Economic Geography and the Optimal Size of Congestion Zones

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Motivation

There is a clear **tradeoff** in congestion zone size:

- Expanding a small congestion zone increases the number of trips subject to the charge...
- ...but if the congestion zone is too large, many trips will have both termini inside the zone
- Larger zones may also come with larger upfront/ongoing maintenance costs

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This Paper

Research question:

How large are optimal congestion zones in practice?

1. How large are optimal congestion zones if one ignores system costs?
2. How do cost functions vary across cities?
3. How large are optimal congestion zones after accounting for city-specific cost functions?

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What can we learn from existing congestion zones?

- There does not seem to be a “natural” or “central” congestion zone size
- Instead, the world’s few cordon zones vary widely in footprint (both in raw terms and relative to city size)
- Cost data across policies seems the most uniform, and may be sufficient for (or at least useful in) inferring optimal size of zones

Comparing Congestion Zones: London

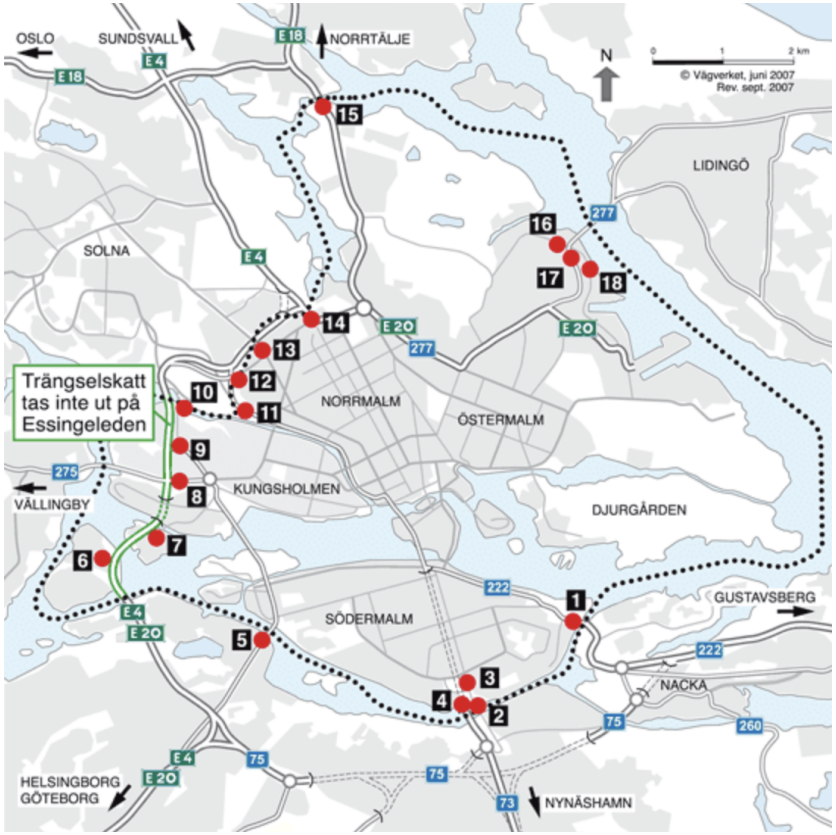
London's cordon zone:

- 21 square kilometers
- 197 entry sites
- 3.4% of the city proper, 0.6% of the metro area
- ~1.5% of London's population live within zone

Comparing Congestion Zones: Stockholm

Stockholm's cordon zone:

- 34.5 square kilometers
- 18 entry points
- 18% of the city proper, 0.6% of the metro area
- ~33% of Stockholm's population live within zone



Comparing Congestion Zones: Milan

Milan's cordon zone:

- 8 square kilometers
- 43 entry points
- 4.4% of the city proper, 0.2% of the metro area
- ~7.5% of Milan's population live within zone

Comparing Congestion Zones: NYC

New York's cordon zone:

- 20 square kilometers
- 110 entry points
- 2.6% of the city proper, 0.2% of the metro area
- ~9.7% of NYC's population live within zone

Optimal Congestion Zone Size: Theory

Existing work on cordon size: (Mun, Konishi, and Yoshikawa, 2003; Zhang and Yang, 2004; Sumalee, 2004; Mun, Konishi, and Yoshikawa, 2005)

Mun et al. 2003:

- Optimal zone size trades off expanding to include more trips against trips becoming completely within-zone
- Accounts for heterogeneous marginal damages and rebound of within-zone trips
- Kraus (1989) also considers the cost of implementing zones, which is a function of the size of the zone

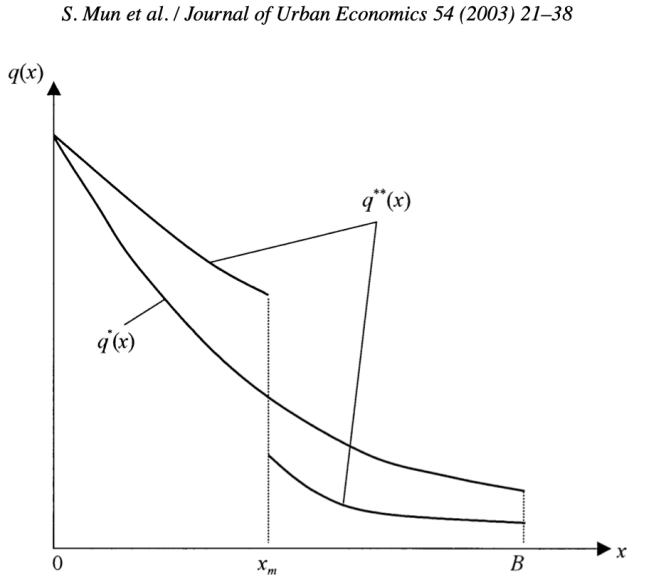


Fig. 1. Spatial variations of trip rates under no-toll equilibrium and cordon pricing.

