# Flight from urban blight: Lead poisoning, crime and suburbanization

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# Research question

**Assess the effect of violent crime on urban structure**

1. **New instrument for violent crime**
2. **Distribution inside the city**:
    - People and firms move from the city center towards suburban areas
    - Sorting firms, people (race and income), transportation

# Urban phenomena

Urbanization

- Percent world population in urban areas: 30 % (1950) to 54 % (2014). Forecast to increase to 66 % (2050)

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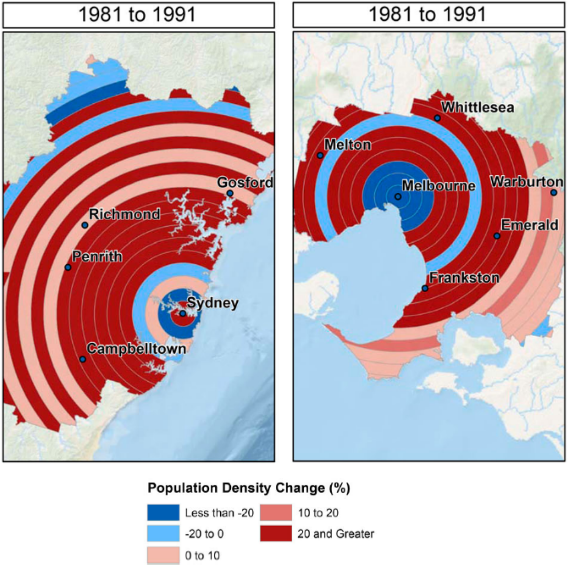
Suburbanization

- City centers are losing population while suburbs are growing.
- Example (Philadelphia from 1960 to 1990)
  - City Center: $2M \rightarrow 1.6M$
  - Rest (Suburbs): $2.4M \rightarrow 3.5M$
  - Percentage in CC: $45\% \rightarrow 31\%$
- Similar trends in other developed and developing countries
  - City Center London: peak in 1911
  - City of Milan: peak in 1971
  - City Center Density: Shanghai $-20\%$ (2000 - 2010)

# Sydney and Melbourne

## Coffee, Lange, Baker (2016)



# Theoretical Framework

Shock to Violent Crime in CC

$\Downarrow$

Decrease in the CC amenities

$\Downarrow$

Population moving out of CC

# Empirical Analysis

## The effect of Violent Crime on the Suburbanization of U.S. cities

## Empirical model

$$sub_{m,t} = \frac{pop^{cc}_{m,t}}{pop^{cc}_{m,t} + pop^{ncc}_{m,t}} = \tau_m + \tau_t + \beta \text{Violent Crime}^{cc}_{m,t} + \tau_g \times \tau_t + \varepsilon_{m,t}$$

m: Metropolitan Statistical Area; t: Year; g: Census Division; cc: City Center CC example

# Empirical strategy

## Empirical model

$$sub_{m,t} = \frac{pop^{cc}_{m,t}}{pop^{cc}_{m,t} + pop^{ncc}_{m,t}} = \tau_m + \tau_t + \beta \text{Violent Crime}^{cc}_{m,t} + \tau_g \times \tau_t + \varepsilon_{m,t}$$

m: Metropolitan Statistical Area; t: Year; g: Census Division; cc: City Center CC example

**Endogeneity problems**:

- Reverse causality
- Omitted variables: local economic activity, public good provision, city racial composition

# Instrument

- **Time variation**: national past level of **lead** used in gasoline
- **Cross-sectional variation**: bio-availability lead in different **soils**

# Lead and Violent Crime

- Lead is a heavy metal, with symbol **Pb.**
- Medical literature has demonstrated that lead **alters the formation of the brain** especially affecting **aggresion and impulsivity** (age of exposure 0-2 years old)
- Evidence in **economics**: Aizer et al. (2016), Aizer and Currie (2017), Billings and Schnepel (2016), Feigenbaum and Muller (2017), Clay et al. (2014), Troesken (2006), Ferrie et al. (2012), Gronqvist et al. (2016), Mielke and Zahran (2012), Wolpaw Reyes (2007), Nevin (2007)

# Human exposure to lead

Since ancient roman times lead was used for his properties to build pipes and in paint.

But the major use of lead is much more recent. Used as an **additive in gasoline** beginning in the 1920s, started to be regulated in the 70's, banned in 1996

Humans are exposed to lead in gasoline trough air, water, food. We use the exposure through **soil**

- Direct contact
- Resuspension
- House dust

History lead | Time series lead use

# Human exposure to lead

Cars emit lead

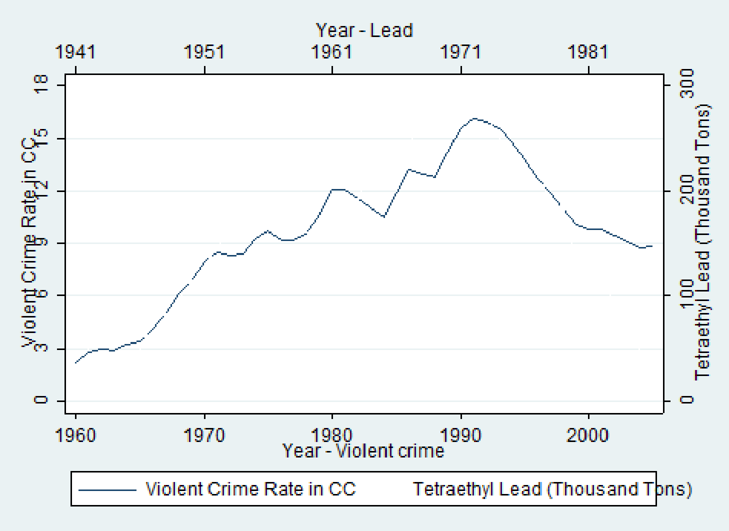
$\Downarrow$

0-2 years olds are exposed to lead

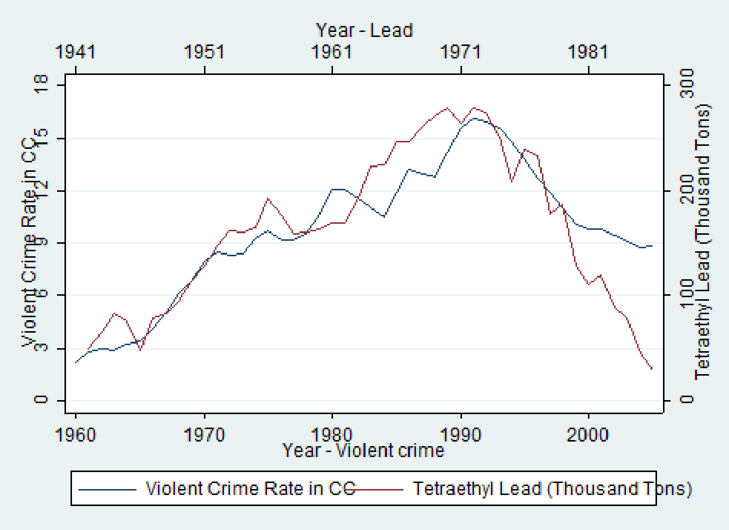
$\Downarrow$

As adult they commit more violent crimes

# Time series variation instrument



# Time series variation instrument



# Soil quality and lead poisoning

US cities where affected differently by this common trend depending on the **pH of the soil**

- Availability of lead depends on how tightly it is held by soil particles and on its solubility
- Near-neutral soil pH decreases the bioavailability of lead
- Chemical literature indicates pH higher than 6.5 or 7
- Water pH used as instrument for lead pipe poisoning (Feigenbaum and Muller, 2017; Clay et al., 2014; Troesken, 2006)

Citations | Baltimore, Mielke (1983) | Relevance

# pH interval

$$VC_{m,t}^{CC} = \mu_m + \mu_t + \beta Lead_{t-19} \times f(pH_m^{CC}) + \epsilon_{m,t}$$

# pH interval

$$VC^{CC}_{m,t} = \mu_m + \mu_t + \beta Lead_{t-19} \times f(pH^{CC}_m) + \epsilon_{m,t}$$

For ease of use we want the pH in the first stage as a **dummy.**
pH interval that maximizes the F-stat:

**Result** of this maximization in line with chemical literature:

$$6.8 \leq pH \leq 7.7 \quad \Rightarrow \quad \textbf{Good soil}$$

Intervals Continous Function

# First stage

$$\text{V.Crime}^{cc}_{m,t} = \mu_m + \mu_t + \beta \left[ \underbrace{Lead_{US,t-19}}_{\substack{\text{National lagged} \\ \text{car poisoning}}} \times \underbrace{\mathbb{1}\left(6.8 \leq pH^{cc}_m \leq 7.7\right)}_{\substack{\text{Good Soil =} \\ \text{Low lead bioavailability}}} \right] + \mu_g \times \mu_t + \epsilon_{m,t}$$

# First stage

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**Pros instrument**:

- Both time and geographically varying
- It can explain both the big rise and fall of U.S. crimes
- It can be used to estimate the effect of crime on many outcomes
- Used in other many countries because is based on easily available data
- Exploit specific timing of the effect of lead on crime, not capturing the effect that lead might have on other outcomes

# Identification assumption - Exogeneity

Without lead poisoning places with good and bad soil should have similar trends in terms of suburbanization (soil pH is as good as randomly assigned)

- No-Geographical clustering State Division Continous PH
- Balanced in terms of crime and population trends Balancing 1
- Balanced in terms of other characteristics Balancing 2
- When lead was phased-out cities return to have similar violent crime Deleading

# Identification assumption - Exclusion restriction

Assumption

- Interaction between lagged national lead and soil quality is only affecting suburbanization trough violent crime
- Bias if lead poisoning is affecting some other variable which:
  - affects surbanization
  - has the same lag structure that violent crime has on suburbanization

# Identification assumption - Exclusion restriction

Timing perfectly fits the relationship lead and crime: Timing

Possible threats

- Agricultural productivity
- Highways
- Education
- Other crimes
- Other controls

# Results

| VARIABLES | (1)<br>Violent crime | (2)<br>Sh. Pop CC | (3)<br>ln(Pop CC) | (4)<br>ln(Pop NCC) | (5)<br>ln(Pop MSA) |
|---|---|---|---|---|---|
| Good soil x Lead | -3.294*** | | | | |
| | (0.239) | | | | |
| Violent crime | | -0.0136*** | -0.0433*** | 0.0217** | 0.00970 |
| | | (0.00293) | (0.0123) | (0.00937) | (0.00731) |
| Observations | 10,058 | 10,055 | 10,058 | 10,055 | 10,055 |
| MSA FE | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES |
| C. div x Year | YES | YES | YES | YES | YES |
| Year | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 |
| s.e. cluster | C. div x Year | C. div x Year | C. div x Year | C. div x Year | C. div x Year |
| Estimation | OLS | IV | IV | IV | IV |
| F | . | 51.81 | 51.74 | 51.81 | 51.81 |

# Magnitude of the effect

Effect of an increase in violent crimes in the city center from their level in 1960 to their maximum level in 1991:

- Decrease of the percentage of people that living in the city center of **14 percentage points**
- Decline in city center population of 45% and an increase of suburbs of 22%
- Responsible for moving **25.8 million people** outside of city centers in the all U.S, that is 0.8 million people by year

# Employment Decentralization

| VARIABLES | (1) All | (2) Manuf | (3) Wholesale | (4) Retail | (5) Finance | (6) Other serv |
|---|---|---|---|---|---|---|
| Violent crime | -0.00184 | -0.00783*** | -0.00420* | -0.00657*** | 0.000495 | -0.00485*** |
| | (0.00191) | (0.00276) | (0.00241) | (0.00249) | (0.00304) | (0.00173) |
| Observations | 5,387 | 5,387 | 5,387 | 5,387 | 5,387 | 5,387 |
| MSA FE | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES |
| C. div x Year | YES | YES | YES | YES | YES | YES |
| Year | 74-91 | 74-91 | 74-91 | 74-91 | 74-91 | 74-91 |
| s.e. cluster | C. div x Year | C. div x Year | C. div x Year | C. div x Year | C. div x Year | C. div x Year |
| Estimation | IV | IV | IV | IV | IV | IV |

