The Value of Piped Water and Sewers: Evidence from 19th Century Chicago

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Our question(s)

- Economic historians: How did the massive investments in sanitation infrastructure in late nineteenth century U.S. cities impact land values and urban development?
- Urban economists: How much does sewer and piped water service contribute to land value? Does this contribution exceed the cost of service provision?

To address these questions we:

- Assemble parcel-level data describing price, date and location for a sample of Chicago real estate transactions, between 1870 and 1890.
- Match transactions to annual maps of sewer access.
- Exploit a natural experiment assigning water and sewer service to streets on the basis of imperceptible changes in elevation to;
  - Estimate marginal and average treatment effects in a quasi-experimental sample.
  - Extrapolate estimates of marginal treatment effect estimates to calculate ATE for all parcels receiving water and sewer service during our study period.
- Compare sewer and water construction and operation expenditures to relevant changes in real estate value.

Main findings

- Quasi-random assignment of water and sewer access about doubles the value of treated parcels on average (LATE $\approx$ ATE $\approx$ Relevant ATE).
- Applying this estimate to the area affected by Chicago's 1874-80 sewer and water expansion we find that increased land value exceeded construction cost by about a factor of 60.

Why is this important?

- Most existing evidence relates sewer and water infrastructure to health and mortality at the city level (Cutler and Miller [2005], Ferrie and Troesken [2008], Alsan and Goldin [2019]). We focus on parcel-level transaction prices.
- Spatially-detailed water and sewer data are scarce. Transportation (Atack et al. [2008], Jaworski and Kitchens [2019]) and power infrastructure [Lewis and Severnini, 2020] are better studied.
- As of 2015, $42\% = 3.01$b w/o piped water on premises. Many in developing world slums [World Health Organization, 2015]. Should policy makers expand access? Can they?
- Methodological contributions: (1) A new cross-sectional research design; (2) new method to extrapolate from local natural experiments to economically relevant areas.

Literature

Available evidence suggests huge effects of better water and sewers in the U.S. and Europe around 1900. For example,

- Cutler and Miller [2005], opening of H2O treatment in 12 big US cities ca. 1920 $\Longrightarrow \frac{13}{1000}$ decrease in child mortality. Baseline $\frac{28}{1000}$. Event study. Anderson et al. [2018] reanalysis much smaller.
- Alsan and Goldin [2019], watershed protection and sewers in Eastern MA ca. 1880 $\Longrightarrow \frac{24}{1000}$ decrease in child mortality. Baseline $\frac{131}{1000}$. Event study, c.f., Haines [2001], Condran and Murphy [2008]).
- Kesztenbaum and Rosenthal [2017], Paris sewer expansion. 10% more HH connections $\Longrightarrow$ 0.1 more year of life. Neighborhood-level panel data, 1881-1913.
- Literature in developing countries typically D-D for particular policies (e.g. water company privatization [Galiani et al., 2005], subsidy for household water connections [Devoto et al., 2012]). No evidence on land values and only indirect evidence for effects of urban construction projects.

Background: Chicago after the Civil War

- Chicago had 300,000 people in 1870 and 1.7 million by 1900.
- Land markets experienced successive waves of booms, panics, and busts (Hoyt 1933).
- Public health environment is disastrous. Flat and swampy terrain complicates efforts to keep sewage and water separate. In 1860:

  The average Chicagoan... used the backyard pump dug 10-12 feet into the sand and clay. Excrements were emptied into privy vaults sunk into the same soil, often in close proximity... the vaults were seldom tight. (Cain 1978).

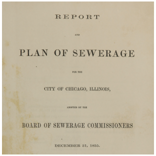
Background: Sanitation infrastructure in Chicago

- Chicago was first U.S. city to construct a comprehensive sewer system with systematic sewage disposal, mostly into local rivers.
- Piped water and sewers were installed together during our study period. Piped water without sewers caused cesspools to overflow.
- Drinking water came from Lake Michigan with no major water quality changes during our main 1874-1889 window. (2 Mile crib (1867), 4 Mile crib (1892), reversal of Chicago River (1900) [Ferrie and Troesken, 2008]).

Sewer construction I

- Typical (gravity) sewers need 1:200 grade [Mara, 1996]. 1:70 is just perceptible on a playing field [Aldous, 1999].
- Chicago is too flat. The intersection of the Eisenhower Expwy (formerly Tyler St.) and Halsted is about 2 miles from and 12 feet above the level of Lake Michigan, an average grade of about 1:880.
- Chicago's sewers relied on a system of manual flushing to allow them to function at a grade of 1:2500, requiring a massive program of regrading streets.

Sewer construction II



REPORT

AND

PLAN OF SEWERAGE

FOR THE

CITY OF CHICAGO, ILLINOIS,

ADOPTED BY THE

BOARD OF SEWERAGE COMMISSIONERS

DECEMBER 31, 1855.

- The 1855 plan for sewerage from noted engineer Chesbrough described Chicago's topography and laid out a strategy for sewering the entire city.
- Beginning in 1863, the city regularly issued sewer ordinances that enumerated streets, block by block, to be sewered and their finished grades.
- Water mains and sewers were typically installed at the same time.
- The 1855 plan called for constantly flushing sewers but this was not adopted at first. Sewers were flushed manually using horse-drawn carts.

Sewer construction III

The assignment of sewers to neighborhoods and streets was probably not independent of land value.

