Optimal City Structure

Treb Allen[1] Costas Arkolakis[2] Xiangliang Li[3]

[1]Dartmouth College and NBER [2]Yale University and NBER

[3]Yale University

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Motivation

- An unprecedented concentration of people in cities:
  - As of 2014, 54% of people live in cities vs 34% in 1960
  - Generating more than 80% of world GDP

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  - **Challenge**: various economic linkages (trade, migration, commuting), agglomeration economies (knowledge spillovers, scale economies), complex geographies
- Little theory work on city policies in urban models:
  - Typically difficult to construct equilibrium, let alone design real-life urban policy

This paper

- A quantitative GE urban model to evaluate design of city policies
  - Urban structure with *production spillover links*: quantitative version of Fujita Ogawa/Lucas Rossi-Hansberg, and also *amenity spillover links*
    - Arbitrary geography, locations separated by time & trade costs.
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- Generalization of urban models (Rosen-Roback) to analyze "place based" policies
  - Sharp characterization of equilibrium properties (existence, uniqueness, efficiency)
  - Straightforward mapping to available spatial micro-data
  - Equilibrium welfare summarized by single value (the eigenvalue of the system)
    - Allows to design planner that yields efficient allocations; map it to market results

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- Zoning: policy that regulates and establishes limits on the use of land/building.
  - Important (and contentious) policy implemented in nearly all cities.
- Apply framework to determine the benefit of relaxing zoning regulations and how close Chicago's current zoning to planner's optimum.

Literature review

- Model encompasses in one GE framework:
  - *Trade*: Anderson '79, Eaton Kortum '02, Melitz-Chaney ....
  - *Geography (Labor mobility)*: Krugman '91, Helpman '98, Redding Sturm '08, Allen Arkolakis '14, Redding '15
  - *Commuting*:
    - Fixed utility, no trade links: Ahlfedlt, Redding, Sturm, Wolf '14
    - Endogenous utility with commuting & trade: Monte, Redding, Rossi-Hansberg '15
  - *Knowledge externalities & endogenous time allocation*: Glaeser '99, Lucas Rossi-Hansberg '03, Rossi-Hansberg '05, Davis Dingel '13, Ioannides '12
- Characterizing equilibrium properties of spatial models
  - Allen Arkolakis '14, Allen Arkolakis Takahashi '14, Allen Arkolakis Li '15
- Urban economics and regional policies
  - Baldwin et al '03, Rossi-Hansberg '07, Glaeser Gottlieb '08, Moretti and Kline '14, Turner '14

Roadmap

- Theoretical framework
- Characterizing the equilibrium
- Optimal (real world) city structure
- Conclusion

Outline of the Talk

Theoretical framework
- Setup
- Gravity of people and goods

Characterizing the equilibrium
- Aggregation
- Equilibrium
- Model Properties
- Social Planner and Welfare

Optimal (real world) city structure
- Data
- Identification
- Optimal City Structure

Conclusion

Setup: Geography

- Locations in the city: $\Theta = \{1, 2, ..., N\}$
  - each location endowed with H_i units of buildings ($i \in \Theta$).
  - buildings can be used in residential (H_{Ri}) or commercial use (H_{Fi}) with

$$H_{Ri} + H_{Fi} \leq H_i.$$

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- Two types of areas:
  - Residential area: $\Theta_R = \{i | i \in \Theta,\ H_{Ri} > 0\}$
  - Commercial area: $\Theta_F = \{i | i \in \Theta,\ H_{Fi} > 0\}$
  - The following cases are allowed
    - Mixed use:$\Theta_R \cap \Theta_F \neq \emptyset$
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- Locations (i, j) separated by :
  - Iceberg trade costs $\tau_{ij} \geq 1$(goods)
  - Travel time costs, $d_{ij} \geq 0$ (people)