# Changes inside the city

| VARIABLES | (1) % Blacks CC | (2) Income CC / MSA | (3) Gini | (4) Num. Hways | (5) ln(Expend. Hways) | (6) % Public Transp. |
|---|---|---|---|---|---|---|
| Violent crime | 0.811*** | -0.0162*** | 0.00106** | 0.0448* | 0.0564* | -0.383** |
| | (0.134) | (0.00359) | (0.000423) | (0.0238) | (0.0279) | (0.162) |
| Observations | 920 | 925 | 925 | 925 | 1,164 | 925 |
| MSA FE | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES |
| C. reg x Year | YES | YES | YES | YES | YES | YES |
| Year | CY 60-90 | CY 60-90 | CY 60-90 | CY 60-90 | CY 60-90 | CY 60-90 |
| s.e. cluster | C. div x Year | C. div x Year | C. div x Year | C. div x Year | C. div x Year | C. div x Year |
| Estimation | IV | IV | IV | IV | IV | IV |
| F | 12.80 | 13.32 | 13.32 | 13.32 | 13.32 | 13.32 |

# Magnitude of the effect

Effect of an increase in violent crimes in the city center from their level in 1960 to their maximum level in 1991:

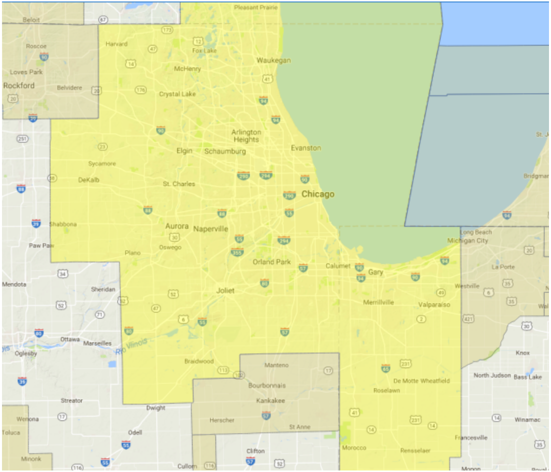
- Increased the percentage of blacks living in the city center by 8.4%
- Generated a gap in income between the median family in CC Vs. Suburbs of 17%

In response of violent crime non-black citizens are 4.8 more likely to move to the suburbs with respect to blacks.

# Conclusion

- Newly constructed **instrument** for violent crime based on lead poisoning
- Increase of **crime** important mechanism to explain U.S. **urban structure**
  - Affects location of people within-city and not between cities
  - Employment decentralization
  - Increases racial segregation and inequalities
- Highlights the indirect effects of crime

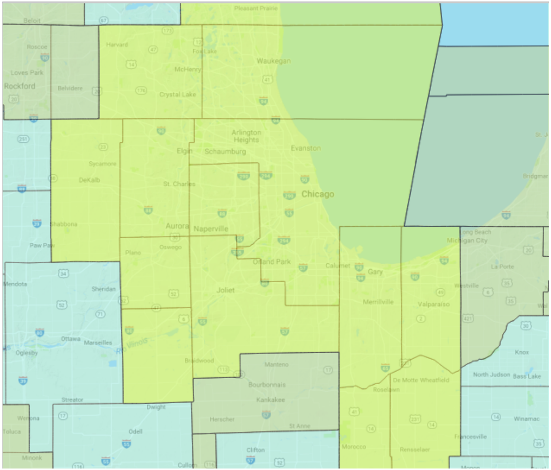
# Chicago: geographical definitions




*Chicago metropolitan area*

Back to Empirical model

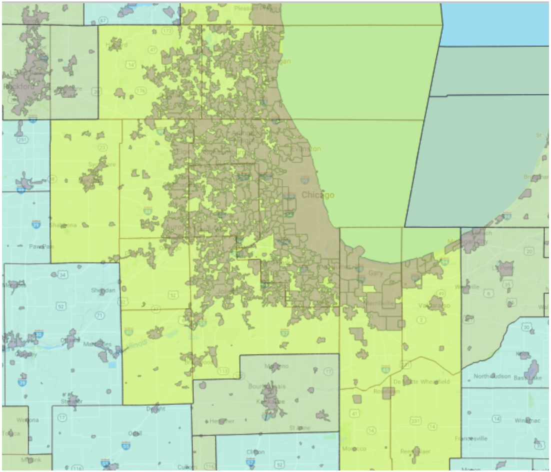
# Chicago: geographical definitions




*Composed of different counties*

Back to Empirical model

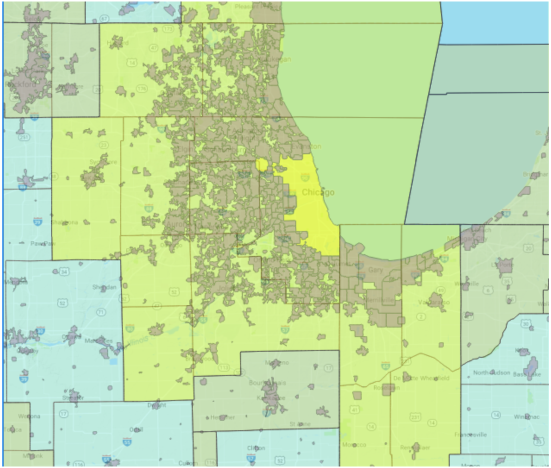
# Chicago: geographical definitions




*Composed of different places*

Back to Empirical model

# Chicago: geographical definitions




*Chicago central city*

Back to Empirical model

# Identification strategy

Lead poisoning can increase crime rate

- Lead is a heavy metal, with symbol **Pb.**
- "Lead is a very potent **neurotoxin**, it has a range of effects on the brain that have been demonstrated through hundreds of different biological studies. Lead **alters the formation of the brain**" (BBC, 2014)
- Lead is toxic because of its ability to inhibit or **mimic calcium**
- "Lead-induced **damage** occurs preferentially in the prefrontal cerebral cortex, hippocampus and cerebellum" (Finkelstein et al., 1998)
- "Lead impairs **brain development** and disrupts **neurotransmitter function** in ways that negatively affect **cognition, attention and short term memory**, and reduce **impulse control** (Aizer et al., 2017)"

# History lead

- White lead used as pigment since 300 BC
- Roman aqueducts use already lead pipes
- Lead production declined after the fall of Rome and come back at similar levels with the Industrial Revolution
- Installation of lead pipes in the U.S. on a major scale from the late 1800s, lasted longer and more malleable than iron
- Early 1900s began scientific awareness of dangers to health of lead pipes and paint
- By 1900, more than 70% of cities with populations greater than 30000 in U.S. used lead water lines
- By the 1920s, many cities and towns were prohibiting or restricting their use
- Tetraethyl lead mixed with gasoline from 1922, it raised the octane level of gasoline
- Use of lead paint peaked in 1920s, through the 1950s and 1960s the use of exterior lead-based paint declined significantly

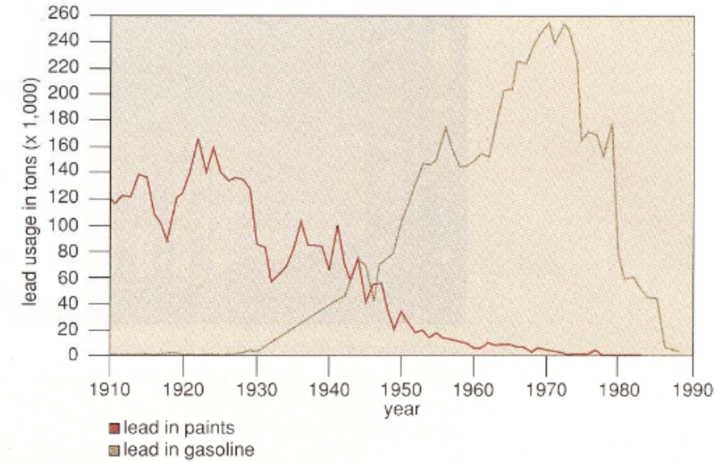
Back to Lead exposure

# History lead

- Lead Industries Association (LIA) was formed in 1928
- Geochemist Clair Patterson brought the airborne lead issue into American consciousness
- Lead-Based Paint Poisoning Prevention Act, which restricted the lead content in paint, signed in 1971
- Lead banned from paint from 1978
- EPA banned leaded solder and pipes in 1986 and mandated that lead additive be reduced by 91 percent
- From 1 January 1996, the U.S. Clean Air Act banned the sale of leaded fuel for use in on-road vehicles.

Back to Lead exposure

# Time series lead use




Back to Lead exposure

# Soil quality and lead poisoning

- "Not all of the lead in soil is available to plants (or to the human body, should the soil be eaten). The **availability of soil lead depends on how tightly it is held by soil particles and on its solubility** (how much of it will dissolve in water).
  At **low soil pH** (pH<5, acidic conditions) lead is held less tightly and is more soluble.
  At **near neutral or higher pH** (pH>6.5, neutral to basic conditions) soil lead is held more strongly, and its solubility is very low.
  Lead is held very tightly by soil organic matter, so as organic matter increases, lead availability decreases."' (Penn State)
  Back to Soil quality and lead poisoning

# Soil quality and lead poisoning

- "**The fate of lead in soil is affected by the specific or exchange adsorption at mineral interfaces**, the precipitation of sparingly soluble solid phases, and the **formation of relatively stable organo-metal complexes** or chelates with the organic matter in soil" (EPA, 1986; NSF, 1977, CDC)
- "Lead accumulates in the **top 1 to 2 inches of soil** [...]. You can decrease the bioavailability (toxicity) of lead in soil by several soil management practices: (1) **maintaining a near-neutral soil pH**, (2) adding phosphorus when soil tests indicate a need, and (3) adding organic matter."' (Oregon State University)
- "It is most dangerous to **children under 6**, who have the highest risk of exposure (crawling on the ground and playing in the dirt) as well as the largest capacity for uptake in this period of rapid growth and development. Adults are at relatively low risk from lead in the soil."' (EPA, Urban Homesteading)

Back to Soil quality and lead poisoning

# Soil quality and lead poisoning

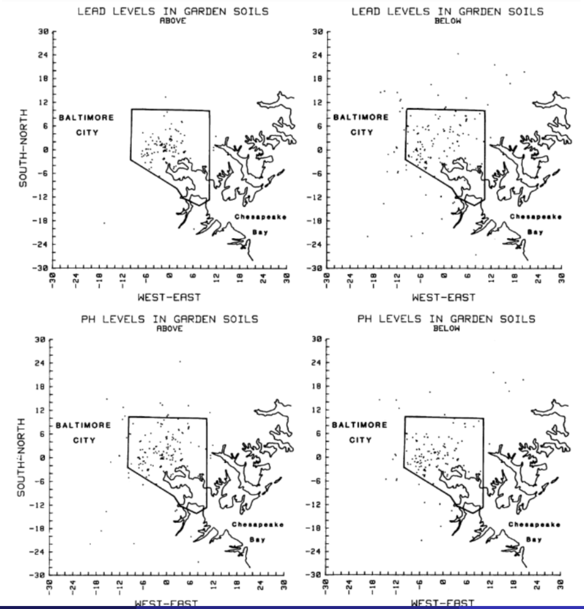
- "Lead released from combustion of leaded gasoline, deterioration of lead-based paint, factory and smelter emissions, and other industrial sources can become airborne and eventually settle onto the surrounding soil." (Kappy, 2016)
- "Plant lead concentrations typically decrease with increasing soil pH. Plants tend to take up the least amount of soil arsenic at neutral soil pH. Amend acidic soils contaminated with lead but not arsenic with agricultural lime (calcium carbonate or dolomite) to **pH 7 or greater**." (Washington State University)
- "Manage soil to reduce lead availability, and therefore, risk. A soil **pH of at least 6.5** reduces the availability of lead." (University of Delaware)
- "As soil pH decreased, the availability and mobility of metal ions increased due to the chemical form in which these metal ions are present in soil solutions" (Reddy et al., 1995)

