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.
- 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?
- If spatial equilibrium reflects the balancing of agglomeration with congestion forces, understanding the importance of sewers for mitigating congestion is fundamental to understanding equilibrium.
- Are the effects of sewers on cities the same everywhere? (as seems to be the case for roads).

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].

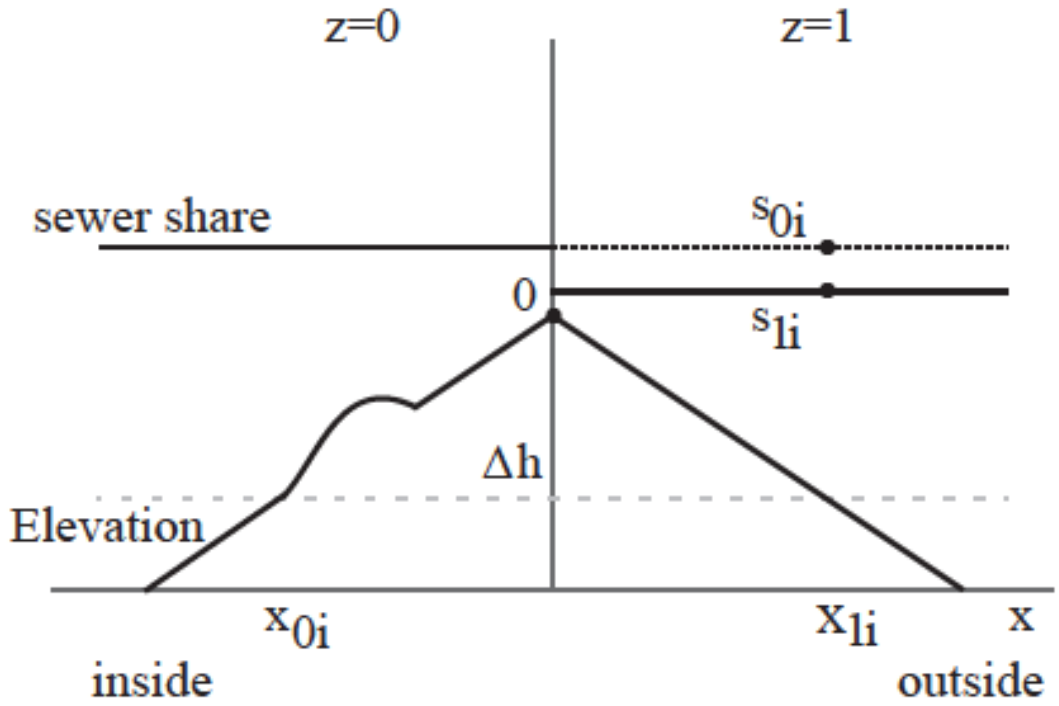
$\Longrightarrow$ weak prior that sewers lead to large increase in density and not much change in demographics. No prior over heterogeneity of effects.

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?

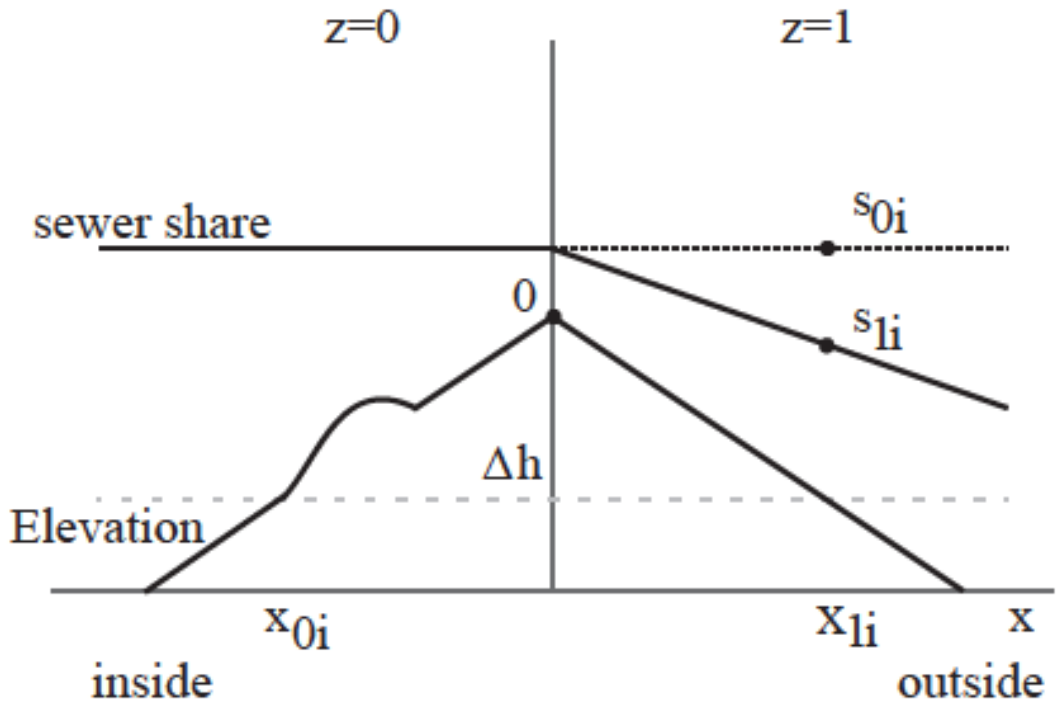
Identification with a discontinuity in sewer share



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.

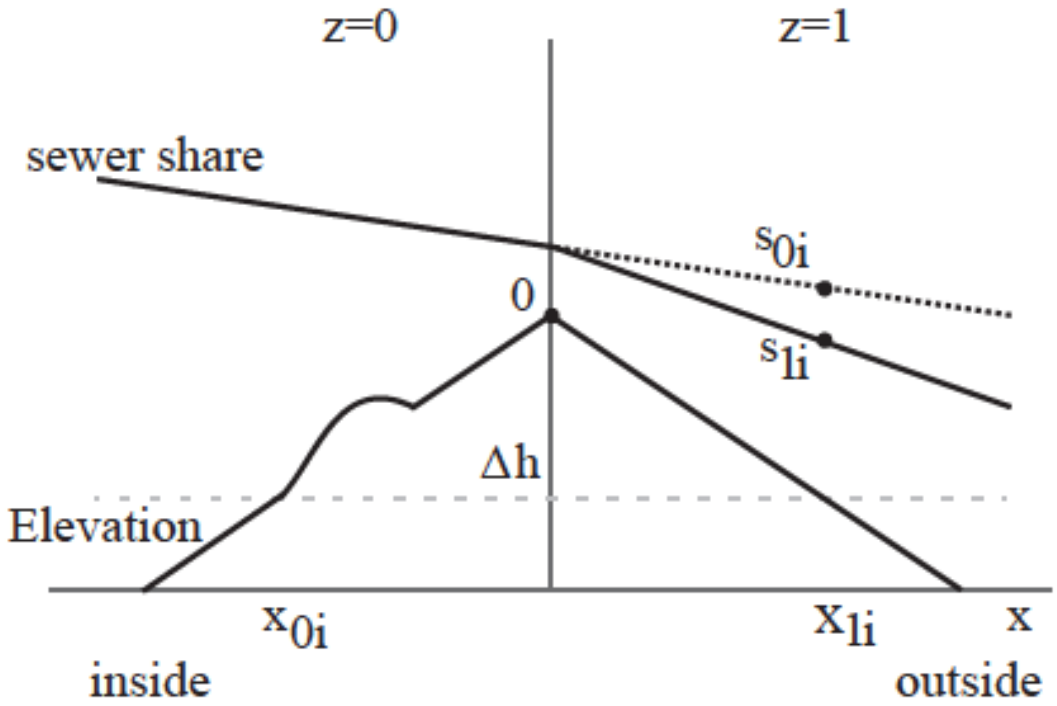
Treatment is $s_0 - s_1$. Without independent effects of elevation or x, inside is a control for outside.

