Willingness to Pay for Clean Air: Evidence from Air Purifier Markets in China

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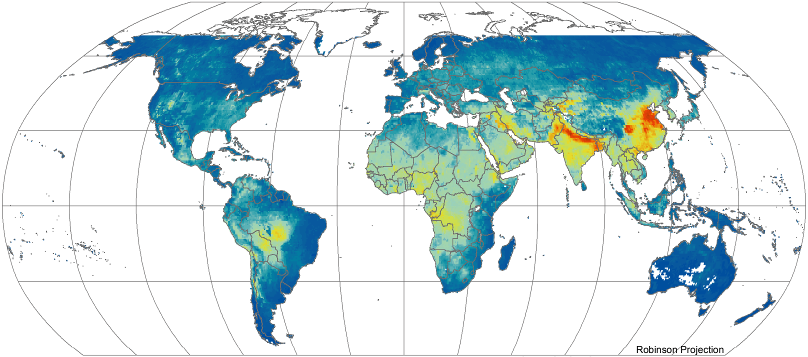
Air pollution is very severe in developing countries

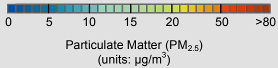
Global Annual Average $PM_{2.5}$ Grids from MODIS and MISR Aerosol Optical Depth (AOD), 2010

Satellite-Derived Environmental Indicators



Map Credit: CIESIN Columbia University, April 2013.

Global Annual $PM_{2.5}$ Grids from MODIS and MISR Aerosol Optical Depth (AOD) data sets provide annual "snap shots" of particulate matter 2.5 micrometers or smaller in diameter from 2001–2010. Exposure to fine particles is associated with premature death as well as increased morbidity from respiratory and cardiovascular disease, especially in the elderly, young children, and those already suffering from these illnesses. The grids were derived from Moderate Resolution Imaging Spectroradiometer (MODIS) and Multi-angle Imaging SpectroRadiometer (MISR) Aerosol Optical Depth (AOD) data. The raster grids have a grid cell resolution of 30 arc-minutes (0.5 degree or approximately 50 sq. km at the equator) and cover the world from 70°N to 60°S latitude. The grids were produced by researchers at Battelle Memorial Institute in collaboration



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Source: Chianews.com

Research question: How much are people willing to pay for clean air in developing countries?

- Severe air pollution $\Rightarrow$ Health and economic costs
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- Severe air pollution $\Rightarrow$ Health and economic costs
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- High costs of pollution $\not\Rightarrow$ Current env. regulations are not optimal
  - Willingness-to-pay is a key parameter to determine optimal environmental regulation (Greenstone and Jack, 2014)
- Yet, limited evidence on WTP for clean air in developing countries
  - Data: Hard to obtain data required to estimate WTP
  - Identification problems: Hard to have exogenous variation

This paper

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- Idea: Estimate demand for home-use air purifiers in Chinese cities
  - Home-use air purifier $\Rightarrow$ main defensive investment for households
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- Data: Scanner data on air purifier sales, prices, and attributes
    - Product-by-store level monthly data in 80 cities for 9 years

- Quasi-experimental variation in pollution levels and purifier prices
    - The Huai River Policy ⇒ A natural experiment to air pollution
    - Road distance from factory/port to market ⇒ IV for purifier prices

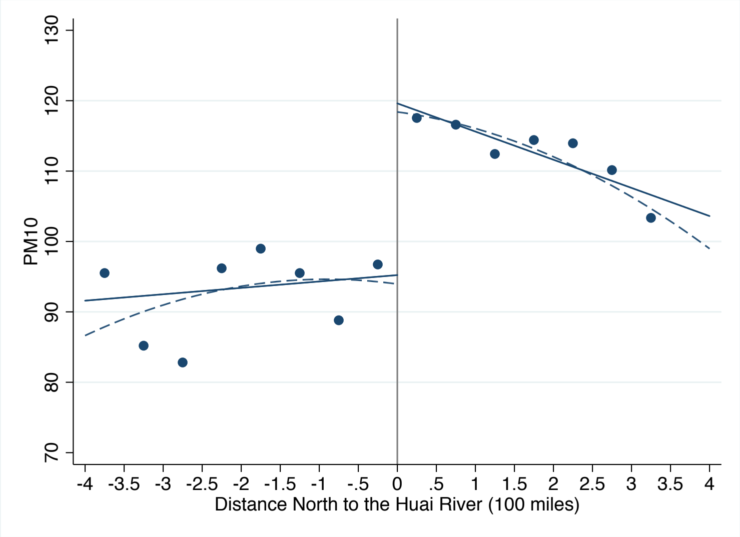
Huai river policy created long-run variation in air pollution

- Government built coal-based centralized heating in the North in 1950's
- Created plausibly exogenous, long-run variation in air pollution

A boiler house in an apartment complex (Shenyang)

Source: Chianews.com

PM_{10} by distance to the Huai River border (raw data)

