Environment: Pollution & Health, Emission & Market, Regulation

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Introduction

- Currie, Neidell, "Air Pollution and Infant Health: What Can We Learn from California's Recent Experience",QJE, (2005)
- Pollution abatement justified to promote health
- Infant mortality is not considered
- Question: examine impact of air pollution on infant health in California over 1990s
- Why infant: link between cause and effect is immediate, whereas for adults, diseases today may reflect pollution exposure that occurred many years ago.
- Examine three "criteria" pollutants: Ozone (O3), carbon monoxide (CO), particulate matter (PM10)
- Hazard models: risk of death is defined over weeks of life

Introduction

- Results:
  - air pollution significantly increase infant mortality even at the relatively low levels of pollution experienced in recent years
  - Reductions in CO in 1990s saved 1000 infant lives in California

Background

- CO bonds with hemoglobin more easily than oxygen ⇒ reduces body's ability to deliver oxygen to organs and tissues
- 90 % of CO in cities comes from motor vehicle
- It is thought that most damaging: smallest particles since inhaled deep into lungs
- PM10 (particles less than 10 microns)
- Ozone (major component of smog) is reactive, damages tissue, reduces lung function
- Infant mortality: death in the first year of life

Background

- Limitation of previous studies: unobserved factor correlated with both air pollution and child outcomes
- For example, areas with high levels of air pollution also tended to have high levels of water pollution
- Chay, Greenstone "natural experiments" of Clean Air Act of 1970 was a solution
- But what about reductions from much lower levels of ambient pollution?
- Whether other pollutants than TPS affect infant health?
- This paper: individual-level data and weekly zip code-level pollution measures and control for many potential confounders in an effort to identify causal effects.

Data

- Weekly measure of pollution for each zip code in CA
- Considerable decline in pollution levels

Panel 2

year	CO (8 hour)	PM10	O3 (8 hour)
1989	2.458	49.651	46.139
1990	2.472	46.575	41.664
1991	2.288	46.377	43.516
1992	2.279	41.285	42.830
1993	1.974	37.040	41.089
1994	2.111	37.384	40.351
1995	1.857	34.256	40.037
1996	1.798	35.790	39.681
1997	1.608	34.052	36.630
1999	1.580	36.510	36.109
2000	1.376	33.572	35.657

- Strong seasonal patterns: CO & PM10 spike in cold, O3 in summer (not shown)

Data

- Data on infant deaths: California Birth Cohort files
- Infant deaths to infants with at least 26 weeks gestation
- Pollution exposure in 1,2,3 trimesters of the pregnancy.
- Pollution on low birth weight (< 2500 g)

Panel 3 year	IMR	Low birth weight	Fetal deaths	Number of births*
1989	5.33	51.02	4.10	388,097
1990	4.76	48.23	3.95	444,021
1991	4.46	47.41	3.79	454,902
1992	4.18	48.15	3.70	445,760
1993	4.08	48.59	3.55	449,374
1994	3.96	49.33	3.46	441,080
1995	3.56	48.42	3.59	419,948
1996	3.27	48.32	3.56	407,923
1997	3.21	48.31	3.20	386,137
1999	2.90	46.64	3.15	372,232
2000	2.96	47.39	3.21	383,527
Total				4,593,001

- 3.91 per 1000 infants born alive (gestation > 26) died in their first year

Data

- Pollution levels in California are well under thresholds

National ambient air quality standards

O3	85 ppb	8-hr
CO	9.5 ppm	8-hr
PM10	155 µg/m3	24-hr

- Los Angeles is out of compliance for both ozone and CO
- Standardized all of three pollution measures using a "z-score": rank areas
- Pollutant worst birth, at the same time worst socioeconomic characteristics

Pollution for Infant Born in Highest/Lowest Pollution

Ranked by:	Pollution Level		Change in pollution between weeks 1&2		Change in pollution between weeks 2&3	
Variable	Lowest 1/3	Highest 1/3	Lowest 1/3	Highest 1/3	Lowest 1/3	Highest 1/3
CO 8-hr level	1.176	2.912	2.008	2.116	1.986	2.121
Weekly change in CO			−0.228	0.268	−0.237	0.249
PM10 24-hr level	25.647	54.139	39.479	41.067	39.685	40.662
Weekly change in PM10			−14.673	14.539	−14.594	14.417
O3 8-hr level	34.837	46.705	41.269	40.283	41.597	40.201
Weekly change in O3			−0.005	0.004	−0.005	0.004
IMR per 1000	3.583	4.406	3.976	3.997	3.976	3.965
Change in Deaths			901.000	929.000	235.000	242.000
Low BW per 1000	47.094	49.506	48.344	48.601	48.360	48.434
Fetal death per 1000	3.370	3.840	3.692	3.638	3.628	3.659
% Male	0.487	0.488	0.488	0.488	0.488	0.488
% Black	0.083	0.083	0.082	0.083	0.082	0.083
% Hispanic	0.317	0.550	0.473	0.471	0.472	0.472
% Asian	0.161	0.089	0.112	0.114	0.113	0.113
% Married	0.725	0.629	0.663	0.663	0.663	0.663
% Foreign mom	0.394	0.524	0.477	0.478	0.476	0.479
% Racial diff parents	0.189	0.139	0.158	0.159	0.158	0.158
% HS dropout	0.254	0.408	0.354	0.352	0.354	0.352
% HS grads	0.359	0.348	0.353	0.352	0.353	0.353
% AD degree	0.148	0.114	0.125	0.125	0.125	0.126
% College grads	0.239	0.130	0.168	0.170	0.168	0.169

Method

- Air pollution affects infants differently before and after birth
- Estimate if birth weight & gestation capture before birth effect
- Probability of death P_{izt}

$$P_{izt} = \alpha(t) + \omega_{iz}\gamma + h_{iz}\zeta + x_{zt1}\beta_1 + x_{zt2}\beta_2 + \phi_{zt} + Y_t$$

  - i: individual, z zip code,
  - $\alpha(t)$linear spline in the weeks since the childs birth,
  - ω_{iz} mother demographic, background characteristics;
  - h_{iz} infant's health and pollution exposure
  - x_{zt1} time-varying measures of pollution exposure after the birth
  - x_{zt2} weather indicators
  - ϕ_{zt} zip code-month specific fixed effects
  - Y_t year dummies

Method

- P_{izt} is then regressed on covariates by ordinary least squares.
- 250 million weekly observations,very large
- For each death randomly take 15 observations with same weeks alive, unbiased
- "harvesting" problem: children who die from exposure to high amounts of pollution in week t might have died at $t + 1$ (mortality displacement)
- If serious problem then overstate the loss of life by pollution
- Actual loss is one week rather than average life expectancy at birth.
- Solution: use longer time units (month) $\Rightarrow$ measurement error
- Point estimates are very stable $\Rightarrow$ strong evidence no harvesting.
- For pollution exposure: include cumulative pollution measures

Method-Prenatal Exposures

- Prenatal exposure on probability of
  - fetal death
  - low birth weight

$$P_{iz} = \omega_{iz}\gamma + p_{z1}\eta_1 + p_{z2}\eta_2 + \phi_{zt} + Y_t$$

  - P_{iz} relevant probability
  - ω_{iz} time-invariant covariates measured at the individual level
  - p_{z1} prenatal pollution exposure in each trimester
  - p_{z2} is a vector of weather variables
  - ϕ_{zt} zip code-month specific fixed effect
  - Y_t year dummies
- Main coefficient of interest η_1

Results

- Pollution have strong effects on mortality
- A one-unit reduction in CO would prevent 34 deaths per 100,000 live births
- Second panel control spline in the child's age, reduces effect, only CO remains significant.
- Third and fourth panels control for all of child and mother characteristics
- Panel 5: live save by one unit reduction in pollution

Effect of Pollution on Infant Mortality

	(1)	(2)	(3)	(4)
1. Controlling for pre- & postnatal pollution, weather, year dummies, month dummies				
CO	5.086			5.427
	[0.570]**			[0.762]**
PM10		0.211		0.037
		[0.035]**		[0.043]
O3			−0.074	0.144
			[0.050]	[0.058]*
R^2	0.004	0.004	0.003	0.004
2. Adding spline in child's age in weeks (1, 2, 3–4, 5–8, 9–12, 13–20, 21–32, >32 weeks)				
CO	2.867			2.566
	[0.512]**			[0.683]**
PM10		0.083		0.001
		[0.032]**		[0.039]
O3			−0.159	−0.054
			[0.045]**	[0.052]
R^2	0.21	0.21	0.21	0.21
3. Adding gender, race, maternal marital status & education, age of mother, parity, insurance, birth weight and gestation				
CO	2.458			2.466
	[0.488]**			[0.651]**
PM10		0.053		−0.026
		[0.031]		[0.037]
O3			−0.141	−0.038
			[0.043]**	[0.050]
R^2	0.27	0.27	0.27	0.27
4. Adding zip code * month fixed effects				
CO	2.631			2.89
	[0.977]**			[1.040]**
PM10		0.002		−0.036
		[0.039]		[0.042]
O3			−0.077	−0.046
			[0.065]	[0.067]
R^2	0.29	0.29	0.29	0.29
5. Magnitudes of the panel 4 effects in lives saved per unit pollution reduction				
CO	16.501			18.125
PM10		0.013		−0.226
O3			−0.483	−0.288

Results-Robustness

- Robustness: (SoCal: Southern California Air Quality Monitoring District)

	(1) SoCal	(2) Add zip-year SoCal only	(3) Drop 1st week	(4) Without prenatal pollution	(5) Without weather	(6) Monitors within 10 miles	(7) Time unit is month	(8) Including lags	(9) Including cumulative	(10) Including leads
CO	3.046	3.614	4.648	2.986	2.169	3.491	2.854	2.212	2.607	2.907
	[1.184]*	[1.226]**	[1.504]**	[1.017]**	[0.952]*	[0.920]**	[1.719]	[1.224]*	[1.021]**	[1.192]**
CO lead or cumulative or lag								1.226	1.048	−0.171
								[1.169]	[2.146]	[1.142]
PM10	0.047	0.014	−0.038	−0.035	−0.038	−0.061	0.128	−0.051	−0.063	−0.049
	[0.051]	[0.054]	[0.058]	[0.042]	[0.042]	[0.039]	[0.089]	[0.045]	[0.040]	[0.043]
PM10 lead or cumulative or lag								0.027	0.175	0.025
								[0.046]	[0.120]	[0.045]
O3	−0.116	−0.114	−0.141	−0.041	−0.099	0.001	−0.128	−0.036	−0.014	−0.026
	[0.082]	[0.085]	[0.095]	[0.065]	[0.061]	[0.065]	[0.118]	[0.078]	[0.068]	[0.076]
O3 lead or cumulative or lag								−0.01	−0.106	−0.047
								[0.076]	[0.125]	[0.076]
# Observations	125259	125259	131488	206352	206352	201990	205214	205958	206352	205981
R^2	0.29	0.27	0.16	0.29	0.29	0.29	0.23	0.29	0.29	0.29

Introduction

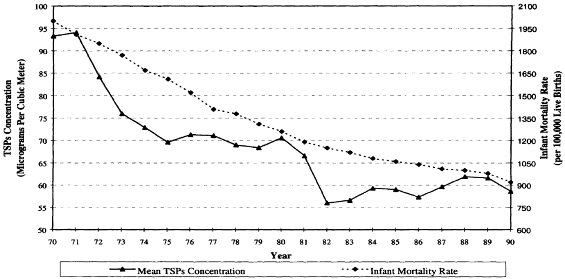
- Chay, Greenstone, "The Impact of Air Pollution on Infant Mortality", QJE (2003),
- Clean Air Act Amendments 1970 (CAAAs), Environmental Protection Agency (EPA)
- Target total suspended particulates (TSPs)
- EPA set maximum allowable concentrations that every county is required to meet
- Presumed TSP is highly non-linear by 3 type studies:
    1. cross-sectional analyses of correlation between adult mortality rates and pollution across cities
    2. time-series analyses of correlation between daily adult mortality rates and pollution levels within a given site
    3. cohort-based longitudinal studies of adults that suggest that particulates pollution results in excess mortality