Generally speaking, in economics, there is less empirical work on optimal congestion zone size than on optimal pricing[2]

[2] See, e.g., Almagro, Barbieri, Castillo, Hickok, and Salz (2024); Kreindler (2024); Verhoef, Nijkamp, and Rietveld (1995); Mangrum and Molnar (2017); Vickrey (1963)

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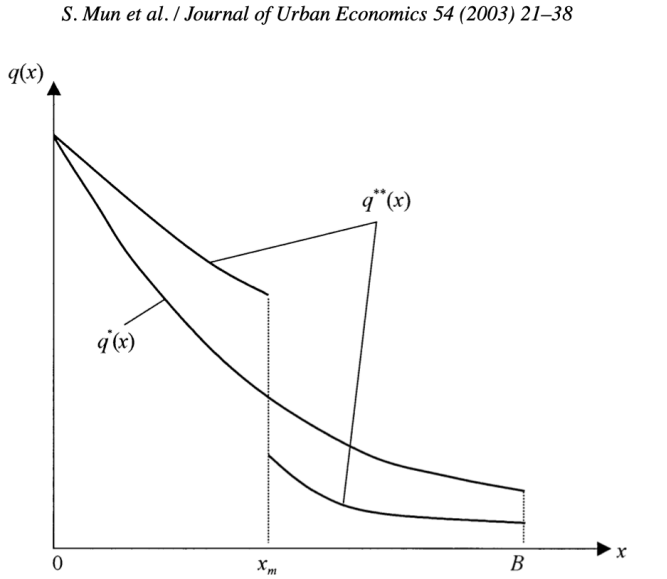

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Data

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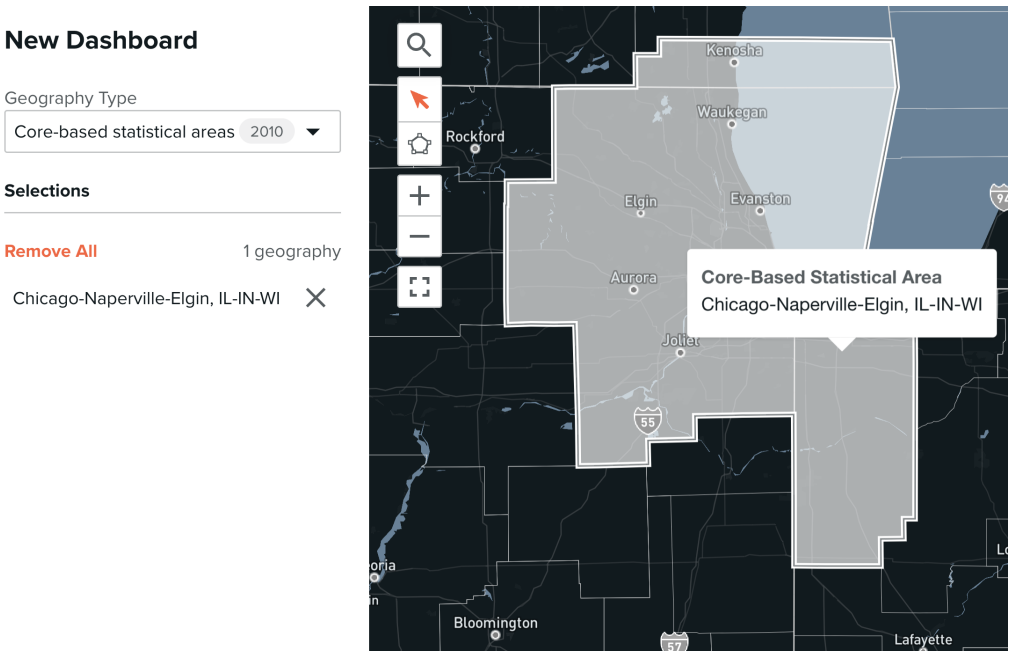

- The main dataset of this project is from **Replica**.
- O-D flows by mode available at the census tract level
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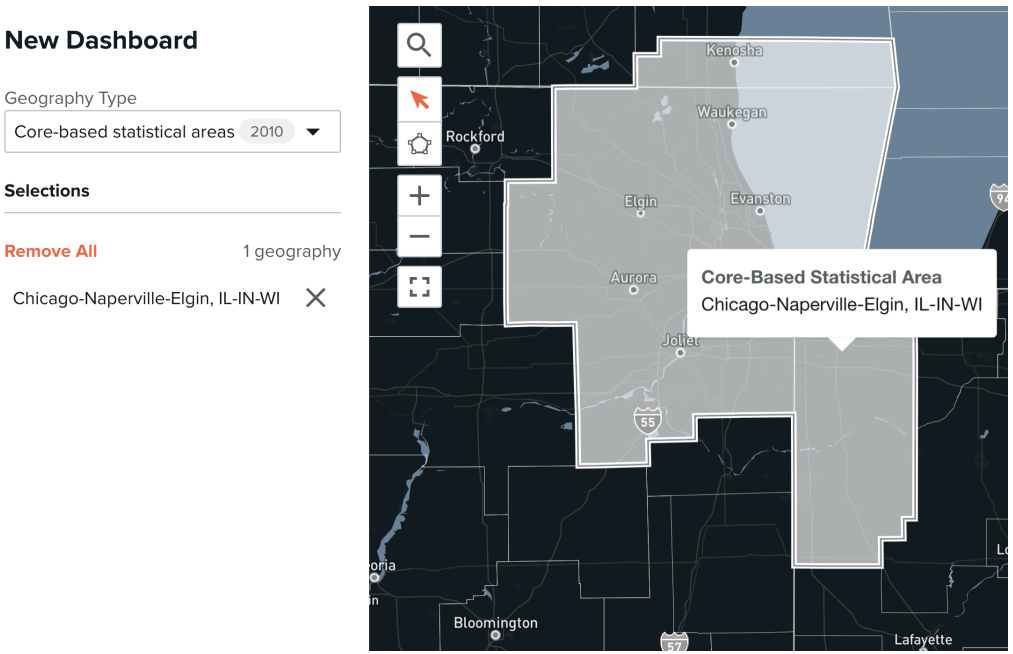

