal effects of air pollution on health.
  - Main Finding:
    1)Turning onthe winter heating system increased the weekly Air Quality Index by 36% and caused 14% increase in mortality rate.
    2)People in poor and rural areas are particu-larly affected by the rapid deterioration in air quality; this implies that the health impact ofair pollution may be mitigated by improved socio-economic conditions.
    3)Exploratory cost-benefit analysis suggests that replacing coal with natural gas for heating can improve socialwelfare.

What's the topic? & Why to research?

- Why to research?
  - Highlight the long-overlooked disparity in air pollu-tion exposure between urban and rural areas.
  - Add to a growing strand of economicresearch investigating the impact of air pollution onmortality in developing countries.
  - Exploitsa new identification strategy embedded in China's win-ter heating policy and provides a different perspectiveto understanding the costs of coal-fired heating.
  - Conduct an exploratory benefit-cost analysis on China's coalreplacement policy.

China's winter heating system

China's winter heating system

- Limited the heating entitlement to areas located in the north.
- Between November 15th and March 15th.
- Increases air pollution by generatingsubstantial particulate matter emissions, SO2, and NOx.
- The replacement of coal with natural gasor electricity as primary fuels for heating.

Data and summary statistics

Winter heating and air pollution data

- Data for the winter heating period of all the cities in China
- National Urban Air Quality Real-time Publishing:
  - real-time Air Quality Index (AQI)
  - concentrations of criteria airpollutants:1497 individual air monitoring stations

Mortality data

- The Chinese Center forDisease Control and Prevention's (CCDC) Disease Surveil-lance Points (DSP) system
  - 324 million people
  - 605 separate locations (322 city districtsand 283 rural counties)
  - detailed cause-of-death data

Weather data

- GlobalSummary of the Day (GSOD)
  - 409 ground weather stations
  - 2014 and 2015
  - temperature, dew point, and precipitation

Matching

- Matching mortality data with air pollution data andweather data at the DSP location level

Summary statistics

Table 1
Summary Statistics.

	Obs.	Mean (1)	Std. Dev. (2)	Min (3)	Max (4)
Mortality	3647	10.98	3.82	1.20	54.56
Urban	1344	10.43	3.40	3.14	44.70
Rural	2303	11.30	4.02	1.20	54.56
CVR	3647	7.92	3.07	0.61	37.38
Non-CVR	3647	3.05	1.43	0.00	19.47
AQI	3647	109.24	45.44	7.04	301.51
Urban	1344	104.24	44.24	18.20	301.51
Rural	2303	112.16	45.89	7.04	300.40
$PM_{2.5}$ ($\mu g/m^3$)	3645	75.95	39.85	5.04	279.23
Temperature	3647	49.31	19.84	−6.11	87.41
Dew Point	3647	34.80	23.15	−17.56	76.73
Precipitation	3647	0.06	0.13	0.00	1.49

Notes: Variables are observed at the county (city district) and week level. Mortality data are from China's Disease Surveillance Points (DSP) System. Air quality data are from the National Real-Time Air Quality Platform. Weather information is from Global Summary of the Day. Mortality is age-adjusted mortality per 100 K. Temperature and dew point are in Fahrenheit. Precipitation is in inches. The full sample includes 114 northern Chinese cities/counties.

Empirical strategy

The impact of winter heating on AQI and mortality

Specification:

$$P_{i,t} = \beta_1 I\left(t \geq WH_{i,t}\right) + \beta_2 f\left(t - WH_{i,t}\right) + \beta_3 I * f\left(t - WH_{i,t}\right) + \gamma W_{it} + \theta_i + u_{i,t}$$
$$Y_{i,t} = \alpha_1 I\left(t \geq WH_{i,t}\right) + \alpha_2 f\left(t - WH_{i,t}\right) + \alpha_3 I * f\left(t - WH_{i,t}\right) + \theta W_{it} + \theta_i + \varepsilon_{i,t}$$

- $P_{i,t}$—the air pollution in location i at time t.
- $Y_{i,t}$—mortality in location i at time t.
- $I\left(t \geq WH_{i,t}\right)$—an indicator variable that equals one if the winter heating system is turned on in location i at week t.
- $t - WH_{i,t}$—running variable,the number of weeks from the turning-on dateand.
- $f\left(t - WH_{i,t}\right)$—control function
- W_{it}—Witareweather controls correlated with air pollution, includingtemperature, precipitation, and dew point.
- $theta_i$—DSP location-specific fixed effect.
- $u_{i,t}, varepsilon_{i,t}$—the error terms.