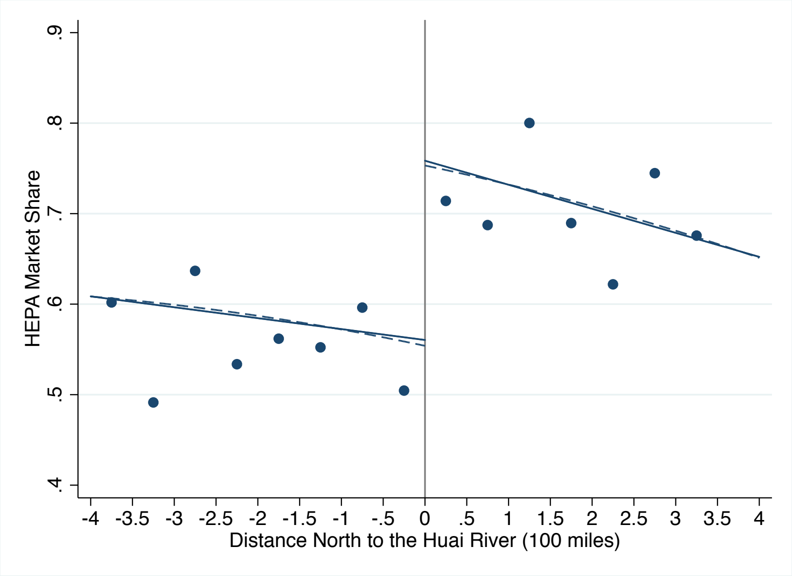


- Note: In the US, average PM_{10} was 55 ug/m^3 in 2014 (it was 85 in 1990)

Our idea: Analyze demand for air purifiers to learn WTP

- Scanner data on air purifier sales, prices, and attributes
  - Sales and prices at the product-city-store-year-month level
  - 690 products by 45 manufacturers in 80 cities for 2006-2014
  - Detailed attributes (HEPA vs. Non-HEPA, coverage area, etc.)

Share of HEPA purifiers sales (raw data)



Roadmap of the paper

1. Develop a framework to estimate WTP for environmental quality from market transaction data on differentiated products
   - Theory work in environmental economics offers an insight (Branden et al. 1991)
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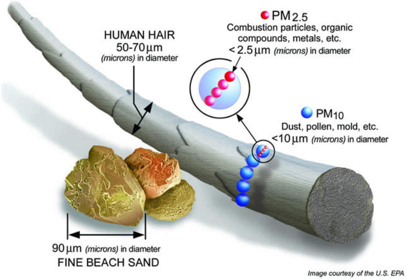
3. Offer important policy implications for environmental policies in China

Outline of this talk

- Introduction
- **Background and Data**
- Demand Model
- Empirical Analysis and Results
- Policy Implications
- Conclusion
- Appendix

1) Air pollution data

- PM_{10}: fine particulate matter $\leq$ 10 micrometers
  - Harmful for health (lung cancer, heart disease, stroke, respiratory infection)



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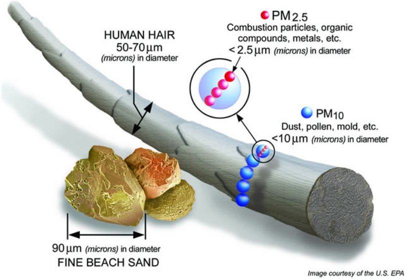

- Data: City-level annual average PM_{10} from 2006 to 2014
  - Source: Environmental yearbook and environmental quality annual report
  - Complementary data: City-level daily API from Chinese EPA

2) Scanner data on air purifier sales and prices

- Available at the product-city-store-year-month level
  - 690 products by 45 domestic and foreign manufacturers
  - Monthly sales and prices in 2006-2014 in 80 cities
  - Detailed attributes (HEPA vs. Non-HEPA, coverage area, etc.)

HEPA vs. Non-HEPA air purifiers

- High Efficiency Particulate Arrestance (HEPA):
  - A necessary attribute for air purifiers to remove PM
  - It must remove 99.97% of particles $\geq$ 0.3 micrometer (US DOE)
  - Ads in Chinese market: it removes $> 99\%$ of $PM_{2.5}$ and PM_{10}
- Non-HEPA filtration systems do not remove PM
  - It does not remove fine particles such as $PM_{2.5}$ and PM_{10}
  - However, it still provides other benefits
  - e.g. Remove Volatile Organic Compounds (VOC), gas and odors

Summary statistics of air purifier data

Panel A: Air purifier attributes

	All purifiers	HEPA purifiers	Non-HEPA purifiers	Difference in means
Price of a purifier ($)	454.52	509.64	369.81	139.84***
	(383.81)	(404.24)	(333.45)	[52.14]
Humidifing (0 or 1)	0.164	0.177	0.143	0.034
	(0.370)	(0.382)	(0.351)	[0.070]
Room coverage (square meter)	41.85	44.97	36.50	8.47*
	(23.65)	(24.93)	(20.27)	[4.42]
Distance to factory or port (in 100 miles)	7.48	7.32	7.72	-0.39
	(2.87)	(2.69)	(3.12)	[0.45]
Price of a replacement filter ($)	46.38	56.39	34.92	21.47*
	(52.21)	(65.68)	(25.91)	[10.70]
Frequency of filter replacement (in months)	9.03	10.08	7.92	2.17
	(5.93)	(6.55)	(4.97)	[1.37]