Back to Soil quality and lead poisoning

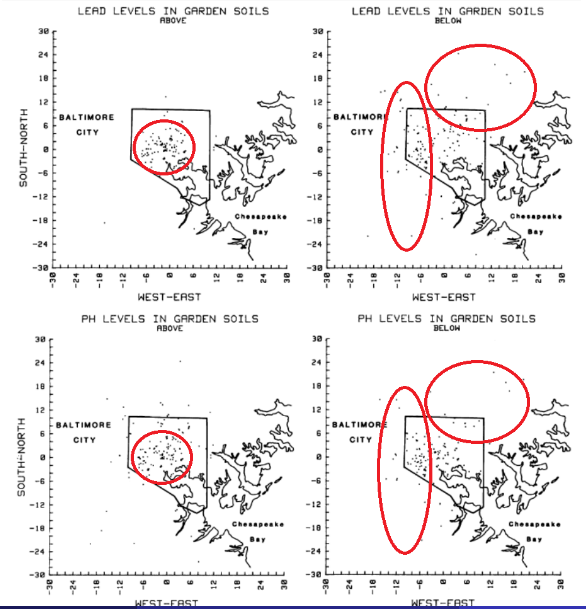
# Soil quality and lead poisoning

- "The aqueous concentrations of heavy metals in soils, sediments, and aquatic environments frequently are controlled by the dissolution and precipitation of **discrete mineral phases.**
  [...] lead oxides, sulfates, and carbonates are all highly soluble in acidic to circumneutral environments, and soil Pb in these forms can pose a significant **environmental risk.**
  Application of soluble or solid-phase phosphates to contaminated soils and sediments induces the dissolution of the "native" Pb minerals, the **desorption of Pb** adsorbed by hydrous metal oxides, and the subsequent formation of pyromorphites in situ. This process results in decreases in the chemical lability and **bioavailability** of the Pb without its removal from the contaminated media. " (Traina and Laperche, 1999)
  Back to Soil quality and lead poisoning

# Lead and pH in Baltimore



# Lead and pH in Baltimore



# Relevance instrument

Lead adsorption and paved cities

- 47 % of London is green space (Independent, 2014)
- **High density cities in 2014 12 % of city area is parkland.** NY: 20 %. SFO: 19 %. Houston: 14%. LA: 12 %. Chicago: 9 %. (The trust for public land, 2015)
- "Due to resuspension of the roadside soil, Pb originally deposited near the roadside has been transported **longer distances beyond the roadside** fringe" (Filippelli et al., 2005)
- Soil particles will become deflated when destabilizing forces such as **drag, lift, and aerodynamic forces** become greater than stabilizing forces such as particle weight and interparticle binding forces (Iverson et al., 1976)
- Sources of elevated Pb loadings inside homes originate from Pb contaminated dusts and soils outside the home transported inside via **soil resuspension** (Laidlaw et al., 2005) and via soil attached to **shoes** (Hunt et al., 2006) and on the feet of family pets"

Back to Soil quality and lead poisoning

# Relevance instrument

Lead resuspension, gasoline and paint

- "**Pb-based house paint could not account for the observed pattern of soil Pb**. [...] Soil around Baltimore's inner city buildings, predominantly unpainted brick, exhibited the highest amounts of Pb, and soils outside of the inner city, where buildings were commonly constructed with Pb-based paint on wood siding, contained comparatively low amounts of Pb" (Mielke et al., 1983; Mielke et al., 2007; Laidlaw and Filippelli, 2008)
- "The source of the exterior Pb loading entering homes is likely a combination of **Pb from past use of leaded gasoline with lesser amounts from Pb in paint.** [...] Source of the Pb in the fine fraction of soil originated from leaded gasoline, and the larger particles that do not penetrate cracks in homes (above) were composed of Pb paint particles. (Clark et al., 2006; Laidlaw and Filippelli, 2008)

Back to Soil quality and lead poisoning

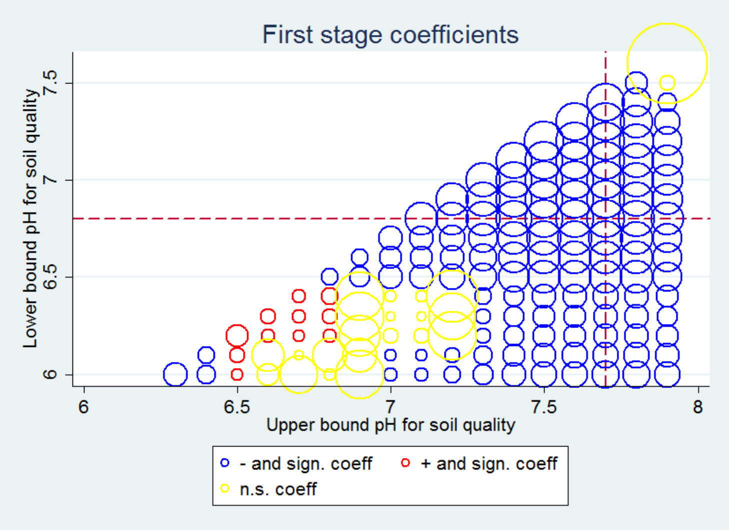
# Soil quality

Soil quality: $6.8 \leq pH \leq 7.7$

- Non-parametric estimation effect of lead on crime wrt pH Margins
- Use interval that maximizes F-statistics, obtain stronger coefficient, and have more robust coefficient to change in interval Intervals
- Different from regression tree methods: instead of minimizing the SSR directly, we maximize the F-statistics.
- Maximize the SSR difference between a model in which we predict violent crime using only the included instrument and a model in which we predict violent crime using the included and excluded instruments.

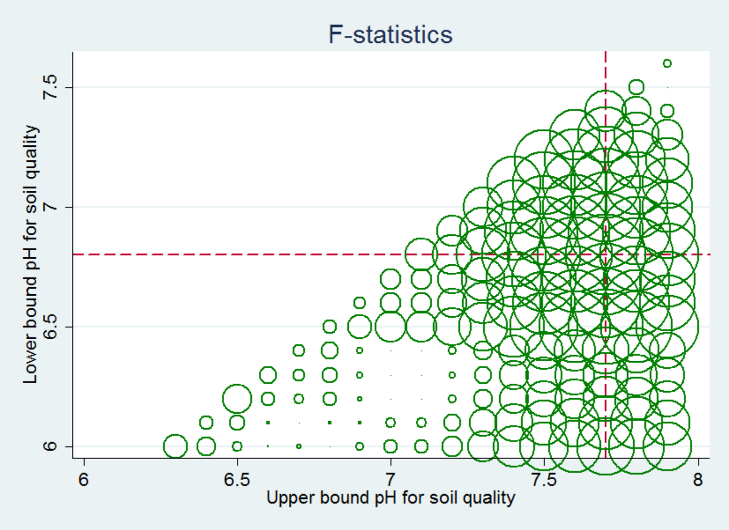
Back to Soil quality and lead poisoning

# First stage coefficients for all possible pH intervals




Back to Soil quality

# F-statistics for all possible pH intervals




Back to Soil quality

# Identification assumption

- In years in which lead poisoning increased, places with good and bad soil would have similar trends in terms of suburbanization
- Soil pH is as good as randomly assigned
- Treated and control places are similar in terms of crime and population trends Pre-trends
- Treated and control places are similar in terms of other characteristics Pre-trends

Back to Soil quality and lead poisoning

# Pre-treatment trends and level

| Variable | Average | Levels | | Trends | |
|---|---|---|---|---|---|
| | | All US | Inside Division | All US | Inside Division |
| Area CC (50) | 27.51 | 3.52 | 0.98 | . | . |
| Area MSA (50) | 2056.36 | 708.11 | -424.82 | . | . |
| Share Pop. CC (50 - 60) | 0.47 | 0.09** | 0.02 | 0.05** | 0.01 |
| Population CC (50 - 60) | 2.0e+05 | -7.7e+04 | -1438.35 | 32129.34* | 6486.92 |
| Population MSA (50 - 60) | 4.3e+05 | -1.7e+05 | 1842.98 | 30009.88 | 40253.98 |
| Pop. Density CC (50 - 60) | 6109.20 | -1535.46*** | 30.86 | 327.39 | 151.63 |
| Pop. Density MSA (50 - 60) | 197.35 | -105.09*** | -8.35 | 12.44 | 27.83 |
| Violent Crime Rate CC (per 10000) (60 - 63) | 13.82 | -2.17 | -0.34 | -0.46 | 0.38 |
| Murder Rate CC (per 10000) (60 - 63) | 0.53 | -0.11 | 0.01 | -0.05 | -0.04 |
| Rape Rate CC (per 10000) (60 - 63) | 0.70 | 0.06 | -0.00 | 0.10 | 0.15 |
| Robbery Rate CC (per 10000) (60 - 63) | 4.71 | 0.43 | -0.15 | -0.27 | 0.19 |
| Agg. Assault Rate CC (per 10000) (60 - 63) | 7.89 | -2.55** | -0.21 | -0.29 | 0.08 |
| Burglary Rate CC (per 10000) (60 - 63) | 59.64 | 5.28 | 1.28 | -0.54 | -2.17 |
| Larceny Rate CC (per 10000) (60 - 63) | 169.71 | 78.02*** | 29.73 | -10.26 | -18.26* |
| Vehicle Theft Rate CC (per 10000) (60 - 63) | 22.91 | 2.75 | -1.78 | 0.24 | -0.13 |
| Total Crimes CC (per 10000) (60 - 63) | 266.43 | 83.87*** | 28.82 | -9.56 | -17.52 |

Back to Exogeneity

# Pre-treatment trends and level

| Variable | Average | Levels | | Trends | |
|---|---|---|---|---|---|
| | | All US | Inside Division | All US | Inside Division |
| Median Gross Rent (housing unit) MSA (60) | 384.91 | 26.96** | 22.12* | . | . |
| Median Single Family House Value MSA (60) | 64628.31 | 4839.84* | 2297.45 | . | . |
| Median Family Income CC (50-60) | 22811.72 | 1995.89*** | 1246.13* | 87.89 | -618.41 |
| Median Family Income MSA (50-60) | 21400.64 | 1837.63*** | 1236.50* | -319.70 | -428.57 |
| Annual Precipitation (77) | 35.86 | -19.38*** | -8.86*** | . | . |
| % Possible Sun (77) | 59.93 | 7.91*** | 2.60 | . | . |
| Average Jan Temp (77) | 34.34 | -1.49 | -3.20 | . | . |
| Average July Temp (77) | 75.76 | 0.25 | -0.12 | . | . |
| % Blacks CC (60) | 13.41 | -7.81*** | -1.21 | . | . |
| % Blacks MSA (60) | 9.45 | -5.47*** | -1.49 | . | . |
| % Foreign CC (60) | 16.40 | -0.41 | -0.70 | . | . |
| % Foreign MSA (60) | 14.47 | 0.70 | -0.07 | . | . |
| Distance Border or Coast | 129.89 | 139.60*** | 35.60 | . | . |
| Unemployment Rate MSA (60) | 5.17 | 0.26 | 0.20 | . | . |
| Labor Force Civilian MSA (50-60) | 0.39 | -0.01 | 0.00 | 0.00 | -0.00 |
| Emp. Rate MSA (50-60) | 36.99 | -1.18 | 0.26 | 0.21 | -0.40 |
| Emp. Rate Agriculture MSA (50-60) | 3.44 | 0.57 | 0.54 | -0.07 | -0.01 |
| Emp. Rate Business Services MSA (50) | 2.29 | 0.50*** | 0.30** | . | . |
| Emp. Rate Construction MSA (50-60) | 2.51 | 0.63*** | 0.19 | -0.06 | 0.09 |
| Emp. Rate Education MSA (60) | 2.18 | -0.02 | -0.16 | . | . |
| Emp. Rate Finance MSA (50-60) | 1.17 | 0.15* | 0.01 | 0.07* | 0.03 |
| Emp. Rate Government MSA (60) | 1.82 | 0.29* | -0.03 | . | . |
| Emp. Rate Manufacturing MSA (50-60) | 9.18 | -5.52*** | -1.52** | 0.82*** | -0.04 |
| Emp. Rate Mining MSA (50) | 0.44 | 0.47 | 0.52 | . | . |
| Emp. Rate Professional MSA (50) | 3.53 | 0.10 | -0.31 | . | . |
| Median Age MSA (50-60) | 29.49 | -0.93* | -0.29 | -1.01*** | -0.39 |
| % Over 65y MSA (50-60) | 7.81 | -0.94** | -0.64 | -0.50* | -0.32 |
| % Non-white MSA (50-60) | 9.98 | -5.17*** | -1.77 | 0.50* | 0.40 |
| % Pub. Transportation to Work MSA (60) | 6.82 | -4.04*** | -2.83*** | . | . |
| Median Years of School MSA (50-60) | 9.57 | 1.42*** | 0.69** | -0.13 | -0.01 |