Setup: Production

- Each location produces differentiated variety
- Cobb-Douglas production function

$$Y_i = A_i L_{Ei}^{\alpha} H_{Fi}^{1-\alpha},$$

  where A_i is productivity, L_{Ei} is the number of effective labor.
- Firms in each location are perfectly competitive, so we have wage and rent:

$$w_i = \alpha p_i L_{Ei}^{\alpha-1} H_{Fi}^{1-\alpha},$$

$$r_{Fi} = (1-\alpha)\, p_i L_{Ei}^{\alpha} H_{Fi}^{-\alpha}$$

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- Agent has one unit of time, which is allocated between commuting d_{ij} and working working $t_{ij} = 1 - d_{ij}$.
- Agent needs to decide where to live, where to work and the consumption over housing and goods.

Agent's Problem

- Agent maximizes utility in each step

$$\max_{i\in\Theta_R}\mathbb{E}\left[\max_{j\in\Theta_F}\max_{h_i(\omega),Q_i(\omega)} u_i h_i\left(\omega\right)^{1-\beta} Q_i\left(\omega\right)^{\beta}\right]$$

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- Three steps of decisions:
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  - Last, knowing above information, agent determines the consumption.

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subject to $\sum_{k \in \Theta_F} p_{ki} q_{ki}(\omega) + r_{Ri} h_i(\omega) \leq e_j(\omega)$ where $Q_i(\omega) = \left(\sum_k q_{ki}(\omega)^{\frac{\sigma-1}{\sigma}}\right)^{\sigma/(\sigma-1)}$.

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  $Q_i(\omega) = \left(\sum_k q_{ki}(\omega)^{\frac{\sigma-1}{\sigma}}\right)^{\sigma/(\sigma-1)}$.
- Second, maximize indirect utility,

$$\max_{j\in\Theta_F} c\frac{e_j(\omega)}{P_i^{\beta} r_{Ri}^{1-\beta}}$$

  where $e_j(\omega) = y^c + w_j a_j(\omega) t_{ij}$, y^c is capital income, $a_j(\omega)$ is realized productivity, $\{a_j(\omega)\}$ follows a i.i.d. Frechet distribution across all $j \in \Theta_F$.
- Last, maximize expected utility,

$$\max_{i\in\Theta_R} u_i \frac{y^c + \Gamma\left(\frac{\theta-1}{\theta}\right) W_i}{P_i^{\beta} r_{Ri}^{1-\beta}}$$

  where $W_i = \left(\sum_j (w_j t_{ij})^{\theta}\right)^{\frac{1}{\theta}}$.

Macro Implications of Agent's Decision

- Gravity of goods

$$X_{ij} = \frac{p_i^{1-\sigma} \tau_{ij}^{1-\sigma}}{P_j^{1-\sigma}} \beta E_j,$$

where $P_j = \left(\sum_i p_i^{1-\sigma} \tau_{ij}^{1-\sigma} \right)^{1/(1-\sigma)}$, is the CES price index

- Gravity of commuting

$$L_{ij} = \frac{(w_j t_{ij})^{\theta}}{W_i^{\theta}} L_{Ri},$$

where $W_i = \left(\sum_j (w_j t_{ij})^{\theta} \right)^{\frac{1}{\theta}}$, is the ex-ante expected wage

Outline of the Talk

Aggregation on trade and commuting

- **Aggregation on Commercial Area Side**
  - (Goods) Production Balance

$$Y_i = \sum_j X_{ij},$$

  - (People) Aggregation of effective labor accounting:

$$L_{Ej} = \sum_i l_{ij} L_{ij}$$

where $l_{ij} = \Gamma\left(\frac{\theta-1}{\theta}\right) \frac{W_i}{w_j t_{ij}} t_{ij}$.