1. HEPA purifiers are on average more expensive than non-HEPA purifiers
2. Other attributes are in general quite similar between the two types

3) Census data

- Demographic and economic variables from the confidential census data
  - We obtained confidential micro data on demographic variables, which include a random sample of households in each city
  - We also collected economic data (e.g. GDP) at the city-year level

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Demand Model

- x_c: Ambient air pollution in city c
- x_{jc}: A reduction in indoor air pollution given the purchase of purifier j

$$x_{jc} = x_c \cdot e_j$$

  - e_j: Effectiveness in removing PM_{10}

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  - e_j: Effectiveness in removing PM_{10}

- Conditional indirect utility of consumer i who purchases purifier j

$$u_{ijc} = \beta_i x_{jc} + \alpha_i p_{jc} + \eta_j + \xi_{jc} + \epsilon_{ijc}$$

  - β: marginal utility for a pollution reduction. α: disutility for price
  - Note: purifiers are durable goods and last for five years on average

1) Standard Logit Demand Approach ($\beta_i = \beta$ & $\alpha_i = \alpha$)

- Assume that $\epsilon_{ijct} \sim$ extreme value type I distribution
- The market share for air purifier j in city c is:

$$s_{jc} = \frac{\exp(\beta x_{jc} + \alpha p_{jc} + \eta_j + \xi_{jc})}{\sum_{k=0}^{J} \exp(\beta x_{kc} + \alpha p_{kc} + \eta_k + \xi_{kc})}$$

  - The outside option ($j = 0$) is not to buy any air purifier
  - We assume that $x_{0c} = 0$ (a reduction in indoor air pollution is zero)

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- Log market share for j minus log market share for outside option:

$$\ln s_{jc} - \ln s_{0c} = \beta x_{jc} + \alpha p_{jc} + \eta_j + \xi_{jc}$$

1) Standard Logit Demand Approach

- Reductions in indoor pollution (x_{jc}) can be written by:

$$x_{jc} = x_c \cdot HEPA_j = \begin{cases} x_c & \text{if } HEPA_j = 1 \\ 0 & \text{if } HEPA_j = 0. \end{cases}$$

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- Our estimate is likely to be a lower bound of MWTP
  - Households may take other avoidance methods for indoor air pollution (e.g. improve building installation) $\rightarrow$ We underestimate their MWTP

2) Random Coefficient Logit Approach

- Allow heterogeneity in β and α:

$$u_{ijc} = \beta_i x_{jc} + \alpha_i p_{jc} + \eta_j + \xi_{jc} + \epsilon_{ijc}$$

  - $\beta_i = \beta_0 + \beta_1 y_i + u_i$
  - $\alpha_i = \alpha_0 + \alpha_1 y_i + e_i$,
  - Preference heterogeneity is allowed to depend on demographic variables (y_i) and unobservables u_i and e_i (log normal)
  - We use confidential household-level census data for y_i

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- Advantage: allows for flexible substitution patterns, less restrictive price elasticity, and heterogeneous tastes (BLP 1995, Nevo 2001)

- Challenge: involves numerical optimization for a highly nonlinear GMM objective function $\rightarrow$ requires careful estimation (Knittel and Metaxoglou 2013)

Note about a potential dynamic decision

- In this paper, we abstract from a consumer's dynamic decision
  - In our setting, exogenous variation in pollution comes from cross-section
  - To exploit this variation, we aggregate our panel data to cross-section

- A new paper in progress: a dynamic discrete choice
  - Test if consumers respond to inter-temporal price variation
  - Investigate how consumers respond to product entries and exits

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Endogeneity in pollution (x) and price (p)

$$\ln s_{jc} = \beta x_c \cdot HEPA_j + \alpha p_{jc} + \eta_j + \lambda_c + \epsilon_{jc}$$

1. Pollution is likely to be correlated with unobserved economic factors
   - We exploit spatial RD of the Huai River heating policy

Huai river policy created long-run variation in air pollution

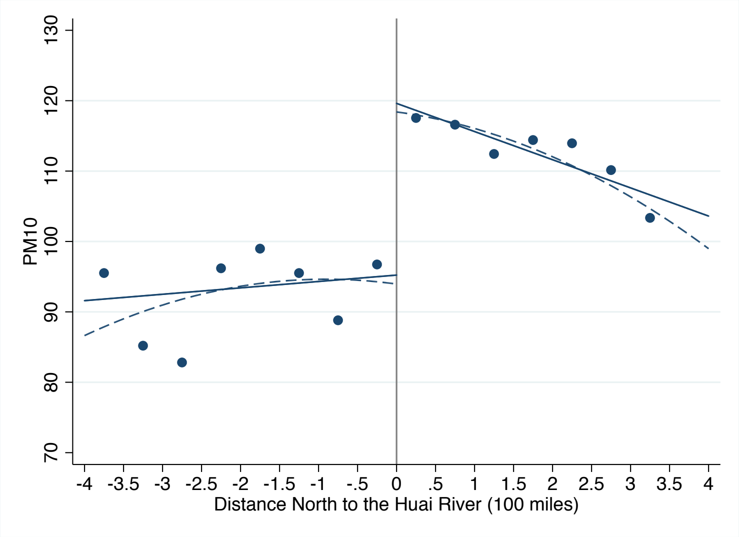
- Government built coal-based centralized heating in the North
- Created plausibly exogenous, long-run variation in air pollution