Introduction

- Air pollution is not randomly assigned across locations
- Air pollution correlated with crime rates⇒ impact adult health
- Lifetime exposure of adults to air pollution is unknown
- Variation in TSP due to 1980-82 recession+infant mortality
- Wide variation in TSP allows to address non-linearity
- Cross section studies, usually result in no association.
- But, this quasi-experimental design: $1\mu g/m^3$ reduction resulting in about 4-7 fewer infant deaths per 100,000 live births (a 0.35 elasticity).
- Treatment and control groups by matching counties with similar income shocks

Facts on TSP and Mortality

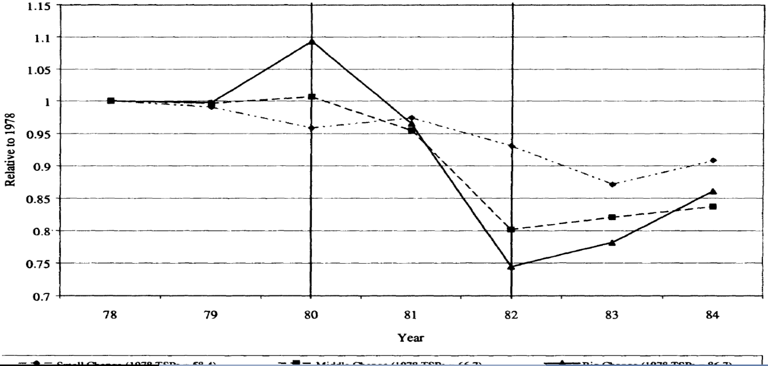
- TSP pollution and infant mortality rate in 1980-82



- Chay, Greenstone (2000): most of improvements in 1970s attributable to CAAAs

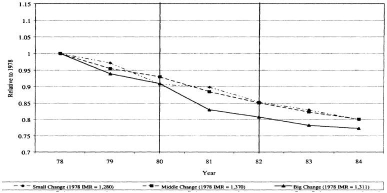
Facts on TSP and Mortality

- In 1980-1982: TSPs reductions due to differential impacts of recession across counties
- TSPs Concentrations, by Change in TSPs Concentration

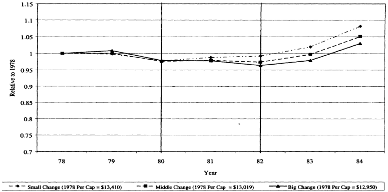


Infant Mortality and Per Capita Trend

- Infant Mortality Rate, by Change in TSPs Concentration



- Per Capita Income, by Change in TSPs Concentration



Empirical Methodology

- Cross sectional model: $y_{jt} = f(x_{jt}, z_{jt}, \omega_{jt}) + \varepsilon_{jt}$
- y: infant mortality, x TSP, z income, ω county chr
- $y_{jt} = x_{jt}\beta + z_{jt}\theta + \omega'_{jt}\Pi + \varepsilon_{jt} \quad \varepsilon_{jt} = \alpha_j + u_{jt}$
- Important ass. $E[x_{jt}.\varepsilon_{jt}] = 0$, not true in all periods
- If recession is quasi-experiment period in reduction of TSP

$$dy_{jt} = y_{j82} - y_{j80} = x_{j82}\beta - x_{j80}\beta + \varepsilon_{j82} - \varepsilon_{j80} = dx_{jt} + d\varepsilon_{jt}$$

- change in TSP may be correlated w/ other factors:

$$dy_{jt} = dx_{jt}\beta + dz_{jt}\theta + d\omega'_{jt}\Pi + d\varepsilon_{jt}, \quad d\varepsilon_{jt} = \lambda_{st} + du_{jt}$$

- λ_{st} state fixed effects

Empirical Methodology

- If $T_j^t = (x_{j1}, \cdots, x_{jt}, z_{j1}, \cdots, z_{jt})$
- Ass. $E(u_{jt}|T_j^t) = 0 \Rightarrow$ lag TSP & income as IV for dx_{jt}, dz_{jt}
- Notice b/c diff equ. so country fixed effect is controlled.
- Censoring bias concern: population of live birth
- TSP reductions during recession $\Rightarrow$ reduction in fetal deaths
- We understate impact of TSP on infant mortality because it is condition on live birth

Data

- Summary stat:

SAMPLE STATISTICS, 1978–1984

	1978	1979	1980	1981	1982	1983	1984
Number of counties in sample	1003	1019	1050	1043	1050	988	952
Total births in sample	2,599,010	2,737,663	2,842,817	2,862,625	2,909,385	2,820,255	2,825,214
Total births in U. S.	3,338,300	3,499,795	3,617,981	3,635,515	3,685,457	3,642,821	3,673,568
Fatalities per 100,000 live births							
Internal causes							
At 1 day	516.6	490.4	470.2	452.3	448.0	431.9	419.2
At 1 month	950.9	895.4	853.2	809.6	775.5	733.9	709.4
At 1 year	1336.4	1274.7	1226.2	1166.4	1121.6	1087.4	1059.8
External causes							
At 1 year	41.5	35.3	38.1	33.7	33.8	30.6	28.5
At 1 year all causes, by race							
Whites	1159.5	1111.6	1066.5	1019.9	978.2	946.8	923.8
Blacks	2217.8	2091.5	2059.4	1947.8	1900.2	1844.5	1789.2
Mean county-level pollution, income, and unemployment rate							
TSPs concentration	69.4	69.1	71.1	66.9	56.4	57.0	59.8
Income per capita ($1982–1984)	$13,117	$13,126	$12,794	$12,850	$12,781	$13,091	$13,825
Unemployment rate (%)	6.2	5.9	7.2	7.7	9.7	9.6	7.6
Mean parental demographic and socioeconomic characteristics							
% Mother H.S. dropout	22.7	18.0	17.4	16.7	16.2	15.6	14.9
Mother's years of education	12.2	12.4	12.4	12.5	12.5	12.6	12.6
Father's years of education	12.8	12.9	12.9	13.0	12.9	13.1	13.1
% Single mother	17.4	18.1	19.6	20.1	20.5	21.6	22.3
% Black	17.5	17.5	17.2	17.0	16.9	17.0	17.1
% Foreign-born	10.8	11.2	11.6	12.4	12.5	12.8	13.1
Mean medical services utilization							
% No prenatal care	1.42	1.29	1.33	1.38	1.53	1.63	1.72
% Prenatal care in 1st trimester	72.0	73.7	74.6	74.8	74.8	74.9	75.2
Number of prenatal care visits	9.6	8.8	9.2	9.2	9.2	9.3	9.2
Mean maternal health endowment							
% Teenage mother	16.0	15.5	15.0	14.2	13.7	13.2	12.6
% Mom >34 years	4.6	4.6	4.7	4.8	5.4	5.9	6.4
% First birth	37.2	37.1	36.6	36.8	36.3	35.9	35.3
% Prior fetal death	16.1	17.1	17.6	18.8	19.2	19.8	20.4
Mean infant health endowment							
Birth weight	3321	3328	3335	3335	3340	3339	3345
% Very low birth weight	1.19	1.17	1.18	1.18	1.20	1.22	1.21
% Low birth weight	7.2	7.1	6.9	6.9	6.9	6.9	6.8

Cross-Sectional Results

- Cross section 1978-1984 [sample sizes, R^2]

Largest estimates: 2 deaths

	Infant deaths due to internal causes (per 100,000 live births)				
	(1)	(2)	(3)	(4)	(5)
1978 Cross section	**1.51**	0.44	0.77	0.53	0.76
	(0.73)	(0.52)	(0.58)	(0.58)	(0.60)
	[1201, .02]	[1188, .41]	[1180, .48]	[1188, .53]	[1120, .48]
1979 Cross section	0.67	0.37	0.22	0.05	0.16
	(0.77)	(0.50)	(0.50)	(0.55)	(0.53)
	[1188, .02]	[1173, .42]	[1163, .51]	[1173, .53]	[1126, .50]
1980 Cross section	0.44	0.36	**1.08**	**1.04**	**1.06**
	(0.65)	(0.54)	**(0.48)**	**(0.51)**	**(0.49)**
	[1174, .02]	[1164, .47]	[1154, .54]	[1162, .57]	[1129, .54]
1981 Cross section	−0.19	−0.92	0.23	0.36	0.08
	(0.71)	(0.58)	(0.65)	(0.68)	(0.67)
	[1122, .01]	[1112, .42]	[1104, .47]	[1111, .51]	[1077, .47]
1982 Cross section	0.39	−0.20	1.14	1.52	1.14
	(1.06)	(0.69)	(0.87)	(0.86)	(0.93)
	[1104, .02]	[1098, .41]	[1091, .49]	[1098, .52]	[1062, .49]
1983 Cross section	1.72	0.64	**1.89**	**2.15**	**2.03**
	(1.23)	(0.61)	**(0.65)**	**(0.67)**	**(0.67)**
	[1076, .02]	[1067, .46]	[1060, .50]	[1067, .53]	[1036, .49]
1984 Cross section	−0.30	−0.09	−0.24	0.23	−0.41
	(0.78)	(0.53)	(0.68)	(0.73)	(0.70)
	[1029, .02]	[1023, .42]	[1016, .49]	[1023, .52]	[991, .47]
Income per capita	Y	Y	Y	Y	Y
Basic natality variables	N	Y	Y	Y	Y
Unrestricted natality	N	N	Y	Y	Y
Weather	N	N	Y	N	Y
State Medicaid	N	N	N	N	Y
Income assistance sources	N	N	N	N	Y
State effects	N	N	N	Y	N

Fixed Effects and Instrumental Variables

- Cross sectional estimates show unobserved heterogeneity
- Country fixed effects, IV from estimating first differences (income lags as IV)

	Infant deaths due to internal causes (per 100,000 live births)							
	1978–1980 data		1982–1984 data		1980–1982 data		1978–1984 data	
	FE	IV	FE	IV	FE	IV	FE	IV
Mean TSPs	−0.96	4.68	0.66	0.54	**3.51**	**5.21**	**5.27**	**3.75**
	(0.67)	(4.00)	(0.87)	(2.87)	**(0.52)**	**(1.99)**	**(0.40)**	**(1.46)**
Income per capita	0.85	−1.69	−0.47	−0.21	0.00	−2.42	−0.31	−0.78
(1/10)	(0.15)	(1.01)	(0.09)	(0.29)	(0.19)	(1.26)	(0.07)	(0.40)
County fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Year effects	N	Y	N	Y	N	Y	N	Y
R^2	0.70	0.00	0.69	0.00	0.71	0.00	0.58	0.00
Depend. var. mean	1276	−53.4	1088	−30.4	1170	−49.7	1179	−44.5
Sample size	3563	2172	3209	1994	3400	2099	7894	6265

- Only 1980-1982 very significant and economically large

Quasi-Experimental Results

- First difference, Lag income as IV, control other variables

	Infant deaths due to internal causes (per 100,000 live births)				
	(1)	(2)	(3)	(4)	(5)
Deaths w/in 1 year					
Mean TSPs	5.21	5.44	4.72	5.21	4.93
	(1.99)	(1.96)	(1.70)	(1.68)	(1.73)
Income per capita (1/10)	−2.42	−2.56	−1.99	−2.88	−2.37
	(1.26)	(1.24)	(1.38)	(1.36)	(1.32)
Deaths w/in 28 days					
Mean TSPs	3.92	4.24	3.83	3.81	3.87
	(1.69)	(1.75)	(1.46)	(1.49)	(1.52)
Deaths w/in 24 hours					
Mean TSPs	3.49	3.84	2.97	2.53	3.01
	(1.32)	(1.41)	(1.07)	(1.08)	(1.11)
Basic natality variables	N	Y	Y	Y	Y
Unrestricted natality	N	N	Y	Y	Y
Weather	N	N	Y	N	Y
State Medicaid	N	N	N	N	Y
Income assistance sources	N	N	N	N	Y
Year effects	Y	Y	Y	N	Y
State-year effects	N	N	N	Y	N
Sample size	2099	2078	2061	2075	2011