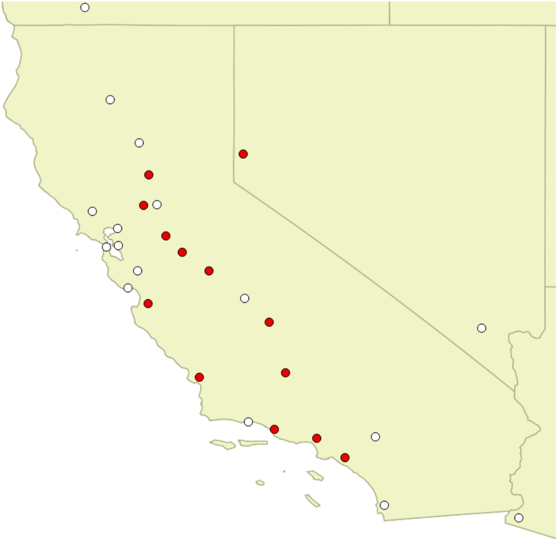
Back to Exogeneity

# Pre-treatment trends and level

| Variable | Average | Levels | | Trends | |
|---|---|---|---|---|---|
| | | All US | Inside Division | All US | Inside Division |
| CC interstate rays (50-60) | 0.04 | -0.05** | -0.08* | 0.17 | -0.03 |
| CC total rays (50-60) | 0.04 | -0.05** | -0.08* | 0.17 | -0.03 |
| 2-digit CC rays (50-60) | 0.03 | -0.03** | -0.05 | 0.20 | -0.08 |
| All interstate CC rays (50-60) | 0.03 | -0.03** | -0.05 | 0.22 | -0.02 |
| Federally funded CC rays (50-60) | 0.02 | -0.02 | -0.03 | 0.26 | -0.00 |
| All rays in MSA (50-60) | 0.06 | -0.07*** | -0.06 | -0.08 | -0.20 |
| 2-digit ray in MSA (50-60) | 0.06 | -0.07*** | -0.05 | -0.06 | -0.23 |
| Federally funded rays in MSA (50-60) | 0.03 | -0.03* | -0.06 | 0.11 | -0.19 |
| Rays in plan running through MSA | 2.10 | -0.24 | -0.46* | . | . |
| Rays in plan running through CC | 1.90 | -0.01 | -0.32 | . | . |

Back to Soil quality

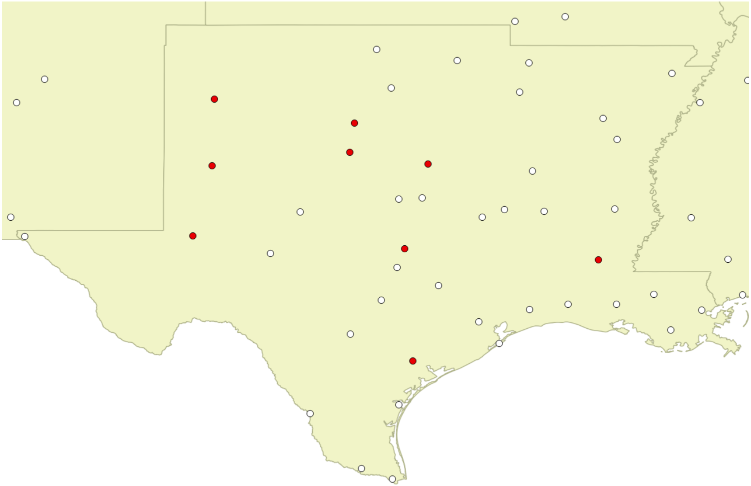
# State variation



Back to Exogeneity

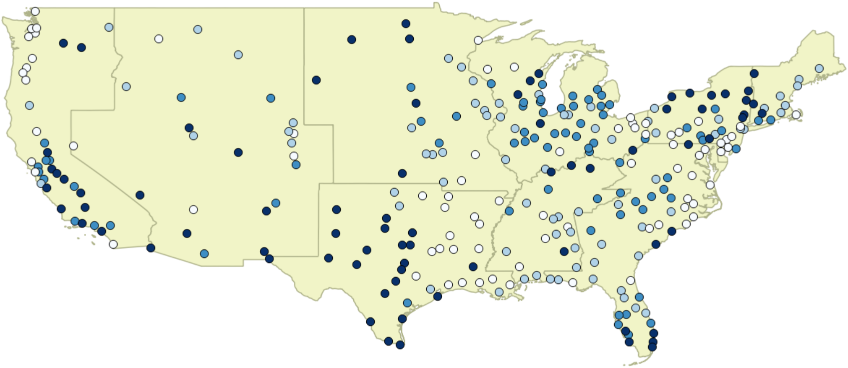
# Census Division Variation

West South Central: Texas, Ohio, Arkansas, Louisiana



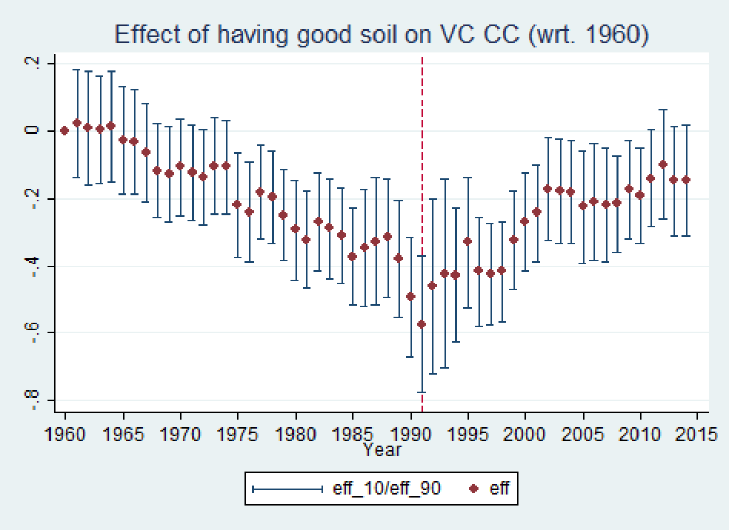
Back to Exogeneity

# Continous Variable Variation



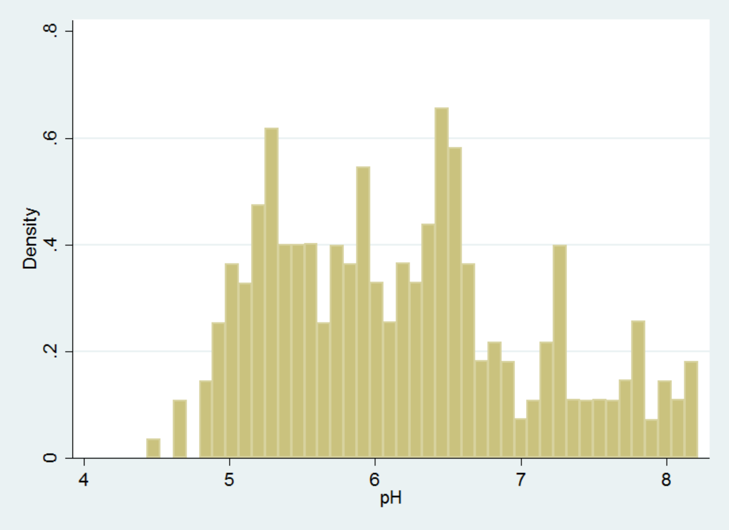
Back to Exogeneity

# Deleading and Timing




Back to Exogeneity Back to Exclusion restriction

# Histogram pH



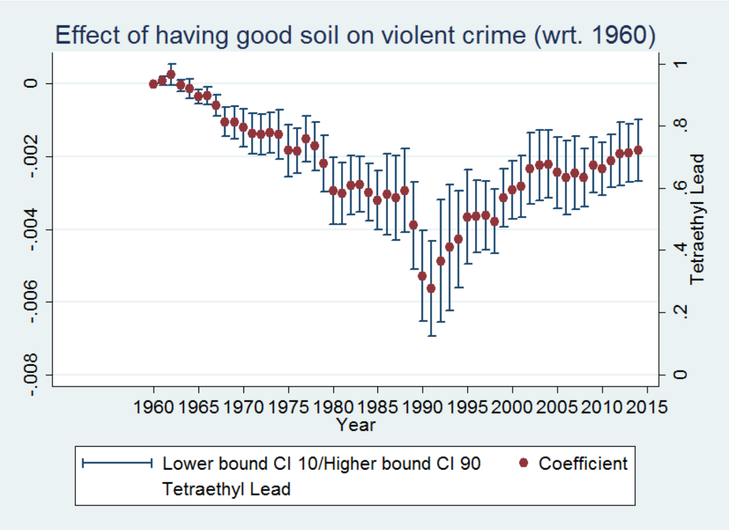

Back to Cross-sectional variation

# First stage with different fixed effects

| VARIABLES | (1) Vc pc | (2) Vc pc | (3) Vc pc | (4) Vc pc | (5) Vc pc |
|---|---|---|---|---|---|
| Good soil x Lead | -0.00184*** | -0.00528*** | -0.00451*** | -0.00327*** | -0.00276*** |
| | (0.000190) | (0.000326) | (0.000362) | (0.000378) | (0.000399) |
| Observations | 9,515 | 9,515 | 9,484 | 9,484 | 9,515 |
| R-squared | 0.005 | 0.527 | 0.538 | 0.553 | 0.678 |
| Place FE | NO | YES | YES | YES | YES |
| Year FE | NO | YES | YES | YES | YES |
| C. region X Year FE | NO | NO | YES | NO | NO |
| C. division X Year FE | NO | NO | NO | YES | NO |
| State X Year FE | NO | NO | NO | NO | YES |
| Year | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 |
| Estimation | OLS | OLS | OLS | OLS | OLS |
| F | | 262.16 | 154.51 | 74.87 | 47.98 |

Back to Cross-sectional variation

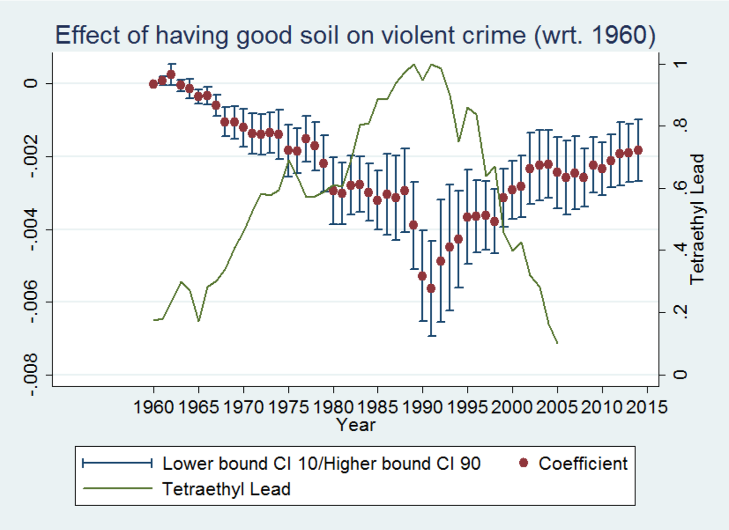
# Effect good soil on crime




Back to Soil quality and lead poisoning

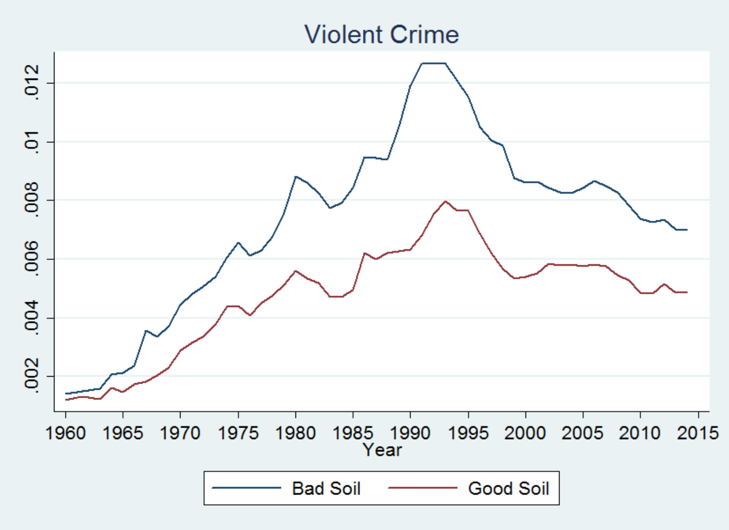
Time series violent crime by soil

# Effect good soil on crime




Back to Soil quality and lead poisoning

# Time series violent crime by soil




Back to Effect of good soil on violent crime

# Data

Data for 306 central cities (places) from 1960 to 1991 Summary statistics

FBI Uniform Crime Reports (1960-2014)