Institutional details of the Huai River heating policy

- In 1958, the Chinese government built centralized heating systems
  - Only for the cities north of the Huai River borderline
  - Reason: Average January temperature is roughly 0°C along the line
  - This line is not used for any other administrative purposes

- Coal-based facilities produce local air pollution
  - Heat is generated by local boilers within a residential complex
  - This create local air pollution for residents in northern cities

1) First stage on PM_{10}



- North of the Huai river $\rightarrow$ Higher PM_{10}

1) First stage on PM_{10}

Dependent variable: PM_{10} in ug/m^3				
	(1)	(2)	(3)	(4)
North	24.54***	24.55***	24.38***	24.19***
	(6.97)	(6.98)	(8.71)	(8.86)
Observations	49	49	49	49
R^2	0.36	0.36	0.56	0.57
Control function for running variable	Linear*North	Quadratic	Linear*North	Quadratic
Demographic controls			Y	Y
Longitude quartile FE			Y	Y

- Main result: Local linear regression with the bandwidth of 400 miles
- Robust to other choices of bandwidths and functional forms (appendix)
- The amount of PM_{10} generated by the Huai River Policy = 24.5 ug/m^3

Identification assumption behind the RD design

- Assumption: Potential outcomes have to be smooth at the RD cutoff
  - As always, this is an untestable assumption (Imbens and Lemieux, 2008)

- We provide two sets of evidence that support this assumption
  1. Smoothness of observable variables at the RD cutoff (next slide)
  2. Include longitude quartile FE to control for west-east unobserved factors

	North	South	Differences in Means	RD Estimates (local linear)
Population (1,000,000)	2.398	2.720	-0.323	-0.388
	(2.266)	(3.189)	[0.625]	[1.411]
Urban population (1,000,000)	1.773	1.974	-0.200	-1.092
	(1.770)	(2.436)	[0.480]	[1.151]
Years of schooling	9.30	8.64	0.667***	-0.101
	(0.88)	(1.12)	[0.227]	[0.671]
Fraction illiterate	0.052	0.069	-0.016**	0.003
	(0.022)	(0.033)	(0.006)	(0.018)
Fraction completed high school	0.338	0.286	0.051**	0.018
	(0.107)	(0.112)	[0.025]	[0.074]
Fraction completed college	0.052	0.048	0.004	-0.019
	(0.033)	(0.031)	[0.007]	[0.021]
Per capita household income	527.52	698.10	-170.58**	-134.54
(USD in 2005)	(152.79)	(388.20)	[67.27]	[107.41]
House size (square meter)	75.24	92.04	-16.80***	-12.25
	(13.32)	(17.52)	[3.51]	[9.34]
Residence built after 1985	0.691	0.718	-0.027	-0.040
	(0.083)	(0.075)	[0.018]	[0.027]
Fraction building materials include	0.668	0.729	-0.061	0.010
reinforced concrete (less insulated)	(0.187)	(0.147)	[0.037]	[0.107]
Fraction moved within city	0.074	0.065	0.009	-0.002
	(0.030)	(0.022)	[0.006]	[0.010]
Fraction occupation involved with	0.218	0.208	0.011	0.032
outdoor activities	(0.106)	(0.099)	[0.023]	[0.074]

Endogeneity in pollution (x) and price (p)

$$\ln s_{jc} \quad = \quad \beta x_c \cdot HEPA_j + \alpha p_{jc} + \eta_j + \lambda_c + \epsilon_{jc}$$

1. Pollution is likely to be correlated with other factors
   - We use spatial regression discontinuity of the Huai River heating policy
2. Price is likely to be correlated with unobserved demand shocks

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   - Remaining concern: produce-city specific unobserved demand shocks
   - An ideal instrument is a supply-side cost shifter at the product-city level

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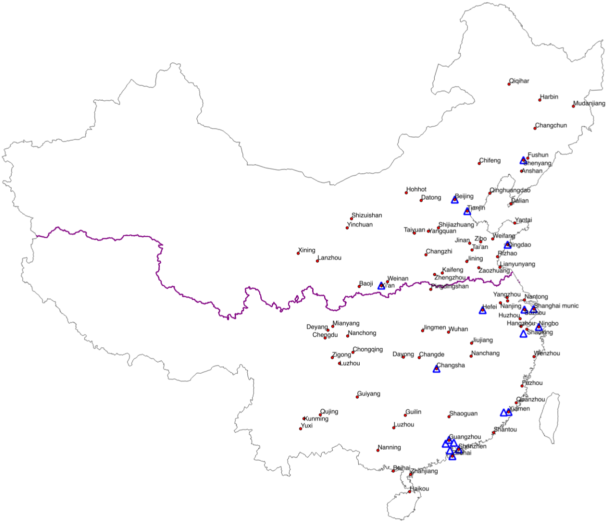
   - An ideal instrument is a supply-side cost shifter at the product-city level
   - Our idea: the transportation cost from factory/port to market