- **Aggregation on Residential Area Side**
  - (Goods) Budget Balance (Price Index):

$$\beta E_i = \sum_j X_{ji}$$

  - (People) Commuting balance

$$L_{Ri} = \sum_j L_{ij}$$

Aggregation of spillovers

- **Spatial Spillovers:**
  - Productivity Spillover

$$A_i = \bar{A}_i \left(\sum_j K_{ij}^A L_{Ej} \right)^\eta$$

  - Amenity

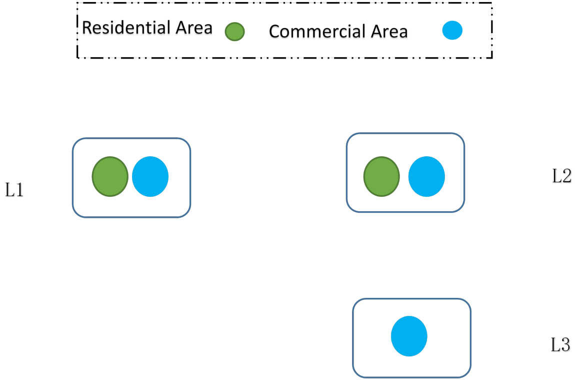
$$u_i = \bar{u}_i \left(\sum_j K_{ij}^u L_{Rj} \right)^\epsilon$$

- **Welfare Equalization**

$$W = \frac{u_i e_i}{P_i^\beta r_{Ri}^{1-\beta}}.$$

where $e_i = y^c + \Gamma\left(\frac{\theta-1}{\theta}\right) W_i$.

Aggregation-Visualization



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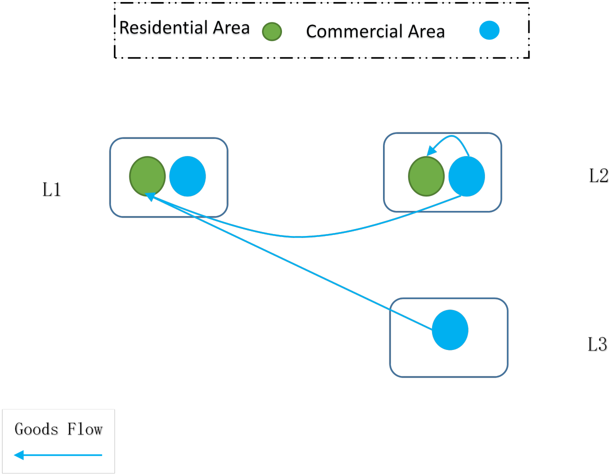

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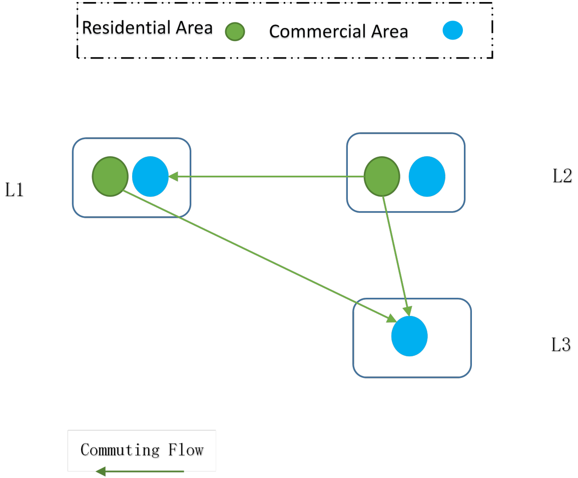

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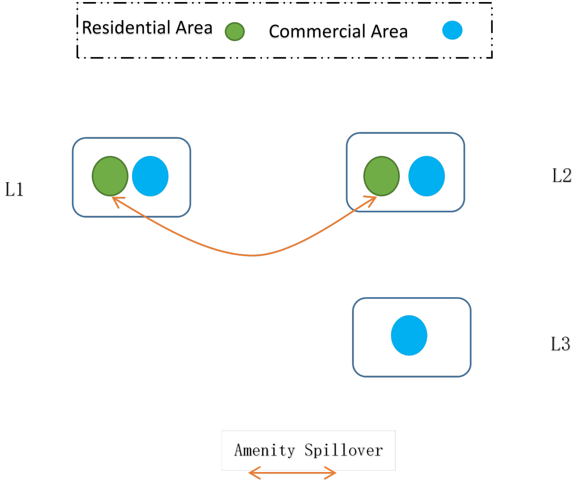