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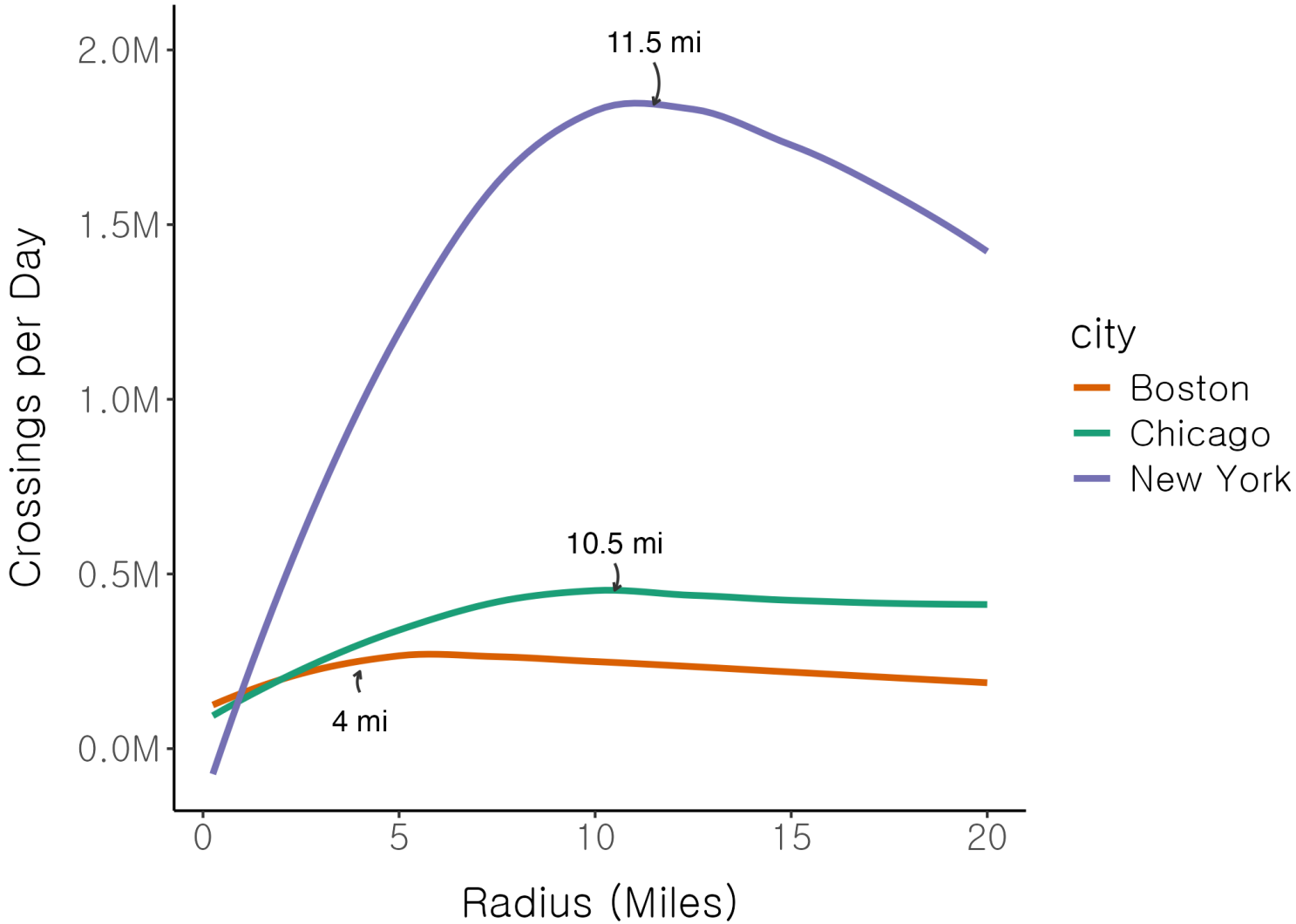
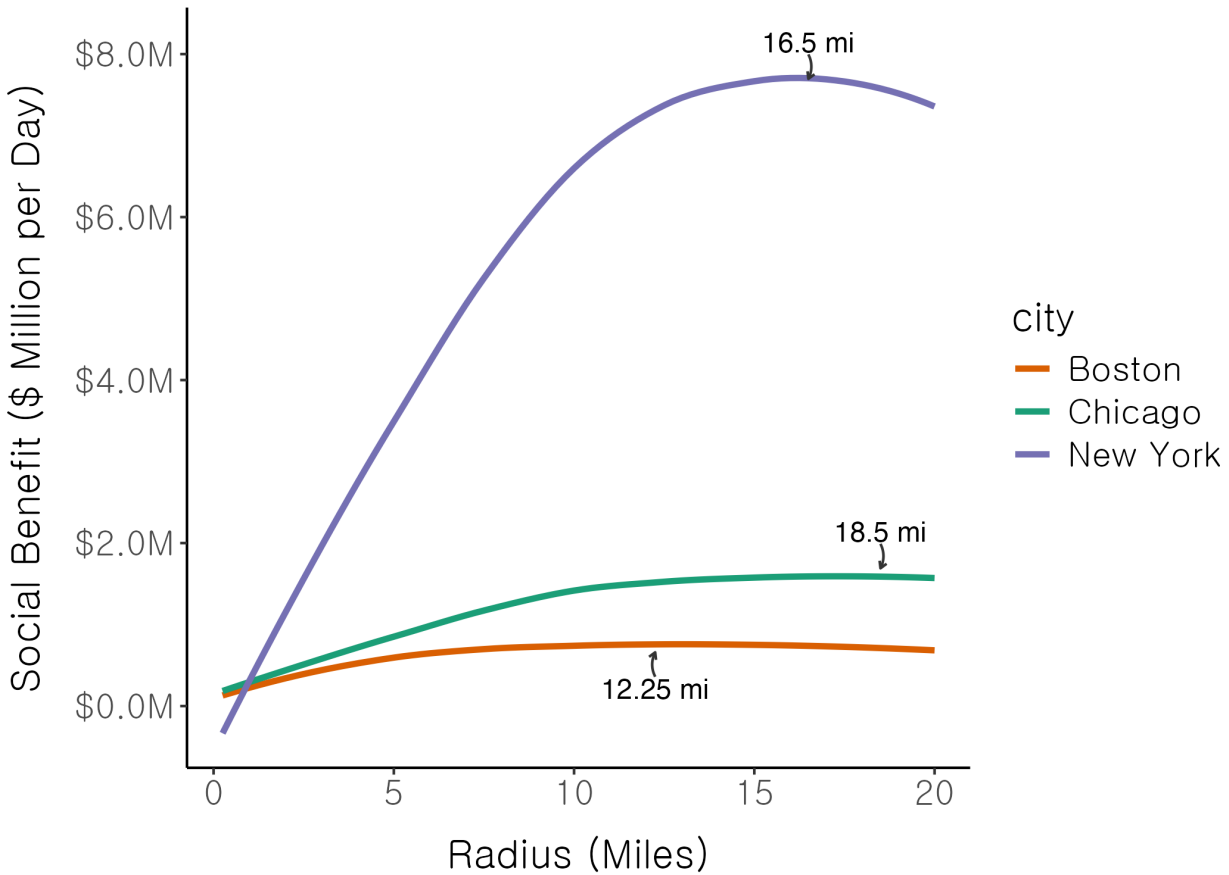
Towards optimal cordon zones: Maximizing crossings