- $1\mu g/m^3$ reduction in TSP, five fewer infant death per 100,000 live birth
- For one month of birth:3.8-4.2 fewer death
- Withing 24 hours: 2.5-3.8 death (70% of death)

Quasi-Experimental Results

- So, TSPs pollution during the gestation is important

	Birth weight	Incidence in birth weight categories (per 100,000 live births)					
		<1500 g	<2000 g	<2500 g	<3000 g	<3500 g	<4000 g
Mean TSPs	−0.317	1.54	0.17	1.96	19.70	16.40	8.05
	(0.121)	(1.80)	(2.42)	(4.69)	(8.05)	(10.87)	(5.61)
Income per capita (1/10)	0.242	−1.51	−1.74	−6.20	−14.70	−12.80	−6.62
	(0.083)	(1.24)	(1.59)	(3.02)	(5.15)	(7.19)	(4.14)
Basic natality variables	Y	Y	Y	Y	Y	Y	Y
Unrestricted natality	Y	Y	Y	Y	Y	Y	Y
State-year effects	Y	Y	Y	Y	Y	Y	Y
Dependent var. mean	3337	1.2%	2.5%	6.9%	23.3%	60.4%	89.2%
Sample size	2075	2075	2075	2075	2075	2075	2075

- $1\mu g/M^3$ reduction in TSP, 0.3 gram inc. in weight
- TSP significant effect in prob. of low birth.
- Seems larger effect on death than weight (contradict cigarette literature)

Matching on Income Shocks

- Match groups of counties with similar changes in per capita income from 1980-1982 but different changes in TSPs.
- Then compare infant mortality rate changes across groups

	Infant deaths due to internal causes (per 100,000 live births)	
	Big vs. small TSPs change	Medium vs. small TSPs change
Small income shock	4.61	5.97
	(1.59)	(2.02)
Medium income shock	4.46	6.65
	(0.81)	(1.19)
Big income shock	2.51	6.91
	(0.96)	(2.06)
Overall	4.16	6.57
	(0.58)	(0.95)
Black infants	10.06	9.59
	(2.18)	(2.53)
White infants	3.28	5.56
	(0.62)	(0.97)

- $1\mu g/m^3$ reduction in TSP, 4.2-6.6 fewer infant death per 100,000 live birth
- Nonlinearity probably due to initial exposure to TSP

Introduction

- Chen, et al. "Evidence on the Impact of Sustained Exposure to Air Pollution on Life Expectancy from China's Huai River Policy".(2013)
- TSP in China double between 1981-2001
- Five times the US before CleanAirAct in 1970
- Paper examines health consequences of these extraordinary pollution by exploiting a seemingly arbitrary Chinese policy that produced dramatic differences in air quality within China
- During the 19501980 period of central planning, government established free winter heating of homes and offices via the provision of free coal for fuel boilers as a basic right
- Combustion of coal in boilers damage to health

Introduction

- Due to budgetary limitations, this right was only extended to areas located in North China, (defined by Huai River and Qinling Mountain range)
- Today, long-lived heating systems continue to make indoor heating much more common in the north.
- Cities north of solid line covered by the home heating policy.

- Cities are Disease Surveillance Points.

Results

- Huai River policy had dramatic impacts on pollution and human health
- North of Huai River, particulate concentrations are 184 $\mu g/m^3$, or 55% higher, life expectancies 5.5 y lower
- 500 million residents of Northern China during 1990s experienced a loss of more than 2.5 billion life years owing to the Huai River policy.
- Long-term exposure to an additional 100 $\mu g/m^3$ of TSPs$\Rightarrow$ reduction in life expectancy at birth of about 3.0 y
- Five times larger than OLS

Introduction

- Contributions:
  - Impact of long-run exposure to TSPs on life expectancy. (hukou [a registration] system restricted mobility)
  - Regression discontinuity design: quasi-experimental approach $\Rightarrow$ a causal relationship
  - Impact of air pollution on life expectancy at very polluted.

Data

- Annual daily average air pollution across Chinese cities
- Issue: manipulated by policymakers to underreport pollution
- Argue:
  - for the period of our study, government officials' evaluations were primarily based on economic growth rather than environmental indices
  - not available or reported in the period and until 1998
  - analysis relies on differences in air pollution, unless manipulated differently north and south of the river, mismeasurement would not bias
- China's Disease Surveillance Points (DSPs) system
- DSP is a set of 145 sites with all details
- Death data by 5 y increment, and what caused

Econometric Model

- Approaches 1: cross-sectional

$$Y_j = \beta_0 + \beta_1 TSP_j + X_j \Gamma + \varepsilon_j$$

- TSP_j total suspended particulates concentration in city j
- X_j observable city characteristics
- Y_j: mortality rates or life expectancy
- Consistent β_1 if unobserved determinants of mortality do not covary with TSP_j after adjustment for X_j
- Second approach: regression discontinuity (RD) design implicit in Huai River policy
- RD: discrete increase in availability of free indoor heating north of Huai River in 1980-2000

Regression Discontinuity

- First, test discontinuous change in TSPs at river and a discontinuous change in life expectancy.
- Assumption: any unobserved determinants of TSPs or mortality change smoothly as they cross the river

$$TSP_j = \alpha_0 + \alpha_1 N_j + \alpha_2 f(L_j) + X_j \kappa + \nu_j$$
$$Y_j = \delta_0 + \delta_1 N_j + \delta_2 f(L_j) + X_j \phi + u_j$$

- $N_j = 1$ for locations north of Huai River
- $f(L_j)$ polynomial in degrees north of Huai River
- If Huai River only influences mortality through its impact on TSPs, then it is valid to treat Eq. 2 as the first stage in a two-stage least-squares (2SLS)

$$Y_j = \beta_0 + \beta_1 T\hat{S}P_j + \beta_2 f(L_j) + X_j \Gamma + \varepsilon_j$$

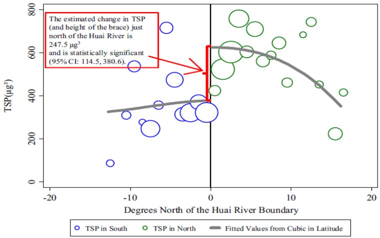
Summary Statistics

- Column (4) adjusts for a cubic polynomial in degrees north of Huai River (test for a discontinuous change on observables)
- Test on unobservables at boundary is impossible
- Analogous test in randomized trials that observable determinants of outcome are independent of treatment status.

Variable	South (1)	North (2)	Difference in means (3)	Adjusted difference in means (4)	*P* value (5)
Panel 1: Air pollution exposure at China's Disease Surveillance Points					
TSPs, μg/m^3	354.7	551.6	196.8***	199.5***	<0.001/0.002
SO_2, μg/m^3	91.2	94.5	3.4	−3.1	0.812/0.903
NO_x, μg/m^3	37.9	50.2	12.3***	−4.3	<0.001/0.468
Panel 2: Climate at the Disease Surveillance Points					
Heating degree days	2,876	6,220	3,344***	482	<0.001/0.262
Cooling degree days	2,050	1,141	−910***	−183	<0.001/0.371
Panel 3: Demographic features of China's Disease Surveillance Points					
Years of education	7.23	7.57	0.34	−0.65	0.187/0.171
Share in manufacturing	0.14	0.11	−0.03	−0.15***	0.202/0.002
Share minority	0.11	0.05	−0.05	0.04	0.132/0.443
Share urban	0.42	0.42	0.00	−0.20*	0.999/0.088
Share tap water	0.50	0.51	0.02	−0.32**	0.821/0.035
Rural, poor	0.21	0.23	0.01	−0.33*	0.879/0.09
Rural, average income	0.34	0.33	0.00	0.24	0.979/0.308
Rural, high income	0.21	0.19	−0.02	0.27	0.772/0.141
Urban site	0.24	0.25	0.01	−0.19	0.859/0.241
Predicted life expectancy	74.0	75.5	1.54***	−0.24	<0.001/0.811

Graphical Analysis

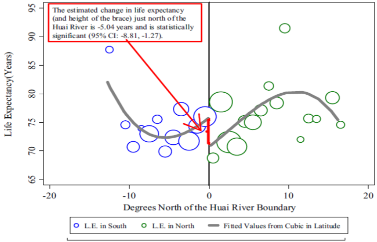
- Fig. plots cities TSP against their degrees north of Huai River boundary



- Line fitted value of first-stage Eq, without adjustment for X_j
- Circles: cities, their size : no. of DSP loc. within 1° bin
- Discontinuity: increase in TSP concentrations by $200\mu g/m^3$

Graphical Analysis

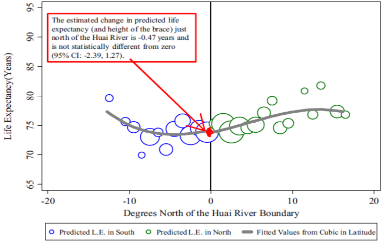
- Fig. 3 plots life expectancy against degrees north of Huai



- Discrete decline in life expectancy at border of 5 y

Graphical Analysis

- Fig. 4 graphically assesses validity of paper's approach
- Tests whether predicted life expectancy vs. distant



- Predicted by its OLS regression on all covariates except TSPs
- Equal just to the north and south of border
- Appendix: dietary & smoking are similar in North and South,

Regression Results-OLS Approach

- Four different dependent variables

Dependent variable	(1)	(2)
ln(All cause mortality rate)	0.03* (0.01)	0.03** (0.01)
ln(Cardiorespiratory mortality rate)	0.04** (0.02)	0.04** (0.02)
ln(Noncardiorespiratory mortality rate)	0.01 (0.02)	0.01 (0.02)
Life expectancy, y	−0.54** (0.26)	−0.52** (0.23)
Climate controls	No	Yes
Census and DSP controls	No	Yes

- $100 \mu g/m^3$ increase in TSP
  - 3% increase in mortality rate (just cardiorespiratory)
  - loss in life expectancy of 0.52 y

Regression Results-RD Approach

- Panel 1: two equations, panel 2: 2SLS results

Dependent variable	(1)	(2)	(3)
Panel 1: Impact of "North" on the listed variable, ordinary least squares			
TSPs, 100 μg/m^3	2.48*** (0.65)	1.84*** (0.63)	2.17*** (0.66)
ln(All cause mortality rate)	0.22* (0.13)	0.26* (0.13)	0.30* (0.15)
ln(Cardiorespiratory mortality rate)	0.37** (0.16)	0.38** (0.16)	0.50*** (0.19)
ln(Noncardiorespiratory mortality rate)	0.00 (0.13)	0.08 (0.13)	0.00 (0.13)
Life expectancy, y	−5.04** (2.47)	−5.52** (2.39)	−5.30* (2.85)
Panel 2: Impact of TSPs on the listed variable, two-stage least squares			
ln(All cause mortality rate)	0.09* (0.05)	0.14** (0.07)	0.14* (0.08)
ln(Cardiorespiratory mortality rate)	0.15** (0.06)	0.21** (0.09)	0.23** (0.10)
ln(Noncardiorespiratory mortality rate)	0.00 (0.05)	0.04 (0.07)	0.00 (0.06)
Life expectancy, y	−2.04** (0.92)	−3.00** (1.33)	−2.44 (1.50)
Climate controls	No	Yes	Yes
Census and DSP controls	No	Yes	Yes
Polynomial in latitude	Cubic	Cubic	Linear
Only DSP locations within 5° latitude	No	No	Yes

- Policy inc. mortality by 22-30%,dec. in life expectancy of 5 y
- Panel 2: $100\mu g/m^3$ increase in TSP:
  - 14% increase in mortality rate
  - loss in life expectancy of 3 y

Various Robustness Check

- Under these robustness checks, results unchanged:
  - men, women
  - young, old
  - sub-sample of cities
  - adjustment for distance from coast
  - cubic polynomial in latitude
  - different polynomial equation for north and south
  - Huai river is 0° in Jan., so include temperature
- challenge: other policies implemented using Huai river border, discussion based on validity of RD that other variables unchanged in border

Table of Content

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Introduction

- Variety of instruments for emissions reduction
- Traditionally “command and control” (CAC)
- Increasingly,emissions trading programs
- Clean Air Act Amendments (CAAAs) of 1990: from CAC towards emissions trading (“cap and trade”)
- Q 1: can these market-based programs reduce emissions beyond what achieved with more prescriptive CAC regulation?
- Why:lower compliance costs, greater compliance flexibility, politically feasible
- Q 2: can permit markets lead to environmental injustice?
- Pollution flow into poor or minority populations live.

