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 they seem 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].

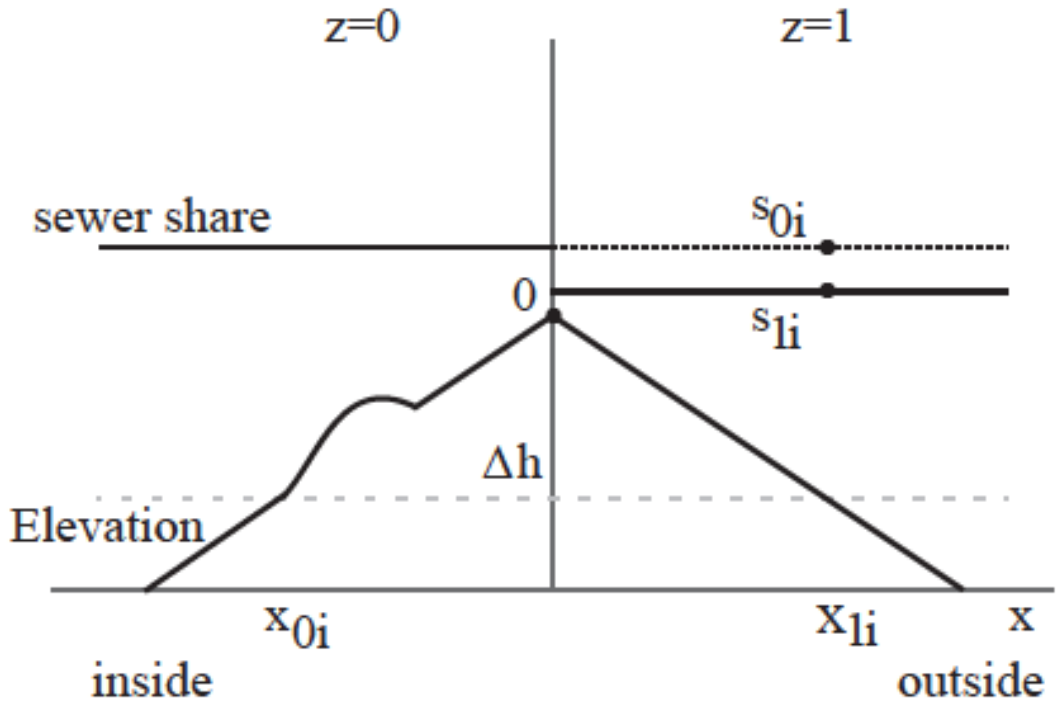
$\Longrightarrow$ weak prior that sewers lead to large increase in density and not much change in demographics. No prior over heterogeneity of effects.

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?

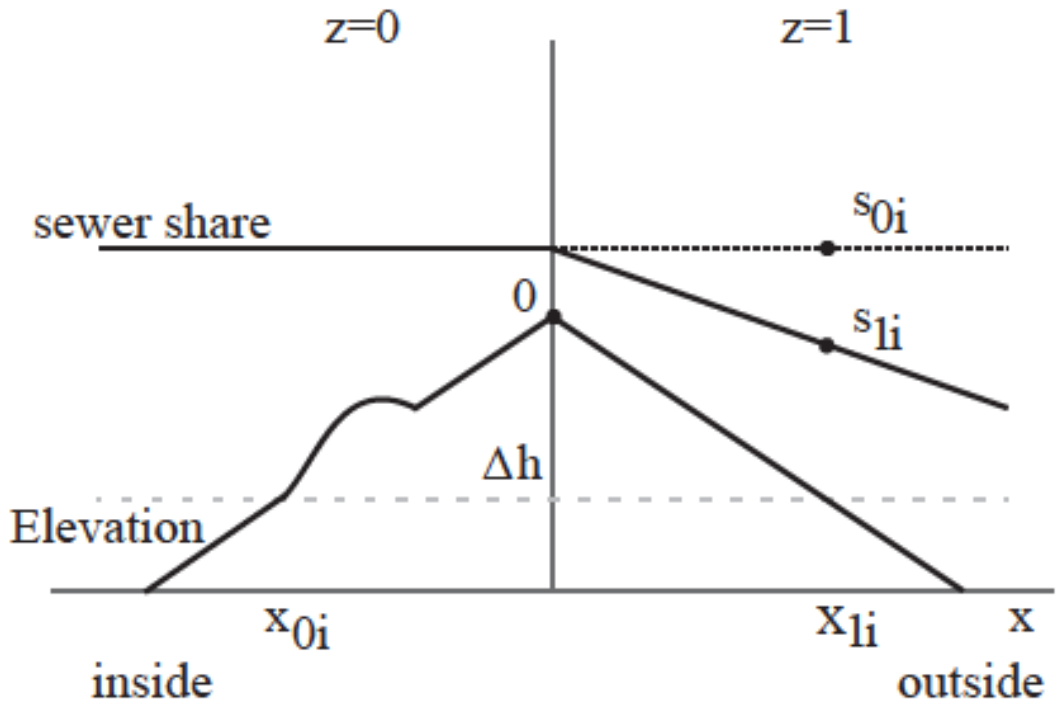
Identification with a discontinuity in sewer share



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.