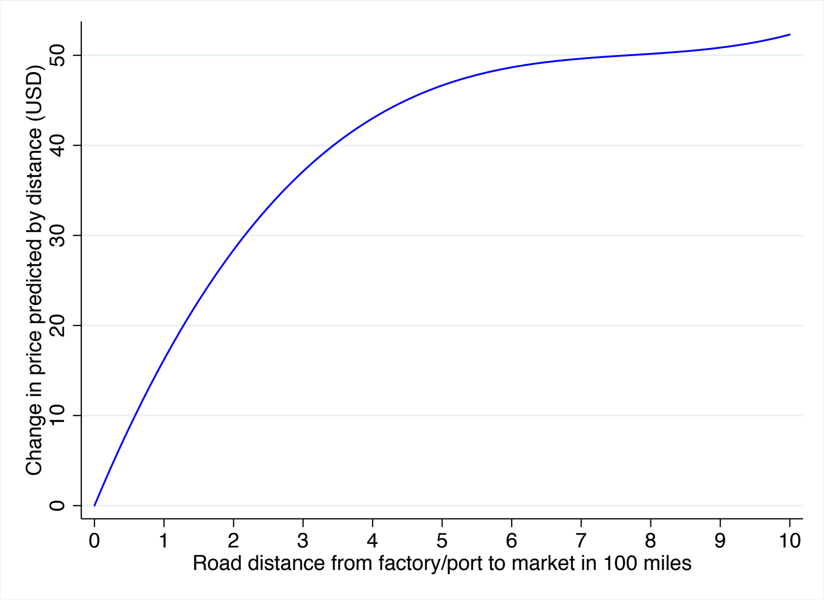
2) First stage on price (IV: road distance to factory/port)



- We collected data on each product's factory/port location
- Use GIS to obtain the road distance from factory/port to market

	Dependent variable: Price ($)			
	(1)	(2)	(3)	(4)
Distance to factory in 100 miles	18.43***	18.39***	12.70**	12.67**
	(4.97)	(4.98)	(4.94)	(4.93)
(Distance to factory in 100 miles)^2	-2.32***	-2.33***	-1.49*	-1.49*
	(0.72)	(0.72)	(0.77)	(0.77)
(Distance to factory in 100 miles)^3	0.10***	0.10***	0.06	0.06
	(0.03)	(0.03)	(0.04)	(0.04)
Observations	7,359	7,359	7,359	7,359
R^2	0.96	0.96	0.96	0.96
Control function for running variable	Linear*North	Quadratic	Linear*North	Quadratic
Product FE	Y	Y	Y	Y
City FE			Y	Y
Longitude quartile FE*HEPA	Y	Y	Y	Y
Predicted effect of 500 miles on price	46.46***	46.30***	33.22***	33.16***
	(12.07)	(12.15)	(11.43)	(11.42)
Predicted effect as % of mean price	10.2%	10.2%	7.3%	7.3%

- Longer distance from factory/port to market → Higher prices



- The predicted price-distance relationship

An alternative instrument for price as a robustness check

- IO theory predicts that p_{jc} can be affected by its competitor's cost
  - Consider imperfect competition in differentiated products markets
  - A firm sets a higher p_{jc} when its competitors have higher marginal costs
  - p_{jc} can be affected by the transportation costs of other firms in market c

An alternative instrument for price as a robustness check

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- IV: Average road distance of the products sold by competing firms

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- IV: Average road distance of the products sold by competing firms
  - Appendix Table A.2: the results remain similar to our main results

3) Second-stage estimating equation

- Final specification with control variables:

$$\ln s_{jc} = \beta x_c \cdot HEPA_j + \alpha p_{jc} + \eta_j + \lambda_c + f(d_c) \cdot HEPA_j + \epsilon_{jc}$$

  - d_c: distance from the Huai River border (the running variable for the RD)
  - $f(d_c)$: local linear or quadratic controls for d_c

3) Second-stage estimating equation

- Final specification with control variables:

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  - We report robustness checks with further narrower bandwidths
  - Standard errors are clustered at the city level

3) Second-stage estimation results

	Dependent variable: ln(market share)	
	(1)	(2)
PM10*HEPA (β)	0.0299***	0.0302***
	(0.0030)	(0.0032)
Price (α)	-0.0048***	-0.0048***
	(0.0001)	(0.0001)
Observations	7,359	7,359
First-stage F-Stat	285.16	292.01
Control function for running variable	Linear*North	Quadratic
MWTP for 5 years ($-\beta/\alpha$)	6.2077***	6.3100***
	(0.6649)	(0.7130)
MWTP per year	1.2415***	1.2620***
	(0.1330)	(0.1426)

- MWTP = \$1.24 per 1 ug/m^3 reduction in PM_{10} per year
- Results are robust to the choice of bandwidths (next slide)