Introduction-Results

- Examine two issues in REgional CLean Air Incentives Market (RECLAIM)
- First mandatory trading program to supplant a CAC regime (same environmental objectives)
- Thia paer: emissions at RECLAIM facilities compared with facilities exempt from RECLAIM
- Advantage: eliminates confounding effects of trends
- Examine correlations between RECLAIM-induced emissions changes and socioeconomic neighborhood characteristics
- RECLAIM fallen by 20% rel. to control facilities
- Fail to reject reductions were equally distributed

History of the Regional Clean Air Incentives Market

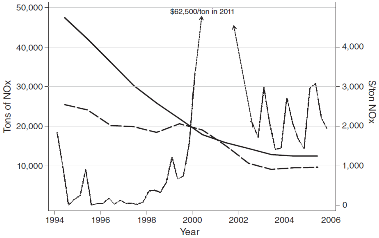
- Los Angeles suffers from some of the worst air quality in the nation
- South Coast Air Quality Management District (SCAQMD) is regulator
- In 1989, SCAQMD rules standards for stationary sources
- Fiercely opposition by industries
- In 1990, Congress : national ambient air quality standards (NAAQS)
- Federal NO_x standards revised (CAAA)
- SCAQMD responded by revising 40 rules
- Severe opposition

RECLAIM Program

- In 1994, RECLAIM included 392 facilities
- Accounted for over 65 % NO_x
- Four tons of annual NO_x, SO_2 emissions
- Public facilities (police,firefighting) excluded
- Command-and-control programs for < 4 tons
- A RECLAIM trading credit (RTC) $=$ right to emit one pound of emissions within a year
- Facilities informed their $\#$ permits per year through 2010
- RTCs distributed based on firms' historical fuel consumption and predetermined production technology characteristics

RECLAIM Program

- Allocation (−), NO_x emissions (−−), permit price (..)



- Permit reduced by 70% over 10 years
- Early on, most firms had excess of credits (political support)
- Cap bind 1999, because can not be stored

RECLAIM Program

- Following crossover, prices grow much larger
- CA electricity. crisis, electricity generating in RECLAIM facilities increased significantly
- So, emissions at these generators exceeded permit allocations, sharp increase in RTC prices
- In May 2001, RECLAIM amended to stabilize RTC market
- Removed 14 power producers from RECLAIM market
- Required a fee of $15,000 per ton > their allocation
- Required to install "best available" control technologies
- Power producers reentered the RECLAIM program in 2007
- By 2002, prices fell below $2,000, concerns low prices provide no incentives to install pollution control technologies

RECLAIM Program

- In 2004, restrictions on power producers were made more stringent
- RTC allocation was reduced by an additional 20 %
- Environmental Justice and Emissions Trading
  - CAAA can consider justice not marker based regulations.
  - Permitted pollution flow into areas where poor populations live, exacerbating preexisting inequalities
  - If polluting facilities with relatively low marginal abatement costs are disproportionately located in traditionally disadvantaged neighborhoods

Research Design

- Previous estimates sensitive to what is emissions and designing counterfactual
- Two regulatory states: RECLAIM vs. CAC
- $D_i = 1$ if in RECLAIM
- $Y_{it}(1), Y_{it}(0)$ annual emissions i at t
- Estimate sample average treatment effect on the treated (SATT):

$$\alpha_{TT} = E[Y_{it'}(1) - Y_{it'}(0)|D_i = 1]$$

- t' year following the introduction of the RECLAIM
- $E[Y_{it'}(0)|D_i = 1]$ not observed
- Estimate this using control facilities (under CAC)
  - 1)outside LA 2)smaller emitters

Research Design

- Simplest estimates: difference-in-differences
- Bias if factors vary across treatment and control
- Mitigate bias is condition on observable
- Regression-based conditioning strategies

$$Y_{it'} - Y_{it^0} = \beta' X_i + \alpha D_i + \varepsilon_i$$

- t^0 prior to RECLAIM
- Problem: X limited overlap across treatment and control

Semiparametric Conditioning Strategies

- Matching estimators
- Advantage: parametric assumptions is avoided

$$\alpha_{\hat{DID}} = \frac{1}{N_1} \sum_{j \in \Omega_1} \left\{ (Y_{jt'}(1) - Y_{jt^0}(0)) - \sum_{k \in \Omega_0} \omega_{jk} (Y_{kt'}(0) - Y_{kt^0}(0)) \right.$$

- Ω_1 program participants, Ω_0 nonparticipants,
- The nearest neighbor matching estimator weights (ω_{jk}) control facilities according to their similarity to treated facilities where similarity is based on X.

Identifying Assumptions

- Biases in unconditional DID estimates is removed by adjusting for differences in observable covariates.
- Distribution of control outcome $Y_{it'}(0)$, conditional on observable is the same
- Conditional unconfoundedness assumption
- Assumption 2: trend of CAC stringency same as RECLAIM introduced
- Assumption 3: support of distribution of conditioning covariates overlap
- Assumption 4: to rule out spillovers and general equilibrium effects, one facility are independent of treatment status of other facilities
- Stable unit treatment value assumption (SUTVA).

Treatment Effect Heterogeneity

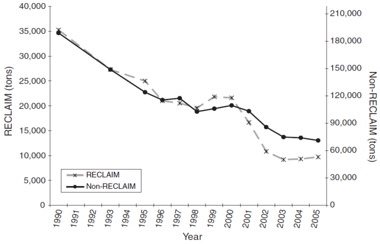
- Whether treatment effects vary systematically across facilities located in neighborhoods with different socioeconomic characteristics.

$$Y_{it'} - Y_{it^0} = \delta_j + \beta' X_j + \theta' X_i D_i + \alpha D_i + \varepsilon_i$$

- δ_j group-specific fixed effects
- Group j comprises treated facility j and its m_j closest matches
- Observations are weighted as in matching
- Socioeconomic and demographic variables are included in X_i
- Answer emissions trading on environmental injustice vis-a-vis CAC regulations,

Data

- 10,000 polluting facilities in CA report annual emissions to the California Air Resources Board (ARB)
- Includes information on industry classification
- Demographics: 1990, 2000 Censuses (income, ethnicity, race)
- Trends in Facility-Level NO_x Emissions



- Early RECLAIM higher, after cross-over sharply declined

Data

- Summary Statistics of NO_x Emissions

Period	RECLAIM	Control	Total
Period 1	101.8	102.8	102.6
(1990–1993)	(304.4)	(430.5)	(411.9)
Period 2	62.7	80.0	77.1
(1997–1998)	(179.8)	(371.0)	(346.3)
Period 3	43.8	67.9	63.8
(2001–2002)	(125.4)	(339.6)	(314.0)
Period 4	30.8	53.0	49.2
(2004–2005)	(117.1)	(290.8)	(269.6)

- Unbalanced. 32 % of RECLAIM facilities close
- Sample selection concern of emitter sizes

Data

- Industrial Composition of the Treatment and Control Groups

Industry	RECLAIM share	Treatment Obs	Treatment Mean	Treatment SD	Control Obs	Control Mean	Control SD	95 percentile overlap
Petroleum refining	37.5%	10	880	978	18	988	1,570	1
Electric services	23.9%	21	378	408	85	393	981	1
Crude petroleum/natural gas	7.1%	10	116	124	191	68	190	1
Cement	4.1%	2	699	909	9	1,885	951	1
Glass containers	3.8%	1	611		5	856	341	1
Natural gas trans. and distribution	2.3%	8	85	83	4	474	612	0.88
Paper mills	1.8%	6	82	166	5	121	170	0.83
Electric and other services combined	1.6%	4	107	83	65	330	854	1
Industrial inorganic chemicals	0.9%	5	31	30	10	223	683	1
Steel works, blast furnaces	0.9%	3	103	120	4	20	36	0.66
Steam and air-conditioning supply	0.9%	7	39	37	2	55	55	0.57
Products of petroleum and coal, NEC	0.8%	1	260		1	580		1
Total for major industries	87%	78	288	498	399	282	768	0.96

Emissions Changes Across Neighborhoods

	Actual change			Relative change		
Group	0.5 miles	1 mile	2 miles	0.5 miles	1 mile	2 miles
White, low income	−23.5***	−56.0**	−58.4***	−8.7**	−12.9**	−14.0***
	(7.4)	(22.1)	(17.6)	(3.4)	(5.7)	(5.3)
White, middle income	−94.9**	−69.6***	−64.6***	−37.2*	−24.1**	−19.3**
	(42.7)	(21.0)	(21.3)	(19.6)	(10.1)	(8.4)
White, high income	−170.3**	−163.5***	−135.3***	−58.5***	−53.5***	−38.9***
	(68.4)	(56.0)	(44.1)	(21.9)	(18.7)	(13.9)
Black, low income	−14.5***	−16.9***	−29.8***	−2.9	−3.6	−11.7**
	(5.3)	(5.1)	(10.2)	(2.5)	(2.5)	(5.7)
Black, middle income	−48.8**	−47.2**	−43.0*	−19.3*	−17.3	−16.0
	(20.7)	(22.2)	(22.5)	(10.9)	(11.9)	(12.5)
Black, high income	−110.0	−108.3	−67.8*	−55.4	−53.5	−25.8
	(74.7)	(71)	(36.4)	(41.7)	(39.7)	(20.3)
Asian, low income	−16.2***	−23.1**	−29.7***	−4.4	−5.4	−9.0*
	(5.7)	(8.8)	(8.7)	(2.8)	(5.3)	(5.1)
Asian, middle income	−36.7***	−38.8***	−46.8**	−13.9***	−12.2**	−13.9*
	(9.5)	(11.5)	(21.3)	(5.2)	(5.9)	(8.4)
Asian, high income	−131.9**	−116.6**	−95.6**	−62.6*	−42.2**	−28.4**
	(55.7)	(45.4)	(39.8)	(34.0)	(17.7)	(14.2)
Hispanic, low income	−20.3***	−28.5***	−33.8***	−4.3*	−6.7	−10.8
	(5.7)	(9.1)	(12.4)	(2.4)	(5.2)	(7.6)
Hispanic, middle income	−35.3***	−34.3***	−33.8***	−12.0***	−7.1	−8.6*
	(10.7)	(10.0)	(8.5)	(3.6)	(4.8)	(4.6)
Hispanic, high income	−108.9***	−90.9***	−66.7***	−48.1**	−35.1***	−19.0***
	(35.6)	(25.5)	(17.6)	(19.8)	(11.0)	(6.9)
All whites	−109.8***	−105.6***	−94.5***	−39.5***	−33.8***	−26.9***
	(35.4)	(30.6)	(27.3)	(13.1)	(10.9)	(9.0)
All blacks	−37.8**	−36.3**	−37.8**	−15.2	−13.5	−14.5
	(16.9)	(15.8)	(15.7)	(9.3)	(8.7)	(8.8)