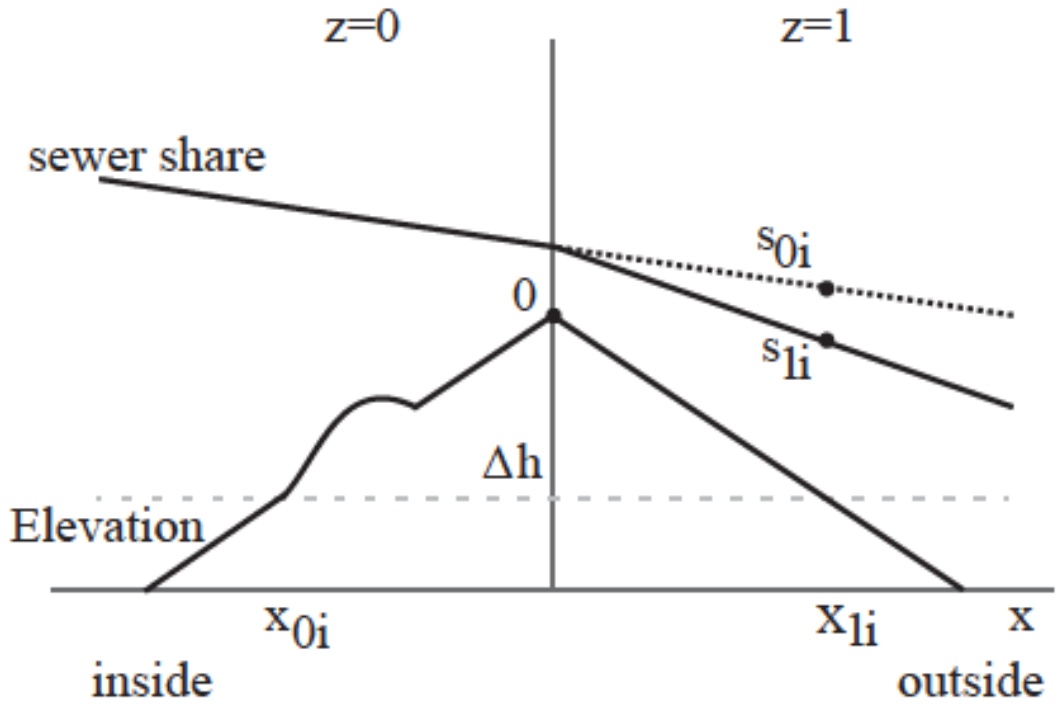
Treatment is $s_0 - s_1$. Without independent effects of elevation or x, inside is a control for outside.

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.

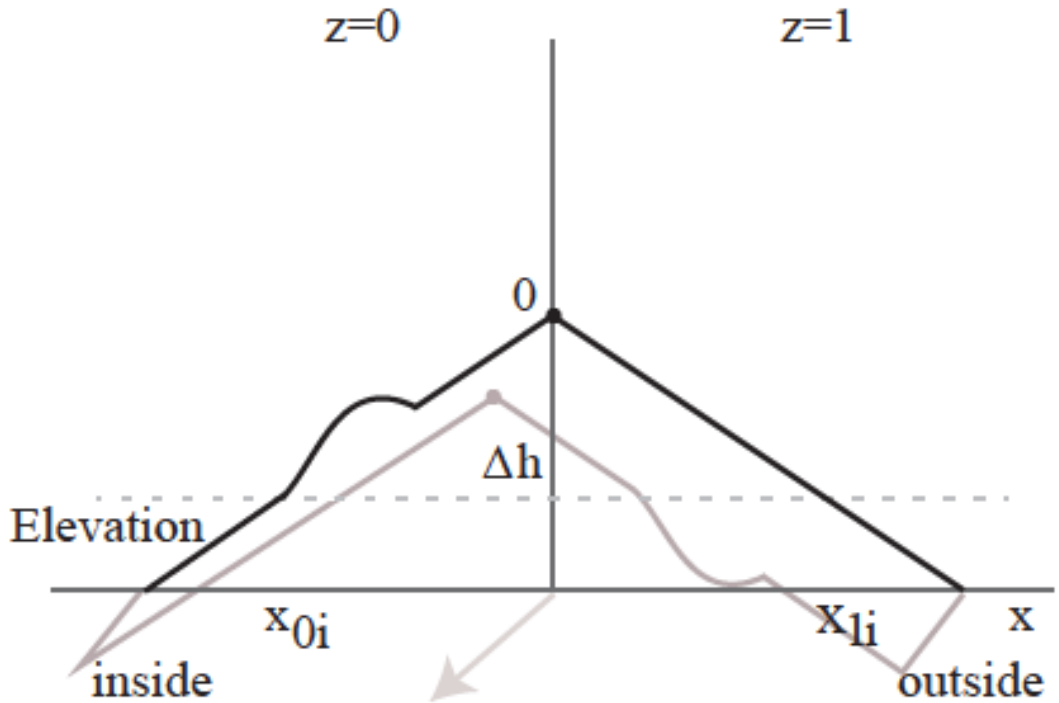
Identification with a kink in sewer share and trend in x



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.

