Sewers and Urban Development

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How does sewer construction affect the development of cities? I

- Rank the most important things a local government does for you, e.g.; water, law and order, sewer, fire, other public health, transportation, schools. Sewers are understudied.
- If spatial equilibrium reflects the balancing of agglomeration with congestion forces, understanding the importance of sewers for mitigating congestion is fundamental to understanding equilibrium.
- The absence of sewers is one of the defining features of slums. How does the provision of modern sanitation change slums? What is the incidence of this change?

Literature

- Water and sewer infrastructure has large, well documented effects on health in the developing world [Ashraf et al., 2017, Bhalotra et al., 2021, Galiani et al., 2005] and in developed world cities in the late 19th/early 20th centuries [Alsan and Goldin, 2019, Anderson et al., 2018, Ferrie and Troesken, 2008]).
- Sewers have no effect on infant mortality in Brazil 1990-2010 [Gamper-Rabindran et al., 2010].
- Sewers have a large effect on land prices in late 19th century Chicago [Coury et al., 2022].
- There does not seem to be a lot of sorting in response to sewers [Alsan and Goldin, 2019].

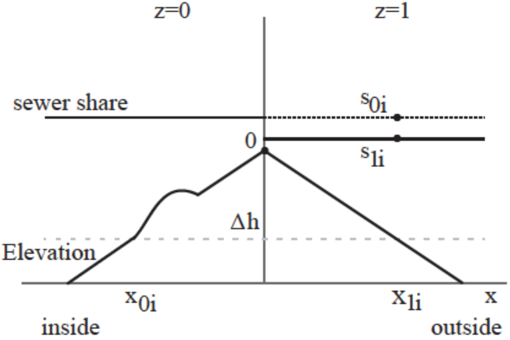
$\Longrightarrow$ weak prior that sewers lead to large increase in density and not much change in demographics.

Identification I

- Sewers work on gravity. Moving sewage on a grade of less than 1:200 is hard. Uphill is harder.
- Sewer networks generally serve a (part of a) single drainage basin.
- Two census tracts on opposite sides of a basin divide should be similar (on average), but one may require moving sewage uphill to get to an existing sewer network.

How can we use this intuition to think about the effect of sewer service on urban development?

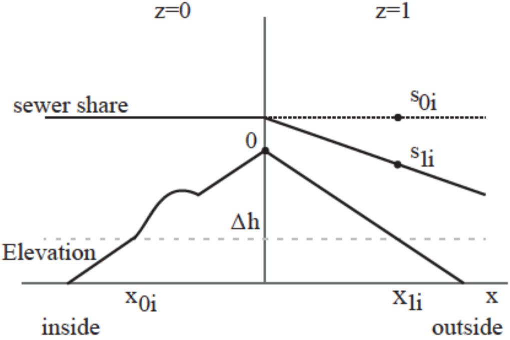
Identification with a discontinuity in sewer share



Plot of elevation and sewer share in a neighborhood of a basin divide. 'inside' is uphill from existing network. x is distance to the basin divide. Elevation is relative to basin divide.

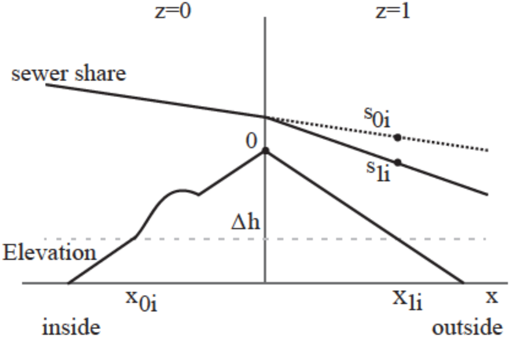
Treatment is $s_0 - s_1$. Without independent effects of elevation or x, inside is a control for outside.

Identification with a kink in sewer share



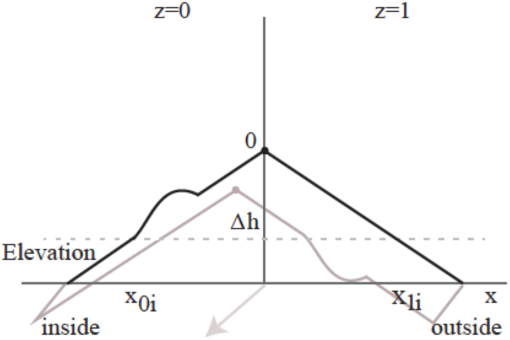
No strong prior over whether crossing a basin divide will lead to a step or a kink in sewer share. It depends on the scale over which costs increase.