Nice ground check: NYC's zone is roughly 2 miles in radius, and has 500,000 to 600,000 entries per day

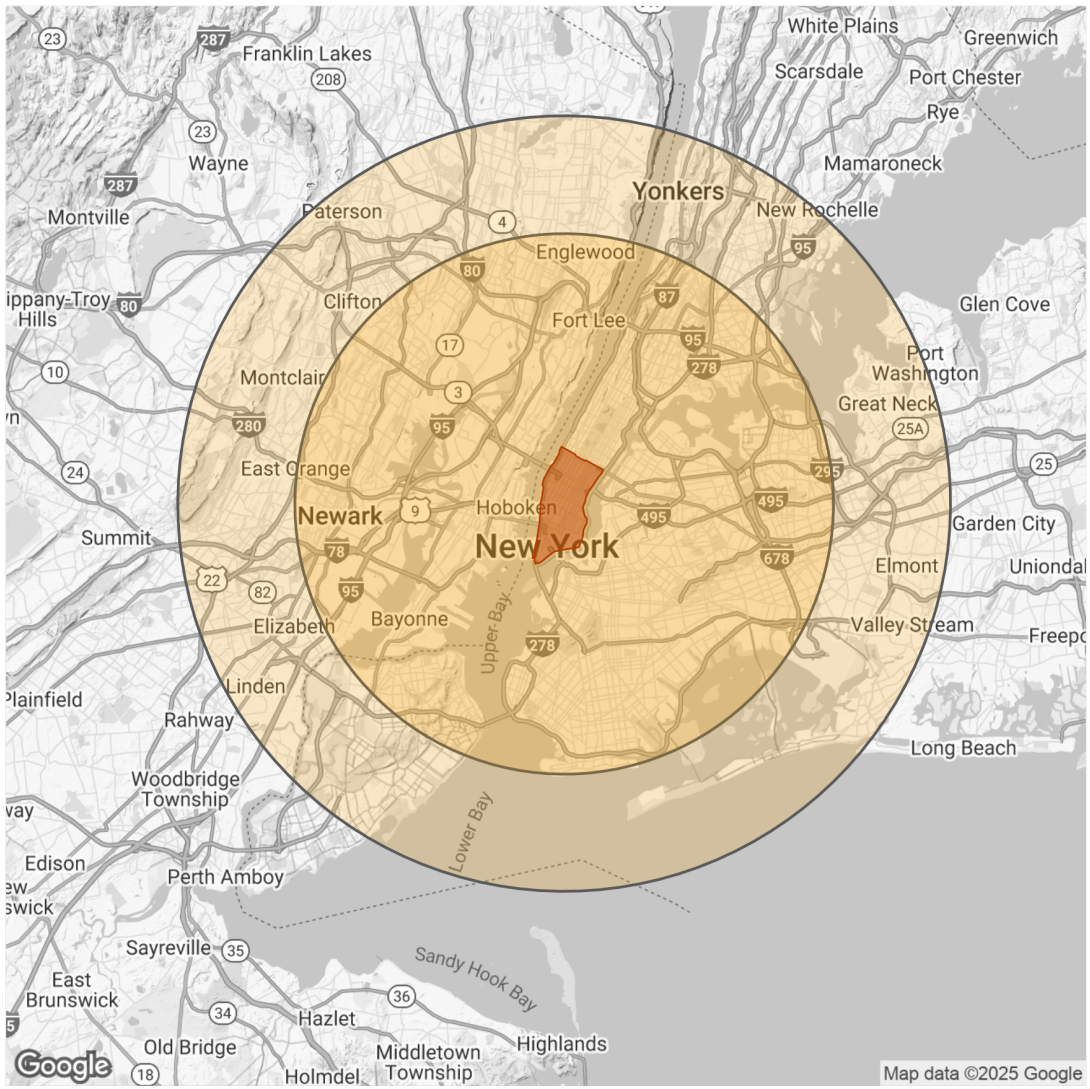
How large are optimal congestion zones, ignoring system costs?

Moving from maximizing **crossings** to **benefits**[3], I account for differences in trip length and rebound for internal trips, in the spirit of Mun, 2003



[3] Benefits reflect off-the-shelf congestion cost (35 cents/kilometer, closest to Almagro et al. (2024), see also Yang, Purevjav, and Li (2020), Langer, Maheshri, and Winston (2017), and Mangrum and Molnar (2017)) and price elasticity (-0.5, see Lehe and Devunuri (2022)) estimates, plus travel time data from Replica.

Before moving on to discussions of cost, note that these radii are *much* larger than existing congestion zones:



Can we rationalize smaller zones?

- This project: **System costs**?

Other possible explanations:

- **Low/convex congestion costs**?
- **Political economy**?