Is x best thought of as (log) displacement perpendicular to the basin divide, or as (log) radial distance to the CBD?

Identification, elevation vs displacement



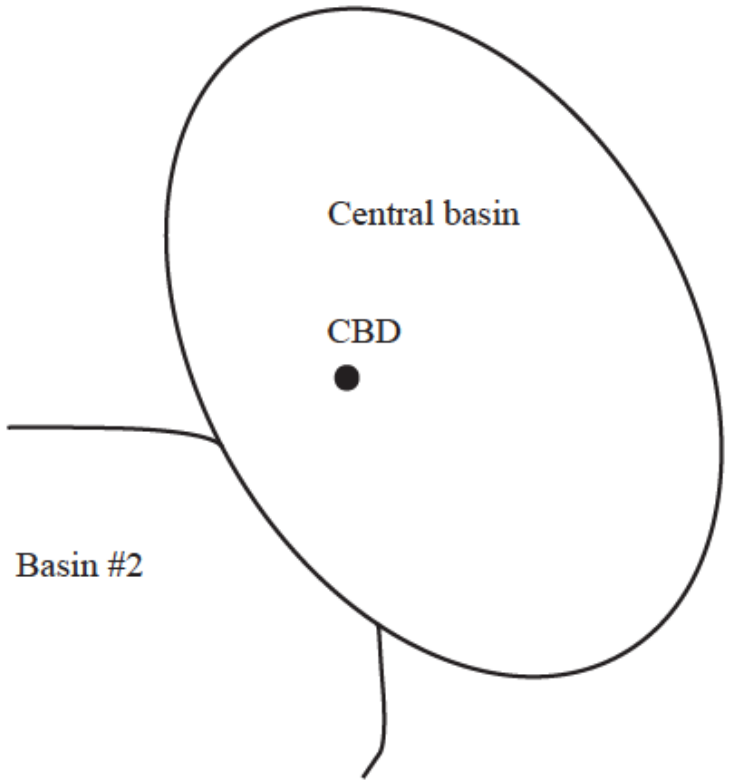
Distance to the basin divide and climbing to the elevation divide should both matter. With elevation, we can exploit variation independent of x.

Identification, further issues

- Taking the presence of gravity as given, crossing a basin divide must increase the cost of sewer access.
- 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?

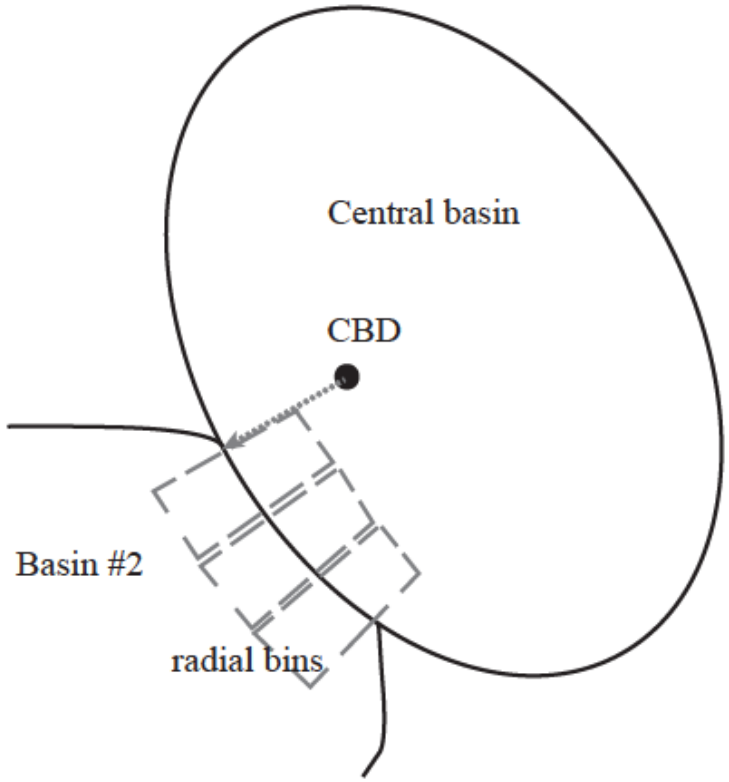
Geography: Central basins

DESA Population Division [2018] gives CBD coordinates for cities with pop. $\geq$ 300,000 in 2014. All have sewer networks. Focus on drainage basins containing CBDs and $<$ 75km from CBD.