Identification with a kink in sewer share



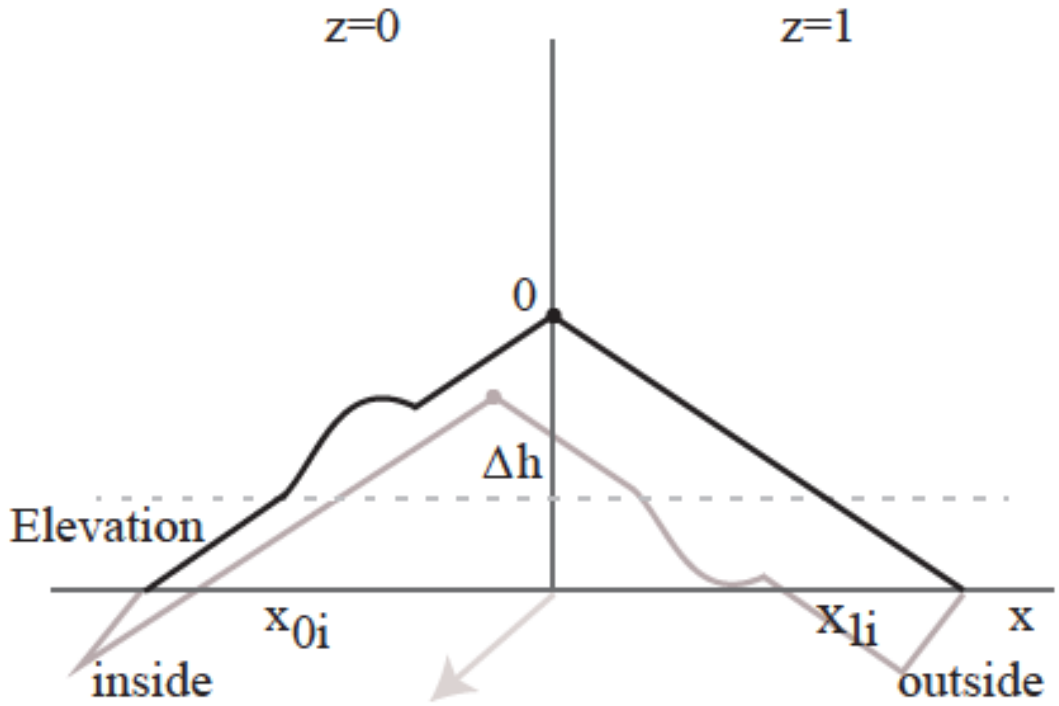
No strong prior over whether crossing a basin divide will lead to a step or a kink in sewer share. It depends on the scale over which costs increase.

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



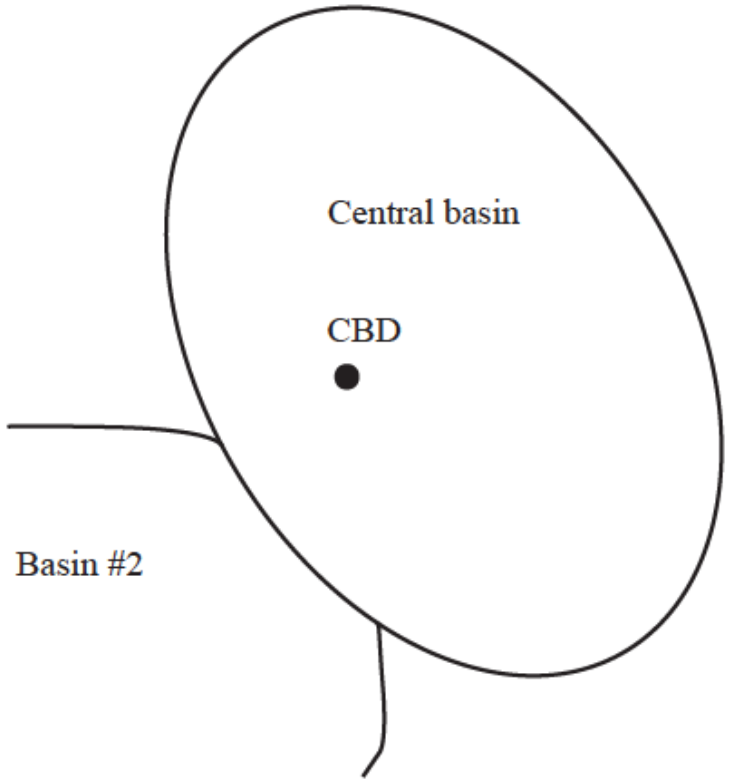
Distance to the basin divide and climbing to the elevation divide should both matter. With elevation, we can exploit variation independent of x.

Identification, further issues

- Taking gravity as given, crossing a basin divide must increase the cost of sewer access for otherwise similar locations.
- To turn this intuition into a research design, we need an empirical analog to the figures.
  - Draw basin divides with DEMs and GIS tools.
  - Define x as 'perpendicular displacement from basin divide'.
  - Define 'inside' as 'in a basin containing a large city'.
  - Translate to a plane? How wide/long a strip should we use?
  - What is the shape of the sewer share response, kink vs. step vs. both?