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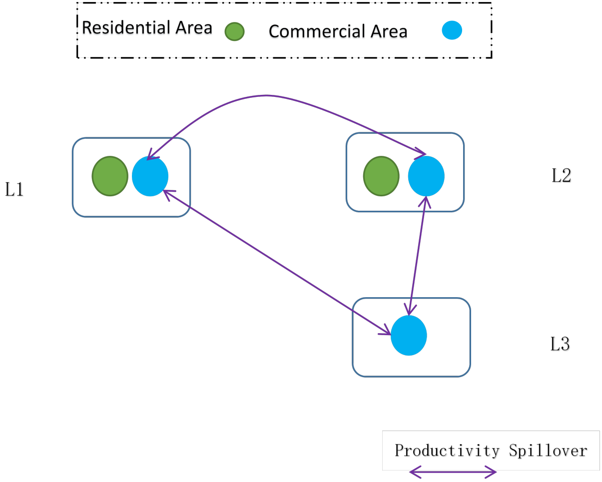

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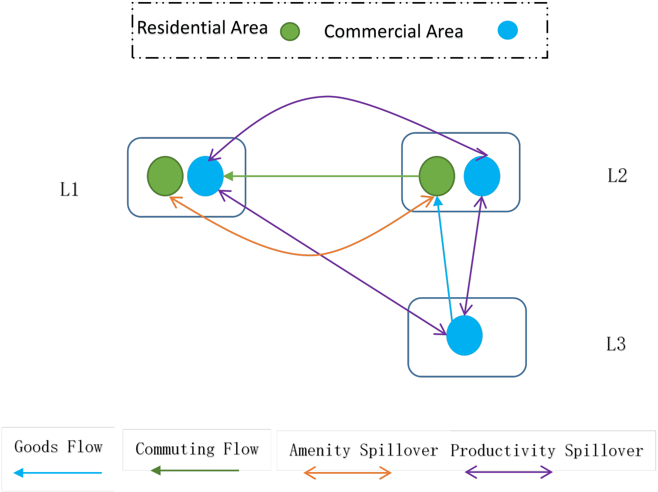

Market Equilibrium vs. zoning

- **Zoning Equilibrium** (denoted as $\mathcal{F}_1$) is characterized by equilibrium equations on commercial area , residential area, spatial spillover equation and welfare equalization condition. In Zoning Equilibrium, $\{H_{Ri}, H_{Fi}\}$ are exogenously given.

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- **Market Equilibrium without zoning** ($\mathcal{F}_2$), $\mathcal{F}_1$ and $\left\{H_i^F\right\}$ and $\left\{H_i^R\right\}$ determined by rent equalization:

$$\begin{cases} r_{Ri} = r_{Fi} & \text{if } H_{Ri} > 0 \\ H_{Ri} = 0 & \text{if } W > \frac{u_i e_i}{P_i^{\beta} r_{Fi}^{1-\beta}} \end{cases}$$

-

$$H_i = H_{Fi} + H_{Ri} \ \forall i \in \{1, ..., N\} \, .$$

Existence and uniqueness

Theorem

(Existence and Uniqueness) Consider the above Zoning Equilibrium $\mathcal{F}_1$,
i) An equilibrium solution always exists.
ii) If trade costs are zero, the equilibrium is unique (for prices variables, it is up-to-scale unique) if the following inequalities are satisfied,

$$|\eta| \leq \frac{\alpha(\sigma-1)(1-\theta)+\sigma\theta}{(\sigma-1)|\theta-1|},$$

$$|\epsilon| \leq \frac{1-\beta}{\beta},$$

and

$$g(|\epsilon|,|\eta|) \leq 0$$

where $g(|\epsilon|,|\eta|)$ increases with $|\epsilon|$ and $|\eta|$.