Identification with a kink in sewer share and trend in x



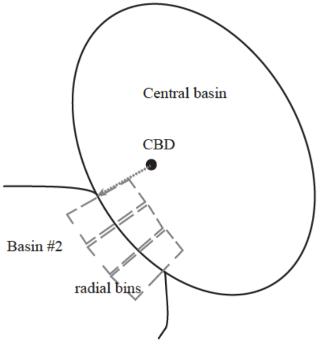
Distance to the basin divide may have an independent effect on sewer share. We need to look for a kink (or step) in sewer share net of the effect of x displacement.

Identification, elevation vs displacement



Distance to the basin divide and climbing to the elevation divide should both matter. With elevation, we can exploit variation independent of x.

Empirical Geography: Central Basins, ‘Inside’, and Radial bins

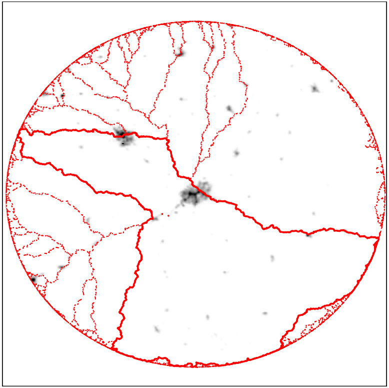


- Drainage basins containing CBDs are ‘central basins’.
- A census tract is ‘inside’ if its centroid lies in a central basin.
- Define ‘radial bins’, 2km wide, and $2 \times$ 2km deep. These are ‘strips’.
- Define ‘segment’ as part of basin divide dividing two basins, also ‘segment bins’. Sometimes these are strips.

Data

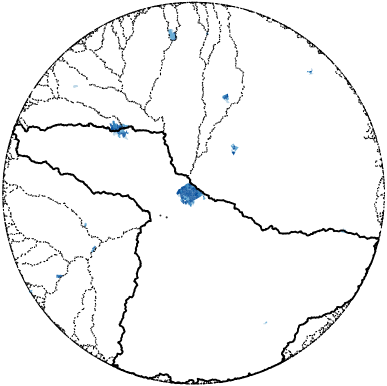
- Unit of observation is a census tract. Sample is tracts with centroid in a radial bin for cities in Brazil, Colombia, South Africa, Jordan, and Tanzania.
- UN Cities data gives CDB coordinates for cities with population$>$300,000 in 2014. They all have some sewer service.
- Sewer data all comes from census questions, e.g., 'Is the bathroom or toilet drain connected to the public sewer system?' Treatment is the share of households in a tract with sewer access.
- Outcomes are tract level; population density, income, and literacy. All from census data.

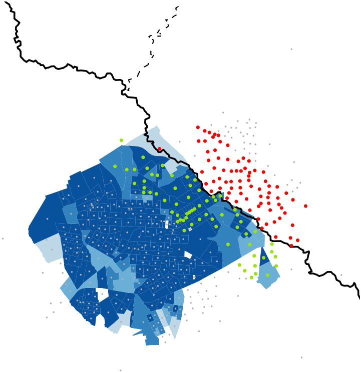
Drainage basins



Drainage basin boundaries in a 75km disk centered on Cascavel, Brazil. Background is lights at night, grey is all drainage basin boundaries.

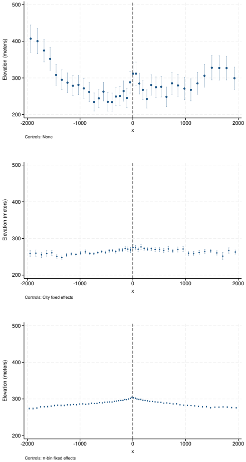
Sewers and 'Inside' near Cascavel, Brazil





- Blue is sewer share.
- Tracts in the central basin are 'inside'.
- Drop tracts with centroids more than 2km from the basin divide.

Why radial-bin controls?



Mean elevation by distance to basin divide; raw data (top), net of city mean (middle), and net of radial bin mean (bottom). NB: On average the divide is not a dramatic feature.

Description

	(1) CBD Basin + 2KM	(2) ± 2KM Basin Divide
Cities	92	92
Mean area CBD basin (KM^2)	1,371	1,371
π-bins	4,094	1,513
Tracts	239,393	50,039
Share inside	0.90	0.54
	(0.30)	(0.50)
Mean tract area (KM^2)	0.63	0.16
	(5.80)	(1.25)
Mean dist to CBD (KM)	13.53	12.06
	(15.04)	(16.10)
Mean log dist to CBD (m)	8.95	8.71
	(1.11)	(1.15)
Mean dist to basin divide (KM)	11.02	0.86
	(8.93)	(0.59)
Sewer share	0.75	0.69
	(0.33)	(0.37)
Mean num people in a tract	339	427
	(367)	(392)
Pop density (persons/KM^2)	28,379	22,348
	(34,882)	(27,093)
Income (per month, 2022 USD)	968	940
	(921)	(834)
Share literate	0.93	0.92
	(0.30)	(0.40)

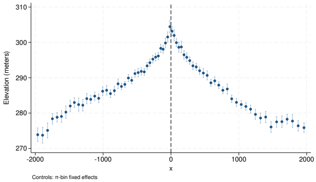
- About 30 tracts per bin.
- Central basins average about 80km square.
- Average population density is modest, $427/0.16 \approx 2700 km^2$. Some tracts are much denser.