Panel A: Control function for the running variable: Linear*North

	Dependent variable: ln(market share)			
	(1) 250 miles	(2) 300 miles	(3) 350 miles	(4) 400 miles
PM10*HEPA (β)	0.0296***	0.0322***	0.0268***	0.0299***
	(0.0029)	(0.0047)	(0.0010)	(0.0030)
Price (α)	-0.0036***	-0.0038***	-0.0042***	-0.0048***
	(0.0002)	(0.0002)	(0.0001)	(0.0001)
Observations	5,619	5,878	7,107	7,359
First-stage F-Stat	1921.77	526.20	1348.93	285.16
MWTP for 5 years ($-\beta/\alpha$)	8.2840***	8.4562***	6.3748***	6.2077***
	(1.0665)	(1.4798)	(0.2764)	(0.6649)
MWTP per year	1.6568***	1.6912***	1.2750***	1.2415***
	(0.2133)	(0.2960)	(0.0553)	(0.1330)

Panel B: Control function for the running variable: Quadratic

	Dependent variable: ln(market share)			
	(1) 250 miles	(2) 300 miles	(3) 350 miles	(4) 400 miles
PM10*HEPA (β)	0.0298***	0.0327***	0.0265***	0.0302***
	(0.0028)	(0.0046)	(0.0010)	(0.0032)
Price (α)	-0.0035***	-0.0037***	-0.0042***	-0.0048***
	(0.0002)	(0.0002)	(0.0001)	(0.0001)
Observations	5,619	5,878	7,107	7,359
First-stage F-Stat	2122.08	467.03	1399.44	292.01
MWTP for 5 years ($-\beta/\alpha$)	8.4464***	8.7436***	6.3470***	6.3100***
	(1.0758)	(1.5087)	(0.3034)	(0.7130)
MWTP per year	1.6893***	1.7487***	1.2694***	1.2620***
	(0.2152)	(0.3017)	(0.0607)	(0.1426)

4) What variation in the data identifies β?

- Recall that the second-stage of the RD design is:

$$\ln s_{jc} = \beta x_c \cdot HEPA_j + \alpha p_{jc} + \eta_j + \lambda_c + f(d_c) \cdot HEPA_j + \epsilon_{jc}$$

- To visualize what variation in the data is identifying β, it is useful to see the reduced-form relationship of the RD design

- Reduced-form relationship of the RD design is:

$$\ln s_{jc} = \rho North_c \cdot HEPA_j + \alpha p_{jc} + \eta_j + \lambda_c + f(d_c) \cdot HEPA_j + \epsilon_{jc}$$

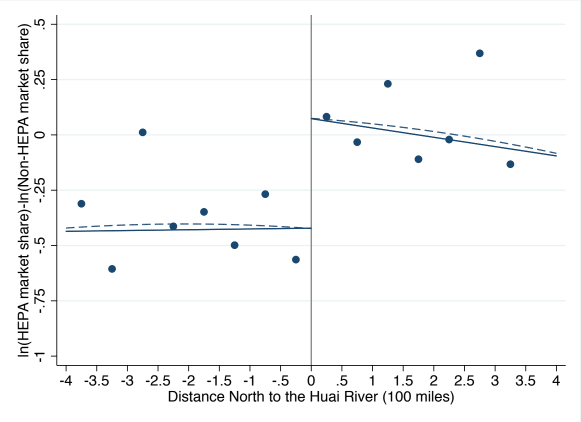
Reduced-form of the RD design

$$\ln s_{jc} = \rho North_c \cdot HEPA_j + \alpha p_{jc} + \eta_j + \lambda_c + f(d_c) \cdot HEPA_j + \epsilon_{jc}$$

	Dependent variable: ln(market share)	
	(1)	(2)
North*HEPA (ρ)	0.4275***	0.4216***
	(0.0329)	(0.0320)
Price (α)	-0.0052***	-0.0052***
	(0.0001)	(0.0001)
Observations	7,359	7,359
First-stage F-Stat	870.29	1115.94
Control function for running variable	Linear*North	Quadratic

Reduced-form of the RD design

$$\ln s_{jc} = \rho North_c \cdot HEPA_j + \alpha p_{jc} + \eta_j + \lambda_c + f(d_c) \cdot HEPA_j + \epsilon_{jc}$$



- ρ captures how $\ln s_{jc}$ for HEPA (relative to non-HEPA) changes at $North_c = 1$
- Scatterplot: $E[\ln s_{cj} | HEPA_j = 1] - E[\ln s_{cj} | HEPA_j = 0]$

5) Random-coefficient logit approach

- Allow heterogeneity in β and α

$$u_{ijc} = \beta_i x_{jc} + \alpha_i p_{jc} + \eta_j + \epsilon_{jc} + \epsilon_{ijc}$$

  - $\beta_i = \beta_0 + \beta_1 y_i + u_i$
  - $\alpha_i = \alpha_0 + \alpha_1 y_i + e_i$,
  - Preference heterogeneity is allowed to depend on demographic variables (y_i) and unobservables u_i and e_i
  - We use micro data on household-level income from census for y_i