- Implication on policy:
    - multiple equilibria when spatial spillover strengths are strong.

Equilibrium Characterization: no trade costs and symmetry

- In general, analytical solutions of the equilibrium do not exist.
- In certain special cases, however, they do: Assume that $\alpha = \beta = 1$ (no land rents) and assume no trade costs
  - We can write equilibrium as

$$\left(L_i^E\right)^{\sigma_1 \tilde{\epsilon}} = \left(\frac{\bar{L}}{W^\theta} \beta^{\frac{\theta}{\sigma}} E^{\frac{\theta}{\sigma}}\right)^{\frac{1}{1+\theta}} \sum_j \tilde{K}_{ij}^A \left(L_j^E\right)^{\eta \tilde{\epsilon}}$$

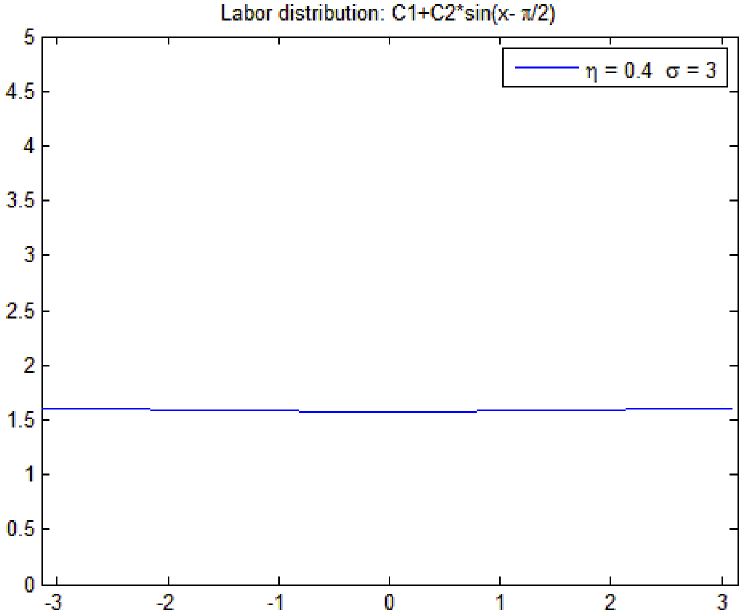
- Consider now the geography of a circle, $S = [-\pi, \pi]$
  - Also assume exogenous productivities, amenities and land is symmetric
  - And that $\tilde{K}_{ij}^A = C \left[\cos\left(\frac{i-j}{2}\right)\right]^2$

- System attains a solution

$$\left(L_i^E\right)^{\sigma_1 \tilde{\epsilon}} = Y + \sqrt{Y^2 + C_1} \sin\left(i + C_2\right)$$

where $Y^2 + C_1 \geq 0$, and C_2 is arbitrary due to symmetry.

Analytical Solution



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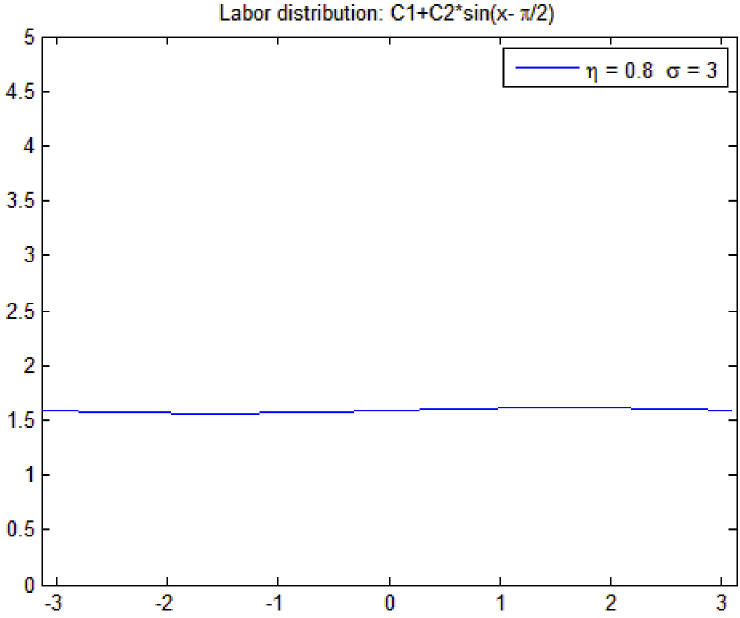