- For each local enforcement agency we know number of crimes monthly for each year for all different kind of crimes and population under agency
- Violent crime per capita: Murder and non-negligent manslaughter + total robberies + forcible rape + aggravated assaults Definitions

USGS U.S. General Soil Map

- For each map unit we can compute weighted level of pH between different components at soil surface

Bureau of Mines Minerals Yearbook PDFs (1941-1986)

- For each year we know tetraethyl lead used as gasoline additives

Baum Snow (2007) and County and City Data Books (1947-1994)

- Information of several characteristics of city centers and MSAs

Back to Soil quality and lead poisoning

# FBI crime definitions

- Murder and nonnegligent manslaughter: Willful killing of one human being by another
- Robbery: Taking or attempting to take anything of value from the care, custody, or control of a person or persons by force or threat of force or violence and/or by putting the victim in fear
- Rape: Penetration, of the vagina or anus with any body part or object, or oral penetration by a sex organ of another person, without the consent of the victim. Attempts or assaults to commit rape included
- Aggravated assaults: Unlawful attack by one person upon another for the purpose of inflicting severe or aggravated bodily injury. Simple assaults excluded
- Burglary: Unlawful entry of a structure to commit a felony or a theft
- Larceny: Unlawful taking, carrying, leading, or riding away of property from the possession or constructive possession of another

Back to Data

# Summary statistics

| Variable | Mean | s.e. | Min | Max | Change 60-93 |
|---|---|---|---|---|---|
| Pop. CC | 1.9e+05 | 5.3e+05 | 1725.00 | 8.2e+06 | 23994.72 |
| Pop. NCC | 3.4e+05 | 5.9e+05 | 1867.00 | 5.6e+06 | 1.9e+05 |
| Prop. Pop. CC | 0.39 | 0.20 | 0.01 | 0.98 | -0.05 |
| Pop. MSA | 5.3e+05 | 9.9e+05 | 15751.00 | 9.3e+06 | 2.2e+05 |
| Area CC (sqkm) | 182.23 | 334.89 | 8.62 | 4526.11 | . |
| Area NCC (sqkm) | 332.90 | 592.68 | 2.11 | 3859.25 | . |
| Area MSA (sqkm) | 503.56 | 727.31 | 20.06 | 4409.11 | . |
| pH CC | 6.18 | 0.88 | 4.44 | 8.22 | . |
| pH NCC | 6.15 | 0.87 | 4.62 | 8.27 | . |
| Tetraethyl Lead (in tonnes) | 1.7e+05 | 73810.31 | 47965.00 | 2.8e+05 | 2.0e+05 |
| Violent Crime Rate CC (per 10000) | 61.26 | 61.90 | 0.00 | 695.15 | 106.65 |
| Murder Rate CC (per 10000) | 0.99 | 0.96 | 0.00 | 8.58 | 0.90 |
| Rape Rate CC (per 10000) | 3.81 | 3.55 | 0.00 | 42.42 | 5.86 |
| Robbery Rate CC (per 10000) | 22.22 | 27.08 | 0.00 | 233.75 | 34.62 |
| Agg. Assault Rate CC (per 10000) | 33.98 | 38.00 | 0.00 | 557.90 | 65.24 |
| Burglary Rate CC (per 10000) | 159.53 | 98.09 | 0.00 | 2258.75 | 110.11 |
| Larceny Rate CC (per 10000) | 388.99 | 211.68 | 0.00 | 5436.55 | 331.24 |
| Vehicle Theft Rate CC (per 10000) | 50.59 | 47.62 | 0.00 | 774.13 | 55.78 |
| Total crimes CC (per 10000) | 717.46 | 413.40 | 0.00 | 9536.94 | 776.58 |

Back to Data

# Reverse causality

$$Sub = \xi_1 VC + \epsilon_1$$

$$VC = \xi_2 SUB + \epsilon_2$$

$$\text{OLS: } Sub = \frac{\xi_1 - 1}{1 - \xi_2} VC + \frac{1}{1 - \xi_2}(\epsilon_1 + \epsilon_2)$$

$$\text{Upward bias OLS: } \frac{\xi_1 - 1}{1 - \xi_2} > \xi_1 \rightarrow \xi_1 > \frac{1}{\xi_2}$$

Back to Results

# Robustness

- Exogeneity test with control function
- Crime spillovers
- Potential confounders
  - Highways
  - Education
  - Agricultural productivity
  - Other controls
- Instrument definition
  - Other good soil definitions
  - Non-parametric function of pH
  - Other lead lags
- Other crimes
- Other robustness
  - Within region and topology variation
  - Weight and subsample wrt city size
  - Standard errors

Back to Results

# Exogeneity test with control function

| VARIABLES | (1)<br>Pop NCC | (2)<br>Pop NCC | (3)<br>Pop NCC | (4)<br>Pop CC |
|---|---|---|---|---|
| Good soil x Lead | -58,400*** | -956.3 | | |
| | (11,170) | (10,795) | | |
| Violent crime | | 59,748*** | 60,800*** | -72,122*** |
| | | (1,981) | (11,707) | (6,088) |
| Residuals first stage | | | -1,052 | 60,590*** |
| | | | (11,875) | (6,174) |
| Observations | 9,716 | 9,481 | 9,481 | 9,515 |
| R-squared | 0.220 | 0.292 | 0.292 | 0.040 |
| Place FE | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES |
| Year | 60-91 | 60-91 | 60-91 | 60-91 |
| Estimation | OLS | OLS | OLS | OLS |

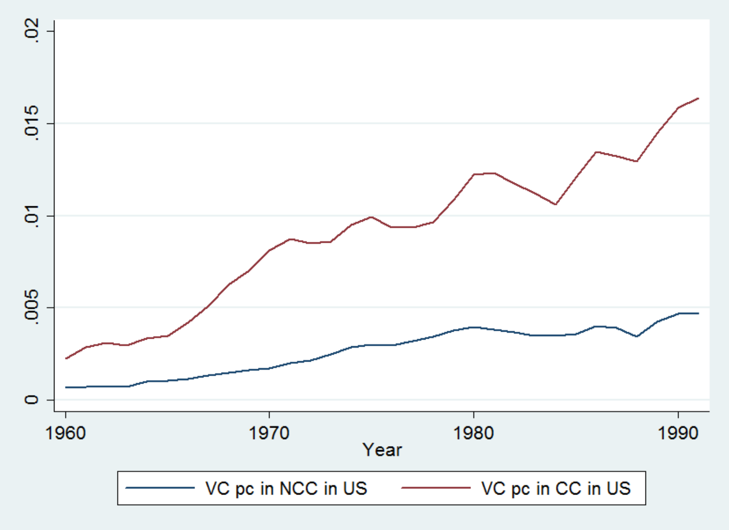
Back to Robustness

# Resulting weighting and using subsample

| VARIABLES | (1)<br>Share pop CC | (2)<br>Share pop CC | (3)<br>Share pop CC |
|---|---|---|---|
| Violent crime | -0.0717***<br>(0.00594) | -0.123***<br>(0.0133) | -0.167***<br>(0.0177) |
| Observations | 9,481 | 6,826 | 9,481 |
| Place FE | YES | YES | YES |
| Year FE | YES | YES | YES |
| Year | 60-91 | 60-91 | 60-91 |
| Sample | All | More than 100000 | All |
| Weight | NO | NO | Pop. MSA |
| Estimation | IV | IV | IV |
| s.e. | Robust | Robust | Robust |
| F | 264.55 | 95.67 | 90.31 |
| FS Beta | -0.909 | -0.776 | -0.663 |
| FS s.e. | 0.056 | 0.080 | 0.169 |

Back to Robustness

# Time series violent crime: CC vs NCC




Back to Robustness

# Results for spillover to violent crime in NCC

| VARIABLES | (1)<br>pH CC | (2)<br>VC pc NCC | (3)<br>VC pc NCC | (4)<br>VC pc NCC | (5)<br>VC pc NCC |
|---|---|---|---|---|---|
| pH NCC | 0.946*** | | | | |
| | (0.0173) | | | | |
| Good soil NCC x Lead | | 0.000491*** | 0.000491 | 0.000682*** | 0.000682 |
| | | (0.000138) | (0.000532) | (0.000193) | (0.000868) |
| Good soil CC x Lead | | | | -0.000276 | -0.000276 |
| | | | | (0.000195) | (0.000872) |
| Observations | 294 | 9,518 | 9,518 | 9,518 | 9,518 |
| Place FE | NO | YES | YES | YES | YES |
| Year FE | NO | YES | YES | YES | YES |
| Year | NO | 60-91 | 60-91 | 60-91 | 60-91 |
| Estimation | OLS | OLS | OLS | OLS | OLS |
| s.e. cluster | NO | NO | MSA | NO | MSA |

Back to Robustness

# Results for spillover to violent crime in CC

| VARIABLES | (1)<br>VC pc CC | (2)<br>VC pc CC | (3)<br>VC pc CC | (4)<br>VC pc CC | (5)<br>VC pc |
|---|---|---|---|---|---|
| Good soil CC x Lead | -0.00528*** | -0.00528*** | -0.00636*** | -0.00636*** | |
| | (0.000326) | (0.000819) | (0.000454) | (0.00120) | |
| Good soil NCC x Lead | | | 0.00155*** | 0.00155 | |
| | | | (0.000455) | (0.00134) | |
| Dummy for CC | | | | | 0.00363*** |
| | | | | | (0.000236) |
| Observations | 9,515 | 9,515 | 9,515 | 9,515 | 19,033 |
| Place FE | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES |
| Year | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 |
| Estimation | OLS | OLS | OLS | OLS | OLS |
| s.e. cluster | NO | MSA | NO | MSA | NO |

Back to Robustness

# Heterogeneity effect in first stage wrt density

| VARIABLES | (1)<br>VC pc CC | (2)<br>VC pc NCC |
|---|---|---|
| Good soil CC x Lead | -0.00494*** | 0.000106 |
| | (0.000553) | (0.000207) |
| Lead x Density CC 1960 | 1.83e-06*** | |
| | (8.02e-08) | |
| Good soil CC x Lead x Density CC 1960 | 1.91e-06** | |
| | (7.77e-07) | |
| Good soil NCC x Lead | | 0.000295* |
| | | (0.000178) |
| Lead x Density NCC 1960 | | -7.42e-08** |
| | | (2.89e-08) |
| Good soil NCC x Lead x Density NCC 1960 | | -6.18e-08 |
| | | (8.60e-08) |
| Observations | 9,515 | 9,198 |
| Place FE | YES | YES |
| Year FE | YES | YES |
| Year | 60-91 | 60-91 |
| Estimation | OLS | OLS |

Back to Robustness

# Results using different fixed effects

| VARIABLES | (1) Share pop CC | (2) Share pop CC | (3) Share pop CC | (4) Share pop CC | (5) Share pop CC |
|---|---|---|---|---|---|
| Violent crime | -0.422*** | -0.223*** | -0.0717*** | -0.0573*** | -0.0843*** |
| | (0.0471) | (0.0157) | (0.00594) | (0.00712) | (0.0120) |
| Observations | 9,481 | 9,481 | 9,481 | 9,481 | 9,481 |
| Place FE | NO | NO | YES | YES | YES |
| Year FE | NO | YES | YES | YES | YES |
| C. region X Year FE | NO | NO | NO | YES | NO |
| C. division X Year FE | NO | NO | NO | NO | YES |
| Year | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 |
| Estimation | IV | IV | IV | IV | IV |
| FS Beta | -0.317 | -0.686 | -0.909 | -0.776 | -0.563 |
| FS s.e. | 0.033 | 0.032 | 0.056 | 0.062 | 0.065 |
| F | | 455.56 | 264.55 | 154.66 | 74.97 |