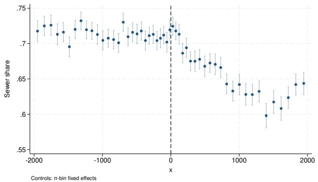
Estimation sample; Brazil, Colombia, South Africa, Jordan

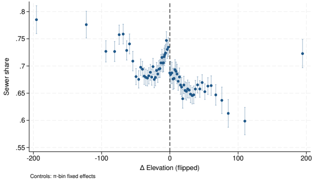
	(1) Cities	(2) π-bins	(3) Tracts	(4) Share inside	(5) Tract area	(6) Pop. Density	(7) Sewer share
Brazil	55	936	22,372	0.54	0.23	17,093	0.68
Colombia	17	285	23,059	0.53	0.07	29,049	0.72
Jordan	2	4	18	0.33	1.34	1,196	0.60
South Africa	12	211	3,053	0.52	0.31	8,635	0.78
Tanzania	6	77	1,537	0.66	0.07	25,803	0.08

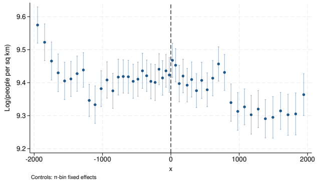
- Jordan is households, not people.
- The economic geography of these places is really different.
- Estimations will be at tract/bin level, so most of the weight will come from Colombia and Brazil.
- Tanzania has no sewers.

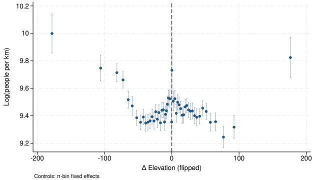
Identification











Estimation (old school)

- First stage is sewer share (s) by tract (j) controlling for; slope and intercept (by radial bin k), and elevation (h).

$$\begin{aligned} s_{jk} = & \mathbb{1}(\pi\text{-bin})_{jk} + \mathbb{1}(\pi\text{-bin})_{jk} x_{jk} + A^s \Delta h_{jk} + \\ & \alpha_0 \mathbb{1}(\text{Outside})_{jk} + \alpha_1 \mathbb{1}(\text{Outside})_{jk} x_{jk} \\ & + \alpha_2 \mathbb{1}(\text{Outside})_{jk} \Delta h_{jk} + \eta^s_{jk}. \end{aligned}$$

- Structural equation,

$$y_{jk} = \mathbb{1}(\pi\text{-bin})_{jk} + \mathbb{1}(\pi\text{-bin})_{jk} x_{jk} + A \Delta h_{jk} + \beta s_{jk} + \eta_{jk}. \quad (1)$$

- Instruments: (1) outside indicator, $\mathbb{1}(\text{Outside})_{jk}$, (2) outside indicator $\times$ displacement, $\mathbb{1}(\text{Outside})_{jk} x_{jk}$, (3) outside indicator $\times$ elevation, $\mathbb{1}(\text{Outside})_{jk} \Delta h_{jk}$.
- NB: Continuous treatment with controls. LATE interpretation of β is difficult.