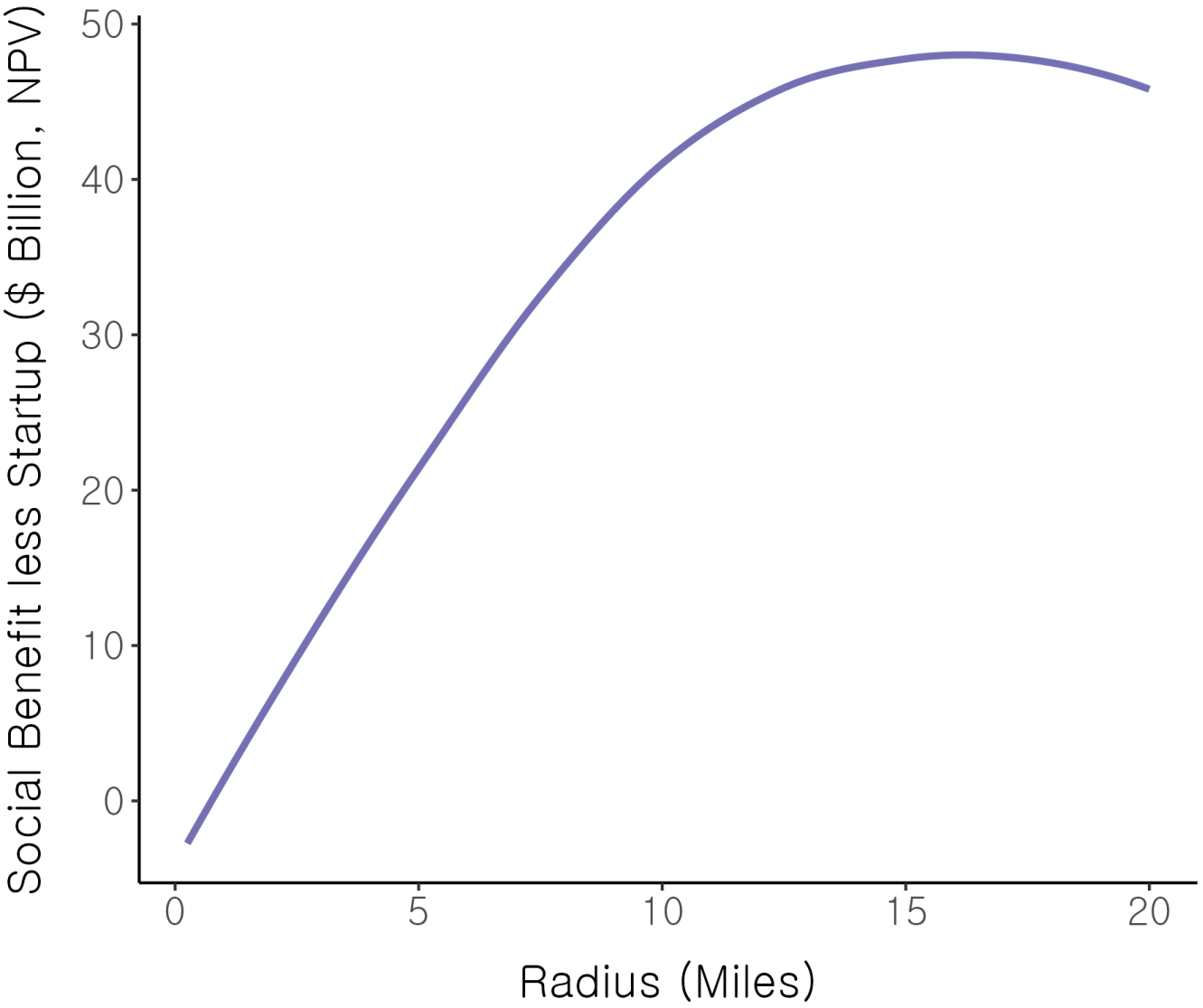
System costs in select congestion zones

	Setup	Annual O & M	Annual O & M per entry point
Milan	30-90	12	0.28
Stockholm	797	18	1.0
London	461	277	1.4
NYC	631	192	1.75

All values in millions of 2025 dollars. This table largely reflects data from the US DoT, plus updates for congestion zones in Milan and New York.

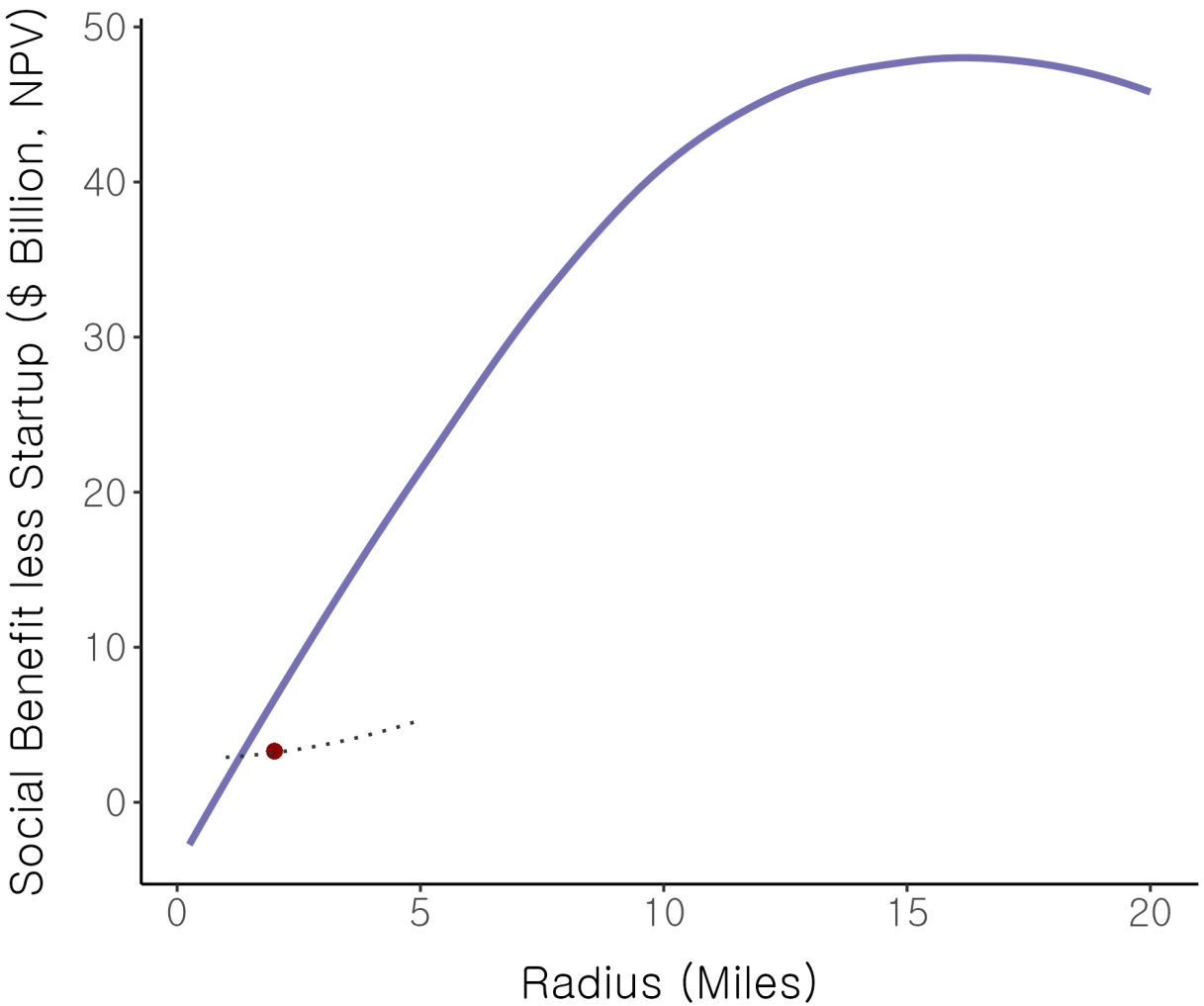
Do NYC's Costs and Benefits Rationalize a Small Zone?

First, take NPV of annual benefits and subtract setup costs:



Do NYC's Costs and Benefits Rationalize a Small Zone?