Geography: Radial bins

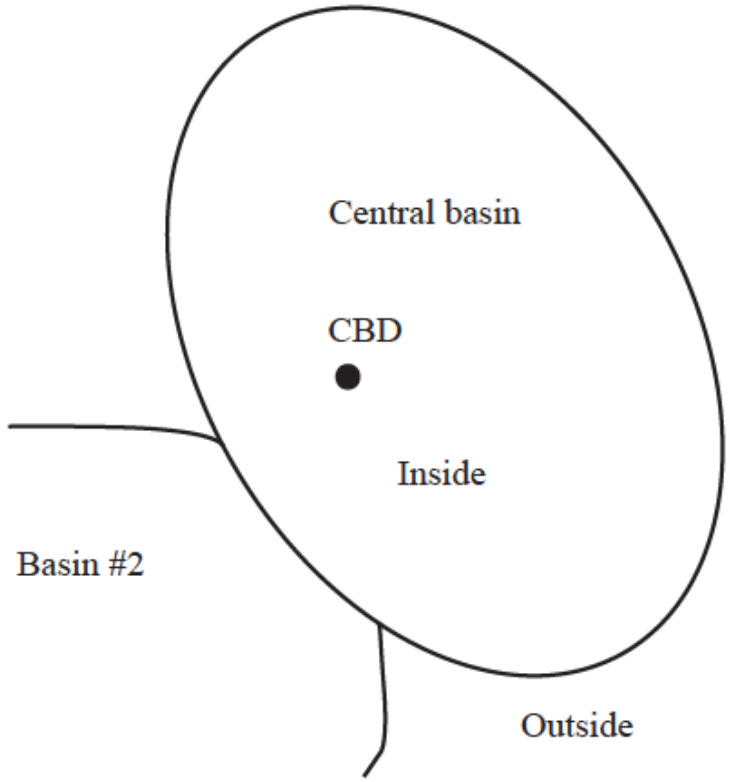
Define 'radial bins', 2km wide, and 2×4km deep. Radial bin zero starts at the point on the basin divide closest to the CBD.



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

‘Inside’

Say a census tract is ‘inside’ or ‘basin 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.

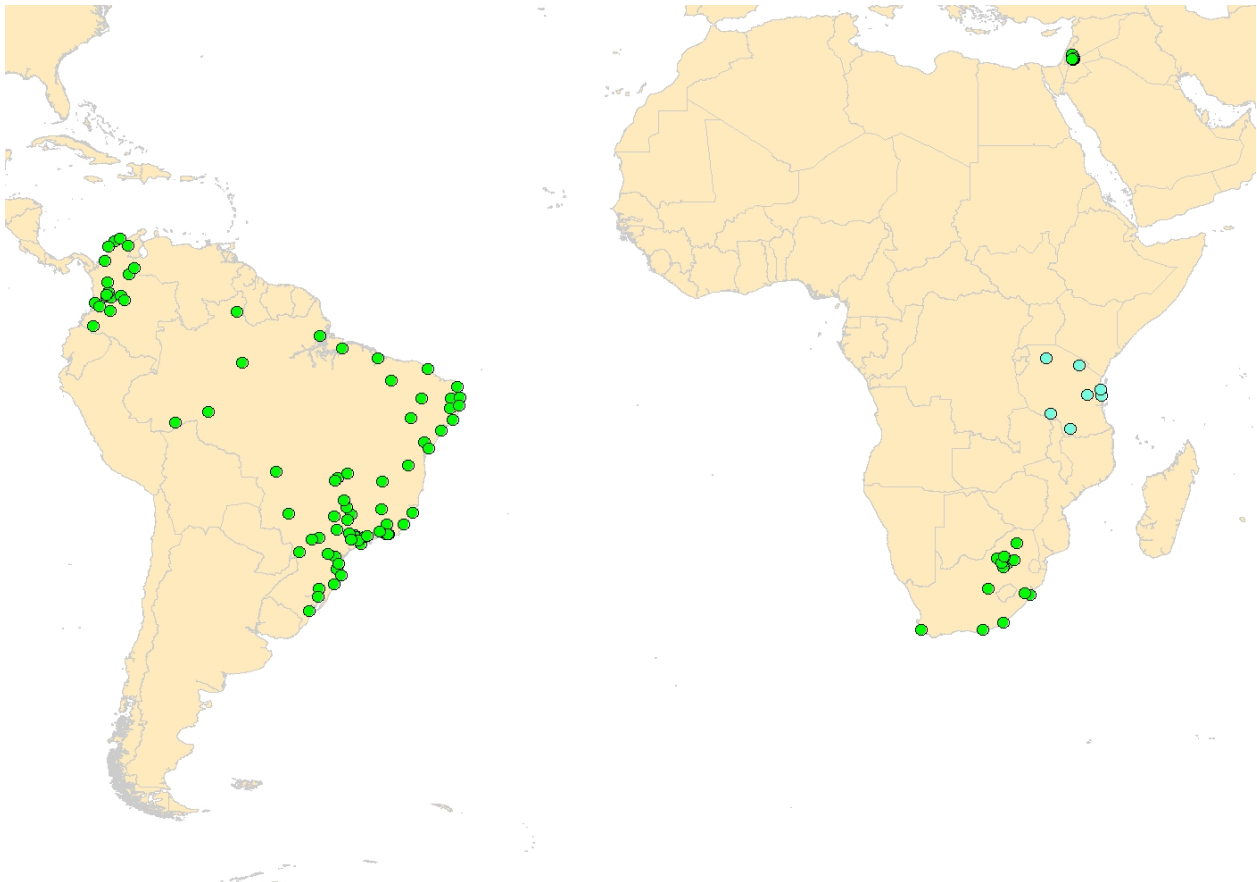
Data I

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 focus attention on areas (1) near the boundary of the drainage basin containing the city center, and (2) within 75km of the city center.
- We estimate treatment effects using 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.