Sewers and population density

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1. OLS									
Sewer share	0.8576***	0.8576***	0.8576***	0.8019***	0.8019***	0.8019***	0.7397***	0.7397***	0.7397***
	(0.0259)	(0.0259)	(0.0259)	(0.0265)	(0.0265)	(0.0265)	(0.0264)	(0.0264)	(0.0264)
2. First-stage									
Outside	-0.0078**	-0.0055	-0.0051	-0.0143***	-0.0037	-0.0049	-0.0098***	-0.0023	-0.0046
	(0.0036)	(0.0040)	(0.0040)	(0.0037)	(0.0044)	(0.0044)	(0.0037)	(0.0047)	(0.0047)
x*Outside	-0.0001***		-0.0001***	-0.0001***		-0.0001***	-0.0001***		-0.0001***
	(0.0000)		(0.0000)	(0.0000)		(0.0000)	(0.0000)		(0.0000)
ΔElev*Outside		-0.0002**	-0.0001		-0.0004***	-0.0004***		-0.0003**	-0.0002*
		(0.0001)	(0.0001)		(0.0001)	(0.0001)		(0.0001)	(0.0001)
3. IV *log(pop density)*									
Sewer share	1.8205***	2.9299**	2.0196***	3.8170***	1.9875**	3.9573***	6.0387***	0.4847	5.9413***
	(0.3540)	(1.4079)	(0.3568)	(0.4469)	(0.8654)	(0.4331)	(0.6026)	(1.5324)	(0.5846)
4. SATE *log(pop density)*									
Sewered	2.3389***	4.8942***	2.6074***	3.7429***	2.9344***	4.0004***	5.7074***	4.0916**	5.7297***
	(0.3641)	(1.2770)	(0.3662)	(0.3681)	(0.8500)	(0.3562)	(0.3850)	(1.4261)	(0.3774)
N	50039	50039	50039	50039	50039	50039	50039	50039	50039
F	93.22	6.617	63.10	84.28	19.78	62.25	73.25	5.924	50.32
Elevation	Y	Y	Y	Y	Y	Y	Y	Y	Y
π-bins	Y	Y	Y	Y	Y	Y	Y	Y	Y
x	Y	Y	Y						
seg$\times$x				Y	Y	Y			
π-bins$\times$x							Y	Y	Y

Note: Robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

- A 1% increase in sewer share gives about a 6% increase in population density.
- No/tiny effects on income and literacy.

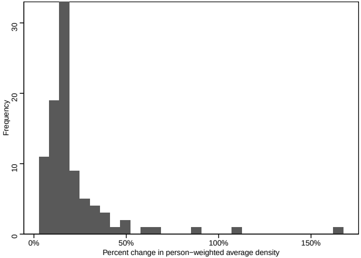
Estimation (better)

- At the *parcel* level, treatment is binary. A parcel is connected, or it is not.
- At the parcel level we have IV with binary treatment and parametric controls.
- This is the problem the LIV framework solves. LIV framework allows calculation of any ATE you want.
- Problem: we observe tract level aggregates of parcel outcomes, not parcel outcomes.
- Solution: Small variance approximation. Take expectations of LIV first stage and structural equation over tracts, and estimate these equations from tract level means and variances of parcel level variables.
- This gives us ATE. It's close to the TSLS treatment effect, but less sensitive to instrument choice.

How important are sewers? v1.0

- Add sewer connections for 1% of people to a city.
- Start with the densest census tract first, and work down to less dense tracts.
- Assume each 1% increase in sewer connections increases tract population by 6%.
- This gives a 6% increase in city population.
- Compare: (1) Baum-Snow [2007] finds that each radial interstate highway decreased the density of US central cities by 9%. (2) Baum-Snow et al. [2017] find that radial highways in China have no impact on total population and lead to a 4% decline in central city population density.

The effect of sewers on city average density (person weighted) is sometimes much larger.



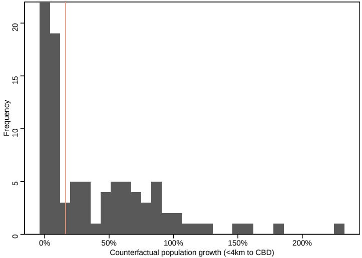
- Median city gets 16% increase in experienced density from 1% more sewer connections.
- With a 5% agglomeration effect, this is 0.8% increase in city average wage.
- ...plus whatever wage increase is experienced by the 6% of new residents.

How important are sewers? v2.0

From Tsivanidis [2019], the Transmilenio BRT allows about 18% of the population of Bogota to access the CBD. How important is this compared to providing 100% sewer access within 4k of CBD?

- Complete the sewer network for all tracts with centroids within 4km of CBD.
- Assume each 1% increase in sewer connections increases tract population by 6% holding city population constant.
- Calculate share of city population that gains access to CBD because of this intervention.

- Percentage of city population gaining walking access to the CBD when central city sewer network in completed.



- Vertical red line at 18% is the share of Bogota's population that gained access to the CBD because of the Transmilenio BRT system.
- There are many cities where finishing the sewer network in the central city will have as big an impact on access to the center as a world class BRT system.
- This suggests that labor market benefits of sewer systems are sometimes of similar magnitude to those of a BRT, on top of direct benefits.

Conclusion I

- We've estimated the effects of sewer access on population density in a sample of developing world cities.
- At 6%, the average effect seems large, both absolutely, and in comparison with estimated effects for transportation infrastructure.
- Re-sorting in response to sewer access is unimportant.
- Estimation technique for IV with parametric controls when treatment is a (continuous) share.

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