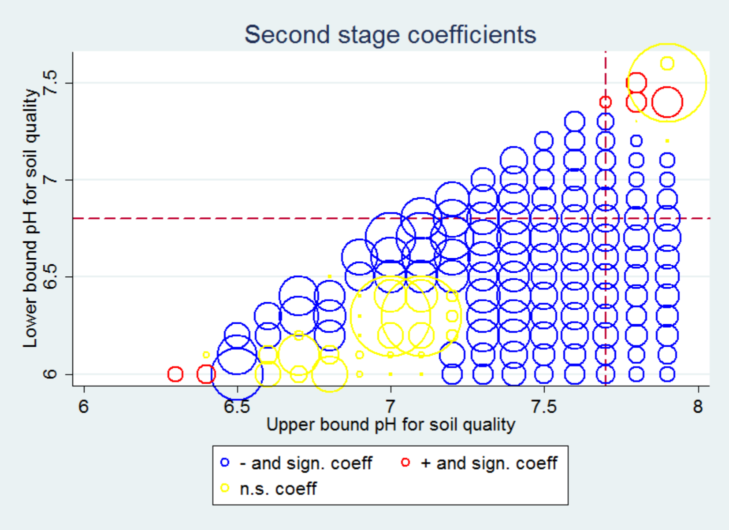
Back to Robustness

# Results using topographic fixed effects

| VARIABLES | (1) Share pop CC | (2) Share pop CC | (3) Share pop CC | (4) Share pop CC |
|---|---|---|---|---|
| Violent crime | -0.0620*** | -0.0620*** | -0.0367*** | -0.0557*** |
| | (0.00489) | (0.00489) | (0.0102) | (0.00694) |
| Observations | 9,481 | 9,481 | 9,481 | 9,481 |
| Place FE | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES |
| Slope pctl X Year FE | NO | YES | NO | NO |
| Precipitation pctl X Year FE | NO | NO | YES | NO |
| Distance water-border pctl X Year FE | NO | NO | NO | YES |
| Year | 60-91 | 60-91 | 60-91 | 60-91 |
| Estimation | IV | IV | IV | IV |

Back to Robustness

# Second stage coefficients for all possible pH intervals




Back to Robustness

# Results using non-parametric function of pH

| VARIABLES | (1) Share pop CC | (2) Share pop CC | (3) Share pop CC | (4) Share pop CC | (5) Share pop CC | (6) Share pop CC |
|---|---|---|---|---|---|---|
| Violent crime | -0.0717*** | -0.0575*** | -0.0486*** | -0.0487*** | -0.0435*** | -0.0424*** |
| | (0.00594) | (0.00506) | (0.00644) | (0.00644) | (0.00543) | (0.00540) |
| Observations | 9,481 | 9,481 | 9,481 | 9,481 | 9,481 | 9,481 |
| Place FE | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES |
| Year | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 |
| Estimation | IV | IV | IV | IV | IV | IV |
| pH used | 6.8-7.7 | 0.5 bounds | 1st poly | 2nd poly | 3rd poly | 4th poly |

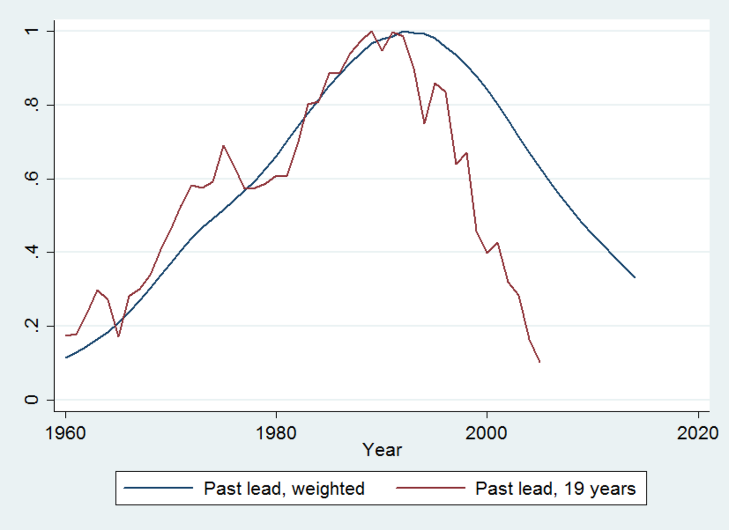
Back to Robustness

# Results using different lags of lead

| VARIABLES | (1) Sh pop CC | (2) Sh pop CC | (3) Sh pop CC | (4) Sh pop CC | (5) Sh pop CC | (6) Sh pop CC | (7) Sh pop CC | (8) Sh pop CC | (9) Sh pop CC |
|---|---|---|---|---|---|---|---|---|---|
| Violent crime | -0.0836*** | -0.0821*** | -0.0779*** | -0.0747*** | -0.0717*** | -0.0677*** | -0.0651*** | -0.0626*** | -0.0575*** |
| | (0.00790) | (0.00769) | (0.00720) | (0.00652) | (0.00594) | (0.00591) | (0.00594) | (0.00607) | (0.00600) |
| Observations | 8,329 | 8,602 | 8,861 | 9,158 | 9,481 | 9,149 | 8,854 | 8,594 | 8,296 |
| Place FE | YES | YES | YES | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES | YES | YES | YES |
| Year | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 |
| Estimation | IV | IV | IV | IV | IV | IV | IV | IV | IV |
| Lag lead | 15 years | 16 years | 17 years | 18 years | 19 years | 20 years | 21 years | 22 years | 23 years |
| F | 192.30 | 197.18 | 209.77 | 235.96 | 264.55 | 250.90 | 236.26 | 216.00 | 204.64 |
| FS Beta | -0.798 | -0.799 | -0.814 | -0.861 | -0.909 | -0.925 | -0.926 | -0.927 | -0.953 |
| FS s.e. | 0.058 | 0.057 | 0.056 | 0.056 | 0.056 | 0.059 | 0.061 | 0.064 | 0.067 |

Back to Robustness

# Time series lead poisoning




Back to Robustness

# Results weighting past lead poisoning by crime propensity over life-cycle

| VARIABLES | (1)<br>Share pop CC | (2)<br>Violent crime | (3)<br>Share pop CC | (4)<br>Violent crime |
|---|---|---|---|---|
| Violent crime | -0.0717*** | | -0.0711*** | |
| | (0.00594) | | (0.00573) | |
| Good soil x Lead 19 years | | -0.909*** | | |
| | | (0.0561) | | |
| Good soil x Lead weighted | | | | -0.866*** |
| | | | | (0.0517) |
| Observations | 9,481 | 9,515 | 9,481 | 9,515 |
| Place FE | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES |
| Year | 60-91 | 60-91 | 60-91 | 60-91 |
| Estimation | IV | OLS | IV | OLS |
| F | 264.55 | . | 283.02 | . |

Back to Robustness

# Robustness controlling for highways

| VARIABLES | (1)<br>Sh pop CC | (2)<br>Rays | (3)<br>Sh pop CC | (4)<br>St VC pc | (5)<br>Sh pop CC | (6)<br>Rays | (7)<br>St VC pc |
|---|---|---|---|---|---|---|---|
| Number of rays in CC | -0.0490*** | | | | 0.0137 | | |
| | (0.0139) | | | | (0.0312) | | |
| Rays in plan x Prop. State hgw | | 0.598*** | | | | 0.334*** | 0.238*** |
| | | (0.0466) | | | | (0.0529) | (0.0599) |
| Violent crime | | | -0.0759*** | | -0.0826** | | |
| | | | (0.0198) | | (0.0334) | | |
| Good soil x Lead | | | | -1.242*** | | -0.158 | -1.082*** |
| | | | | (0.174) | | (0.258) | (0.240) |
| Observations | 939 | 1,174 | 1,184 | 1,189 | 921 | 939 | 921 |
| R-squared | 0.947 | 0.842 | 0.920 | 0.744 | 0.919 | 0.908 | 0.756 |
| Place FE | YES | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES | YES |
| Year | CY 60-90 | CY 60-90 | CY 60-90 | CY 60-90 | CY 60-90 | CY 60-90 | CY 60-90 |
| Sample | Restricted | Restricted | Restricted | Restricted | Restricted | Restricted | Restricted |
| Estimation | IV | OLS | IV | OLS | IV | OLS | OLS |
| Cluster s.e. | MSA | MSA | MSA | MSA | MSA | MSA | MSA |
| F | 140.25 | . | 49.12 | . | 7.02 | . | . |

Back to Exclusion Restriction

# Cognitive abilities as confounder

- Human capital of people in city center
  - Later lags of lead on education
  - Control for education
- My own cognitive abilities
  - Profile of suburbanized: 31 years old, highly educated, white
- Use the probabilities of being violent criminal to construct IV

Back to exclusion restriction

# Robustness controlling for education

| VARIABLES | (1) Sh pop CC | (2) St VC pc | (3) Sh pop CC | (4) H.s. | (5) St VC pc | (6) Sh pop CC | (7) H.s. | (8) St VC pc |
|---|---|---|---|---|---|---|---|---|
| Standardized vc p.c. | -0.0974** | | -0.0691** | | | -0.0973** | | |
| | (0.0445) | | (0.0266) | | | (0.0405) | | |
| Good soil x Lead | | -0.640*** | | -6.847*** | -0.673*** | | -6.728*** | -0.682*** |
| | | (0.167) | | (1.581) | (0.171) | | (1.585) | (0.170) |
| Perc. people with h.s. | | | -0.00434 | | | -0.00181 | | |
| | | | (0.00436) | | | (0.00497) | | |
| H.s. U.S. x age school entry | | | | 0.0102** | -0.00310*** | | | |
| | | | | (0.00461) | (0.000881) | | | |
| H.s. U.S. x age school leave | | | | | | | 0.00564** | -0.00118** |
| | | | | | | | (0.00239) | (0.000470) |
| Observations | 1,184 | 1,186 | 917 | 935 | 1,182 | 917 | 935 | 1,182 |
| R-squared | 0.904 | 0.565 | 0.943 | 0.974 | 0.578 | 0.914 | 0.974 | 0.571 |
| Place FE | YES | YES | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES | YES | YES |
| C. region X Year FE | YES | YES | YES | YES | YES | YES | YES | YES |
| Year | CY 60-90 | CY 60-90 | CY 60-90 | CY 60-90 | CY 60-90 | CY 60-90 | CY 60-90 | CY 60-90 |
| Estimation | IV | OLS | IV | OLS | OLS | IV | OLS | OLS |
| Cluster s.e. | MSA | MSA | MSA | MSA | MSA | MSA | MSA | MSA |
| F | 10.87 | . | 16.09 | . | . | 9.67 | . | . |

Back to cognitive abilities

# Lead Lags and Education

| VARIABLES | (1)<br>Violent Crime | (2)<br>%High School |
|---|---|---|
| Good Soil X Lead(t-7) | 0.0681 | 3.157 |
| | (0.0827) | (2.803) |
| Good Soil X Lead(t-14) | 0.0473 | -4.608 |
| | (0.190) | (3.789) |
| Good Soil X Lead(t-21) | -0.312** | 4.976 |
| | (0.146) | (5.425) |
| Good Soil X Lead(t-28) | -0.556** | -9.978* |
| | (0.236) | (5.156) |
| Observations | 9,484 | 1,174 |
| MSA FE | YES | YES |
| Year FE | YES | YES |
| Year | 60-91 | CY60-90 |
| Estimation | OLS | OLS |
| F | . | . |

Back to cognitive abilities

# Profile of recent suburbanized in 1980

| Variable | Recent suburbanized | Difference wrt people staying in CC |
|---|---|---|
| Mean age | 31.03 | -2.86*** |
| Mean number children | 0.67 | 0.10*** |
| Prop. married | 0.62 | 0.09*** |
| Prop. white | 0.85 | 0.16*** |
| Prop. black | 0.11 | -0.15*** |
| Prop. high school or higher | 0.63 | 0.14*** |
| Prop. high school or higher of whites | 0.64 | 0.11*** |
| Prop. employed | 0.55 | 0.11*** |
| Prop. unemployed | 0.03 | -0.00*** |
| Prop. people not working in CC | 0.24 | 0.21*** |
| Mean occupational score | 18.69 | 4.18*** |