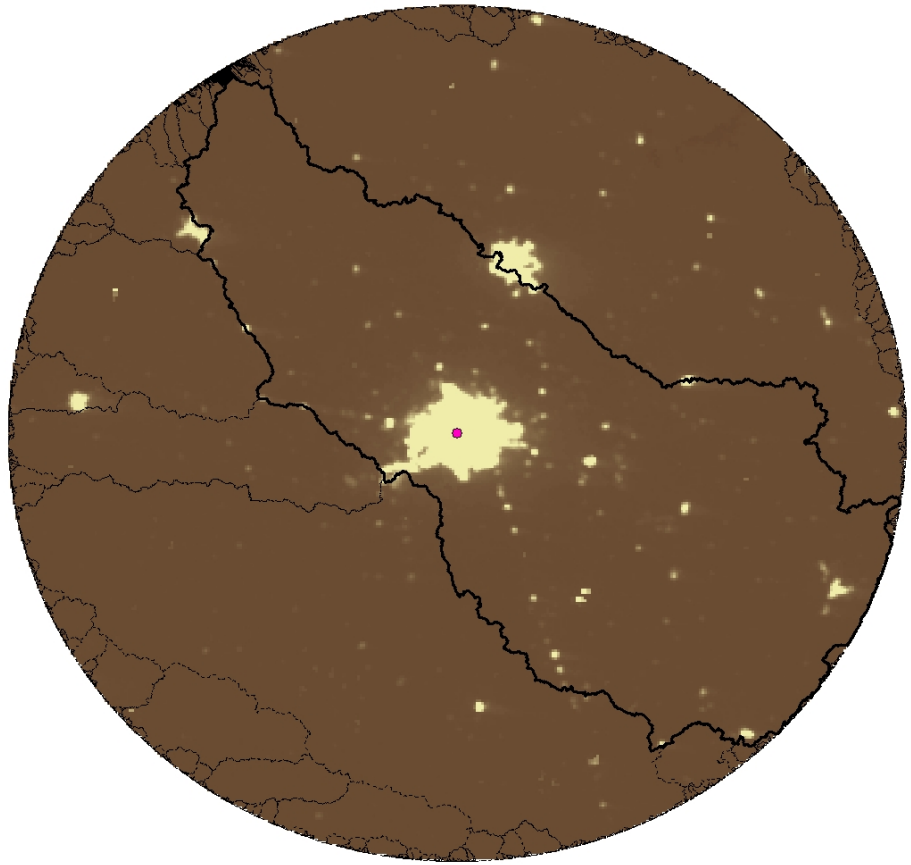
For all countries but Jordan, population density is the full count of people divided by tract area. For Jordan, it is the full count of households divided by tract area.

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

Data

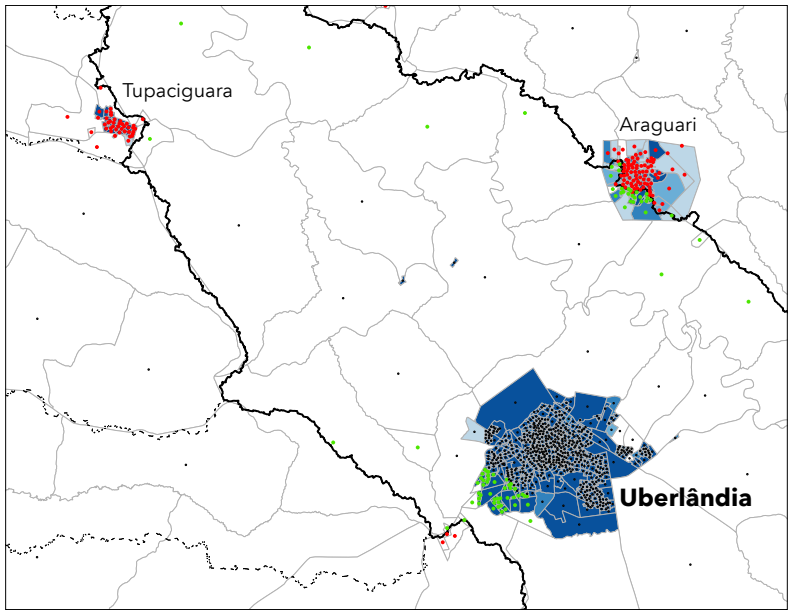
Drainage basins

- 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].