> *... the unsewered portion of the city is that which, of all others, most needs it. ... These neighborhoods are densely populated by people who have not the means to adopt any sanitary measures. - Chicago Tribune (6/25/1873)*

The Southwest Triangle

From the 1855 sewer plan:

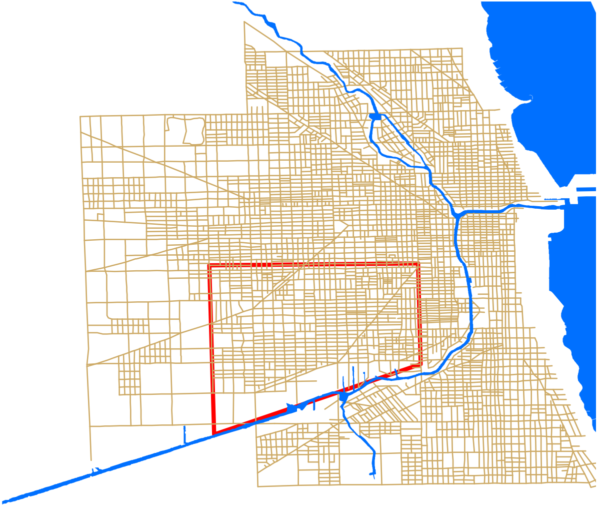
- "It will be necessary to raise the grades of streets an average of eighteen inches per 2500 feet going west."
- "Extreme south-west part of city too low..." to provide sewers, the "depth of filling required to raise streets over it, would average two feet" (p. 16).
- This area was defined as the "triangle" south of Tyler Street (now the Eisenhower Expressway) and west of Halsted Street.
- "As this part of the city may not be improved for several years, it is deemed sufficient for present purposes to state the general depth of filling that would be required..." (p. 16).

Sewer and piped water provision in this area is delayed ONLY due to the expense of 6" of marginal fill. Western edge of $\triangle$ is not given. We set it at 14000' from the CBD.

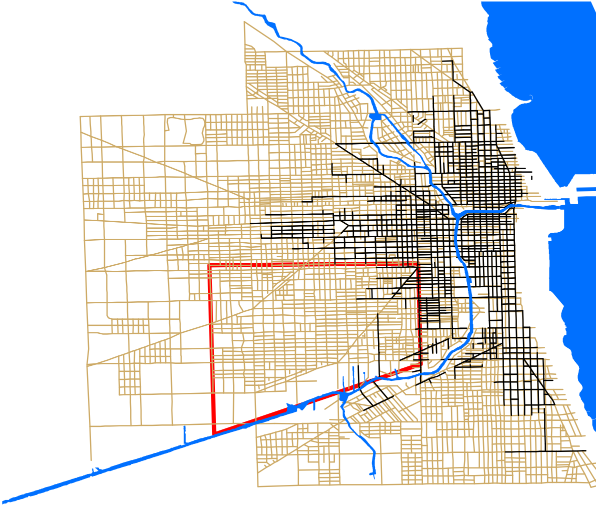
Data: Sewer networks by year

- The spatial sewer data we use was constructed from Annual Reports of the Chicago Department of Public Works.
- Fogel's Early Indicators Project created the Historical Urban Ecological Data for seven major cities, including Chicago.
- Files include ward boundaries and year by year GIS files showing build out of sewer and water system for 1830-1930.