The impact of AQI on mortality

Fuzzy RD:

- Pollution exists before the winter heating starts, making our context naturally analogous to a fuzzy RD.
- Individuals' actions to protect themselves from the resulting health problems of pollution.

Main results

Visualizing the data using RD plots

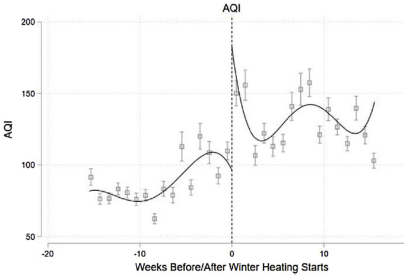

Fig. 1. RD Plot for AQI.
Notes: The figure shows the mean and 95% confidence interval of across the DSP locations within a week. The solid line represents a qua polynomial fit of AQI separately for each side of the threshold.

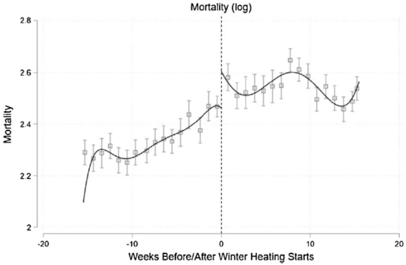

Fig. 2. RD Plot for Mortality.
Notes: The figure shows the mean and 95% confidence interval of mortality rate across the DSP locations within a week. The solid line represents a quartic polynomial fit of mortality separately for each side of the threshold.

Visualizing the data using RD plots

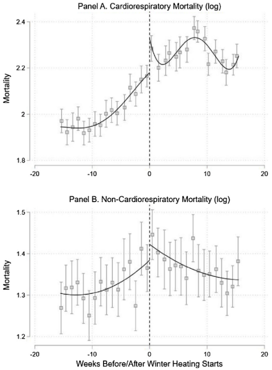

Fig. 3. RD Plots for Cardiorespiratory and Non-Cardiorespiratory Mortality.
Notes: The figure shows the mean and 95% confidence interval of CVR and non-CVR mortality rates across the DSP locations within a week. The solid line represents a quartic polynomial fit of CVR (or Non-CVR) mortality separately for each side of the threshold..

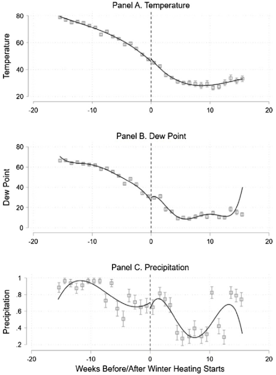

Fig. 4. RD Plots for Weather Conditions.
Notes: Each figure shows the mean and 95% confidence interval of a weather variable across the DSP locations within a week. The solid line represents a quartic polynomial fit of each variable separately for each side of the threshold.

The impacts of winter heating on AQI and mortality

Table 2
RD Estimates of the Impacts of Winter Heating on AQI and Mortality.

	RD Estimates			
	(1)	(2)	(3)	(4)
Panel A: Winter Heating and AQI				
	AQI			
Heating On	30.4**	20.5**	40.0**	43.3**
	(7.3)	(6.5)	(6.8)	(5.7)
Bandwidth (Left)	2.67	2.35	1.96	1.96
Bandwidth (Right)	1.63	1.69	3.95	3.95
Panel B: Winter Heating and Mortality				
	Overall Mortality (log)			
Heating On	0.124**	0.134**	0.138**	0.127**
	(0.041)	(0.036)	(0.035)	(0.031)
Bandwidth (Left)	2.81	2.59	2.89	2.89
Bandwidth (Right)	6.00	5.40	5.32	5.32
Panel C: Winter Heating and CVR Mortality				
	CVR Mortality (log)			
Heating On	0.135**	0.157**	0.154**	0.141**
	(0.045)	(0.040)	(0.038)	(0.032)
Bandwidth (Left)	2.72	2.44	2.79	2.79
Bandwidth (Right)	5.20	4.66	4.81	4.81
Panel D: Winter Heating and Non-CVR Mortality				
	Non-CVR Mortality (log)			
Heating On	0.086	0.079	0.076	0.070
	(0.050)	(0.045)	(0.046)	(0.039)
Bandwidth (Left)	3.57	3.38	3.41	3.41
Bandwidth (Right)	4.94	4.47	4.14	4.14
RD Estimates	Bias-Cor. Robust	Bias-Cor. Robust	Bias-Cor. Robust	Conventional
Weather Controls	N	N	Y	Y
DSP Fixed Effects	N	Y	Y	Y
Kernel	Epanech.	Epanech.	Epanech.	Epanech.
Observations	3647	3647	3647	3647

Notes: Each cell in the table represents a separate RD estimate. The discontinuities are estimated using local linear regressions and MSE-optimal bandwidth selectors proposed by Calonico et al. (2014) and Calonico (2019). Weather controls include temperature, relative humidity, and precipitation. Standard errors clustered at the (DSP) county level are reported below the coefficients. * significant at 5% ** significant at 1%.