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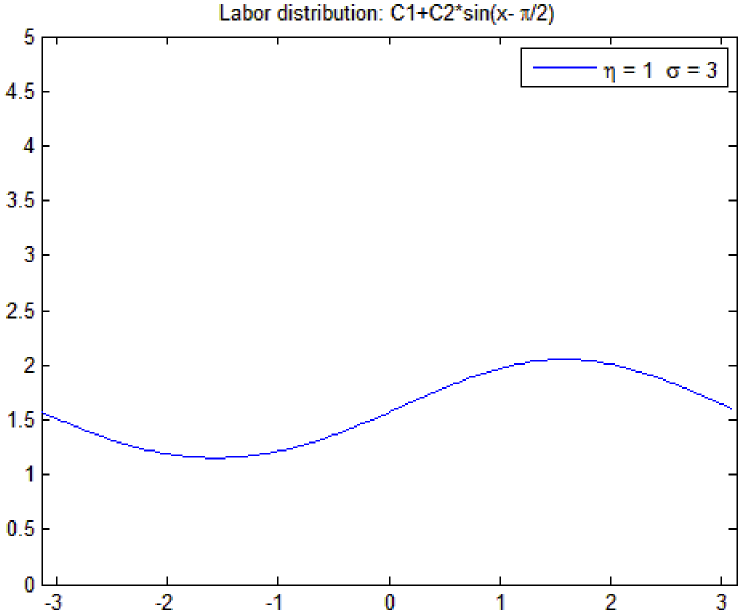

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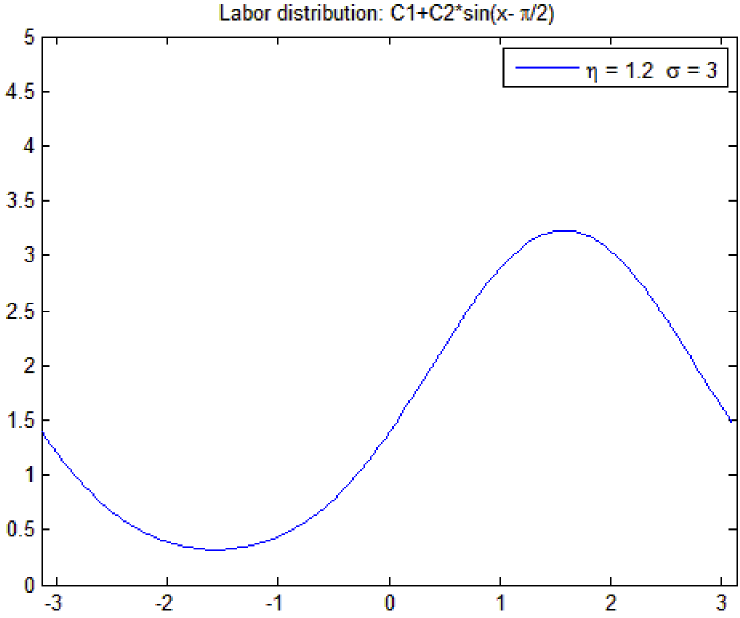