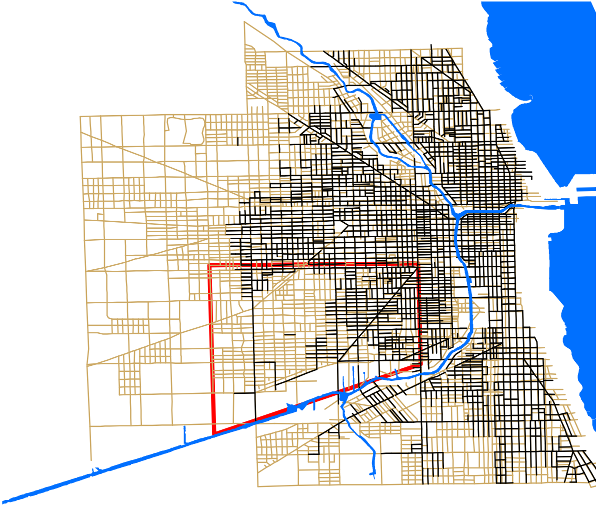
1880 Street Map and SW Triangle



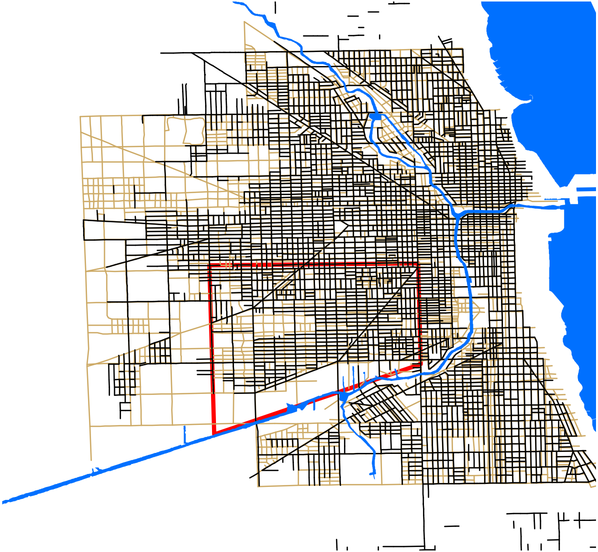
1870 Sewer Network



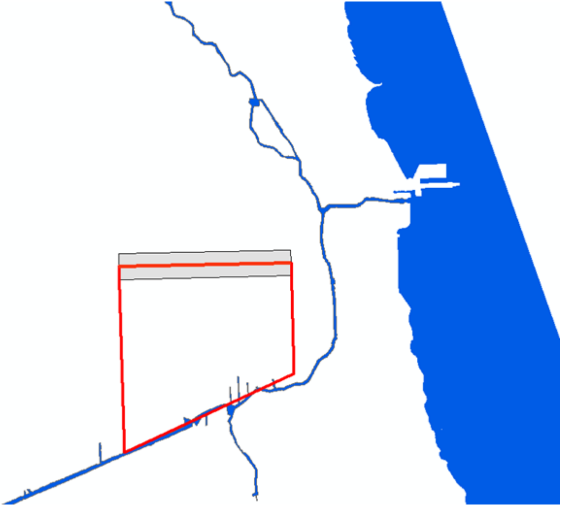
1880 Sewer Network



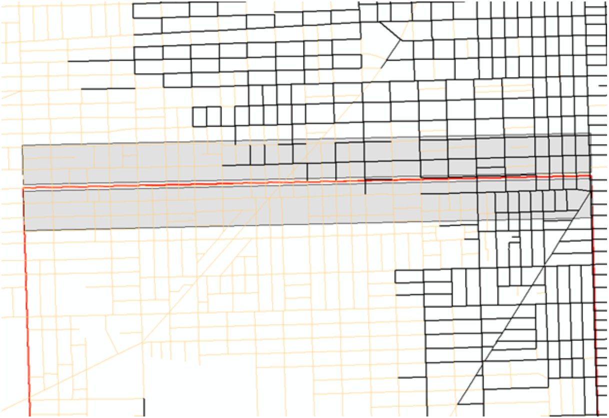
1890 Sewer Network



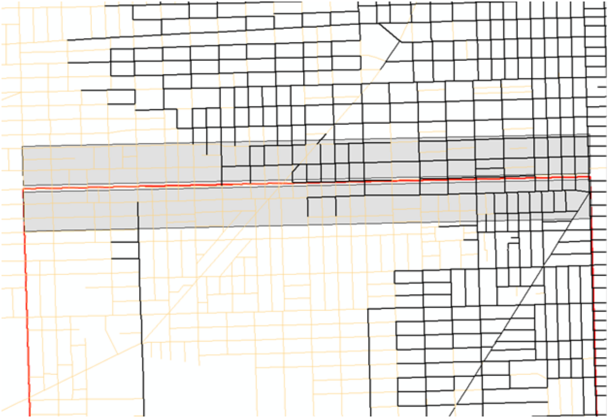
SW Triangle and 1000' buffer around EW leg



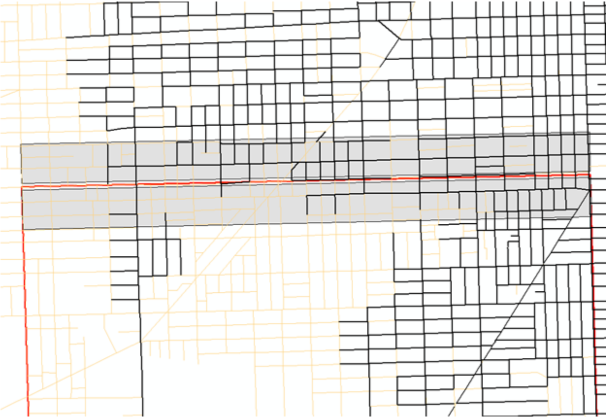
1874 Sewers, 1000' buffer around EW leg



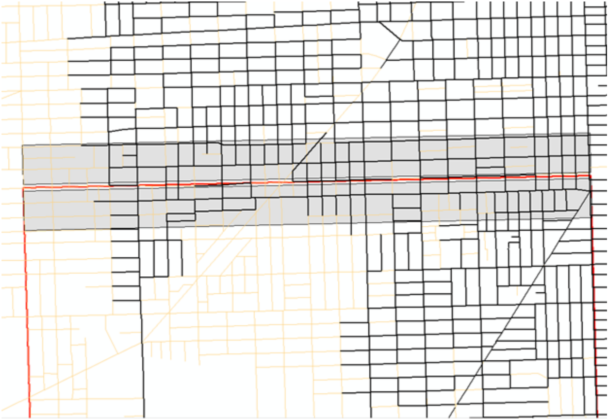
1876 Sewers, 1000’ buffer around EW leg



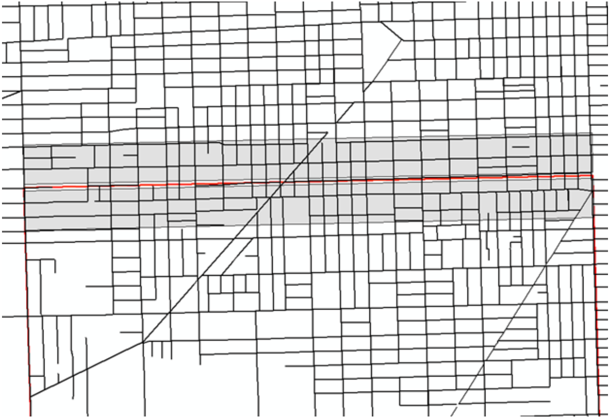
1878 Sewers, 1000’ buffer around EW leg



1880 Sewers, 1000' buffer around EW leg



1890 Sewers, 1000' buffer around EW leg



Data: Real Estate Transactions

- The Chicago Tribune regularly published a record of every parcel sale that was filed at the courthouse the previous day, including price, dimensions, date of sale, and an indicator for "improvement," and nearest intersection.
- We collect the parcel transactions for every Sunday paper from 1874 to 1889, when the Tribune stopped reporting transfers less than $1000
- We obtained around 700 observations per year in the 1870s and 1000 observations per year in the 1880s. We successfully geocoded 77% of transactions by matching street intersection names to the Logan 1880 street map and Google Maps API.

Parcel Transactions from the Tribune; Sundays, 1874-1889

SATURDAY'S TRANSFERS.

The following instruments were filed for record Saturday, April 10:

CITY PROPERTY.