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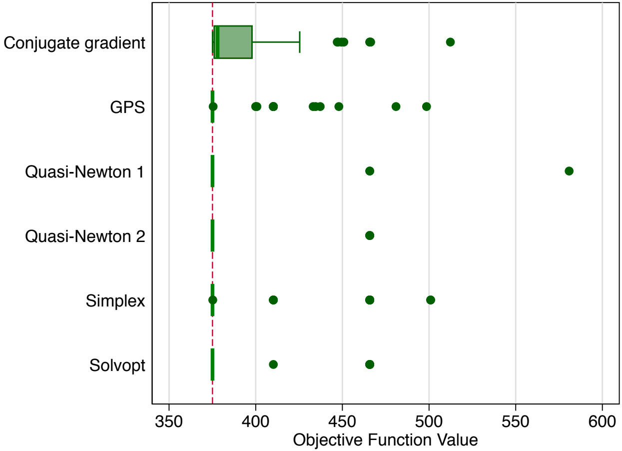
- Nonlinear numerical optimization requires careful investigation
  1. Test several nonlinear search algorithms
  2. Test 100 sets of random starting values for each search algorithm
  3. Use conservative tolerance levels for fixed-point iterations

Box plot: Objective function values from 100 staring points



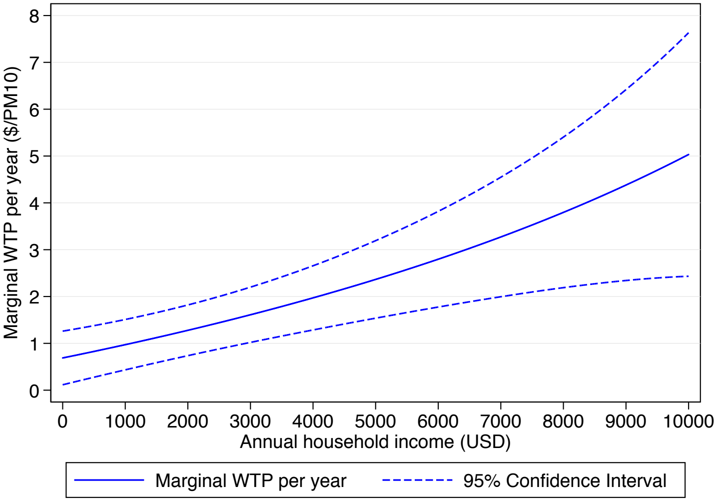
- Implications
  1. Testing many staring values is important for nonlinear optimization
  2. In our case, all search algorithms (except for conjugate gradient) reached the same minimum for more than 90% of the 100 sets of starting values

Random-coefficient logit results

	(1)	(2)
PM10 · HEPA		
Mean coefficient (β_0)	0.0459***	0.0498***
	(0.0084)	(0.0092)
Interaction household income (β_1)	0.0924***	0.0891***
	(0.0224)	(0.0253)
Standard deviation (σ_β)	0.0056***	0.0102***
	(0.0020)	(0.0021)
Price		
Mean coefficient (α_0)	-0.0069***	-0.0071***
	(0.0007)	(0.0007)
Interaction with household income (α_1)	0.0028**	0.0028**
	(0.0011)	(0.0011)
Standard deviation (σ_α)	0.0026	0.0024
	(0.0030)	(0.0030)
Observations	7,359	7,359
Control function for running variable	Linear*North	Quadratic
GMM objective function value	375.05	378.93

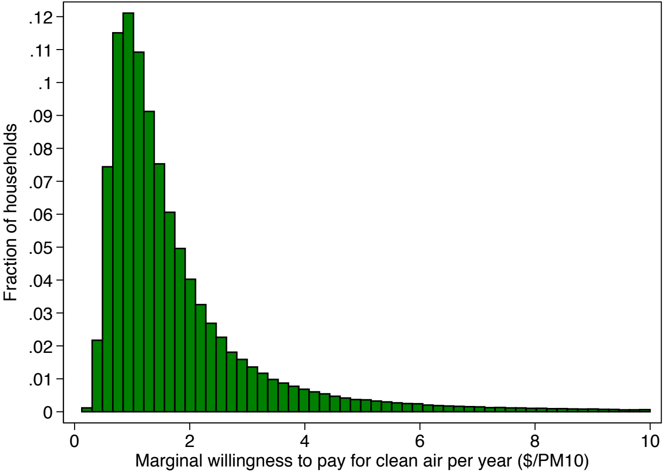
- Higher income → Value clean air more ($\beta_1 > 0$) & less price-elastic ($\alpha_1 > 0$)

The relationship between MWTP and household income



- Estimated marginal WTP for clean air is increasing in household income

Heterogeneity in MWTP for clean air



- Substantial heterogeneity in MWTP
- Mean ($1.34) is not largely different from the standard logit result ($1.24)

7) Does MWTP for clean air depend on information?