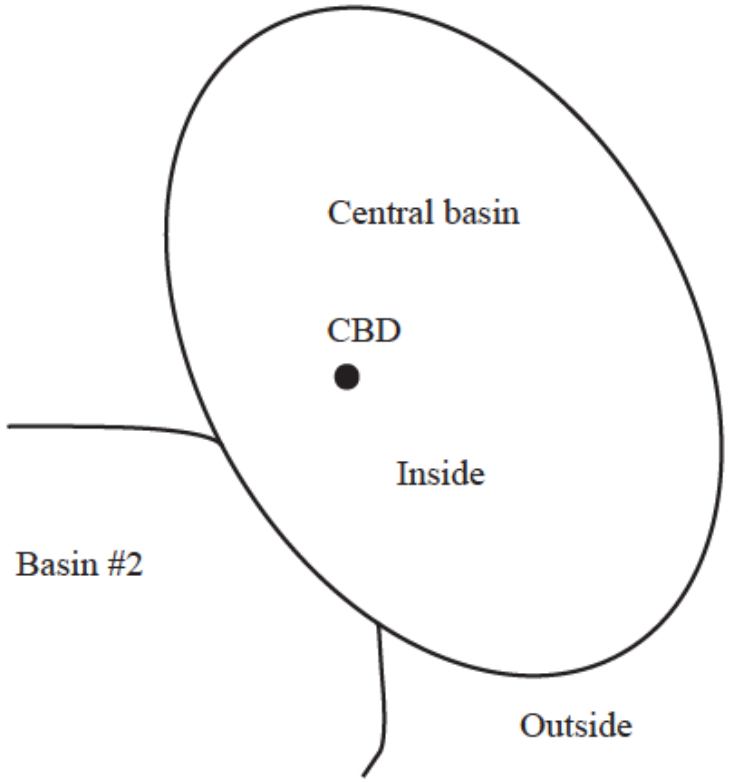
Geography: Central basins

Consider drainage basins containing CBDs. These are ‘central basins’.



‘Inside’

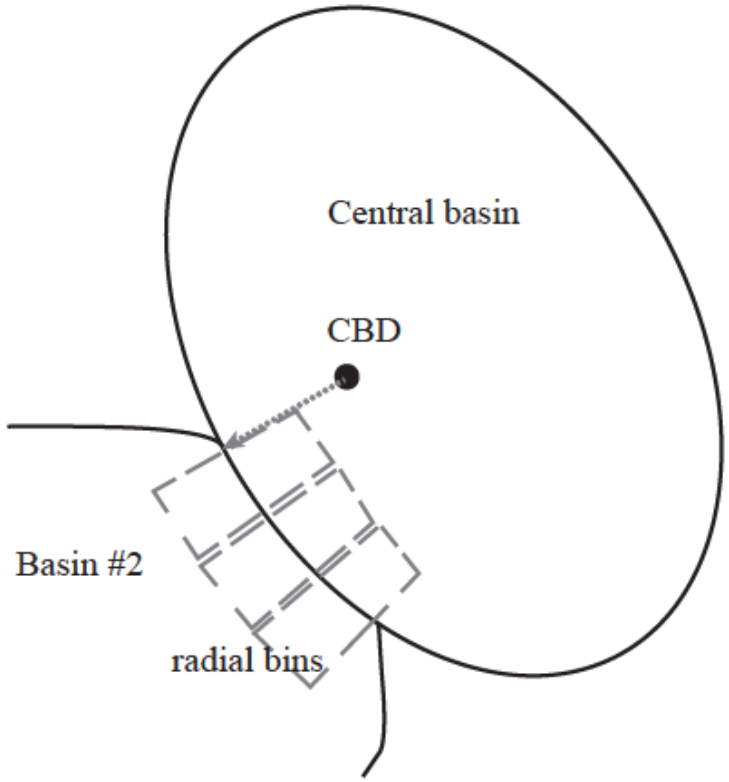
Say a census tract is ‘inside’ if its centroid lies in the central basin.



If Basin #2 is also a CBD basin, then ‘inside’ is defined based on closest CBD.

Geography: Radial bins

Define 'radial bins', 2km wide, and 2×2km deep. Radial bin zero starts at the point on the basin divide closest to the CBD.



Tract elevation is relative to highest tract centroid in the same radial bin $\leq$ 2km from the basin divide. NB: larger elevations are lower.

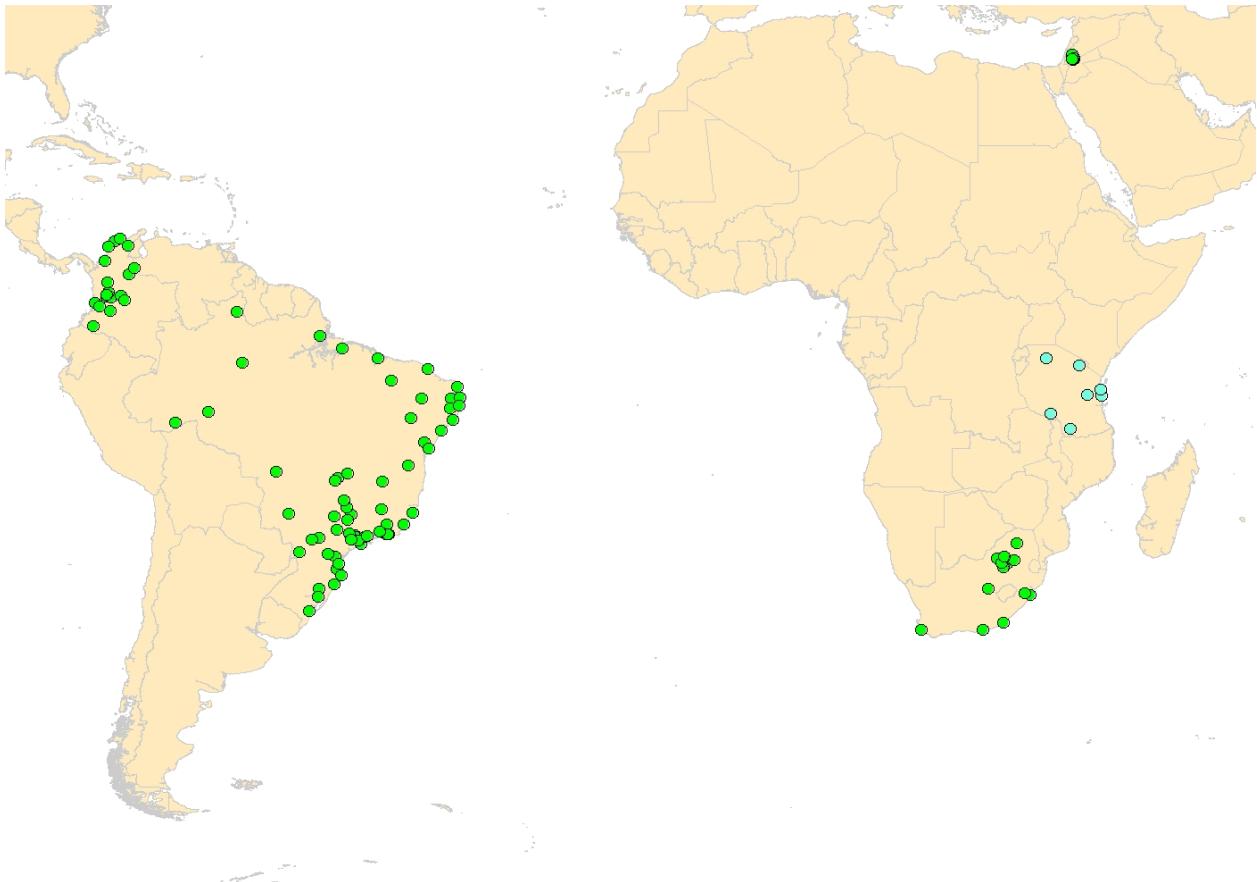
Data I

Cities

- The UN Cities data is a census of all cities that had a population 300,000 or more in 2014. These data report the location of the center of each city.
- We consider areas (1) near the boundary of the drainage basin containing the city center, and (2) within 75km of the city center.
- We use all Cities in the UN Cities data in; Brazil, Colombia, South Africa, Jordan, and Tanzania (Zambia, Pakistan, TBD).