Walnut st, 120 ft e of Western av, s f, 30x 126 ft, dated April 10 (A. E. and C. M. Hemler to John T. Shannon).............$ 2,025

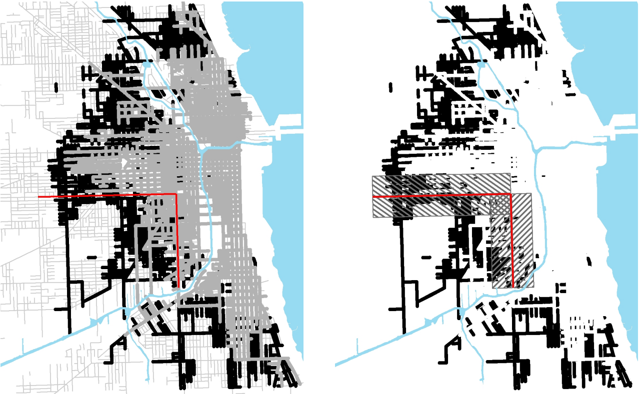
West Superior st, 49 4-10 ft e of Lincoln, n f, 25x128 ft, dated April 10 (B. F. Crosby to O. B. Olson).................... 600

Cleaver st, 225 ft s of Bradley, w f, 37½ x125 ft, dated April 8 (Mat Schillo et al. to M. Kufel et al.)...................... 750

West Madison st, 428 ft w of Staunton, s f, undivided $\frac{1}{3}$ of 24x126 ft, dated April 6 (Mary J. Seymour to C. L. Wehe)................................ 2,400

Each record reports location, price, area, "improved." houses

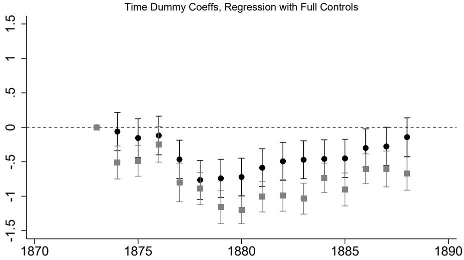
Study areas



Left: Sewers < 1874, $1874 - 1880$, > 1880, and boundaries of SW$\triangle$. *Right*: 'Relevant' sample area (1874-1880 expansion) and 'Quasi-experimental' sample areas.

Quasi-experimental areas extend $+/-$ $[75', 2000']$ from SW $\triangle$ boundary $< 14000'$ from the CBD (sometimes just the area near the EW leg).

Land prices in Chicago and Quasi-experimental sample



Mean ln(Price) by year in Quasi-experimental sample (Gray) and all of Chicago (Black). Controls: ln(miles to CBD), improved, corner, ln(Area).

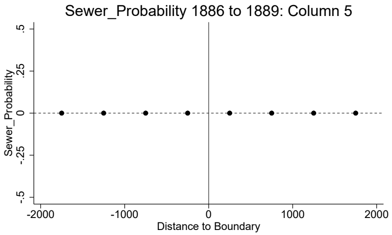
Quasi-experimental sample is a small part of a large market. We can ignore general equilibrium effects.

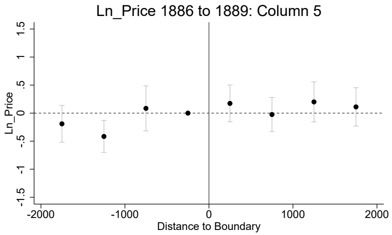
Trends match Hoyt (1933): 1877 "filled [landowners'] cup of misery to the brim," recovery in early 1880s.

Summary Statistics 1886-1889

	SW$\triangle = 1$	SW$\triangle = 0$	T-test	Relevant
Share Sewered	1.00	1.00	.	0.99
	(0.00)	(0.00)		(0.11)
Log Price	8.35	8.56	1.56	7.74
	(0.94)	(0.78)		(0.91)
Log Distance to CBD	9.08	8.98	-1.46	9.45
	(0.35)	(0.48)		(0.24)
Log Area	8.29	8.19	-0.99	8.12
	(0.67)	(0.51)		(0.46)
Share Improved	0.22	0.15	-1.11	0.19
	(0.42)	(0.36)		(0.39)
Share Corner	0.09	0.10	0.34	0.10
	(0.29)	(0.31)		(0.29)
Distance to Horsecar	751	374	-5.50	1887
	(527)	(314)		(1404)
Distance to Major Street	512	438	-1.11	430
	(431)	(390)		(370)
Year	1887.19	1887.35	0.95	1887.19
	(0.95)	(1.07)		(1.04)
Observations	68	86		598

Sewer share and price by distance to boundary, **1886-9**





Left: Share of parcels sewered 1874-80 by 500' bins of distance to SW$\triangle$ boundary, $x < 0$ is 'inside'. $x \in [-500, 0]$ is y intercept. Conditional on year, ln(area), ln(mi. to CBD).

Right: Same as left panel but y-axis is ln(Price). Note that low interior prices are far from the border.

Prices at the border are the same after sewer and water provision in the SW$\triangle$.

Placebo - **1886-9**

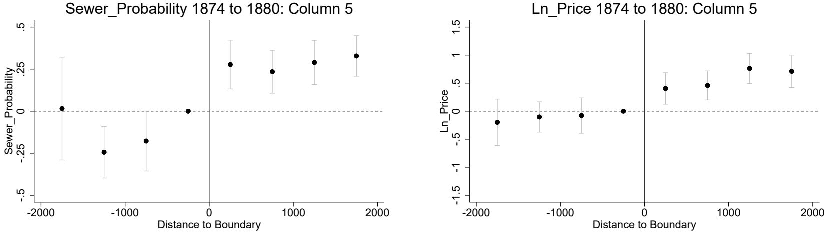
Reduced Form: ln(Price)						
SW $\triangle = 1$	-.174	-.233***	.165	-.183*	-.146	-.164*
	(.119)	(.096)	(.225)	(.105)	(.1)	(.09)
Miles to Boundary			1.03			
			(.539)			
R-squared	0.364	0.580	0.590	0.598	0.330	0.454
Year FE & ln(Area)	Y	Y	Y	Y	Y	Y
ln(mi. CBD)	Y	Y	Y	Y	Y	Y
Improved and Corner		Y	Y	Y		Y
Horsecar and Major Street				Y		
Sample	Q.E.	Q.E.	Q.E.	Q.E.	E.Q.E.	E.Q.E.
Observations	143	143	143	143	213	213

Whole SW$\triangle$ is sewered by 1886-9. Price gap is small economically and statistically.