Data

- High-income: largest actual reductions
- Smallest reductions: low-income blacks
- Right panel: isolate changes attributable to RECLAIM (vis-a-vis CAC)
- No group was exposed to more emissions due to emissions trading

Results

- Recall 14 generator removed in period 3 but reentered later
- Long-term: changes between period 1, 4

	Levels	Logs	RECLAIM facilities	Controls
Panel A. Change in NO_x emissions between periods 1 and 4				
OLS	−32.58**	−0.30***	212	1,222
	(13.77)	(0.10)		
Nearest neighbor matching (base specification)	−20.59***	−0.25***	212	1,222
	(7.63)	(0.09)		
Nearest neighbor matching (alternative specification)	−18.12	−0.11	211	1,191
	(11.51)	(0.08)		
Nearest neighbor matching (restricted sample)	−14.16**	−0.20**	199	1,222
	(6.86)	(0.09)		
Panel B. Change in NO_x emissions between periods 2 and 3				
OLS	−6.84	−0.22***	255	1,577
	(6.65)	(0.04)		
Nearest neighbor matching (base specification)	−8.29**	−0.26***	255	1,577
	(3.85)	(0.06)		
Nearest neighbor matching (alternative specification)	−6.18	−0.16***	252	1,493
	(5.06)	(0.06)		
Nearest neighbor matching (unrestricted sample)	−6.37	−0.23***	268	1,577
	(4.57)	(0.06)		

- Difference-in-Differences Estimates
  - -32.58 tons per year (33% of average), use log -0.3
  - not significant between cross-over (period 2,3)

Semiparametric Matching

- Nonparametric nearest neighbor (NN) matching estimator
- If m nearest neighbors for each participant, $\omega_{jk} = 1/m$ for neighbors, zero for all other
- Match on four-digit standard industrial classification code, attainment status, historic NO_x (base model)
- Also matching on other observable factors (demographic, racial characteristics, size)
- Restricted sample exclude 14 generator
- Results consistent, check previous table

Evaluating the Underlying Assumptions

- Main assumptions: conditional unconfoundedness, stable unit treatment values
- Not directly testable in principle
- Assessing Unconfoundedness:
  - $Y_{it'}(0)$ distributed similarly within subpopulations
  - Test idea: two types of control distributed similarly
  - facilities located within SCAQMD exempt from RECLAIM, and similar facilities located outside the SCAQMD
  - These two control groups are likely to have different biases

Assessing Unconfoundedness

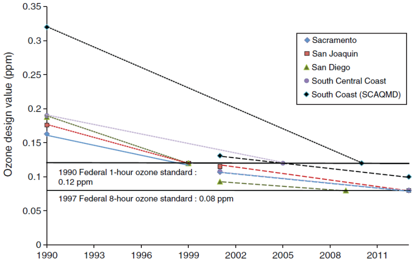
- Treated facilities in SCAQMD under CAC

	Levels	Logs	Treated facilities	Controls
Panel A. Change in NO_x emissions between periods 1 and 4				
Nearest neighbor matching (base specification)	−0.96 (2.13)	−0.07 (0.06)	265	554
Nearest neighbor matching (alternative specification)	3.01 (2.49)	−0.05 (0.07)	249	520
Panel B. Change in NO_x emissions between periods 2 and 3				
Nearest neighbor matching (base specification)	−0.35 (1.98)	0.08 (0.06)	434	642
Nearest neighbor matching (alternative specification)	0.02 (1.17)	0.01 (0.06)	394	547

- Not statistically different from control
- Same emissions trajectories
- Consistent with weak unconfoundedness condition

Assessing Unconfoundedness

- Compliance requirements required under CAAA (dot 1990)



- This figure helps to illustrate how mandated ozone concentration reduction trajectories were similar across California's nonattainment counties

Assessing the Stability of Unit Treatment Values

- Assumption: treatment received by one facility does not affect emissions at other facilities
- Or: RECLAIM caused emissions shift to CAC
- Should shift to
  - close facilities not far facilities
  - less stringent regulations
  - within a parent company
- Adjust control groups accordingly, no changes estimates

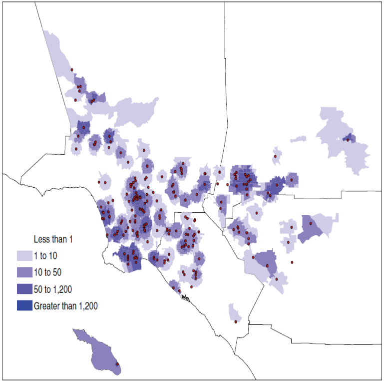
Control group	Levels	Logs	RECLAIM facilities	Controls
Panel A. Change in NO_x emissions between periods 1 and 4				
Base specification	−20.59***	−0.25***	212	1,222
	(7.63)	(0.09)		
Exclude L.A. facilities	−23.50***	−0.34***	210	778
	(7.96)	(0.09)		
Exclude northern CA	−26.60***	−0.23**	210	767
	(7.58)	(0.11)		
Severe nonattainment only	−21.65**	−0.29**	208	475
	(7.89)	(0.11)		
Single facility only	−19.92**	−0.23**	210	781
	(7.60)	(0.10)		
Panel B. Change in NO_x between periods 2 and 3				
Base specification	−8.29**	−0.26***	255	1,577
	(3.85)	(0.06)		
Exclude L.A. facilities	−8.49*	−0.21***	247	877
	(4.40)	(0.07)		
Exclude northern CA	−14.24***	−0.28***	255	1,090
	(3.90)	(0.07)		

Heterogeneous Treatment Effects

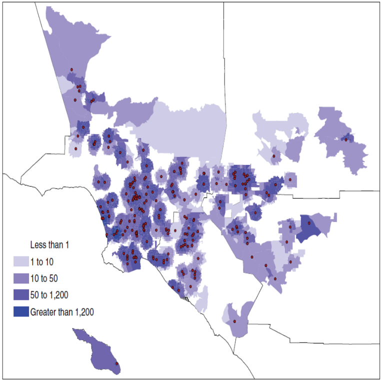
- Whether traditionally disadvantaged neighborhoods in SCAQMD experienced similar emission reductions?

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. Change in NO_x emissions between periods 1 and 4							
Treatment	−20.64**	−20.38*	−17.49**	−20.46**	−18.52**	−15.26***	−17.71**
	(7.81)	(8.85)	(6.17)	(7.41)	(7.04)	(4.36)	(5.29)
Treat × Period 1 NO_x	−0.19			−0.19	−0.19		−0.18
	(0.11)			(0.11)	(0.11)		(0.11)
Treat × income		−1.27		−0.65		0.42	−0.02
		(0.96)		(1.09)		(1.95)	(1.53)
Treat × %Minority			0.94		0.43	1.04	0.41
			(0.60)		(0.36)	(0.96)	(0.51)
Period 1 NO_x	−0.48***	−0.49**	−0.49**	−0.48***	−0.48***	−0.49**	−0.48***
	(0.11)	(0.15)	(0.15)	(0.11)	(0.11)	(0.14)	(0.11)
Income		0.10		0.16		−0.66	−0.24
		(0.80)		(0.74)		(1.47)	(1.04)
%Minority			−0.35		−0.22	−0.52	−0.28
			(0.31)		(0.26)	(0.56)	(0.37)
R^2	0.87	0.85	0.85	0.87	0.87	0.85	0.87
Panel B. Change in NO_x between periods 2 and 3							
Treatment	−6.70***	−7.19**	−6.29***	−7.16***	−6.62***	−6.45***	−7.05***
	(1.43)	(2.22)	(1.35)	(1.45)	(1.25)	(1.85)	(1.23)
Treat × Period 1 NO_x	−0.06***			−0.07***	−0.07***		−0.07**
	(0.02)			(0.02)	(0.02)		(0.02)
Treat × income		−0.16		−0.09		−0.12	−0.22
		(0.24)		(0.17)		(0.36)	(0.35)
Treat × %Minority			0.09*		−0.004	0.05	−0.07

Actual emissions under RECLAIM



Counterfactual emissions under command-and-control



Introduction

- Banzhaf, Walsh, "Do People Vote with Their Feet? An Empirical Test of Tiebout's Mechanism", AER, 2008
- Tiebout's (1956): people vote with their feet to find the community that provides their optimal bundle of taxes and public goods
- Model for increase in population for environment improvement
- Test with difference-in-difference model: shock entry of a device measures Toxics Release Inventory (TRI)
- Random communities by non parametric matching estimator
- Find evidence consistent with Tiebout model

Model

- General equilibrium model of location choice
- Income $y \sim f(y)$ support over $[y_l y_h]$
- Communities $j \in 1, \cdots, J$, G environmental quality
- Indirect utility $V(y, P, G)$, P house price
- Housing demand $(D(P, y))$ independent of G
- Housing supply $S_j(p)$, M total mass of households
- Equilibrium: ordering of low-price, low-quality communities to high-price, high-quality communities
- Boundary households $\tilde{Y}_{j,j+1}$ (identified by income) indifferent between two communities

$$V(\tilde{Y}_{j,j+1}, P_j, G_j) = V(\tilde{Y}_{j,j+1}, P_{j+1}, G_{j+1}) \qquad \forall j \in 1, \cdots, J-1$$

$$M \int_{y \in c_j} D(P_j, y) f(y) dy = S^j(p_j) \qquad \forall j \in 1, \cdots, J$$

Two Community Model

- Fixed G_2, what happen to equil. when G_1 change?
- Proposition1: if $G_1 \neq G_2$ then

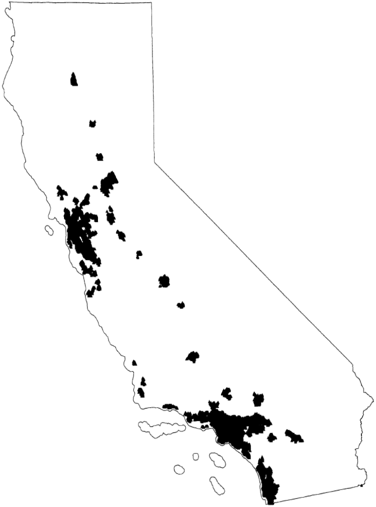
$$\frac{dPOP_1}{dG_1} > 0, \frac{dPOP_1}{dG_1} < 0, \frac{dP_1}{dG_1} > 0, \frac{dP_2}{dG_1} < 0, \frac{d\bar{Y}_1}{dG_1} > 0, \frac{d\bar{Y}_2}{dG_1} > 0,$$

- $\bar{Y}$: mean income
- Proposition 2:when $G_1 = G_2$ there is a unique equilibrium price $\bar{P}_{G_1=G_2}$ and a continuum of equilibrium household sortings
- Proposition 3: $\lim_{G_1 \to G_2} P_1 = \lim_{G_1 \to G_2} P_2 = \bar{P}_{G_1=G_2}$,$\lim_{G_1 \to G_2^-} POP_1 > \lim_{G_1 \to G_2^+} POP_1$, $\lim_{G_1 \to G_2^-} POP_2 < \lim_{G_1 \to G_2^+} POP_2$

Data-Definition of Communities

- Fixed boundary communities between 1990-2000
- Census tracts is problematic
  - they change
  - are picked to be homogeneous sample
  - range greatly in size (some big some small)
  - too aggregate a unit
- Neighborhoods: half-mile-diameter circles in urban area
- California yields 6,218 "communities" within one mile circles and 25,166 "communities" based on half-mile circles

Location of Communities



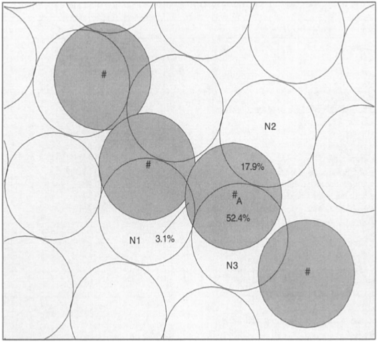
Census Data, 1999 and 2000

- Homeownership rates, rental rates, self-assessed home values
- Block-group-level data: incomes, educational attainment, workforce descriptors