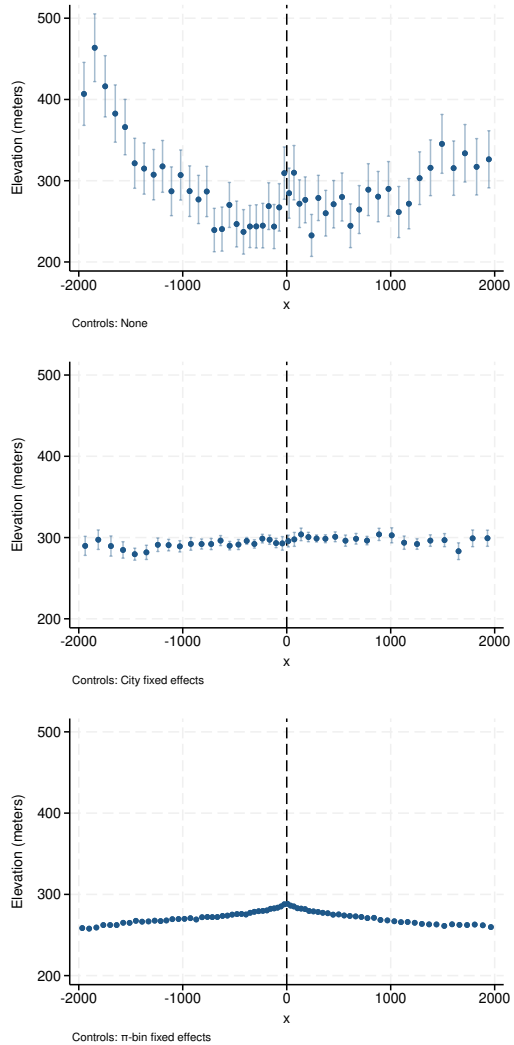
Drainage basin boundaries in a 75km disk centered on Uberlandia, Brazil. Background is lights at night, grey is all drainage basin boundaries calculated from the ASTER DEM. Black is the boundary of the drainage basin containing the center city.

Sewers and ‘Inside’ near Uberlandia, Brazil



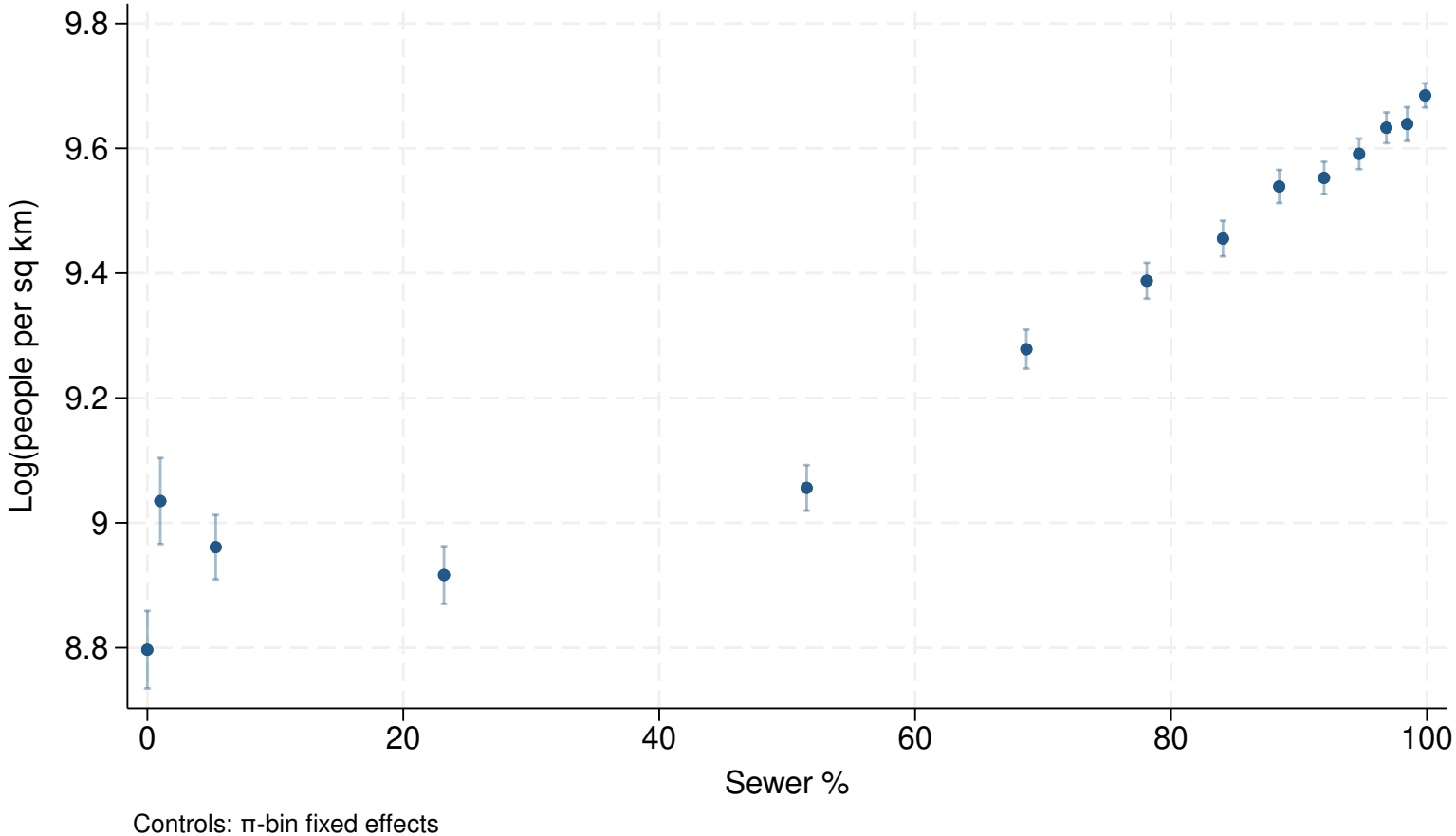
- Blue is sewer share.
- Tracts in the central basin are ‘inside’.
- Drop tracts with centroids more than 4km from the basin divide.