Summary Statistics 1874-1880

	SW$\triangle = 1$	SW$\triangle = 0$	T-test	Relevant
Share Sewered	0.47	0.92	11.04	0.70
	(0.50)	(0.27)		(0.46)
Log Price	7.70	8.42	8.44	7.41
	(0.86)	(0.76)		(0.91)
Log Distance to CBD	9.13	9.10	-0.89	9.49
	(0.38)	(0.38)		(0.25)
Log Area	8.12	8.26	1.88	8.17
	(0.62)	(0.69)		(0.54)
Share Improved	0.11	0.23	2.99	0.15
	(0.31)	(0.42)		(0.36)
Share Corner	0.11	0.13	0.42	0.14
	(0.32)	(0.33)		(0.34)
Distance to Horsecar	884	427	-9.53	1757
	(573)	(335)		(1351)
Distance to Major Street	564	475	-2.13	441
	(427)	(363)		(372)
Year	1877.18	1877.45	1.14	1877.60
	(2.19)	(2.17)		(2.26)
Observations	150	211		1358

Sewer incidence and land price by distance to boundary, 1874-80



Left: Share of parcels sewered 1874-80 by 500' bins of distance to SW$\triangle$ boundary, $x < 0$ is 'inside'. $x \in [-500, 0]$ is y intercept. Conditional on year, ln(area), ln(mi. to CBD).

Right: Same as left panel but y-axis is ln(Price).

TSLS-LATE 1874-80

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A: OLS								
Sewer=1	.413***	.39***	.4***	.328***	-.018	.194***	.276***	.239***
	(.086)	(.082)	(.084)	(.139)	(.101)	(.08)	(.081)	(.078)
R-squared	0.386	0.502	0.504	0.567	0.598	0.505	0.376	0.439
B: Red. Form								
SW Triangle=0	.657***	.568***	.714***	.439***	.292*	.3***	.336***	.332***
	(.072)	(.069)	(.073)	(.093)	(.151)	(.068)	(.063)	(.059)
R-squared	0.486	0.568	0.591	0.606	0.602	0.527	0.397	0.462
C. 1^{st} Stage								
SW Triangle=0	.432***	.443***	.451***	.323***	.194**	.443***	.259***	.259***
	(.039)	(.04)	(.043)	(.057)	(.097)	(.04)	(.031)	(.031)
R-squared	0.451	0.455	0.455	0.456	0.474	0.455	0.333	0.335
F-stat	119.729	125.018	110.664	32.311	3.992	125.018	71.711	71.283
D. IV								
Sewer=1	1.522***	1.283***	1.582***	1.36***	1.501	.678***	1.296***	1.283***
	(.22)	(.191)	(.209)	(.352)	(1.067)	(.164)	(.277)	(.266)
Mouriffe Wan 95%	1	1	1	1	1	1	0	0
Year FE & ln(Area)	Y	Y	Y	Y	Y	Y	Y	Y
ln(mi. CBD)	Y	Y	Y	Y	Y	Y	Y	Y
Imp. & Corner		Y	Y	Y	Y	Y		Y
H.car & Maj. St.			Y					
Sample	Q.E.	Q.E.	Q.E.	Q.E. 1k'	Q.E.	Q.E.	E.Q.E.	E.Q.E.
Observations	351	351	351	172	351	351	533	533

N.B: $e^{1.3} \approx 3.7$.

Notation for MTE framework

$$
\begin{aligned}
Y &\sim \ln(\text{Parcel Transaction Price})\\
X &\subseteq \{\text{Transaction year}, f(\text{distance to CBD}), \ln(\text{Area}),\\
&\qquad\qquad \text{Corner, `Improved'}\}\\
D &\sim \begin{cases} 1 & \text{Sewer and water}\\ 0 & \text{Not}\end{cases}\\
Z &\sim \begin{cases} 1 & \text{Not in SW } \triangle\\ 0 & \text{In SW } \triangle\end{cases}\\
P &\sim \text{Quasi-experimental sample and}\\
&\quad \text{distribution of } (Y, X, Z, D, U_1, U_0, U_D)\\
P^* &\sim \text{Relevant sample and}\\
&\quad \text{distribution of } (Y^*, X^*, Z^*, D^*, U_1^*, U_0^*, U_D^*)
\end{aligned}
$$

MTE Framework,Carneiro et al. [2010]

$$
\begin{aligned}
Y_1 &= X'\beta_1 + U_1 \\
Y_0 &= X'\beta_0 + U_0 \\
D &= \mathbb{1}[v(X,Z) - U_D \geq 0] \\
(X,Z) &\perp (U_1, U_0, U_D)
\end{aligned}
\tag{1}
$$

for Y_1 'treated', Y_0 'not treated'.

Assuming cubic control function in $\widehat{p}$.

$$
\begin{aligned}
\Longrightarrow p &= F(X,Z) \\
Y &= X'\delta_0 + \widehat{p}X'(\delta_1 - \delta_0) + \gamma_1\widehat{p} + \gamma_2\widehat{p}^2 + \gamma_3\widehat{p}^3 + \varepsilon
\end{aligned}
$$

$$
\begin{aligned}
&\Longrightarrow MTE(X, U_D) = X'(\delta_1 - \delta_0) + \gamma_1 + 2\gamma_2 U_D + 3\gamma_3 U_D^2 \\
&\Longrightarrow ATE = E(X)'(\delta_1 - \delta_0) + \gamma_1 + \gamma_2 + \gamma_3
\end{aligned}
$$

N.B.: U_D rescaled so $P_{U_D} \sim U[0,1]$.