Back to cognitive abilities

# Relation between potential yield of crops and good soil

| VARIABLES | (1) Corn | (2) Soy | (3) Wheat | (4) Alfalfa | (5) Cotton |
|---|---|---|---|---|---|
| pH 6.8-7.7 | 0.325 | 0.275 | 0.109 | 0.120 | -0.0316 |
| | (0.641) | (0.216) | (0.344) | (0.0735) | (0.111) |
| Observations | 305 | 305 | 305 | 305 | 305 |
| R-squared | 0.207 | 0.033 | 0.224 | 0.100 | 0.184 |
| C. Region FE | YES | YES | YES | YES | YES |
| Estimation | OLS | OLS | OLS | OLS | OLS |

# Marginal effect of pH on potential yield of crops


Back to Exclusion Restriction

# Robustness using different controls

| VARIABLES | (1) Share pop CC | (2) Share pop CC | (3) Share pop CC | (4) Share pop CC | (5) Share pop CC |
|---|---|---|---|---|---|
| Standardized vc p.c. | -0.115** | -0.115** | -0.130** | -0.103* | -0.104* |
| | (0.0527) | (0.0527) | (0.0652) | (0.0565) | (0.0567) |
| % Blacks MSA | | 0.00556 | 0.00688 | 0.00349 | 0.00356 |
| | | (0.00446) | (0.00546) | (0.00376) | (0.00378) |
| Median family income | | | 4.72e-06* | 2.57e-06 | 3.18e-06 |
| | | | (2.77e-06) | (1.84e-06) | (1.95e-06) |
| % people over 25 | | | | 0.0482 | 0.0328 |
| | | | | (0.124) | (0.125) |
| % people over 65 | | | | | 0.00376 |
| | | | | | (0.00488) |
| Observations | 922 | 922 | 922 | 691 | 691 |
| Place FE | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES |
| C. region x Year FE | YES | YES | YES | YES | YES |
| Year | CY 60-90 | CY 60-90 | CY 60-90 | CY 70-90 | CY 70-90 |
| Estimation | IV | IV | IV | IV | IV |
| s.e. | Robust | Robust | Robust | Robust | Robust |
| F | 36.47 | 18.01 | 13.37 | 8.72 | 8.34 |
| FS Beta | -0.543 | -0.628 | -0.561 | -0.798 | -0.799 |
| FS s.e. | 0.062 | 0.276 | 0.275 | 0.431 | 0.432 |

# Robustness using different controls

| VARIABLES | (1) Share pop CC | (2) Share pop CC | (3) Share pop CC | (4) Share pop CC |
|---|---|---|---|---|
| Standardized vc p.c. | -0.125** | -0.0937** | -0.0997* | -0.104* |
| | (0.0584) | (0.0446) | (0.0516) | (0.0568) |
| % Blacks MSA | | 0.00437 | 0.00335 | 0.00339 |
| | | (0.00373) | (0.00356) | (0.00382) |
| Median family income | | -2.29e-06 | 1.30e-06 | 3.39e-06* |
| | | (3.49e-06) | (2.02e-06) | (1.96e-06) |
| % people over 25 | | 0.0528 | 0.00250 | 0.0375 |
| | | (0.113) | (0.126) | (0.126) |
| % people over 65 | | 0.00263 | 0.00314 | 0.00341 |
| | | (0.00458) | (0.00479) | (0.00492) |
| Median gross rent | | 0.000382 | | |
| | | (0.000271) | | |
| Share pop. CC 1950 x Trend | -0.00902*** | | | |
| | (0.00251) | | | |
| Median house value | | | 3.72e-07 | |
| | | | (3.39e-07) | |
| House rent / value | | | | 4.052 |
| | | | | (7.227) |
| Observations | 923 | 691 | 691 | 691 |
| Place FE | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES |
| C. region x Year FE | YES | YES | YES | YES |
| Year | CY 60-90 | CY 70-90 | CY 70-90 | CY 70-90 |
| Estimation | IV | IV | IV | IV |
| s.e. | Robust | Robust | Robust | Robust |
| F | 4.61 | 3.93 | 3.87 | 3.43 |
| FS Beta | -0.596 | -0.920 | -0.845 | -0.800 |
| FS s.e. | 0.278 | 0.421 | 0.430 | 0.432 |

Back to Exclusion Restriction

# First stage using different crimes

| VARIABLES | (1) Violent | (2) Aggr. assaults | (3) Total | (4) Murder | (5) Rape (Tot) | (6) Robbery (Tot) | (7) Assaults (Tot) | (8) Burglary (Tot) | (9) Larceny (Tot) |
|---|---|---|---|---|---|---|---|---|---|
| Good soil x Lead | -0.00451*** | -0.00262*** | -0.0171** | -2.71e-05** | -0.000234*** | -0.00175*** | -0.00683** | -0.00306 | -0.00301 |
| | (0.00107) | (0.000816) | (0.00779) | (1.28e-05) | (8.10e-05) | (0.000346) | (0.00265) | (0.00217) | (0.00361) |
| Observations | 9,484 | 8,338 | 9,484 | 9,484 | 9,428 | 9,484 | 9,484 | 9,484 | 9,484 |
| R-squared | 0.763 | 0.686 | 0.783 | 0.688 | 0.722 | 0.779 | 0.739 | 0.750 | 0.715 |
| Place FE | YES | YES | YES | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES | YES | YES | YES |
| C. Region x Year | YES | YES | YES | YES | YES | YES | YES | YES | YES |
| Year | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 |
| Estimation | OLS | OLS | OLS | OLS | OLS | OLS | OLS | OLS | OLS |
| Cluster s.e. | State | State | State | State | State | State | State | State | State |
| F | 17.65 | 10.29 | 4.82 | 4.51 | 8.36 | 25.75 | 6.65 | 1.99 | 0.70 |

Back to Exclusion Restriction

# Results using different standard errors

| VARIABLES | (1) Share pop CC | (2) Share pop CC | (3) Share pop CC | (4) Share pop CC | (5) Share pop CC |
|---|---|---|---|---|---|
| Violent crime | -0.0717*** | -0.0717*** | -0.0717*** | -0.0717*** | -0.0717*** |
| | (0.00594) | (0.0255) | (0.00724) | (0.00714) | (0.0109) |
| Observations | 9,481 | 9,481 | 9,481 | 9,481 | 9,481 |
| R-squared | 0.940 | 0.940 | 0.940 | 0.940 | 0.940 |
| Place FE | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES |
| Year | 60-91 | 60-91 | 60-91 | 60-91 | 60-91 |
| Estimation | IV | IV | IV | IV | IV |
| s.e. cluster | NO | Place | Year | Place-year | State-year |
| F | 264.55 | 273.37 | 264.55 | 264.55 | 264.55 |
| FS Beta | -0.909 | -0.909 | -0.909 | -0.909 | -0.909 |
| FS s.e. | 0.056 | 0.141 | 0.085 | 0.046 | 0.068 |

Back to Robustness

# Externality parameters

$$\lambda_A = \left(1-\beta-\gamma\right)\hat{B}_N + \left(1-\gamma\right)\hat{B}_w \lambda_\theta = \alpha\hat{B}_P - \hat{B}_w \lambda_L = \hat{B}_N + \hat{B}_w - \frac{\delta}{\delta-1}\hat{B}_P$$

Back to Reduced form equations

# Parameters

- $\alpha$: share of total consumption expenditure to housing
  - US BLS Consumption Expenditure Survey: $\alpha \approx 0.3$
- $\beta$ and $\gamma$: share of labour and traded capital in production function
  - Glaeser (2009): $\beta \approx 0.6$ and $\gamma \approx 0.3$
- $\delta$: convexity of construction cost with respect to height
  - Ahlfeldt and McMillen (2015): $\delta \approx 2.7$
  - Inverse of elasticity of building height wrt land price. 0.3 for residential and 0.45 for commercial

Back to Reduced form equations

# Spatial equilibrium Model

- Spatial equilibrium

$$log\left(\bar{v}\right) = (1-\alpha)\,log\,(1-\alpha) + \alpha\,log\,(\alpha) + log\,(\theta) + log\,(w) - \alpha\,log\left(p_H\right)$$

- Labour demand

$$log\,(w) = log\left(\beta\right) + \frac{\gamma}{1-\gamma}log\left(\gamma\right) + \frac{1}{1-\gamma}log\,(A) + \frac{1-\beta-\gamma}{1-\gamma}\left[log\left(\bar{Z}\right) - log\left(\bar{N}\right)\right]$$

- Height demand

$$log\,(h) = \frac{1}{1-\delta}\left[log\,(c_0) + log\,(\delta)\right] + \frac{1}{\delta-1}log\left(p_H\right)$$

- Housing market equilibrium

$$h\bar{L} = HN$$

$$log\left(p_H\right) = \frac{1}{\delta}\left[log\,(c_0) + log\,(\delta)\right] + \frac{\delta-1}{\delta}\left[log\,(\alpha) + log\,(w) + log\,(N) - log\left(\bar{L}\right)\right]$$

Back to Problems

# Structural form equations

$$log\left(p_H\right) = K_P + \frac{(\delta-1)\left[log\,(A) + \beta log\,(\theta) - \left(1-\beta-\gamma\right) log\left(\bar{L}\right)\right]}{\delta\left(1-\beta-\gamma\right) + \alpha\beta\,(\delta-1)}$$

$$log\,(w) = K_w + \frac{\alpha\,(\delta-1)\, log\,(A) - \delta\left(1-\beta-\gamma\right) log\,(\theta) - \alpha\,(\delta-1)\left(1-\beta-\gamma\right) log\left(\bar{L}\right)}{\delta\left(1-\beta-\gamma\right) + \alpha\beta\,(\delta-1)}$$

$$log\,(N) = K_N + \frac{\left[\delta - \alpha\,(\delta-1)\right] log\,(A) + \delta\left(1-\gamma\right) log\,(\theta) + \alpha\,(\delta-1)\left(1-\gamma\right) log\left(\bar{L}\right)}{\delta\left(1-\beta-\gamma\right) + \alpha\beta\,(\delta-1)}$$

Back to Theoretical predictions

# Reduced form equations

$$log\left(p_H\right) = K_P + B_P log\left(\widehat{VC}_{cc}\right) + \mu_P$$

$$B_P = \frac{(\delta-1)\,\lambda_A + \beta\,(\delta-1)\,\lambda_\theta + (\delta-1)\left(1-\beta-\gamma\right)\lambda_L}{\alpha\beta\,(\delta-1) + \delta\left(1-\beta-\gamma\right)}$$

$$log\,(N) = K_N + B_N log\left(\widehat{VC}_{cc}\right) + \mu_N$$

$$B_N = \frac{[\delta\,(1-\alpha)+\alpha]\,\lambda_A + \delta\left(1-\gamma\right)\lambda_\theta + \alpha\,(delta-1)\,\lambda_L}{\alpha\beta\,(\delta-1) + \delta\left(1-\beta-\gamma\right)}$$

$$log\,(w) = K_w + B_w log\left(\widehat{VC}_{cc}\right) + \mu_w$$

$$B_w = \frac{(\delta-1)\,\alpha\lambda_A + \delta\left(1-\beta-\gamma\right)\lambda_\theta + \alpha\,(delta-1)\left(1-\beta-\gamma\right)\lambda_L}{\alpha\beta\,(\delta-1) + \delta\left(1-\beta-\gamma\right)}$$

Back to Reduced forms

# Reduced form estimation

| VARIABLES | (1) Log h. rent MSA | (2) Log income MSA | (3) Log Pop. MSA |
|---|---|---|---|
| Log VC p.c. in CC | 0.0832 | 0.0908* | 0.148 |
| | (0.0682) | (0.0531) | (0.139) |
| Observations | 918 | 918 | 918 |
| R-squared | 0.917 | 0.912 | 0.990 |
| Place FE | YES | YES | YES |
| Year FE | YES | YES | YES |
| C. division x Year | YES | YES | YES |
| Year | CY 60-90 | CY 60-90 | CY 60-90 |
| Estimation | IV | IV | IV |
| Cluster s.e. | MSA | MSA | MSA |
| F | 17.64 | 17.64 | 17.64 |

Back to Externality parameters

# Model reduced form estimation robustness

| VARIABLES | (1)<br>Log h. value MSA | (2)<br>Sh. Pop. CC |
|---|---|---|
| Log VC p.c. in CC | 0.0577 | -0.109** |
| | (0.108) | (0.0541) |
| Observations | 917 | 918 |
| R-squared | 0.924 | 0.925 |
| Place FE | YES | YES |
| Year FE | YES | YES |
| C. division x Year | YES | YES |
| Year | CY 60-90 | CY 60-90 |
| Estimation | IV | IV |
| Cluster s.e. | MSA | MSA |
| F | 18.04 | 17.64 |