Data II

Cities



Locations of cities in our sample.

Data

Sewers

Sewer data all comes from census questions;

- Brazil: Brazilian Institute of Geography and Statistics [2012], 'Is the bathroom or toilet drain connected to the public sewer system?'
- Colombia: National Administrative Department of Statistics [2018], 'Does your house have sewage service?'
- South Africa: Statistics South Africa [2011], 'Is the main type of toilet facility used by this household a flush toilet connected to sewerage system'
- Tanzania: National Bureau of Statistics (Tanzania), Office of the Chief Government Statistician [2012], 'Does your house have a flush toilet connected to a piped sewer system?'
- Jordan: Department of Statistics (Jordan) [2015], 'Does your house have sanitation connected to a public network?'

We calculate the share of households in a 'tract' with sewer access and map the extent of tracts with sewers.

Data

Population density, other outcomes

Population density, income measures, and other outcomes all come from the same censuses.

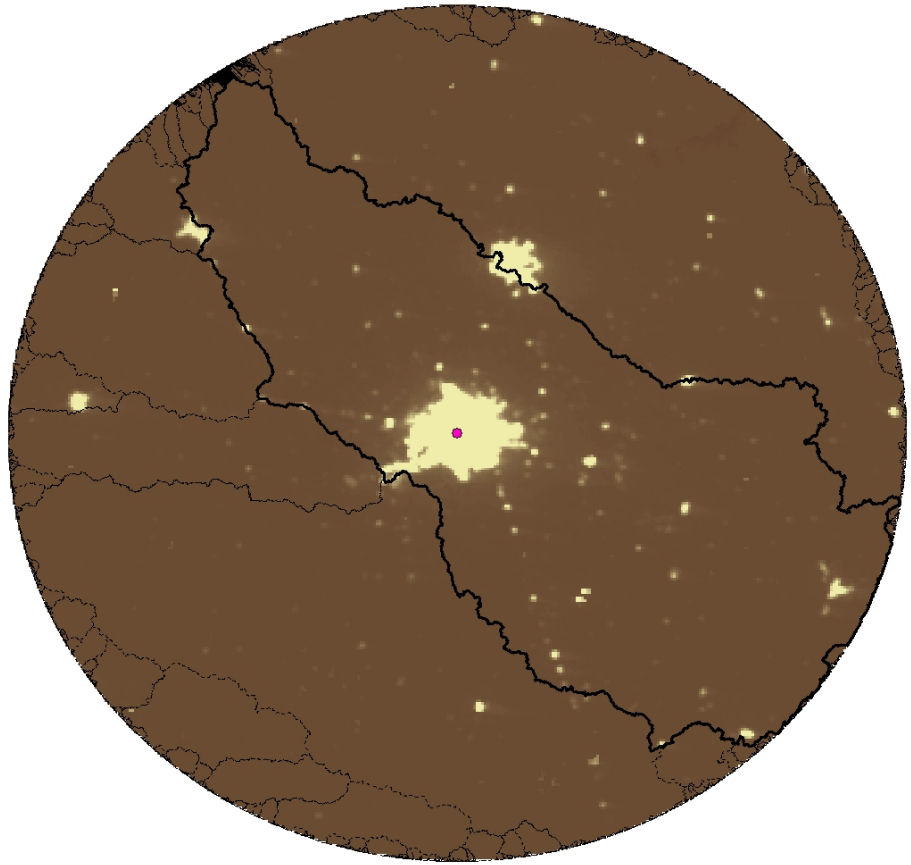
For all countries but Jordan, population density is the full count of people divided by tract area. For Jordan, it is the full count of households divided by tract area.

Demographic and neighborhood outcomes also come from these censuses and vary from country to country.

Data

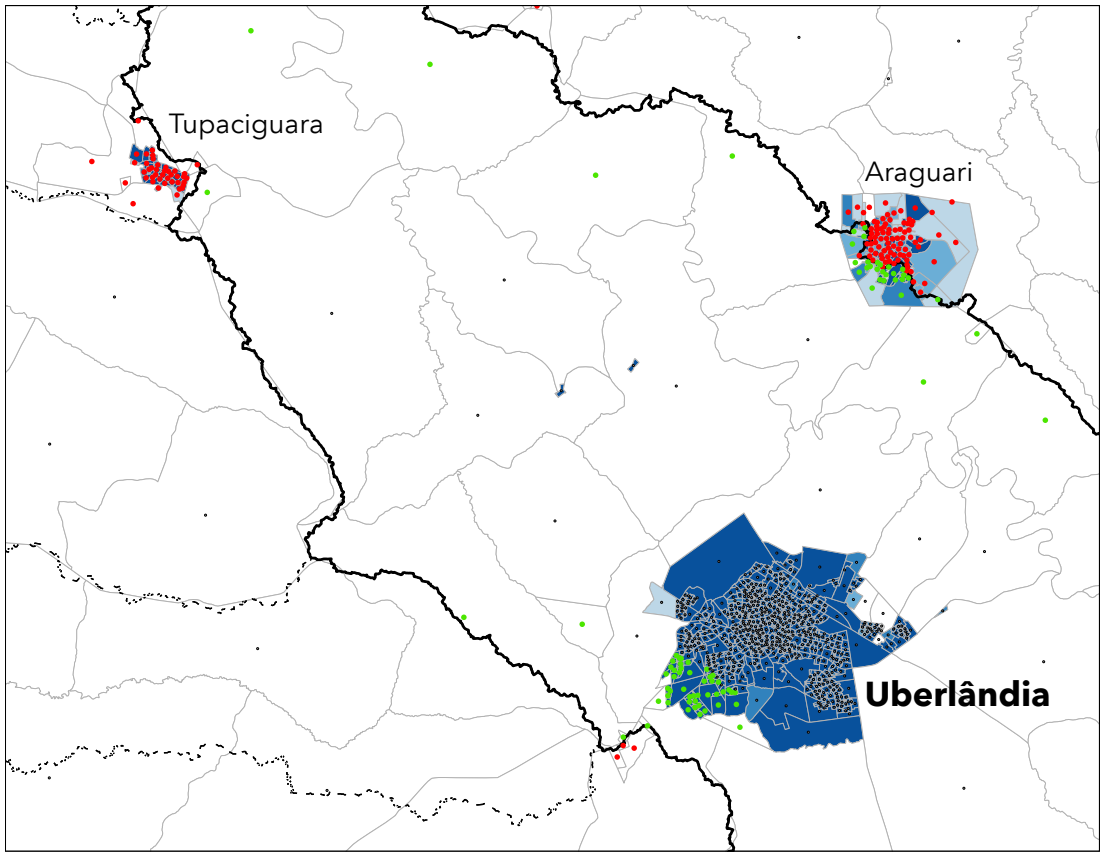
Drainage basins

- We construct drainage basins from digital elevation maps using tools for this purpose in ARCGIS.
- We use two DEMs; the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM and the Shuttle Radar Topography Mission (SRTM) DEM.
- ASTER is derived from stereoscopic imagery that is thought to be less prone than SRTM to confuse trees and rooftops with the ground. We rely primarily on the ASTER DEM, but consider SRTM for robustness checks.
- A comparison with LIDAR data shows that average error of ASTER is about 4m in four small study areas. SRTM is about the same. [Uuemaa et al., 2020].