The impact of air pollution on mortality

Table 3
Fuzzy RD Estimates on the Impacts of the AQI on Mortality.

	Mortality (log)			
	(1)	(2)	(3)	(4)
Panel A: Impact of the AQI on Mortality				
AQI (per 10 points)	0.026**	0.034**	0.022**	0.020**
	(0.008)	(0.010)	(0.007)	(0.006)
Bandwidth (Left)	2.69	2.08	3.03	3.03
Bandwidth (Right)	4.40	3.84	3.53	3.53
Panel B: Impact of the AQI on CVR Mortality				
AQI (per 10 points)	0.037**	0.040**	0.027**	0.024**
	(0.011)	(0.011)	(0.008)	(0.007)
Bandwidth (Left)	2.52	1.90	2.89	2.89
Bandwidth (Right)	4.42	3.76	3.45	3.45
Panel C: Impact of the AQI on Non-CVR Mortality				
AQI (per 10 points)	0.012	0.015	0.010	0.010
	(0.010)	(0.013)	(0.009)	(0.007)
Bandwidth (Left)	2.99	2.52	3.06	3.06
Bandwidth (Right)	4.17	3.51	3.56	3.56
RD Estimates	Bias-Cor. Robust	Bias-Cor. Robust	Bias-Cor. Robust	Conventional
Weather Controls	N	N	Y	Y
DSP Fixed Effects	N	Y	Y	Y
Kernel	Epanech.	Epanech.	Epanech.	Epanech.
Observations	3647	3647	3647	3647

Notes: Each cell in the table represents a separate fuzzy RD estimate. The discontinuities are estimated using local linear regressions and MSE-optimal bandwidth selectors proposed by Calonico et al. (2014) and Calonico (2019). Weather controls include temperature, relative humidity, and precipitation. Standard errors clustered at the (DSP) county level are reported below the coefficients. * significant at 5% ** significant at 1%.

The impact of air pollution on mortality

Table 4
OLS Estimates on the Association between the AQI and Mortality.

	Overall Mortality (log)		
	(1)	(2)	(3)
Panel A. Overall Mortality			
AQI (per 10 points)	0.016**	0.018**	0.006**
	(0.002)	(0.002)	(0.001)
R-Squared	0.062	0.307	0.390
Panel B. CVR Mortality			
AQI (per 10 points)	0.020**	0.022**	0.008**
	(0.002)	(0.002)	(0.001)
R-Squared	0.082	0.327	0.431
Panel C. Non-CVR Mortality			
AQI (per 10 points)	0.003	0.004**	0.000
	(0.002)	(0.001)	(0.002)
R-Squared	0.002	0.335	0.341
Weather Controls	N	N	Y
DSP Fixed Effects	N	Y	Y
Observations	3647	3647	3647

Notes: Each cell in the table represents a separate OLS regression. Weather controls include temperature, relative humidity, and precipitation. Standard errors clustered at the (DSP) county level are reported below the coefficients. * significant at 5% ** significant at 1%.

Robustness checks

- Takethe log of mortality rates—reduce the influence of outliers.
- Experiment with alternative ways to matchbetween DSP locations and air pollution monitor sites.
- Use southern cities to conduct a placebo test.
- Experiment with high-order (up to 4th polynomial) weather controls.

Comparison with related studies in the literature

Table 5
The Impacts of PM2.5 on Mortality (Log).

	Mortality (log)		CVR Mortality (log)		Non-CVR Mortality (log)	
$PM_{2.5}$ (per 10 µg/m3)	0.023**	0.025**	0.027**	0.029**	0.012	0.013
	(0.006)	(0.007)	(0.007)	(0.008)	(0.007)	(0.009)
Bandwidth (Left)	2.60	3.04	2.48	2.89	3.54	3.10
Bandwidth (Right)	4.31	3.81	4.55	3.88	4.15	4.13
RD Estimates	Conv.	Bias-Cor. Robust	Conv.	Bias-Cor. Robust	Conv.	Bias-Cor. Robust
Kernel	Epanech.	Epanech.	Epanech.	Epanech.	Epanech.	Epanech.
Weather Controls	Y	Y	Y	Y	Y	Y
DSP Fixed Effects	Y	Y	Y	Y	Y	Y
Kernel	Epanech.	Epanech.	Epanech.	Epanech.	Epanech.	Epanech.
Observations	3645	3645	3645	3645	3645	3645