Back to Model reduced form estimation

# Example model identification

Increase in violent crime, keeping constant land spread

# Example model identification

Increase in violent crime, keeping constant land spread

Effect on $w$ $\hat{B}_w > 0$

# Example model identification

Increase in violent crime, keeping constant land spread

Effect on $w$ $\quad \hat{B}_w > 0$ then and/or $\begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \uparrow w \\ \end{cases}$

# Example model identification

Increase in violent crime, keeping constant land spread

$$\text{Effect on } w \quad \hat{B}_w > 0 \text{ then and/or } \begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \uparrow w \\ \uparrow VC \rightarrow \uparrow \text{productivity} \rightarrow \uparrow w \end{cases}$$

# Example model identification

Increase in violent crime, keeping constant land spread

Effect on $w$ $\hat{B}_w > 0$ then and/or $\begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \uparrow w \\ \uparrow VC \rightarrow \uparrow \text{productivity} \rightarrow \uparrow w \end{cases}$

Effect on $p_H$ $\hat{B}_P = 0$

# Example model identification

Increase in violent crime, keeping constant land spread

$$\text{Effect on } w \quad \hat{B}_w > 0 \text{ then and/or } \begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \uparrow w \\ \uparrow VC \rightarrow \uparrow \text{productivity} \rightarrow \uparrow w \end{cases}$$

$$\text{Effect on } p_H \quad \hat{B}_P = 0 \begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \downarrow p_H \\ \end{cases}$$

# Example model identification

Increase in violent crime, keeping constant land spread

Effect on $w$ $\quad \hat{B}_w > 0$ then and/or $\begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \uparrow w \\ \uparrow VC \rightarrow \uparrow \text{productivity} \rightarrow \uparrow w \end{cases}$

Effect on $p_H$ $\quad \hat{B}_P = 0 \begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \downarrow p_H \\ \uparrow VC \rightarrow \uparrow \text{productivity} \rightarrow \uparrow p_H \end{cases}$

# Example model identification

Increase in violent crime, keeping constant land spread

Effect on $w$ $\quad \hat{B}_w > 0$ then and/or $\begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \uparrow w \\ \uparrow VC \rightarrow \uparrow \text{productivity} \rightarrow \uparrow w \end{cases}$

Effect on $p_H$ $\quad \hat{B}_P = 0 \begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \downarrow p_H \\ \uparrow VC \rightarrow \uparrow \text{productivity} \rightarrow \uparrow p_H \end{cases}$

Effect on $N$ $\quad \hat{B}_N = 0$

# Example model identification

Increase in violent crime, keeping constant land spread

Effect on $w$ $\quad \hat{B}_w > 0$ then and/or $\begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \uparrow w \\ \uparrow VC \rightarrow \uparrow \text{productivity} \rightarrow \uparrow w \end{cases}$

Effect on $p_H$ $\quad \hat{B}_P = 0 \begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \downarrow p_H \\ \uparrow VC \rightarrow \uparrow \text{productivity} \rightarrow \uparrow p_H \end{cases}$

Effect on $N$ $\quad \hat{B}_N = 0 \begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \downarrow N \\ \end{cases}$

# Example model identification

Increase in violent crime, keeping constant land spread

Effect on $w$ $\quad \hat{B}_w > 0$ then and/or $\begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \uparrow w \\ \uparrow VC \rightarrow \uparrow \text{productivity} \rightarrow \uparrow w \end{cases}$

Effect on $p_H$ $\quad \hat{B}_P = 0 \begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \downarrow p_H \\ \uparrow VC \rightarrow \uparrow \text{productivity} \rightarrow \uparrow p_H \end{cases}$

Effect on $N$ $\quad \hat{B}_N = 0 \begin{cases} \uparrow VC \rightarrow \downarrow \text{amenities} \rightarrow \downarrow N \\ \uparrow VC \rightarrow \uparrow \text{productivity} \rightarrow \uparrow N \end{cases}$

Back to Externality parameters

# Results on employment decentralization

The effect of crime on proportion of MSA employment in central city county

| VARIABLES | (1) All | (2) Industry | (3) Service | (4) Ind/serv | (5) Manufacturing | (6) Finance |
|---|---|---|---|---|---|---|
| Violent crime | -0.0112** | -0.0197*** | -0.0240*** | 0.0137 | -0.0241*** | -0.0110 |
| | (0.00463) | (0.00736) | (0.00481) | (0.0105) | (0.00863) | (0.00969) |
| Observations | 5,352 | 5,352 | 5,352 | 5,352 | 5,352 | 5,352 |
| Place FE | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES |
| Year | 74-91 | 74-91 | 74-91 | 74-91 | 74-91 | 74-91 |
| Estimation | IV | IV | IV | IV | IV | IV |

Back to Mediation

# Results on employment decentralization

The effect of crime on proportion of MSA employment in central city county

| VARIABLES | (1) All | (2) Industry | (3) Service | (4) Ind/serv | (5) Manufacturing | (6) Finance |
|---|---|---|---|---|---|---|
| Violent crime | -0.0112** | -0.0197*** | -0.0240*** | 0.0137 | -0.0241*** | -0.0110 |
| | (0.00463) | (0.00736) | (0.00481) | (0.0105) | (0.00863) | (0.00969) |
| Observations | 5,352 | 5,352 | 5,352 | 5,352 | 5,352 | 5,352 |
| Place FE | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES |
| Year | 74-91 | 74-91 | 74-91 | 74-91 | 74-91 | 74-91 |
| Estimation | IV | IV | IV | IV | IV | IV |

*Overall decrease in proportion of employment in the central county*

Back to Mediation

# Results on employment decentralization

The effect of crime on proportion of MSA employment in central city county

| VARIABLES | (1) All | (2) Industry | (3) Service | (4) Ind/serv | (5) Manufacturing | (6) Finance |
|---|---|---|---|---|---|---|
| Violent crime | -0.0112** | -0.0197*** | -0.0240*** | 0.0137 | -0.0241*** | -0.0110 |
| | (0.00463) | (0.00736) | (0.00481) | (0.0105) | (0.00863) | (0.00969) |
| Observations | 5,352 | 5,352 | 5,352 | 5,352 | 5,352 | 5,352 |
| Place FE | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES |
| Year | 74-91 | 74-91 | 74-91 | 74-91 | 74-91 | 74-91 |
| Estimation | IV | IV | IV | IV | IV | IV |

*Decentralization for both industry and service*

Back to Mediation

# Results on employment decentralization

The effect of crime on proportion of MSA employment in central city county

| VARIABLES | (1) All | (2) Industry | (3) Service | (4) Ind/serv | (5) Manufacturing | (6) Finance |
|---|---|---|---|---|---|---|
| Violent crime | -0.0112** | -0.0197*** | -0.0240*** | 0.0137 | -0.0241*** | -0.0110 |
| | (0.00463) | (0.00736) | (0.00481) | (0.0105) | (0.00863) | (0.00969) |
| Observations | 5,352 | 5,352 | 5,352 | 5,352 | 5,352 | 5,352 |
| Place FE | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES |
| Year | 74-91 | 74-91 | 74-91 | 74-91 | 74-91 | 74-91 |
| Estimation | IV | IV | IV | IV | IV | IV |

*Manufacturing decentralizes*

Back to Mediation

# Results on employment decentralization

The effect of crime on proportion of MSA employment in central city county

| VARIABLES | (1) All | (2) Industry | (3) Service | (4) Ind/serv | (5) Manufacturing | (6) Finance |
|---|---|---|---|---|---|---|
| Violent crime | -0.0112** | -0.0197*** | -0.0240*** | 0.0137 | -0.0241*** | -0.0110 |
| | (0.00463) | (0.00736) | (0.00481) | (0.0105) | (0.00863) | (0.00969) |
| Observations | 5,352 | 5,352 | 5,352 | 5,352 | 5,352 | 5,352 |
| Place FE | YES | YES | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES | YES | YES |
| Year | 74-91 | 74-91 | 74-91 | 74-91 | 74-91 | 74-91 |
| Estimation | IV | IV | IV | IV | IV | IV |

*Finance is the only sector to not decentralize*

Back to Mediation

# Results on amenity

| VARIABLES | (1) Pub transp MSA | (2) Highway MSA | (3) H. price MSA | (4) Pop. MSA |
|---|---|---|---|---|
| Violent crime | -3.670*** | 0.509* | 31.75 | -12,013 |
| | (0.819) | (0.295) | (21.14) | (20,958) |
| Observations | 921 | 921 | 921 | 9,481 |
| Place FE | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES |
| Year | 60-91 | 60-91 | 60-91 | 60-91 |
| Estimation | IV | IV | IV | IV |
| s.e. cluster | MSA-year | MSA-year | MSA-year | MSA-year |

*Congestions might have increased: lower amount of people taking public transport and more highways built*

Back to Mediation

# Results on amenity

| VARIABLES | (1) Pub transp MSA | (2) Highway MSA | (3) H. price MSA | (4) Pop. MSA |
|---|---|---|---|---|
| Violent crime | -3.670*** | 0.509* | 31.75 | -12,013 |
| | (0.819) | (0.295) | (21.14) | (20,958) |
| Observations | 921 | 921 | 921 | 9,481 |
| Place FE | YES | YES | YES | YES |
| Year FE | YES | YES | YES | YES |
| Year | 60-91 | 60-91 | 60-91 | 60-91 |
| Estimation | IV | IV | IV | IV |
| s.e. cluster | MSA-year | MSA-year | MSA-year | MSA-year |

*House prices and population do not react*

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# Model reduced form estimation controlling for highway

| VARIABLES | (1) Log h. rent MSA | (2) Log income MSA | (3) Log Pop. MSA |
|---|---|---|---|
| Log violent crime | 0.0766 | 0.0893* | 0.137 |
| | (0.0644) | (0.0508) | (0.133) |
| Highways in MSA | 0.0197* | 0.00444 | 0.0314 |
| | (0.0107) | (0.00841) | (0.0209) |
| Observations | 918 | 918 | 918 |
| R-squared | 0.917 | 0.913 | 0.990 |
| Place FE | YES | YES | YES |
| Year FE | YES | YES | YES |
| C. division x Year | YES | YES | YES |
| Year | CY 60-90 | CY 60-90 | CY 60-90 |
| Estimation | CF | CF | CF |
| Cluster s.e. | MSA | MSA | MSA |

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# Model reduced form estimation controlling for employment decentralization

| VARIABLES | (1) Log h. rent MSA | (2) Log income MSA | (3) Log Pop. MSA |
|---|---|---|---|
| Log violent crime | -0.0511 | -0.0384 | 0.00567 |
| | (0.119) | (0.0848) | (0.102) |
| Empl centralization | -0.318 | -0.187 | 0.147 |
| | (0.309) | (0.218) | (0.208) |
| Observations | 444 | 444 | 444 |
| R-squared | 0.905 | 0.922 | 0.998 |
| Place FE | YES | YES | YES |
| Year FE | YES | YES | YES |
| C. division x Year | YES | YES | YES |
| Year | CY 60-90 | CY 60-90 | CY 60-90 |
| Estimation | CF | CF | CF |
| Cluster s.e. | MSA | MSA | MSA |

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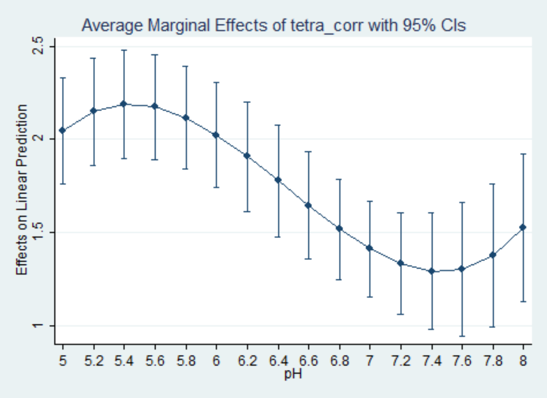
# Soil quality

We explore this estimating the following equation:

$$VC_{m,t}^{CC} = \mu_m + \mu_t + \beta Lead_{t-19} \times f(pH_m^{CC}) + \epsilon_{m,t}$$

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