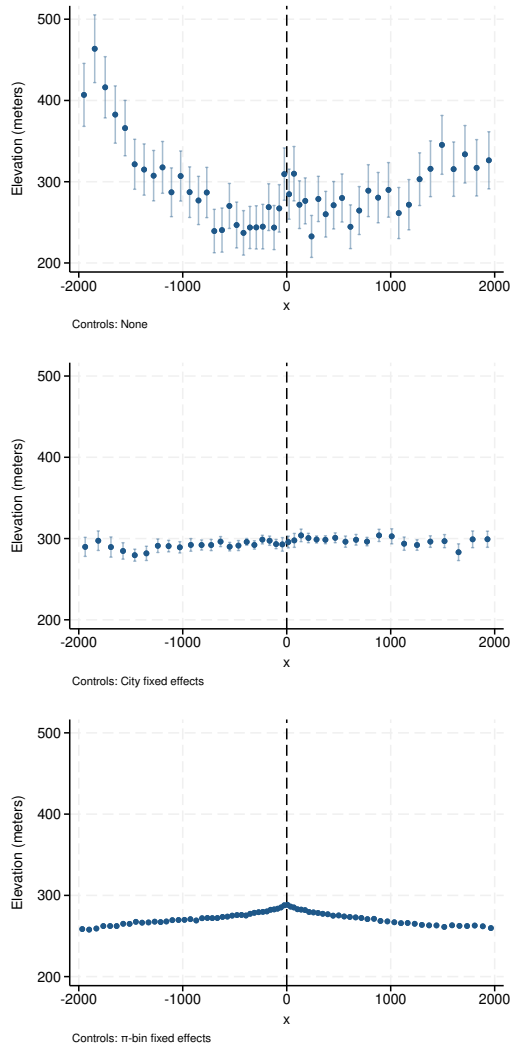
Drainage basin boundaries in a 75km disk centered on Uberlandia, Brazil. Background is lights at night, grey is all drainage basin boundaries calculated from the ASTER DEM. Black is the boundary of the drainage basin containing the center city.

Sewers and ‘Inside’ near Uberlandia, 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 segment mean (middle), and net of radial bin mean (bottom). NB: On average the divide is not a dramatic feature.

Description

	CBD Basin + 2km	± 2km Basin Divide
Num cities	91	91
Mean area cbd basin (kmsq)	1,411	.
Num segments	821	547
Num π-bins	4,003	1,882
Num tracts	248,635	53,775
Share inside	0.90	0.53
Mean tract area (kmsq)	0.62	0.21
Mean dist to CBD (km)	13.47	12.05
Mean log dist to CBD (m)	8.94	8.74
Mean dist to basin divide (km)	11.34	0.86
Sewer share	0.76	0.72
Mean num people in a tract	339	447
Pop density (persons per kmsq)	28,330	21,873
Income (per month, 2022 USD)	955	911
Share literate	0.94	0.92
Elevation(meters)	920	272
Elevation std (meters)	795	507

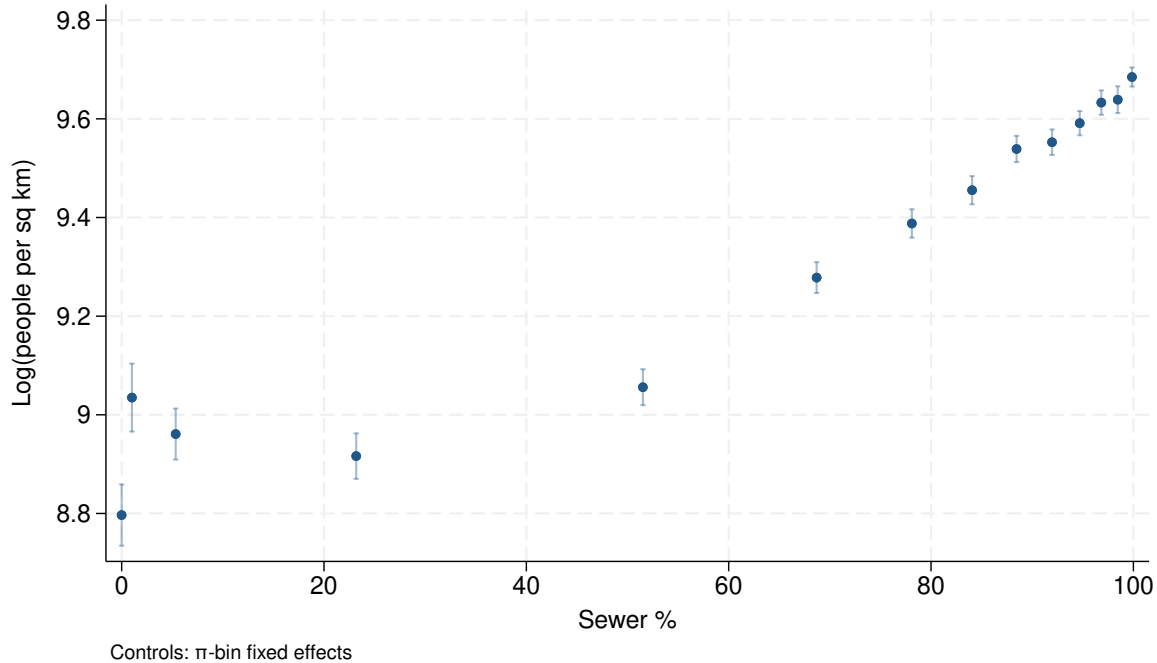
- About 15 tracts per bin.
- Tracts are about 1km square. Central basins average about 80km square.
- Population density is high. Quarter acre lots with 4 people per household is about 4000 per km^2.