	Half-mile circles	One-mile circles
Count	25,166	6,218
Blocks per circle (1990)		
25th percentile	4	11
50th percentile	10	29
75th percentile	19	55
Max	132	383
Blocks per circle (2000)		
25th percentile	6	17
50th percentile	13	38
75th percentile	22	64
Max	136	408
Circles with TRI exposure		
¼-mile buffer	3,109	1,295
½-mile buffer	5,179	1,795
TRI sites for exposed circles		
¼-mile buffer		
25th percentile	1	1
50th percentile	2	2
75th percentile	3	4

TRI Data

- Toxics Release Inventory of pollution at facilities
- Publicly available in 1989 ⇒ lagged migratory responses
- Assign emissions: shaded (TRI sites) unshaded (communities)



- 3.1% of TRI site A emission to community N1

Descriptive Statistics

Baseline demographic data (1990)	*Mean*	*Standard deviation*
Population (density)	772	930
Share black	0.05	0.11
Share Hispanic	0.19	0.20
Share Asian	0.08	0.10
Share other minority	0.01	0.02
Percentage households with single-parent families	0.08	0.07
Mean rental rate ($)	689	263
Mean housing value ($)	229,872	138,199
Share owning their homes	0.66	0.27
Percentage employed	0.94	0.05
Percentage of employed in manufacturing, if employed	0.15	0.08
Percentage not graduating from high school	0.10	0.07
Percentage with bachelor's degree	0.49	0.14
Average household income ($)	46,461	21,551
Changes in demographics (1990–2000)		
Population	92	256
Income	23,035	24,086
TRI data		
Share with baseline TRI exposure (1988–1990)	0.10	NA
Share with new TRI exposure (1998–2000)	0.01	NA
Share losing TRI exposure (1998–2000)	0.04	NA
Baseline emissions	300,714	4,718,020
Baseline emissions, among those exposed	3,006,542	1.46e7
Locational data		
1990 FBI crime index	0.08	0.28
Change in crime index	−0.03	0.14

Estimation Strategy

- Tiebout model: TRI facility causes ind. to leave community

$$\Delta POP_i = \delta_0 + \delta_{BL} I_i^{BL} + \delta_{NEW} I_i^{NEW} + \delta_{EXIT} I_i^{EXIT} + \delta_y y_i^{1990}$$
$$+ \delta_{\Delta y+}(\Delta y_i | \Delta y_i > 0) + \delta_{\Delta y-}(\Delta y_i | \Delta y_i < 0) + \delta_D D_i + \delta_L L_i + u_i$$

- I_i^{BL} any 1990 baseline exposure
- I_i^{NEW} went from no exposure to some exposure
- I_i^{EXIT} went from some exposure to no exposure
- y_i^{1990} level of baseline toxicity-weighted exposure
- $\Delta y_i | \Delta y_i > 0$ change in toxicity-weighted exposure, if positive
- D_i demographic, L_i locational variables.
- For income reg.replace ΔPOP_i with ΔINC_i

Estimation Strategy

- Average baseline treatment $= \hat{\delta}_{BL} + \hat{\delta}_y \left(\frac{1}{N_{BL}} \sum_{i \in BL} y_i^{1990} \right)$
- Average new treatment $= \hat{\delta}_{NEW} + \hat{\delta}_{y+} \left(\frac{1}{N_{NEW}} \sum_{i \in NEW} \Delta y_i \right)$
- Average exit treatment $= \hat{\delta}_{EXIT} + \hat{\delta}_{y-} \left(\frac{1}{N_{EXIT}} \sum_{i \in EXIT} \Delta y_i \right)$
- Four regressions: 1) No D,or L 2) basic controls 3) School district fixed effects 4)Zip code fixed effects

Results-Scale Effects

- Baseline exposure to TRI emissions is associated with relative population declines that range from 10 to 16%

	Average effect of baseline TRI exposure		Average effect of new TRI exposure		Average effect of exiting TRI exposure		R^2
Effect on population levels							
No controls	−30	(<0.01)	−13	(0.37)	43	(<0.01)	0.00
Basic controls	−54	(<0.01)	−35	(<0.01)	39	(<0.01)	0.07
School district fixed effects	−59	(<0.01)	−35	(<0.01)	42	(<0.01)	0.11
Zip code fixed effects	−71	(<0.01)	−36	(<0.01)	45	(<0.01)	0.26
Matching estimator	−32	(<0.01)	27	(0.16)	31	(<0.01)	—
Effect on percentage change in population							
No controls	−15.6	(<0.01)	−5.3	(0.29)	7.1	(0.04)	0.00
Basic controls	−10.7	(<0.01)	−7.3	(0.11)	5.0	(0.09)	0.04
School district fixed effects	−10.3	(<0.01)	−8.3	(0.07)	6.1	(0.04)	0.09
Zip code fixed effects	−12.0	(<0.01)	−9.3	(0.05)	6.3	(0.04)	0.19
Matching estimator	−10.7	(<0.01)	−12.11	(0.05)	4.3	(0.04)	—

- Population gains of 5 to 7% for communities that lose exposure
- Can weight by baseline population

Results-Income Effects

- Income effects only for large changes in public goods that affect the relative rankings of the communities.
- Baseline TRI exposure causes communities to have a differential growth in average income of about $2,000 or $3,000

	Average effect of baseline TRI exposure		Average effect of new TRI exposure		Average effect of exiting TRI exposure		R^2
No controls	−7,619	(<0.01)	−7,652	(<0.01)	1,899	(<0.01)	0.01
Basic controls	−2,618	(<0.01)	624	(0.52)	1,344	(0.06)	0.31
School district fixed effects	−2,458	(<0.01)	−277	(0.75)	1,693	(0.01)	0.41
Zip code fixed effects	−2,194	(<0.01)	−189	(0.82)	1,416	(0.03)	0.50
Matching estimator	−3,182	(0.01)	−6,115	(<0.01)	530	(0.33)	—

Table of Content

Currie, Neidell, “Air Pollution and Infant Health: What Can We Learn from Ca Recent Experience”,QJE, (2005), Chay, Greenstone, “The Impact of Air Pollution on Infant Mortality”, QJE (2003), Chen, et al. “Evidence on the Impact of Sustained Exposure to Air Pollution on Life Expec. from China's Huai River”.(2013)

Fowlie, Holland, Mansur, “What Do Emissions Markets Deliver and to Whom? Evidence from Southern Ca NO_x Trading Program”,AER, 2012, Banzhaf, Walsh, "Do People Vote with Their Feet? An Empirical Test of Tiebout'", AER, 2008

Greenstone, “The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 CAAA and the Census of Manufactures”, JPE, (2002), Walker “The transitional costs of sectoral reallocation: Evidence from CAAA and the workforce” QJE (2013)

Introduction

- Firm $30 billion a year to comply with environmental regulations
- Lost job in global competition
- Question: do these regulations restrict economic progress?
- No conclusive evidence yet
- This paper study impact of Clean Air Act (CAAA)
- Passed in 1963 and amended in 1970, 1977, and 1990
- Environmental Protection Agency (EPA) established air quality standards

Introduction

- A minimum level of air quality that all counties are required to meet
- Four criteria pollutants:
  - carbon monoxide (CO)
  - tropospheric ozone (O3)
  - sulfur dioxide (SO2)
  - total suspended particulates (TSPs)
- Every U.S. county receives separate nonattainment or attainment designations for each of the four pollutants annually
- Emitters of the regulated pollutant in nonattainment counties are subject to stricter regulatory oversight

CAAA and Regulation

- Ideal analysis
  - regulations randomly assigned to plants
  - changes in activity causally related to regulation
- Alternative
  - similar plants face different levels of regulation
  - amendments introduce substantial crosssectional and longitudinal variation in regulatory intensity

CAAAs and Enforcement

- Before 1970 by state governments
- By CAAA assign nonattainment to each county
- In their nonattainment counties, states are required to develop plant-specific regulations for every major source of pollution
- Substantial investments: installation of state-of-the-art pollution abatement equipment and by permits that set emissions ceilings.
- 1977: any increase in emissions from new investment be offset by a reduction in emissions from another source within the same county
- In attainment counties, the restrictions on polluters are less stringent.
- nonpolluters are free from regulation in both sets of counties.

CAAAs and Enforcement

- Federal EPA approve all state regulation programs
- States run inspection and frequently fine noncompliers.
- EPA can impose penalties on states not enforce enough (Nadeau (1997), Cohen (1998))

CAAAs and Targeted Industries

- Standard industrial classification [SIC]
  - O3 (printing 271189; organic chemicals 286169; rubber and miscellaneous plastic products 30; fabricated metals 34; and motor vehicles, bodies, and parts 371)
  - SO2 (inorganic chemicals 281219)
  - TSPs (lumber and wood products 24),
  - CO/SO2 (nonferrous metals 33334)
  - CO/O3/SO2 (petroleum refining 2911)
  - O3/SO2/TSPs (stone, clay, glass, and concrete 32)
  - CO/O3/SO2/TSPs (pulp and paper 261131 and iron and steel 331213, 332125)
- Remaining industries: clean category.

CAAAs and Variation in Regulation

- Sources of variations:
  1. Regulation for nonattainment counties: cross-sectional: identify industry
  2. County's nonattainment vary over time: longitudinal: identify plant fixed effects
  3. Within nonattainment counties, only emitters subject to regulations: county-by-period fixed effect
- Nonattainment variation over time could be due to weather

Data Sources and Structure

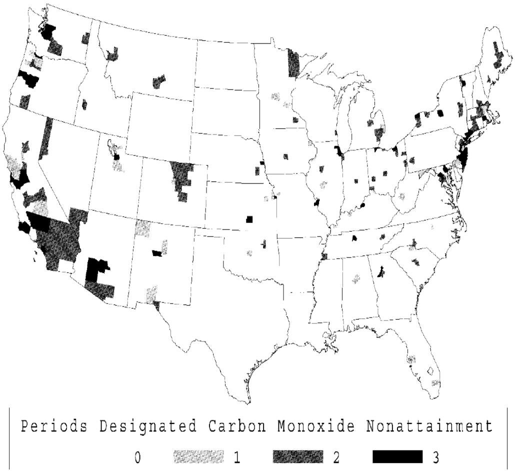
- Manufacturing: census 1967 to 1987
  - employment, capital stock, shipments, age, is multiunit firm, is a survey or administrative record
- four periods: 1967-72, 1972-77, 1977-82, 1982-87
- All counties are attainment in 1967-72 (no CAAAs)

Incidence of the Nonattainment Designations

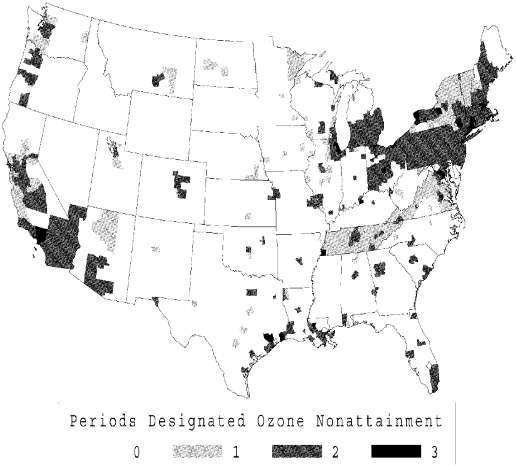
- Lots of movements in attainment

	Nonattainment Period t (1)	Attainment Period $t-1$ and Nonattainment Period t (2)	Nonattainment Period $t-1$ and Attainment Period t (3)
	A. Carbon Monoxide (CO)		
1967–72	0	0	0
1972–77	81	81	0
1977–82	144	90	27
1982–87	137	15	22
	B. Ozone (O_3)		
1967–72	0	0	0
1972–77	32	32	0
1977–82	626	595	1
1982–87	560	104	170
	C. Sulfur Dioxide (SO_2)		
1967–72	0	0	0
1972–77	34	34	0
1977–82	87	75	22
1982–87	60	7	34
	D. Total Suspended Particulates (TSPs)		
1967–72	0	0	0
1972–77	296	296	0
1977–82	235	108	169
1982–87	176	24	83