MTE estimation (2)

χ^2	220	221	237	243	245
H0: $\delta_1 - \delta_0, \gamma_1, \gamma_2, \gamma_3 = 0$	0	0	0	.005	.002
H0: $\delta_1 - \delta_0 = 0$	.108	.07	.074	.298	.205
H0: $\gamma_2, \gamma_3 = 0$	.002	0	.001	.656	.498
H0: $\delta_1 - \delta_0, \gamma_2, \gamma_3 = 0$	.001	.001	.001	.15	.076
ATE	1.04^{***}	$.72^{**}$	$.8^{***}$	1.31^{*}	1.31^{**}
	(.4)	(.35)	(.32)	(.69)	(.65)
ATE*	1.04^{***}	$.75^{***}$	$.89^{***}$	1.05^{**}	$.87^{**}$
	(.31)	(.27)	(.36)	(.46)	(.41)
Carr & Kitagawa	0.156	0.154	0.434	0.792	0.916
Year FE & ln(Area)	Y	Y	Y	Y	Y
ln(mi. CBD)	Y	Y	Y	Y	Y
Improved and Corner		Y	Y		Y
Horsecar and Major Street			Y		
Sample	Q.E.	Q.E.	Q.E.	E.Q.E.	E.Q.E.
Observations	351	351	351	533	533

$$p = F(X, Z)$$

$$Y = X'\delta_0 + \widehat{p}X'(\delta_1 - \delta_0) + \gamma_1\widehat{p} + \gamma_2\widehat{p}^2 + \gamma_3\widehat{p}^3 + \varepsilon$$

$$MTE(X, U_D) = X'(\delta_1 - \delta_0) + \gamma_1 + 2\gamma_2 U_D + 3\gamma_3 U_D^2$$

$$ATE = E(X)'(\delta_1 - \delta_0) + \gamma_1 + \gamma_2 + \gamma_3$$

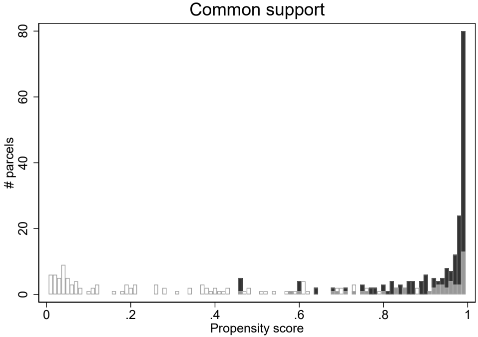
MTE estimation (1)

$\widehat{p}$	.74	1.21	1.3	2.39	3.59
	(2.84)	(2.73)	(2.8)	(2.91)	(2.92)
$\widehat{p}^2$	-3.56	-3.04	-2.74	-.94	-1.71
	(4.83)	(4.41)	(4.23)	(4.51)	(4.1)
$\widehat{p}^3$	3.81	3.65	3.26	1.05	1.59
	(3.03)	(2.77)	(2.62)	(2.72)	(2.5)
$\widehat{p}\ln(\text{Area})$	-.1	.02	.02	.09	.16
	(.23)	(.23)	(.22)	(.23)	(.23)
$\widehat{p}\mathbb{1}(\text{Year} = 1875)$	-.97***	-.93***	-.77***	-.66*	-.69*
	(.33)	(.32)	(.29)	(.37)	(.36)
$\widehat{p}\mathbb{1}(\text{Year} = 1876)$	-.64*	-.6	-.39	-.35	-.38
	(.39)	(.4)	(.38)	(.46)	(.46)
$\widehat{p}\mathbb{1}(\text{Year} = 1877)$	-1.4***	-1.66***	-1.4***	-.93*	-1.02**
	(.54)	(.56)	(.49)	(.5)	(.46)
$\widehat{p}\mathbb{1}(\text{Year} = 1878)$	-1.24**	-1.58***	-1.18***	-1.04*	-1.19**
	(.54)	(.55)	(.44)	(.6)	(.53)
$\widehat{p}\mathbb{1}(\text{Year} = 1879)$	-1.09*	-1.43***	-1.17**	-.36	-.64
	(.59)	(.54)	(.55)	(.67)	(.61)
$\widehat{p}\mathbb{1}(\text{Year} = 1880)$	-.51	-1.2*	-.62	.78	.21
	(.72)	(.62)	(.62)	(1.01)	(.83)
$\widehat{p}\ln(\text{mi. CBD})$	-.11	.14	.07	-.57	-.92
	(.68)	(.61)	(.62)	(.85)	(.81)
$\widehat{p}\mathbb{1}(\text{Improved})$		.38	.28		0
		(.56)	(.51)		(.69)
$\widehat{p}\mathbb{1}(\text{Corner})$		-.14	-.01		-.05
		(.36)	(.34)		(.39)
Sample	Q.E.	Q.E.	Q.E.	E.Q.E.	E.Q.E.
Observations	351	351	351	533	533

$$p = F(X, Z)$$

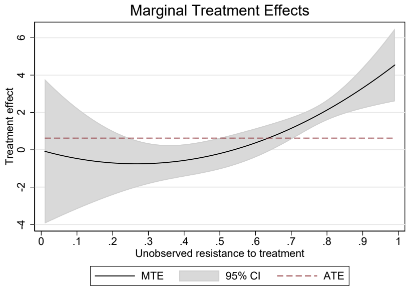
$$Y = X'\delta_0 + \widehat{p}X'(\delta_1 - \delta_0) + \gamma_1\widehat{p} + \gamma_2\widehat{p}^2 + \gamma_3\widehat{p}^3 + \varepsilon$$

Common support



Density of treated and untreated parcels by propensity score. The propensity score distribution is skewed toward one, but conditional on a mass of propensity scores, treated and untreated parcels both occur. Based on column 2 of main table.