Estimation sample; Brazil, Colombia, South Africa, Jordan

	cities	π-bins	tracts	Share inside	Tract area km^2	People/km^2	Sewer share
Brazil	59	1,246	27,373	0.53	0.28	17,523	0.71
Colombia	18	355	23,199	0.53	0.10	28,880	0.72
Jordan	2	8	26	0.35	2.35	878	0.43
South Africa	12	273	3,177	0.52	0.47	8,358	0.77
Tanzania	7	105	1,593	0.65	0.13	24,936	0.08

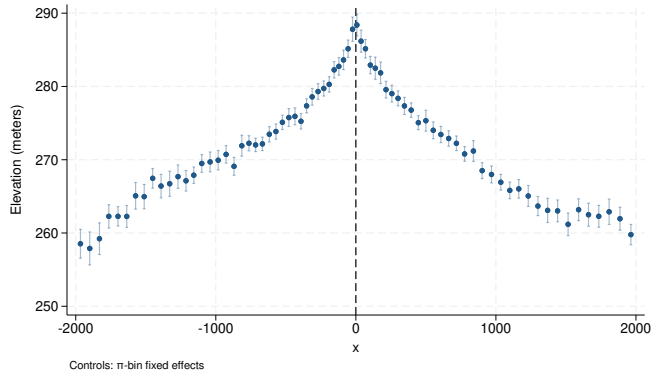
- Jordan is households, not people.
- The economic geography of these places is really different.
- Estimations will be at tract/bin level, so most of the weight will come from Colombia and Brazil.
- Tanzania has no sewers.

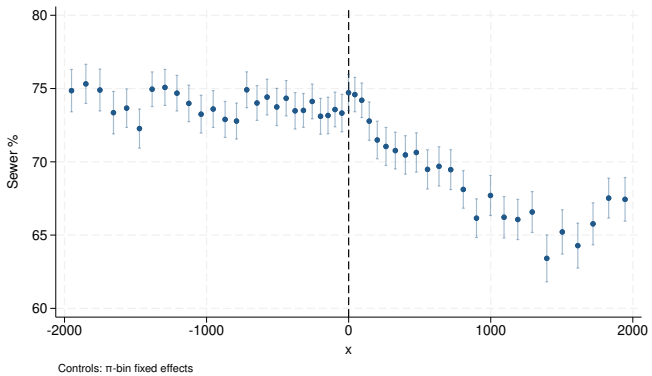
Population density vs sewer %

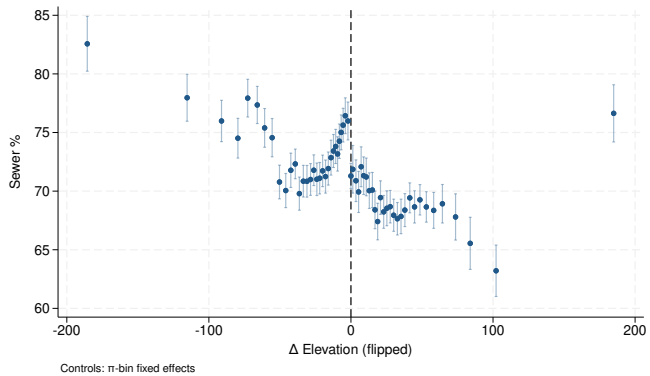


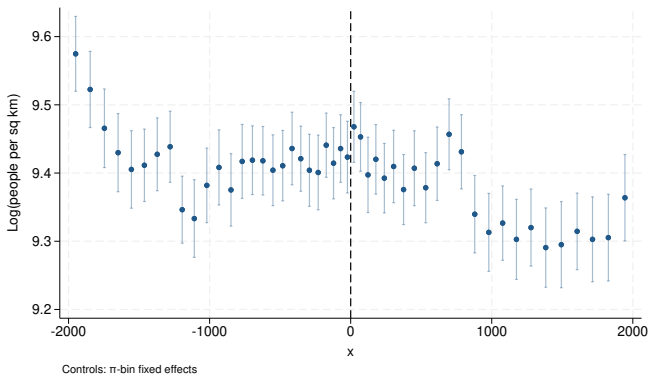
Mean log population density by tract sewer percentage. All tracts within 2km of a basin divide, conditional on radial bin. 100% increase in sewer share increases population density by $\approx e^{0.7} \approx 2.0$.