Notes: Each cell in the table represents a separate RD estimate. All regressions control for weather conditions (temperature, relative humidity, and precipitation) and DSP fixed effects. The discontinuities are estimated using local linear regressions and two different MSE-optimal bandwidth selectors proposed by Calonico et al. (2014) and Calonico (2019). Standard errors clustered at the (DSP) county level are reported below the coefficients. * significant at 5% ** significant at 1%.

Heterogeneity

Rural-urban difference

Table 7
The Impacts of Winter Heating and AQI by Gender and Age Group.

	Impact of Winter Heating on Mortality		Impact of AQI on Mortality: Fuzzy RD	
	(1)	(2)	(3)	(4)
Panel A: By Gender				
Male	0.118**	0.125**	0.026**	0.029*
	(0.035)	(0.040)	(0.010)	(0.012)
Female	0.136**	0.143**	0.023**	0.024*
	(0.043)	(0.051)	(0.008)	(0.010)
Panel B: By Age Group				
Old People (>=60)	0.150**	0.158**	0.024**	0.025**
	(0.033)	(0.038)	(0.006)	(0.007)
Young People (<60)	0.058	0.063	0.012	0.013
	(0.034)	(0.041)	(0.007)	(0.008)
RD Estimates	Conv.	Bias-Cor. Robust	Conv.	Bias-Cor. Robust
Weather Controls	Y	Y	Y	Y
DSP Fixed Effects	Y	Y	Y	Y
Kernel	Epanech.	Epanech.	Epanech.	Epanech.
Observations	3645	3645	3645	3645

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Effects by gender and age group

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RD Estimates	Conv.	Bias-Cor. Robust	Conv.	Bias-Cor. Robust
Weather Controls	Y	Y	Y	Y
DSP Fixed Effects	Y	Y	Y	Y
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Benefits and costs of replacing coal with natural gas for winter heating

Averted deaths from cleaner air and its values

Table 8
Estimated Benefit of Replacing Coal by Natural Gas For Winter Heating.

	Effect Size	Source	Costs/Benefits Calculation	Monetary Value
Pane A. Short-term Benefit				
Pre-mature Deaths	A 10-point increase in the AQI would cause a 3.8% increase in weekly mortality.	Self-calculation	AQI difference between northern and southern China during the winter × the impact of AQI on mortality rate × population in 13 northern Chinese proinvces × 16 weeks × VSL (7.46 million CNY) × 70% (discounted VSL for the elderly) × 89,664 premature deaths = 469 billion CNY	72 billion USD
Defensive Expenditures	A northern household is willing to pay about 43 USD per year to clean the air.	Ito and Zhang (forthcoming)	32.7 USD per year × 1/4 (for winter season) × households in 13 northern Chinese provinces = 1.75 billion USD	1.75 billion USD
Medical Expenditures	A reduction of 10 μg/m3 in PM2.5 would lead to total annual savings of 11.7 billion USD.	Barwick et al. (2018)	9 billion USD × 1/4 (winter season) × PM2.5 difference between northern and southern China during the winter = 3.6 billion USD	3.6 billion USD
Total				77.35 billion USD
Panel B. Long-term Benefit				
Life Expectancy	Winter heating causes a 3.1-year loss in life expectancy for Northern Chinese people	Ebenstein et al. (2017)	Life years will be saved each year: 3.1 Years/76 Years × population in 13 northern Chinese provinces × = 25.5 million years; Each life year worth: 5.83 million CNY/76 years = 76.7 thousand CNY/year; Total benefit: 25.5 million × 76.7 thousand = 1956 billion CNY/year	266 billion USD

Cost of replacing coal with natural gas

- Expenditures on new stoves and pipelines.
- Operational expenditures (higher fuel costand maintenance).
- The costs of replacing coal with natural gas(156 billion to 170 billion USD) are greater than thebenefits (77.35 billion USD) in the short term;

  Thelong-run health benefits (301 billion USD) still signifi-cantly outweigh the costs.

  In conclusion, policymakersshould anticipate potential backlash in implementing thesechanges because the costs of the switch are quite substan-tial and it takes a long period to reap the total benefits oflowering air pollution.

Potential biases

- Harvesting effect—the short-term estimates tend tounderestimate.
- The rate of economic growth will positivelyaffect the VSL.