Marginal Treatment Effects



Expected MTE as a function of U_D. Dashed line shows ATE for this sample/specification and sample average X's. Based on column 2 of main table.

Model Validity

[Vytlacil, 2002] shows that the MTE model (1) implies

$$Pr(Y_{D,Z=1} = Y_{D,Z=0}) = 1 \,(\text{Exogeneity})$$
$$Pr(D_{Z=1} \geq D_{Z=0}) = 1 \,(\text{Monotonicity})$$
$$Z \perp (Y_{11}, Y_{10}, Y_{01}, Y_{00}, D_1, D_0 | X) \,(\text{Randomness})$$

Balke and Pearl [1997] show that for any subset A of the support of $Y \implies$

$$Pr(Y \in A, D = 1 | Z = 1, X) \geq Pr(Y \in A, D = 1 | Z = 0, X)$$

and

$$Pr(Y \in A, D = 0 | Z = 0, X) \geq Pr(Y \in A, D = 0 | Z = 1, X)$$

Carr and Kitagawa [2021] proposes a test based on this intuition. We usually pass this test (the controls are important).

Proposition: Extrapolation of MTE estimates

$$
\begin{aligned}
Y_1^* &= X^*\beta_1 + U_1^* \\
Y_0^* &= X'\beta_0 + U_0^* \\
D^* &= \mathbb{1}[v(X^*, Z^*) - U_D^* \geq 0]
\end{aligned}
$$

$$\cancel{(X, Z)} \cancel{\perp (U_1, U_0, U_D)}$$

$$P^*_{U_1,U_0,U_D} = P_{U_1,U_0,U_D}$$

Then we can extrapolate MTE to Relevant sample to get

$$ATE^* = E(X^*)'(\delta_1 - \delta_0) + \gamma_1 + \gamma_2 + \gamma_3$$

For comparison sake,

$$ATE = E(X)'(\delta_1 - \delta_0) + \gamma_1 + \gamma_2 + \gamma_3$$

Validity of Extrapolation

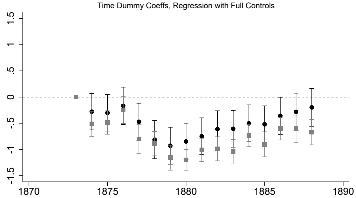
Extrapolating our estimations from Quasi-experimental to Relevant sample requires

- No heterogeneous treatment effects (so $MTE = ATE$).

Or,

- That the structural equations and joint distribution of residuals is the same in both samples.
- We do not have a test for this condition.
- We can show that patterns in the two data sets are broadly similar.

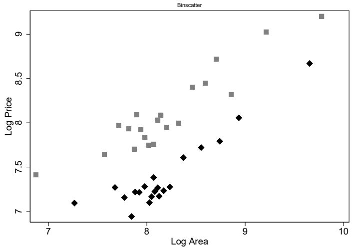
Land prices by year and sample



Mean Y by year in main Quasi-experimental (gray) sample and the Relevant (black) sample. Conditional on: ln(Area), ln(miles to CBD), improved, corner.

Means and variances of Y in the two samples are similar conditional on year.

Land prices by parcel size and sample

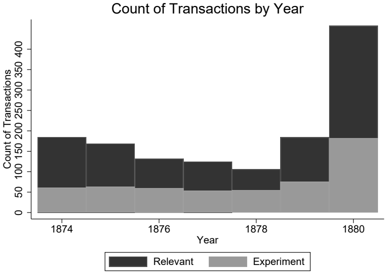


Gray: Transaction price by parcel area in Quasi-experimental sample.

Black: Transaction price by parcel area in Relevant sample.

Price elasticity of area about the same in Quasi-experimental and Relevant sample.

Transaction frequency by year and sample



Relevant sample is larger, but distribution of transactions across years is similar in Quasi-experimental and relevant samples.

The spike in 1880 reflects a change in sampling effort, not in transaction volume.

MTE estimation (2) (repeat)

χ^2	220	221	237	243	245
H0: $\delta_1 - \delta_0,\, \gamma_1,\, \gamma_2,\, \gamma_3 = 0$	0	0	0	.005	.002
H0: $\delta_1 - \delta_0 = 0$	.108	.07	.074	.298	.205
H0: $\gamma_2,\, \gamma_3 = 0$	.002	0	.001	.656	.498
H0: $\delta_1 - \delta_0,\, \gamma_2,\, \gamma_3 = 0$	.001	.001	.001	.15	.076
ATE	1.04^{***}	$.72^{**}$	$.8^{***}$	1.31^{*}	1.31^{**}
	(.4)	(.35)	(.32)	(.69)	(.65)
ATE*	1.04^{***}	$.75^{***}$	$.89^{***}$	1.05^{**}	$.87^{**}$
	(.31)	(.27)	(.36)	(.46)	(.41)
Carr & Kitagawa	0.156	0.154	0.434	0.792	0.916
Year FE & ln(Area)	Y	Y	Y	Y	Y
ln(mi. CBD)	Y	Y	Y	Y	Y
Improved and Corner		Y	Y		Y
Horsecar and Major Street			Y		
Sample	Q.E.	Q.E.	Q.E.	E.Q.E.	E.Q.E.
Observations	351	351	351	533	533

$$p = F(X, Z)$$

$$Y = X'\delta_0 + \widehat{p}X'(\delta_1 - \delta_0) + \gamma_1\widehat{p} + \gamma_2\widehat{p}^2 + \gamma_3\widehat{p}^3 + \varepsilon$$

$$MTE(X, U_D) = X'(\delta_1 - \delta_0) + \gamma_1 + 2\gamma_2 U_D + 3\gamma_3 U_D^2$$

$$ATE = E(X)'(\delta_1 - \delta_0) + \gamma_1 + \gamma_2 + \gamma_3$$

The value of water and sewer service

Apply our estimate of ATE^* to Relevant sample.