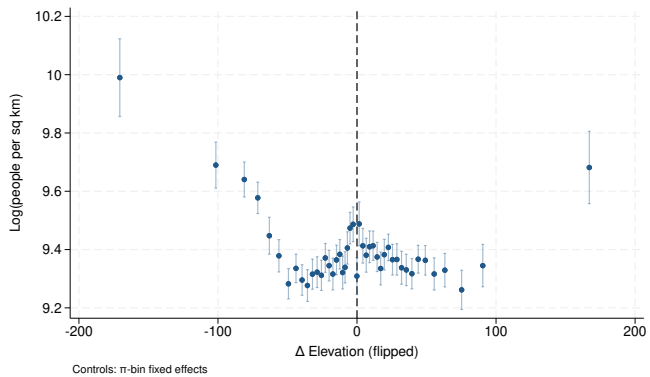
Identification, Universe









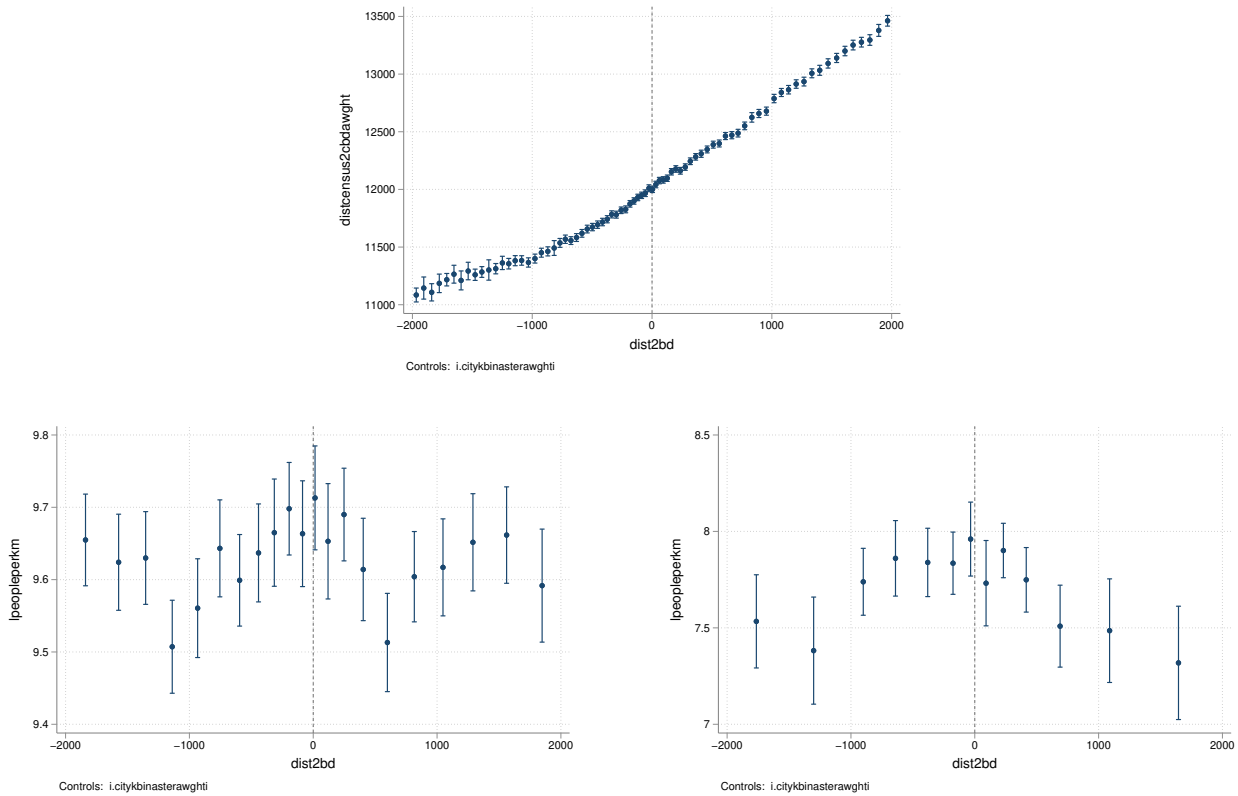


Estimation/Identification (1)

First stage is sewer share by tract as a linear function of

- Controls: Radial bin indicators and radial bin by perpendicular distance. That is, slope and intercept by radial bin. Also Elevation.
- Instruments are: (1) 'outside indicator', (2)'outside indicator times displacement', (3) 'outside indicator times elevation'.

Figure: Placebo and balance tests



Note: *x-axis ∼ displacement from basin divide. Top: Bin Distance to cbd net of radial bin mean. Bottom: population density for bins where tract mean sewer percentage is above/below (left/right) 90% within 2km of the basin divide.*

Sewers and population density, Universe

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1. OLS									
sewer %	0.0086***	0.0086***	0.0086***	0.0082***	0.0082***	0.0082***	0.0074***	0.0074***	0.0074***
	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)
N	53775	53775	53775	53775	53775	53775	53775	53775	53775
2. First stage									
outside	-0.7760**		-0.5459	-1.2318***		-0.8456**	-0.7621**		-0.6454
	(0.3409)		(0.3840)	(0.3408)		(0.4184)	(0.3492)		(0.4449)
x*Outside	-0.0050***			-0.0050***			-0.0054***		
	(0.0004)			(0.0004)			(0.0005)		
ΔElev*Outside		-0.0184***	-0.0144**		-0.0442***	-0.0349***		-0.0301***	-0.0221**
		(0.0064)	(0.0072)		(0.0070)	(0.0086)		(0.0073)	(0.0093)
N	53775	53775	53775	53775	53775	53775	53775	53775	53775
3. Reduced form log(pop density)									
outside	0.0335**		0.0778***	0.0373**		0.0807***	0.0236		0.0338
	(0.0147)		(0.0182)	(0.0156)		(0.0209)	(0.0157)		(0.0215)
x*Outside	-0.0001***			-0.0002***			-0.0003***		
	(0.0000)			(0.0000)			(0.0000)		
ΔElev*Outside		-0.0013***	-0.0019***		-0.0016***	-0.0025***		-0.0010***	-0.0014***
		(0.0003)	(0.0004)		(0.0004)	(0.0005)		(0.0004)	(0.0005)
N	53775	53775	53775	53775	53775	53775	53775	53775	53775
4. IV log(pop density)									
sewer %	0.0211***	0.0734***	0.0353**	0.0371***	0.0364***	0.0241***	0.0533***	0.0324**	0.0225**
	(0.0036)	(0.0255)	(0.0154)	(0.0039)	(0.0086)	(0.0073)	(0.0051)	(0.0127)	(0.0108)
N	53775	53775	53775	53775	53775	53775	53775	53775	53775
F	88.88	9.654	5.861	103.5	43.57	24.04	86.69	17.92	10.15
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×x				Y	Y	Y			
π-bins×x							Y	Y	Y

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

Sewers and income, Brazil and South Africa

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1. OLS									
sewer %	0.0045***	0.0045***	0.0045***	0.0040***	0.0040***	0.0040***	0.0039***	0.0039***	0.0039***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
N	30549	30549	30549	30549	30549	30549	30549	30549	30549
2. First stage									
outside	-0.9758**		-1.9388***	-1.5302***		-2.1438***	-1.2016***		-2.0142***
	(0.4561)		(0.4962)	(0.4544)		(0.5390)	(0.4648)		(0.5721)
x*Outside	-0.0018***			-0.0029***			-0.0035***		
	(0.0005)			(0.0005)			(0.0006)		
ΔElev*Outside		0.0304***	0.0416***		-0.0135*	0.0080		-0.0094	0.0129
		(0.0065)	(0.0070)		(0.0078)	(0.0094)		(0.0080)	(0.0101)
N	30549	30549	30549	30549	30549	30549	30549	30549	30549
3. Reduced form log(income)									
outside	0.0236**		0.0020	0.0167*		0.0079	0.0237**		0.0174
	(0.0095)		(0.0106)	(0.0093)		(0.0108)	(0.0097)		(0.0118)
x*Outside	-0.0001***			-0.0001***			-0.0001***		
	(0.0000)			(0.0000)			(0.0000)		
ΔElev*Outside		0.0009***	0.0009***		0.0000	-0.0001		0.0001	-0.0001
		(0.0002)	(0.0002)		(0.0002)	(0.0002)		(0.0002)	(0.0003)
N	30549	30549	30549	30549	30549	30549	30549	30549	30549
4. IV log(income)									
sewer %	0.0303***	0.0301***	0.0152***	0.0158***	-0.0009	-0.0034	0.0110***	-0.0114	-0.0088
	(0.0082)	(0.0080)	(0.0048)	(0.0036)	(0.0160)	(0.0049)	(0.0037)	(0.0298)	(0.0064)
N	30549	30549	30549	30549	30549	30549	30549	30549	30549
F	8.430	16.50	15.77	27.63	2.272	9.543	27.12	1.006	7.475
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×x				Y	Y	Y			
π-bins×x							Y	Y	Y