We know the annual cost of a zone that is $\sim$ 2 miles in radius in NYC.
The question is: what does the slope of this cost curve look like?



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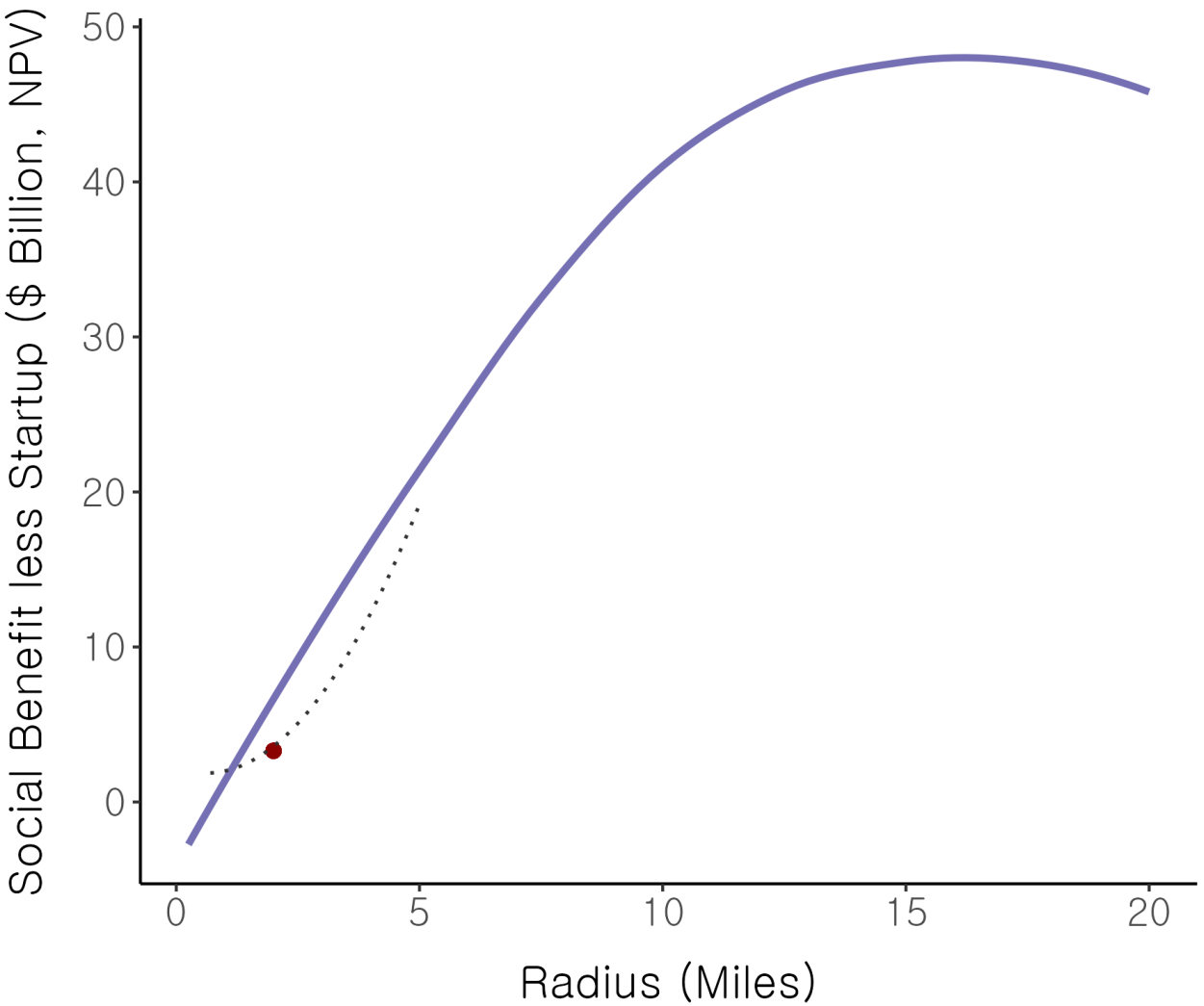

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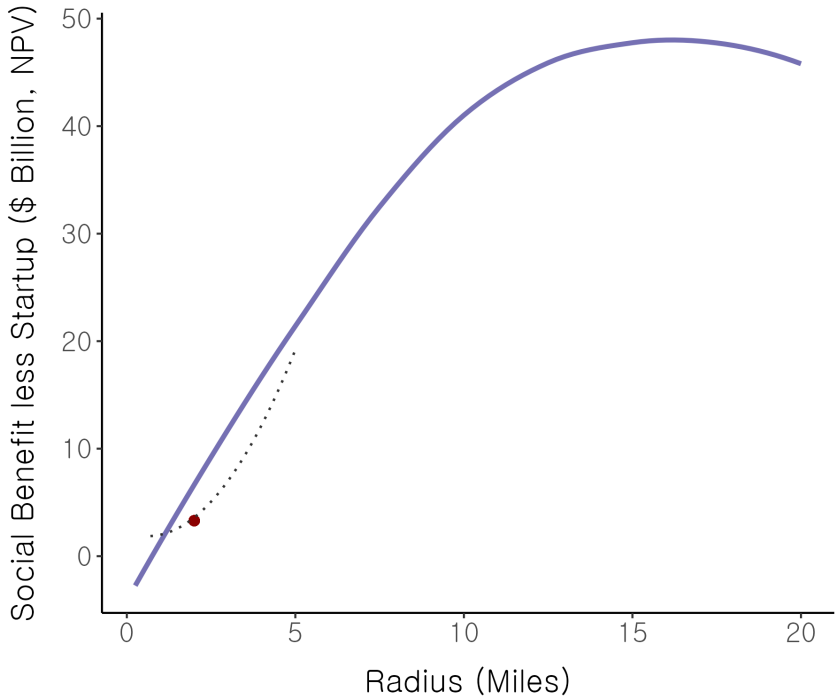

To rationalize current zone, slope ≈ an increase in radius of 1 mile costing $195 million/year, cost curve *must be convex*

- This is right order of magnitude, given costs we see
- But (a) it is easy to expand the zone with little to no cost, and (b) it is not clear that the cost curve should be convex...