Why radial-bin controls?



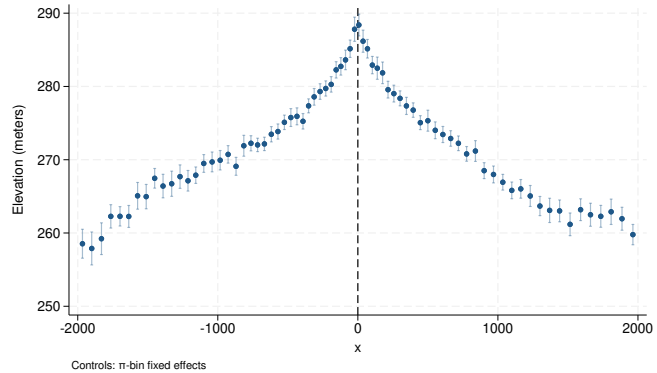
Mean elevation by distance to basin divide; raw data (top), net of segment mean (middle), and net of radial bin mean (bottom). NB: On average the divide is not a dramatic feature.

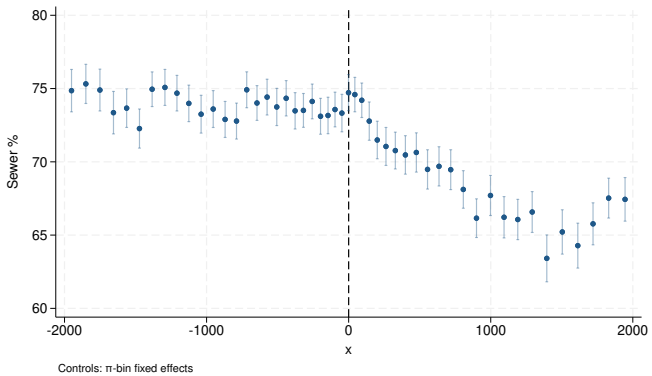
Population density vs sewer %

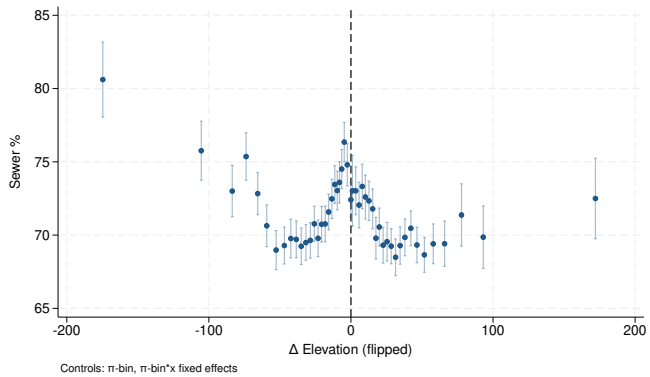


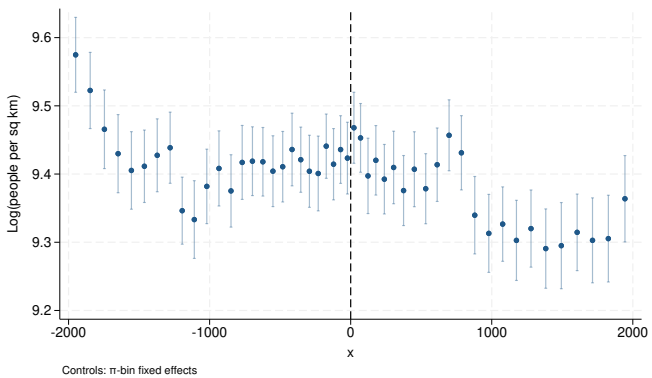
Mean log population by tract sewer percentage. All tracts within 2km of a basin divide, conditional on radial bin. 100% increase in sewer share increases population density by $\approx e^{0.7} \approx 2.0$.

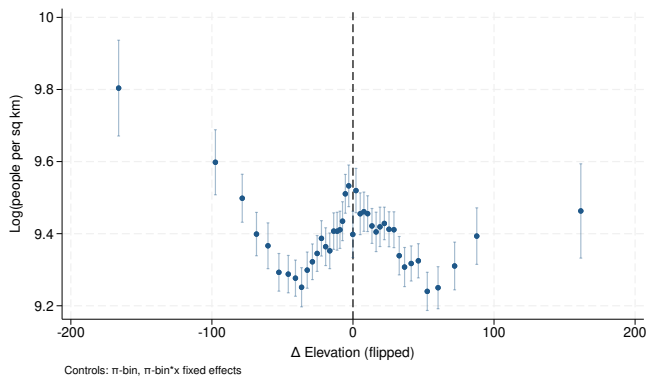
Identification, Universe











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'. The last two are both significant and have the right negative signs. Idea is to compare 'inside' to 'outside'. I think I like (3) best, but results so far are still preliminary.