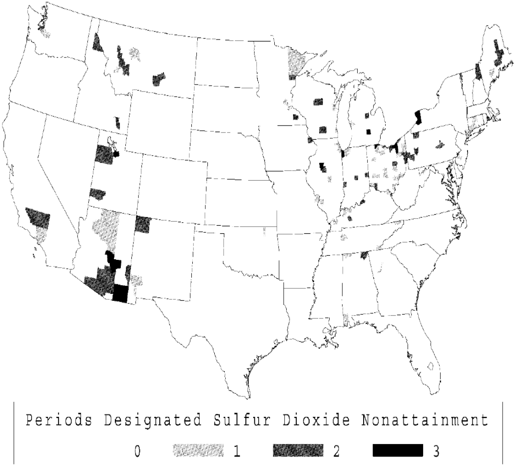
Incidence of nonattainment by county



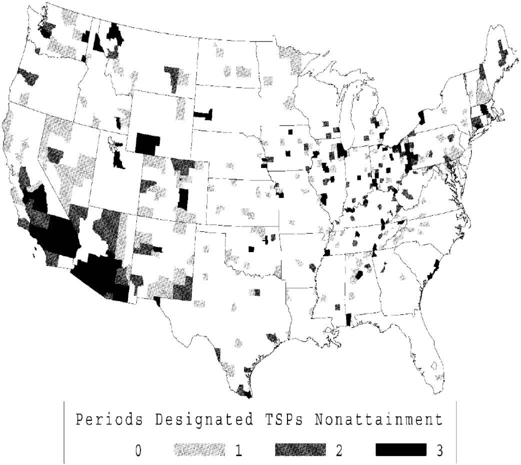
Incidence of nonattainment by county



Incidence of nonattainment by county



Incidence of nonattainment by county



Manufacturing Employment

	1967–72 (1)	1972–77 (2)	1977–82 (3)	1982–87 (4)
CO-emitting plants	1,111,534	1,040,563	951,515	744,061
CO attainment	1,111,534	839,456	648,526	517,767
CO nonattainment	...	201,108	302,989	226,294
O_3-emitting plants	5,453,418	5,581,151	5,542,548	5,412,151
O_3 attainment	5,453,418	5,108,078	1,294,500	1,492,627
O_3 nonattainment	...	473,073	4,248,048	3,919,524
SO_2-emitting plants	1,783,243	1,717,904	1,598,742	1,358,083
SO_2 attainment	1,783,243	1,468,781	1,233,592	1,170,479
SO_2 nonattainment	...	249,123	365,150	187,604
TSPs-emitting plants	2,101,561	2,071,924	1,899,173	1,697,843
TSPs attainment	2,101,561	1,303,442	1,114,749	1,160,430
TSPs nonattainment	...	768,482	784,424	537,413
Total manufacturing sector	17,438,187	17,350,726	17,521,355	17,100,413

Nonattainment Status and Plant Growth

- Are observables balanced across counties by attainment

	CO Attainment, 1972–77 (1*a*)	CO Attainment, 1972–77, and CO Nonattainment, 1977–82 or 1982–87 (1*b*)	CO Nonattainment, 1972–77 (2)
	A. County Characteristics in 1970		
Number of counties	2,989	100	81
Population	47,157	395,376	620,654
Population density	1,826	6,354	4,868
% urban	.65	.90	.94
% ≥12 years of education	.50	.55	.57
% ≥16 years of education	.10	.11	.13
% employment in manufacturing	.262	.266	.242
Unemployment rate	.044	.045	.046
Poverty rate	.119	.082	.081
Income per capita (1982–84 dollars)	7,456	8,712	9,414
Per capita government revenues	248	296	403
	B. CO-Emitting Plant Characteristics in 1972		
Number of CO-emitting plants	1.0	6.8	14.2
Average employment	269	362	175
% operating at least 10 years	55.2	59.3	51.3
% part of multiunit firm	34.6	40.7	40.1

Nonattainment Status and Plant Growth

- Is Nonattainment Status Orthogonal to Observable Determinants of Plant Growth?
- Comparison 1a and 2 (all sample)
  - differ between non/attainment status
- 1b is "counterfactual"
- County fixed effects refines counterfactual group
- Columns 1b and 2 more similar
- Nonattainment status is not orthogonal to observable county- or plant-level determinants of plant growth
- Must estimate statistical models to control for differences

Do Countywide Shocks Covary with Nonattainment Status

- Identifying assumption: nonattainment status is orthogonal to county-specific determinants of growth that are common to polluters and nonpolluters.
- Pervasive in the previous literature
- Estimates of regulation of each pollutant on employment growth
- First estimate: sample limited to plants that emit the relevant pollutant
- Column 2 estimate is obtained from all plant observations with nonmissing employment growth.
- Dummy: $= 1$ if county is nonattainment, plant emitter
- County fixed effects and industry by period indicators.

Do Countywide Shocks Covary with Nonattainment Status

- Percent change in employment with one regulation effect

	Carbon Monoxide		Ozone		Sulfur Dioxide		Total Suspended Particulates	
	CO Emitters (N=14,456) (1)	All Plants (N=1,620,942) (2)	O_3 Emitters (N=543,121) (1)	All Plants (N=1,620,942) (2)	SO_2 Emitters (N=99,854) (1)	All Plants (N=1,620,942) (2)	TSPs Emitters (N=257,135) (1)	All Plants (N=1,620,942) (2)
CO regulation effect	−.041	−.074						
	(.040)	(.031)						
O_3 regulation effect			.068	.025				
			(.011)	(.009)				
SO_2 regulation effect					−.049	−.040		
					(.030)	(.027)		
TSPs regulation effect							−.021	−.016
							(.017)	(.014)
R^2	.127	.100	.112	.100	.095	.100	.121	.100

- 1 unbiased if regulation is the only county-level determinant of employment that differs between non/attainment counties.
- 2 controls for unobserved, permanent county-level common to non/emitters

Do Countywide Shocks Covary with Nonattainment Status

- Comparison of 1 & 2
- Differ if nonemitters growth rate covaries with nonattainment status.
- SO2 & TSPs are similar
- CO & O3 in 1 appear to be biased upward
- Column 1 O3 suggests 6.8% increase in employment due to regulation!!
- CO & O3, nonattainment status is not orthogonal to county-level shocks to growth

Identification Strategy

$$
\begin{aligned}
\%\Delta E_{pt} &= \frac{E_{pt} - E_{pt-5}}{(E_{pt} + E_{pt-5})/2} \\
&= \beta_1 X_{pt-5} + \beta_2 ind_t + \beta_{3t} nonattain_{ct-5} \\
&+ \beta_4 1(emit\ CO = 1\ \&\ nonattain\ CO = 1)_{ct-5} \\
&+ \beta_5 1(emit\ O_3 = 1\ \&\ nonattain\ O_3 = 1)_{ct-5} \\
&+ \beta_6 1(emit\ SO_2 = 1\ \&\ nonattain\ SO_2 = 1)_{ct-5} \\
&+ \beta_7 1(emit\ TSPs = 1\ \&\ nonattain\ TSPs = 1)_{ct-5} + \Delta\varepsilon_{pt}
\end{aligned}
$$

- $\Delta\varepsilon_{pt} = \alpha_p + \gamma_{ct} + \Delta u_{pt}$, p plant, c county, i industry
- E employment, capital stock, and the value of shipments

Vector of Variables

- X_{pt-5} vector of variables, "pretreatment"
  - Four size indicators:$< p50, p50 < \& < p75, p75 < \& < \bar{x}, \bar{x} <$
  - Whether the plant $>$ 10 years
  - ownership by a firm with multiple establishments
  - whether is a response to Census questionnaire or is derived from federal administrative records
  - Average industry-specific wage (labor costs)
  - Number of employees at other plants in the same industry within the same county (agglomeration effects)
- ind_i industry indicator variables
  - 13 time-varying industry indicators: one for each of the 12 pollutant industries, one "clean" industries
- $nonattain_{ct-5}$: dummy for each of the four pollutant specific nonattainment designations
  - Control unobserved factors that equally affect polluting and nonpolluting plants in nonattainment counties

Parameters

- $\beta_1 - \beta_7$ capture variation in the dependent variables specific to polluting plants (relative to nonpolluters)
  - mean effect of pollutant-specific regulations on plants that are directly targeted by them
- Effect of each regulation while holding the others constant
- 735,000 plant fixed effects
  - Regulation effects are identified from within-plant comparisons of growth rates under non/attainment

Amendments Impact on Manufacturing Sector Activity

- In theory, impact of regulation on input demand: ambiguous
- Percentage on employments:

	(1)	(2)	(3)	(4)
CO regulation effect (β_4)	−.084	−.075	−.086	−.163
	(.032)	(.031)	(.030)	(.045)
O_3 regulation effect (β_5)	.001	.022	−.011	−.049
	(.011)	(.010)	(.010)	(.015)
SO_2 regulation effect (β_6)	−.004	−.016	.003	.001
	(.029)	(.028)	(.029)	(.036)
TSPs regulation effect (β_7)	−.024	−.010	−.020	−.024
	(.014)	(.013)	(.013)	(.024)
R^2	.109	.119	.144	.504
Industry by period fixed effects	yes	yes	yes	yes
Nonattainment by period fixed effects	yes	yes	no	no
County fixed effects	no	yes	no	no
County by period fixed effects	no	no	yes	yes
Plant fixed effects	no	no	no	yes

- C1: identif. by compare between all att. and nonatt. counties
- C2: identif. by compare counties change att. status over time
- C3: identif. by compare emitter vs non in nonatt. county
- C4: identif. by compare plant change

Amendments Impact on Manufacturing Sector Activity

- Capital Stock, (de)investment due to regulation

	(1)	(2)	(3)	(4)
	A. Capital Stock (N=1,607,332)			
CO regulation effect (β_4)	−.047	−.047	−.097	−.092
	(.043)	(.042)	(.043)	(.062)
O_3 regulation effect (β_5)	−.009	.016	−.001	−.041
	(.022)	(.021)	(.021)	(.029)
SO_2 regulation effect (β_6)	−.024	−.048	−.057	−.063
	(.047)	(.049)	(.055)	(.048)
TSPs regulation effect	.026	.042	.010	−.043
(β_7)	(.027)	(.025)	(.024)	(.039)
R^2	.074	.109	.155	.462
	B. Shipments (N=1,737,753)			
CO regulation effect (β_4)	−.058	−.036	−.072	−.146
	(.029)	(.029)	(.029)	(.046)
O_3 regulation effect (β_5)	.022	.048	.019	−.032
	(.018)	(.018)	(.016)	(.024)
SO_2 regulation effect (β_6)	−.007	−.026	−.027	−.010
	(.033)	(.030)	(.030)	(.039)
TSPs regulation effect	−.014	−.002	−.010	−.032
(β_7)	(.019)	(.018)	(.018)	(.034)
R^2	.127	.142	.185	.516
Industry by period fixed effects	yes	yes	yes	yes
Nonattainment by period fixed effects	yes	yes	no	no
County fixed effects	no	yes	no	no
County by period fixed effects	no	no	yes	yes
Plant fixed effects	no	no	no	yes

Amendments Impact on Manufacturing Sector Activity

- Nonattainment status retards investment, but the evidence is less decisive than in the employment regressions.
- CO nonattainment status is associated with a 3.6-7.2% decrease in shipments by CO emitters
- Effect other regulations is small
- Overall all estimates, the estimates suggest that the nonattainment designations cause the growth of employment, capital stock, and shipments to decline by roughly equivalent proportions