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

Sewers and literacy rate, Universe

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1. OLS									
sewer %	0.0000	0.0000	0.0000	-0.0000	-0.0000	-0.0000	0.0002***	0.0002***	0.0002***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0000)	(0.0000)	(0.0000)
N	53747	53747	53747	53747	53747	53747	53747	53747	53747
2. First stage									
outside	-0.7829**		-0.5585	-1.2404***		-0.8520**	-0.7661**		-0.6476
	(0.3409)		(0.3841)	(0.3408)		(0.4184)	(0.3491)		(0.4448)
x*Outside	-0.0050***			-0.0050***			-0.0054***		
	(0.0004)			(0.0004)			(0.0005)		
ΔElev*Outside		-0.0182***	-0.0142**		-0.0443***	-0.0349***		-0.0302***	-0.0221**
		(0.0064)	(0.0072)		(0.0070)	(0.0086)		(0.0073)	(0.0093)
N	53747	53747	53747	53747	53747	53747	53747	53747	53747
3. Reduced form literacy rate									
outside	0.0046*		0.0029	0.0017		0.0028	0.0013		0.0016
	(0.0027)		(0.0029)	(0.0023)		(0.0036)	(0.0012)		(0.0016)
x*Outside	-0.0000**			-0.0000**			-0.0000**		
	(0.0000)			(0.0000)			(0.0000)		
ΔElev*Outside		0.0001***	0.0001*		-0.0000	-0.0001		-0.0000	-0.0000
		(0.0000)	(0.0000)		(0.0000)	(0.0001)		(0.0000)	(0.0000)
N	53747	53747	53747	53747	53747	53747	53747	53747	53747
4. IV literacy rate									
sewer %	0.0014**	-0.0044**	-0.0045**	0.0007**	0.0006	0.0003	0.0006**	0.0000	-0.0003
	(0.0006)	(0.0022)	(0.0022)	(0.0003)	(0.0008)	(0.0006)	(0.0003)	(0.0007)	(0.0007)
N	53747	53747	53747	53747	53747	53747	53747	53747	53747
F	88.72	9.506	5.835	102.9	43.72	24.15	86.28	17.97	10.19
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×x				Y	Y	Y			
π-bins×x							Y	Y	Y

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

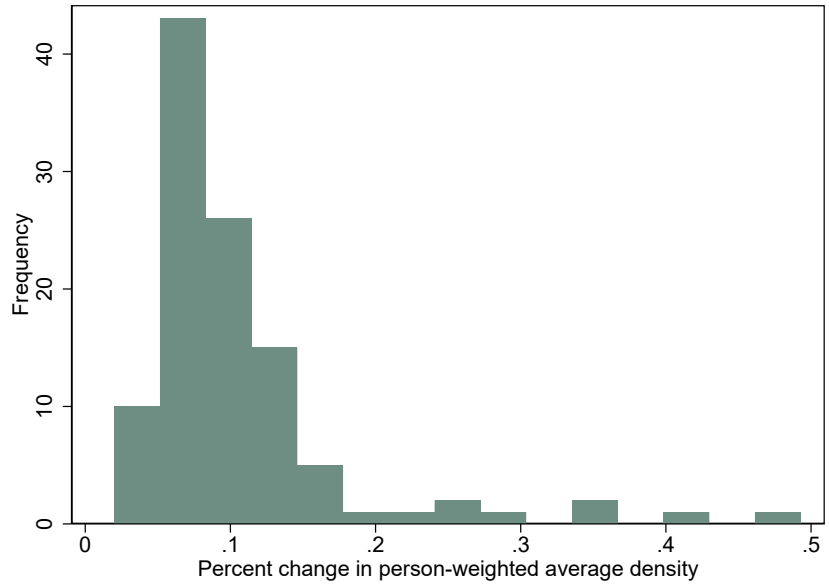
Summary

- A 1% increase in sewer share gives about a 3% increase in population density in the Universe. This is about the same for both instruments, and double or triple the OLS effect. This conclusion has been robust to different sampling rules
- There is preliminary evidence for heterogeneity across countries. The treatment effect is smaller for Colombia, is around 4% for Brazil and South Africa, and Jordan is too small to allow us to say much.
- No effect on income or literacy.

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 3%.
- This gives a 3% increase in 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 much larger,

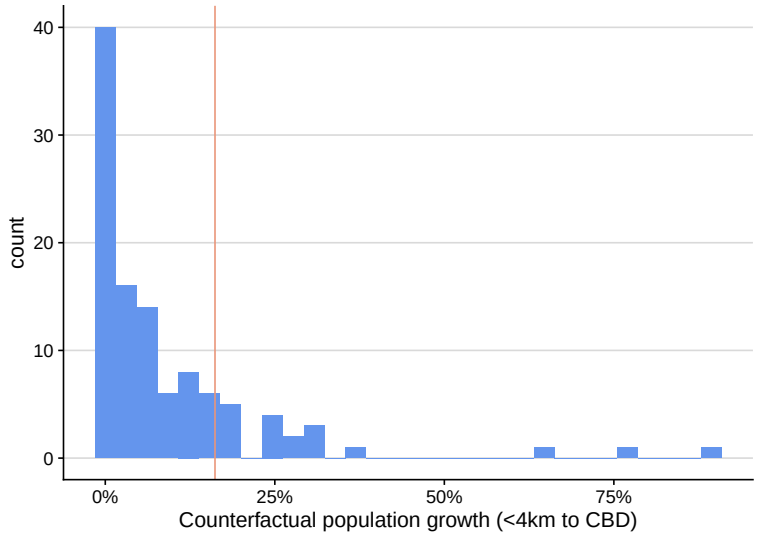


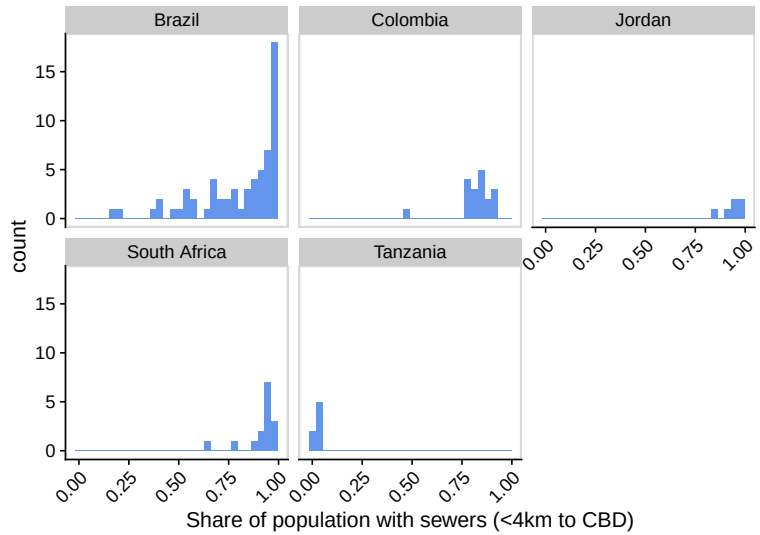
- 1% of sewer connection often results in a 10% increases in person weighted density.
- With a 5% agglomeration effect, this is 0.5% increase in city average wage.
- ...plus whatever wage increase is experienced by the 3% of new residents.

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 3% holding city population constant.
- Calculate share of city population that gains access to CBD because of this intervention.





- (L) Histogram showing change in % near CBD by city (R) Histogram % of total city connections required to connect walkable core.
- 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.
- We have two distinct identification strategies.
- At 3%, the average effect seems large, both absolutely, and in comparison with (nearly) comparable estimates for highways.
- Resorting in response to sewer access is unimportant.
- There is a lot of cross-country heterogeneity.
- TBD. Work out econometrics that allow for heterogenous treatment effects.

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