- Limited information may attenuate WTP for environmental quality
  - Especially important in developing countries (Greenstone and Jack, 2013)
  - However, it is generally difficult to test this with non-experimental data

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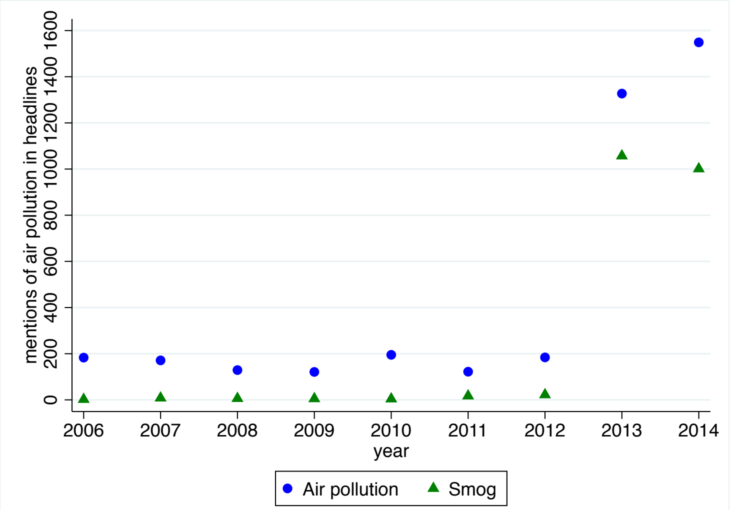
- We use widespread media coverage on air pollution after January 2013
  - On January 12th 2013, the US Embassy in Beijing posted air quality index (AQI) of 755, beyond the scale's maximum 500
  - New York Times and other foreign medias started extensive coverage
  - Resulted in widespread media coverage in Chinese newspapers

Widespread media coverage has started in January, 2013



- Annual number of newspaper headlines from all 631 newspapers in China
- We test if the preference for clean air (β) changed in response to this event

We find that MWTP became higher after 2013

	(1)	(2)	(3)
PM10*HEPA	0.0192***	0.0174***	0.0193***
	(0.0018)	(0.0027)	(0.0025)
PM10*HEPA*Post-2013	0.0329***	0.0307***	0.0280***
	(0.0076)	(0.0079)	(0.0090)
Price	-0.0072***	-0.0072***	-0.0064***
	(0.0001)	(0.0002)	(0.0002)
Observations	10,780	10,780	10,780
First-stage F-Stat	113.39	112.01	189.15
Control function for running variable	Linear*North	Linear*North	Linear*North
Product FE*Post-2013	Y	Y	Y
City FE*Post-2013	Y	Y	Y
Longitude quartile FE*HEPA*Post-2013	Y	Y	Y
Salary*HEPA		Y	Y
Salary*Price			Y
MWTP per year before 2013	0.5313***	0.4867***	0.6001***
	(0.0595)	(0.0874)	(0.0918)
MWTP per year after 2013	1.4438***	1.3458***	1.4707***
	(0.1475)	(0.1376)	(0.2009)
Difference in MWTP per year	0.9124***	0.8591***	0.8706***
	(0.1961)	(0.2040)	(0.2647)

Outline of this talk

- Introduction
- Background and Data
- Demand Model
- Empirical Analysis and Results
- **Policy Implications**
- Conclusion
- Appendix

Policy implications

- Policy debate on the tradeoff between growth and environment
  - Chinese Premier Li Keqiang declared "War Against Pollution" in 2014
  - A key question is whether such policies enhance social welfare

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  - Chinese Premier Li Keqiang declared "War Against Pollution" in 2014
  - A key question is whether such policies enhance social welfare
- Example: A pilot reform for the Huai river policy
  - Recently implemented by the Chinese government and the World Bank
  - Make the heating system more efficient and less polluted in pilot cities

Make the heating system more efficient and less polluted

Source: Chianews.com

- The cost-effectiveness of this policy is still under debate
- How can we use our WTP estimate for this policy discussion?

1) Cost-benefit analysis of heating system reform

- World Bank (2014)
  - The cost of the policy was $2.25M/year for seven pilot cities
  - The policy generated a reduction in PM_{10} by 11.91 ug/m^3

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  - This implies that WTP for the 11.91 ug/m^3 reduction is \$120.63M
  - Benefit-cost ratio $= 53.6$ ($= 120.63/2.25$)

- Benefit-cost ratio > 0, even with our lower bound MWTP estimate

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- We provide a similar benefit-cost calculation for this question
  - Result: Our WTP estimate by itself is unlikely to justify this proposal

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- We provide a similar benefit-cost calculation for this question
  - Result: Our WTP estimate by itself is unlikely to justify this proposal
- Reason: Coal is substantially cheaper than other options in China
  - Natural gas in China is not as inexpensive as the one currently in the US
  - Renewables are still substantially more expensive than coal in China

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Summary

1. Develop a framework to estimate WTP for environmental quality from market transaction data on differentiated products

2. Provide among the first revealed preference estimates of WTP for clean air in developing countries
   - MWTP (mean) $=$ \$1.34 per 1 ug/m^3 reduction in PM_{10} per year
   - Substantial heterogeneity in MWTP among households
   - Income and information are key determinants of the heterogeneity

3. Offer policy implications for environmental policies in China
   - Heating system reform is likely to be a welfare-enhancing policy
   - Coal power replacement is unlikely to be justified by our WTP estimate