Is There Heterogeneity in Effects across Industries

- May one industry generates all results
- Further, that industry (like metal) have secular decline regardless of regulation
- Plant fixed effects, county by period effects, and industry by period effects,
- Result: not small subset of emitting industries derive the results
- Regulations harsh on industries that emit multiple pollutants

Magnitude of the Regulation Effects

	Estimated Regulation-Induced Change, 1972–77 to 1982–87		Change 1972–77 to 1982–87	Mean of 1972–77 and 1982–87 Levels	Ratio of Col. 1 to Col. 3	Ratio of Col. 1 to Col. 4
	Mean (1)	95% Confidence Interval (2)	(3)	(4)	(5)	(6)
		A. Total Employment				
CO emitters	−119,100	[−54,600, −183,500]	−296,502	892,312	.402	−.133
O_3 emitters	−423,400	[−169,400, −677,400]	−169,000	5,496,651	2.505	−.077
SO_2 emitters	800	[57,400, −55,800]	−359,821	1,537,994	−.002	.001
TSPs emitters	−50,200	[48,200, −148,500]	−374,081	1,884,883	.134	−.027
All manufacturers	−591,900	[−118,400, −1,065,200]	−250,183	17,215,016	2.366	−.034
		B. Capital Stock (Millions of Dollars)				
CO emitters	−7,500	[2,400, −17,500]	65,977	110,639	−.114	−.068
O_3 emitters	−18,600	[7,200, −44,300]	175,235	258,645	−.106	−.072
SO_2 emitters	−4,800	[2,400, −11,900]	85,092	144,078	−.056	−.033
TSPs emitters	−5,700	[4,500, −15,900]	56,635	108,261	−.101	−.053
All manufacturers	−36,600	[16,400, −89,600]	409,687	565,888	−.089	−.065
		C. Shipments (Millions of 1987 Dollars)				
CO emitters	−25,700	[−9,800, −41,500]	−25,601	235,616	1.003	−.109
O_3 emitters	−40,500	[19,000, −100,000]	2,281	773,443	−17.751	−.052
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Introduction

- Walker, W. Reed. "The transitional costs of sectoral reallocation: Evidence from the clean air act and the workforce." The Quarterly journal of economics (2013)
- Regulation costs: "job lost"
- But worker find jobs elsewhere, may lost some earning
- Cost of reallocating
- Paper observes worker-specific nonemployment durations and any long-run earnings changes
- Focus on 1990 CAAA as a strict amendments
- Focus on PM10 & Ozone

Clean Air Act

- EPA compliance
  - can withhold federal grant money in case on non/attainment (highway construction funds)
  - direct EPA enforcement and control (through federal implementation plans)
  - bans on the construction of new establishments with the potential to pollute

Data

- Longitudinal Employer Household Dynamics Files
  - Quarterly earnings records for tax records (2.8 billion observations)
  - Age, race, and education
- Longitudinal Business Database
  - employment, payroll, firm age, industry, location, entry/exit years
- EPA Air Facility Subsystem
  - plant-level regulatory status, permit,

Empirical Strategy

- Three margins of variation
  - county nonattainment status ($c \in$ Attain, Nonattain)
  - sectoral polluter status ($s \in$ PM10, ozone, both PM10 and ozone, neither PM10 nor ozone)
  - two time periods ($t \in$ Pre, Post)
- Variables
  - $N_c^\rho = 1$ counties newly nonattainment for pollutant ρ
  - P_s^ρ indicator sector of plants emit ρ
  - $1(\tau_t > 0)$ indicator for years after new regulations.
  - $N_c^\rho \times P_s^\rho \times 1(\tau_t > 0) = 1$ sectors change regulatory status from 1990 CAAA
  - Average effect of nonattainment designation on sectors
  - DDD estimator

Empirical Strategy

- Y_{jcst} earnings or employment in polluting sector s of industry j in county c in year t

$$Y_{jcst} = \eta_1[N_c^{\rho} \times P_s^{\rho} \times 1(\tau_t > 0)] + X_{jcs} + n_{ct} + p_{st} + \Phi_{jt} + \varepsilon_{jcst}$$

- DDD estimator of change in outcome Y_{jcst} attributable to changes in nonattainment designation for polluting sectors affected by designation
- All first and second-order interaction terms associated with a triple-difference estimator are implicitly included

Empirical Strategy-Extension

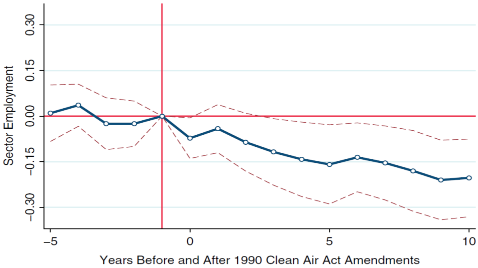
- Heterogeneous impacts of nonattainment designation: η_1^r pollutant-specific regulatory heterogeneity
- Allow regulatory changes evolve incrementally for m years before and M years after regulations

$$Y_{jcst} = \sum_{k=-m}^{M} \eta_1^k [N_c^\rho \times P_s^\rho \times 1(\tau_t > 0)] + X_{jcs} + n_{ct} + p_{st} + \Phi_{jt} + \varepsilon_{jcst}$$

- May correlation between nonattainment status for counties within the same metropolitan area: cluster standard errors by commuting zones (CZs) to account for this form of spatial dependence
- Weighted by the sector or cohort employment size in the years before the change in regulations to account for heteroskedasticity-associated with differences in group sizes

Results-Employment

- Regulation Leads to a Reduction in Sectoral Employment
- Focus on sectoral employment rather than plant employment to account both intensive and extensive margin



- No trends in employment in years prior to change (important validity test)

Results-Wage

- Wage Costs of Sectoral Reallocation: Evidence from Cohorts

	(1)	(2)	(3)	(4)	(5)	(6)
Regulation $(t+0)$	-0.033^{**}	-0.031^{**}	-0.034^{**}	-0.036^{**}	-0.036^{**}	-0.033^{***}
	(0.014)	(0.012)	(0.017)	(0.015)	(0.017)	(0.010)
Regulation $(t+1)$	-0.058^{***}	-0.056^{***}	-0.057^{***}	-0.059^{***}	-0.056^{***}	-0.051^{***}
	(0.012)	(0.014)	(0.019)	(0.011)	(0.014)	(0.012)
Regulation $(t+2)$	-0.046^{***}	-0.045^{***}	-0.062^{***}	-0.040^{***}	-0.051^{***}	-0.030^{**}
	(0.012)	(0.011)	(0.009)	(0.009)	(0.010)	(0.012)
Regulation $(t+3)$	-0.036^{**}	-0.034^{**}	-0.048^{*}	-0.028^{**}	-0.035^{**}	-0.019^{**}
	(0.017)	(0.016)	(0.026)	(0.012)	(0.016)	(0.009)
Regulation $(t+4)$	-0.041	-0.040	-0.054	-0.034^{**}	-0.040^{**}	-0.019^{**}
	(0.026)	(0.025)	(0.033)	(0.016)	(0.019)	(0.008)
Regulation $(t+5)$	-0.011	-0.010	-0.020^{**}	-0.013	-0.015	-0.011
	(0.014)	(0.015)	(0.009)	(0.014)	(0.009)	(0.014)
Regulation $(t+6)$	0.000	0.001	-0.002	-0.003	0.001	-0.011^{*}
	(0.016)	(0.017)	(0.012)	(0.012)	(0.009)	(0.006)
Regulation $(t+7)$	0.003	0.004	0.008	-0.004	0.007	-0.010
	(0.012)	(0.012)	(0.013)	(0.011)	(0.012)	(0.009)
Regulation $(t+8)$	0.005	0.006	0.009	0.001	0.004	0.008
	(0.010)	(0.010)	(0.008)	(0.011)	(0.009)	(0.008)
9-year PDV	-0.202^{***}	-0.191^{***}	-0.241^{***}	-0.199^{***}	-0.204^{***}	-0.162^{***}
	(0.047)	(0.046)	(0.050)	(0.044)	(0.044)	(0.054)
N	153,249	153,249	153,249	153,249	153,249	153,249
2-digit SIC × year FE				X	X	
County trends		X		X		
County × year FE			X		X	
County × SIC × year FE						X

Results-Wage

- Each column separate regression, report $exp(\eta_1^k) - 1$
- Control for education, (dummy) age, interactionw/ time
- Discounted sum of coefficients $\sum_0^8 \beta^k (exp(\eta_1^k) - 1)$
- Average worker in the affected cohort experienced a present discounted earnings loss of around 20.2% of their preregulatory earnings
- Multiplying by average annual earnings in that sector ($39,000) and by number of employees in the polluting sector of all "switching" counties (1 million workers), total forgone wage bill is $7.8 billion

Results-Separation

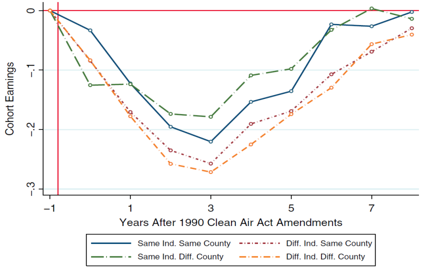
- Effects of Regulations for “Stayers”, “Leavers” in separate models

	(1) Stayer	(2) Separator	(3) Separator: same industry same county	(4) Separator: diff. industry same county	(5) Separator same industry diff. county	(6) Separator diff. industry diff. county
Regulation $(t+0)$	−0.011	−0.087***	−0.033	−0.084***	−0.125***	−0.084***
	(0.019)	(0.007)	(0.021)	(0.011)	(0.015)	(0.008)
Regulation $(t+1)$	−0.027**	−0.184***	−0.123***	−0.171***	−0.124***	−0.178***
	(0.012)	(0.011)	(0.012)	(0.011)	(0.022)	(0.012)
Regulation $(t+2)$	0.004	−0.265***	−0.195***	−0.235***	−0.174***	−0.258***
	(0.009)	(0.026)	(0.026)	(0.029)	(0.012)	(0.022)
Regulation $(t+3)$	0.004	−0.267***	−0.220***	−0.257***	−0.179***	−0.272***
	(0.012)	(0.039)	(0.064)	(0.046)	(0.012)	(0.029)
Regulation $(t+4)$	−0.008	−0.208***	−0.153***	−0.190***	−0.109***	−0.225***
	(0.018)	(0.036)	(0.054)	(0.045)	(0.020)	(0.022)
Regulation $(t+5)$	0.014	−0.169***	−0.136***	−0.169***	−0.098***	−0.174***
	(0.015)	(0.021)	(0.046)	(0.028)	(0.016)	(0.013)
Regulation $(t+6)$	0.019*	−0.113***	−0.023	−0.107***	−0.032	−0.130***
	(0.011)	(0.011)	(0.016)	(0.012)	(0.021)	(0.013)
Regulation $(t+7)$	0.006	−0.063***	−0.026	−0.069***	0.004	−0.056***
	(0.012)	(0.010)	(0.017)	(0.011)	(0.014)	(0.010)
Regulation $(t+8)$	0.007	−0.034**	−0.002	−0.030	−0.014*	−0.040***
	(0.016)	(0.014)	(0.010)	(0.020)	(0.008)	(0.007)
9-year PDV	−0.000	−1.225***	−0.810***	−1.155***	−0.770***	−1.244***
	(0.053)	(0.098)	(0.141)	(0.120)	(0.067)	(0.082)
N	152,988	153,160	151,523	152,715	151,929	153,025

- Earnings of stayers unaffected by the regulatory change
- Leavers: average earnings declines rapidly
- Present discounted earning decline for separators: 120%

Results-Robustness

- Control for heterogeneity



- Other robustness stratification by worker age, income, gender, firm size,