- Average parcel is 125' deep. Treated area is (installed sewer length 1874-80) $\times 250' \approx 138 \times 10^6$ ft^2.
- Area of untreated parcels transacted in relevant sample 1874-1880 $\approx 1.8 \times 10^6$ ft^2. Total price $\approx 0.81 \times 10^6$\$ (1880 dollars) $\Longrightarrow$ 0.45\$ ft^2.
- Value of sewers and piped water

$$\begin{aligned} V^* &\approx 0.45 \times (e^{ATE^*} - 1) \times (138 \times 10^6) \\ &\approx 69 \times 10^6 \$ \end{aligned}$$

for $ATE^* = 0.75$ (one of our smallest).

Flows vs Stocks

- An average unsewered parcel in our Quasi-experimental receives sewer service in 4 years after we observe it.
- Interest rates were about 8% during this period (Hoyt).
  - $r = 0.08 \Longrightarrow \delta = \frac{1}{1+r} \approx 0.93$.
  - V^* is PV of four years of flow.
  - Full asset price is

$$
\begin{aligned}
V^{*\infty} &= \sum_{t=0}^{\infty} (\delta^4)^t V^* \\
&\approx 3.8 V^*
\end{aligned}
$$

    That is, we should scale up by about a factor of 4 for asset value.
  - $3.8 \times 69m \approx 262m\$$.
- To the extent that the taxes used to pay back sewer bonds are capitalized into land prices, our estimates of the value of plumbing and piped water is understated.

Expenditure on water and sewer

- We digitized expenditures on water and sewer for the entire period [Chicago Board of Public Works, 1873].
- Water system had large pumping stations while sewer system was mainly just pipes.
- Financed primarily by bonds paid by property taxes, not special assessments as for roads.
- Expenditures 1874-1880:
  - Sewer Construction: \$1.5 M
  - Maintenance: \$0.4 M
  - Waterworks construction: \$2.4 M
  - Total: \$4.3 M (1880 dollars)
- $\frac{\text{Increased land value}}{\text{Total cost}} = \frac{262 \times 10^6 \$1880}{4.3 \times 10^6 \$1880} \approx 60$

Conclusions

- Water and sewer infrastructure is understudied relative to its likely importance for two reasons,
  - Data availability
  - Credible research designs

  We resolve these problems with purpose collected data and a new research design.
- We also develop a methodology for extrapolating MTE estimates from samples with quasi-experimental variation to economically relevant samples.
- Both our research design and and the extrapolation methodology should find wider application.
- Sewer and water infrastructure constructed in Chicago from 1874-1880 at least doubled the transaction price of treated parcels on average. This leads to an increase in land value of about 60 times the cost of construction.

Other stuff

- Calculation of sewer value relative to annual wage/housing expenditure.
- Sewers and density? Total population?

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Citywide OLS

VARIABLES	In Sample 1874-1880 ln(Price)	Not in Sample 1874-1880 ln(Price)	Citywide 1874-1880 ln(Price)
Sewer=1	0.248*	0.246***	0.244***
	(0.134)	(0.0342)	(0.0331)
Ln_Area	0.674***	0.797***	0.789***
	(0.0685)	(0.0197)	(0.0190)
To CBD	-0.000627**	-0.000143***	-0.000138***
	(0.000270)	(1.10e-05)	(1.08e-05)
To Lake		-4.77e-05***	-4.83e-05***
		(2.18e-06)	(2.14e-06)
To River		9.61e-05***	9.53e-05***
		(4.10e-06)	(3.90e-06)
YEAR FE	Y	Y	Y
o(3) To CBD	Y	Y	Y
Observations	212	4,186	4,398
R^2	0.537	0.515	0.512

back

Census Outcomes within 3000' of EW Leg

	1880 Census			1900 Census		
VARIABLES	Population Density	%Foreign	Mean_SES	Population Density	%Foreign	Mean_SES
SW Tri=1	-18,313	10.69**	-9.825***	4,197	3.833**	-1.383
	(11,960)	(3.501)	(2.109)	(4,414)	(1.723)	(1.023)
centroid_to_cbd	32.83**	0.00454	-0.000617	17.64***	0.00986***	-0.00319**
	(13.57)	(0.00322)	(0.00250)	(5.340)	(0.00242)	(0.00150)
centroid_to_lake	-33.00**	-0.00644	-8.98e-05	-21.53***	-0.0112***	0.00253*
	(14.04)	(0.00375)	(0.00260)	(5.073)	(0.00232)	(0.00151)
centroid_to_river	-3.027	0.000889	0.00157	2.487	0.000515	0.00215***
	(4.415)	(0.00222)	(0.00156)	(1.896)	(0.000610)	(0.000459)
Observations	17	17	17	81	81	81
R^2	0.709	0.912	0.858	0.608	0.768	0.659

Parcel Transactions with House and Improved Transfers

Saturday's Transfers.

The following instruments were filed for record Saturday, Jan. 31:

CITY PROPERTY.

Orchard st, 160 ft s of North av, w f, 20x90 ft, dated Jan. 15 (O. B. Green to Carl Kahl)..$ 800

The premises No. 31 Twenty-ninth st, dated Jan. 20 (Williard F. Myrick to Frederick Keeler).. 5,250

Hanover st, 175 ft s of Thirty-second, e f, 25x124 ft, dated July 28, 1884 (J. R. Winterbotham to Catherine Stone)........... 550

The premises No. 111 Hoyne av, dated Jan. 31 (M. C. and J. H. Drury to Richard R. Evans).. 5,000

Morgan st, 194 ft n of Twentieth, in rear, 26x87½ ft, improved, oated Jan. 16 (M. and R. Voda to Joseph Srotir)............. 1,707

Arnold st, 308 ft n of Thirtieth, e f, 25x120 ft, dated Jan. 31 (B. F. Ayer to Noble S. Elderkin).. 1,396

Each record reports location, price, area, "improved." back