Summary

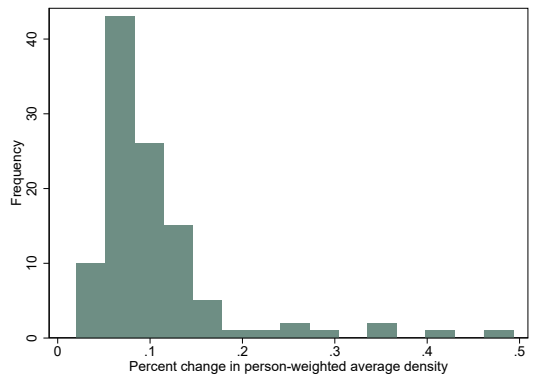
- A 1% increase in sewer share gives about a 3% increase in population density in the Universe. This is about the same for both instruments, and double or triple the OLS effect. This conclusion has been robust to different sampling rules
- There is preliminary evidence for heterogeneity across countries. 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.
- Preliminary results indicate no effect on income.

How important are sewers? I

- 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.

How important are sewers? II

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.

Conclusion I

- We've estimated the effects of sewer access on population density in a sample of developing world cities.
- At 3%, the average effect seems large, both absolutely, and in comparison with (nearly) comparable estimates for highways.
- We have two distinct identification strategies.
- There is no evidence for resorting in response to sewer access (preliminary).
- There is a lot of cross-country heterogeneity (preliminary).
- TBD. Work out econometrics that allow for heterogenous treatment effects.

Bibliography I

Nava Ashraf, Edward Glaeser, Abraham Holland, and Bryce Millett Steinberg. Water, health and wealth. Technical report, National Bureau of Economic Research, 2017.

Sonia R Bhalotra, Alberto Diaz-Cayeros, Grant Miller, Alfonso Miranda, and Atheendar S Venkataramani. Urban water disinfection and mortality decline in lower-income countries. *American Economic Journal: Economic Policy*, 13(4):490–520, 2021.

Sebastian Galiani, Paul Gertler, and Ernesto Schargrodsky. Water for life: The impact of the privatization of water services on child mortality. *Journal of Political Economy*, 113(1):83–120, 2005.

Marcella Alsan and Claudia Goldin. Watersheds in child mortality: The role of effective water and sewerage infrastructure, 1880–1920. *Journal of Political Economy*, 127(2):586–638, 2019.

Bibliography II

D Mark Anderson, Kerwin Kofi Charles, and Daniel I Rees. Public health efforts and the decline in urban mortality. Technical report, National Bureau of Economic Research, 2018.

Joseph P Ferrie and Werner Troesken. Water and chicago's mortality transition, 1850–1925. *Explorations in Economic History*, 45(1):1–16, 2008.

Shanti Gamper-Rabindran, Shakeeb Khan, and Christopher Timmins. The impact of piped water provision on infant mortality in brazil: A quantile panel data approach. *Journal of Development Economics*, 92(2):188–200, 2010.

Michael Coury, Toru Kitagawa, Allison Shertzer, and Matthew Turner. The value of piped water and sewers: Evidence from 19th century chicago. Technical report, National Bureau of Economic Research, 2022.

Bibliography III

UN DESA Population Division. World urbanization prospects: the 2018 revision, 2018.

Brazilian Institute of Geography and Statistics. Brazil demographic census 2010. Technical report, 2012. Rio de Janeiro, Brazil, 2012.

National Administrative Department of Statistics. Colombia population and housing census 2018. Technical report, 2018. Bogotá, Colombia: National Administrative Department of Statistics.

Statistics South Africa. Census 2011. Technical report, 2011. Pretoria, South Africa: Statistics South Africa.

Bibliography IV

National Bureau of Statistics (Tanzania), Office of the Chief Government Statistician. Tanzania population and housing census 2012. Technical report, 2012. National Bureau of Statistics (Tanzania), Office of the Chief Government Statistician (Zanzibar).

Department of Statistics (Jordan). Jordan population and housing census 2015. Technical report, 2015. Department of Statistics, Aman Jordan.

Evelyn Uuemaa, Sander Ahi, Bruno Montibeller, Merle Muru, and Alexander Kmoch. Vertical accuracy of freely available global digital elevation models (aster, aw3d30, merit, tandem-x, srtm, and nasadem). *Remote Sensing*, 12(21):3482, 2020.

Nathaniel Baum-Snow. Did highways cause suburbanization? *The Quarterly Journal of Economics*, 122(2):775–805, 2007.

Bibliography V

Nathaniel Baum-Snow, Loren Brandt, J Vernon Henderson, Matthew A Turner, and Qinghua Zhang. Roads, railroads, and decentralization of chinese cities. *Review of Economics and Statistics*, 99(3):435–448, 2017.