Cost Functions in Real Cities

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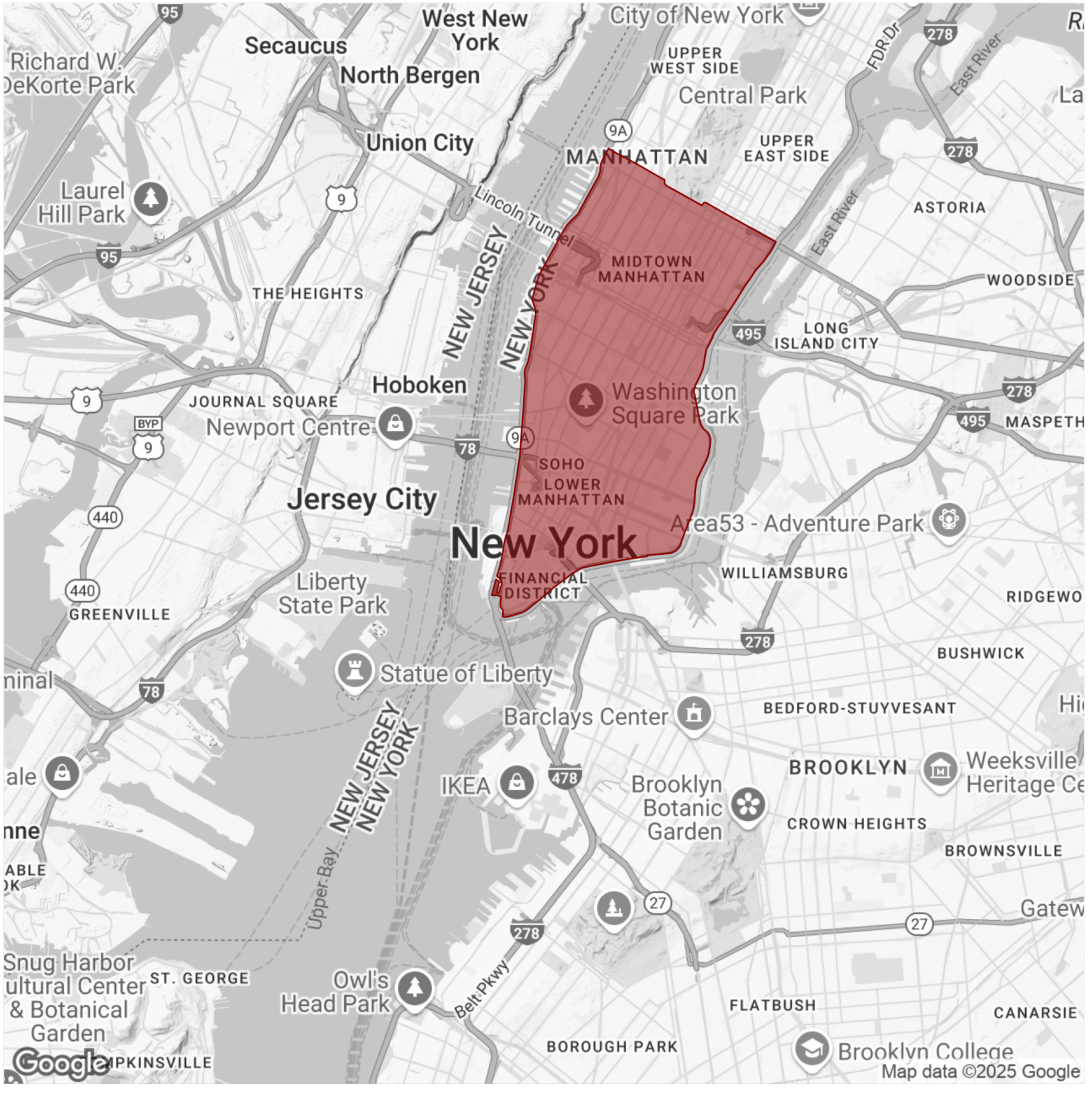
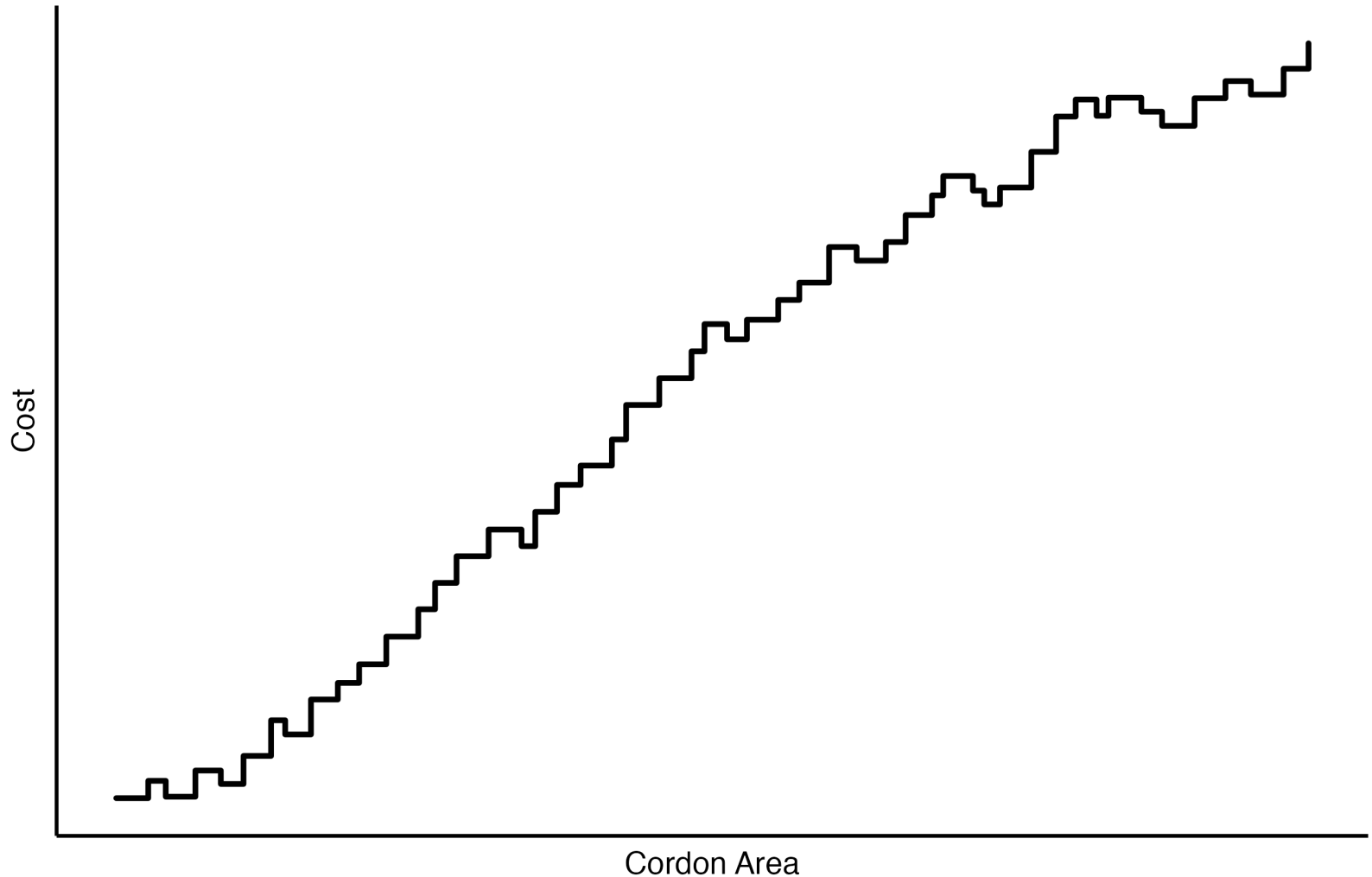
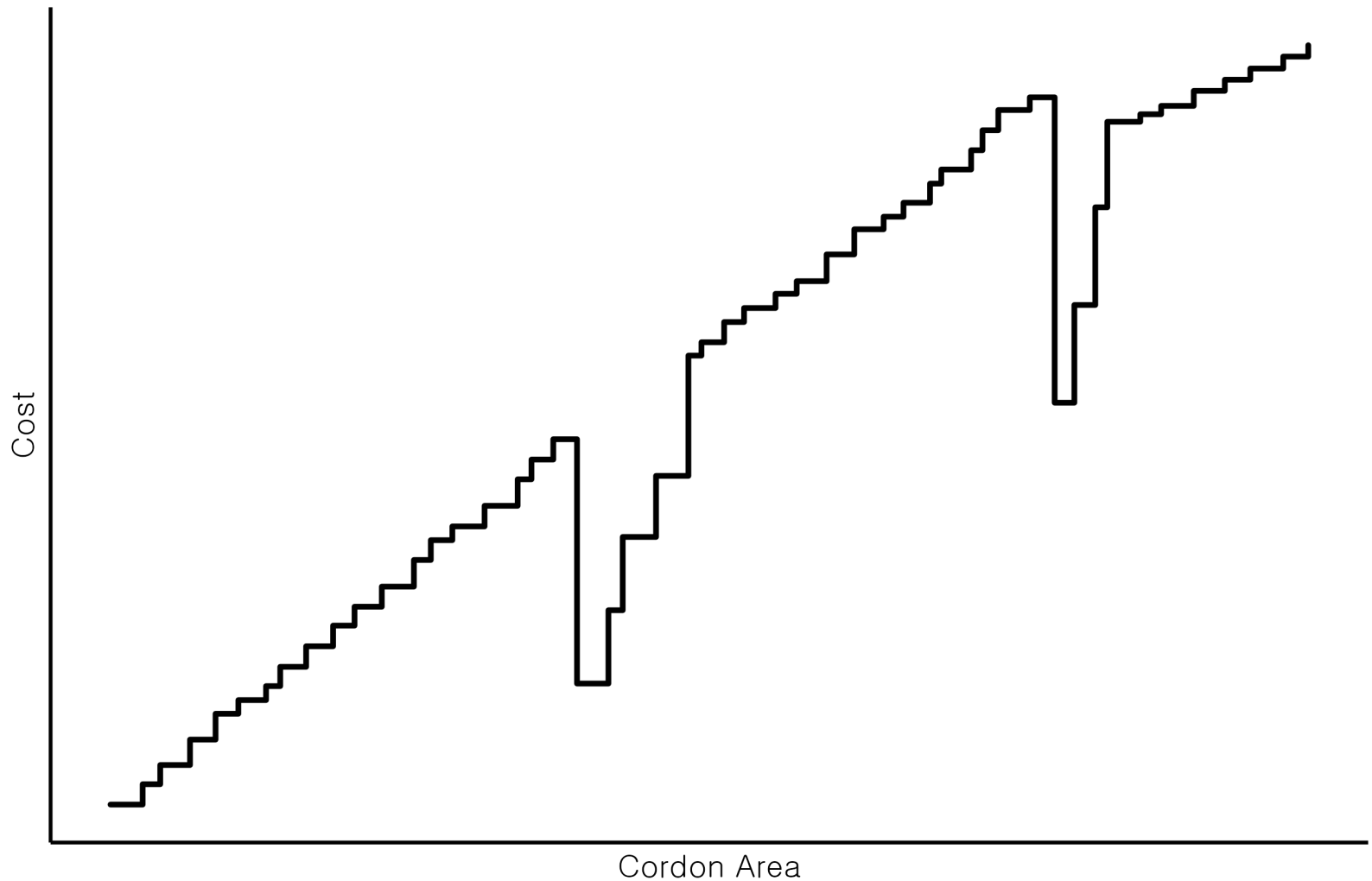


In a city with a relatively uniform street network and few natural/built boundaries, variable costs as a function of radius may be roughly linear:



In more fragmented cities (e.g., due to topography, water, or planning choices), cost functions should have **notches**:



Future work: Estimating Cost Functions

If O/M costs scale with **camera sites**, a cost function requires understanding the **minimum number of camera sites to make a zone of a given radius**.

- This problem is analogous to a graph partition problem
- The street network is a graph: nodes are intersections, edges are roads
- one instance of this problem is: What is the minimum number of “cuts” (camera locations) required to partition the graph into an “inside” and an “outside”
- If you answer this problem many times for different definitions of “inside”, then you can draw out a cost function
- Unfortunately, this class of problem is NP-hard, and therefore very computationally expensive

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Future work: Estimating Cost Functions

NetworkX is a Python package for the creation, manipulation, and study of the structure, dynamics, and functions of complex networks.

Current approach: **NetworkX** python package + OSM + a few simplifying shortcuts (most significant: limiting boundaries to road classes “above” residential).

Summary

- O-D data show that both **crossings** and **social benefits** (ignoring costs) peak at radii much larger than existing zones
- Costs **unlikely to rationalize** small size of existing zones
- But more work needed to determine cost function shape

Next steps:

- Cost function based on street network for select US cities
- Further research into the determinants of costs in existing zones
- Robustness around off-the-shelf inputs (elasticities, congestion costs, travel times)

Thank you!

Comments, complaints, and other thoughts: **tarduno@uic.edu**

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