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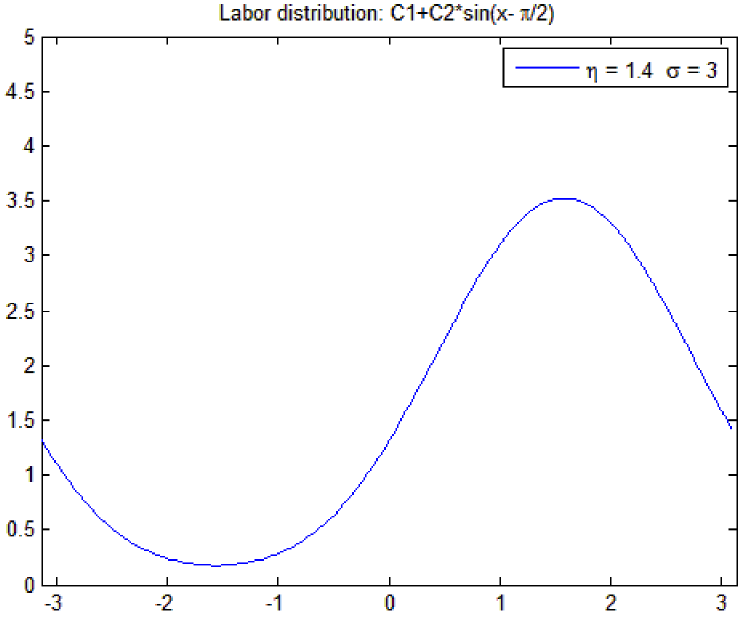

The Planner and the role for zoning

- Zoning Social Planner, S^Z, is social planner who maximizes W

$$\max_{\{H_{Fi}, H_{Ri}\}_{i\in\Theta}} W$$

subject to

$$H_i = H_{Fi} + H_{Ri}$$

and the zoning equilibrium $\mathcal{F}_1$.

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(ii) When $\eta, \epsilon \neq 0$*, the market equilibrium* $\mathcal{F}_2$ *does not solve the Ramsey problem, i.e. zoning can improve upon the market equilibrium.*

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(ii) When $\eta, \epsilon \neq 0$*, the market equilibrium* $\mathcal{F}_2$ *does not solve the Ramsey problem, i.e. zoning can improve upon the market equilibrium.*

(iii) (preliminary) There exists a set of (Pigovian) taxes on labor such that the market equilibrium $\mathcal{F}_2$ *achieves at least as high social welfare function as the solution to the Ramsey problem, i.e. zoning is a "second best" policy instrument.*

The welfare effect of zoning

Proposition

Suppose we observe global parameters,$\boldsymbol{\kappa} = \theta, \alpha, \beta, \sigma, \eta, \epsilon$, *data matrices on bilateral flows of goods and people* $\boldsymbol{\pi}$*. Then:*

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1. **(Global counterfactual)** *In a unique equilibrium, the change in welfare for any change in* $\hat{H}_{Fi}$ *and* $\hat{H}_{Ri}$ *can be uniquely determined as a function of* $\boldsymbol{\kappa}$,$\boldsymbol{\pi}$ *alone.*

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2. **(Local counterfactual)** *For any observed equilibrium, the elasticity of welfare for small changes in* H_{Ri} *or* H_{Fi} *can be expressed as a function of* $\boldsymbol{\kappa}$,$\boldsymbol{\pi}$ *alone:*

$$\frac{d \ln W}{d \ln H_{Ri}} = G^R(\boldsymbol{\kappa},\boldsymbol{\pi}) \text{ and } \frac{d \ln W}{d \ln H_{Fi}} = G^F(\boldsymbol{\kappa},\boldsymbol{\pi})$$

where $G^R(\boldsymbol{\kappa},\boldsymbol{\pi})$ *and* $G^R(\boldsymbol{\kappa},\boldsymbol{\pi})^H$ *are closed form expressions (see paper).*

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3. **(Necessary optimality condition)** *At the optimal zoning, following FOCs hold for* $H_{Ri} > 0$*:*

$$\frac{d \ln W}{d \ln H_{Fi}} \frac{1}{H_{Fi}} = \frac{d \ln W}{d \ln H_{Ri}} \frac{1}{H_{Ri}}$$

Outline of the Talk

Data

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- For $\sim$2,000 census block groups in 2010 we observe:
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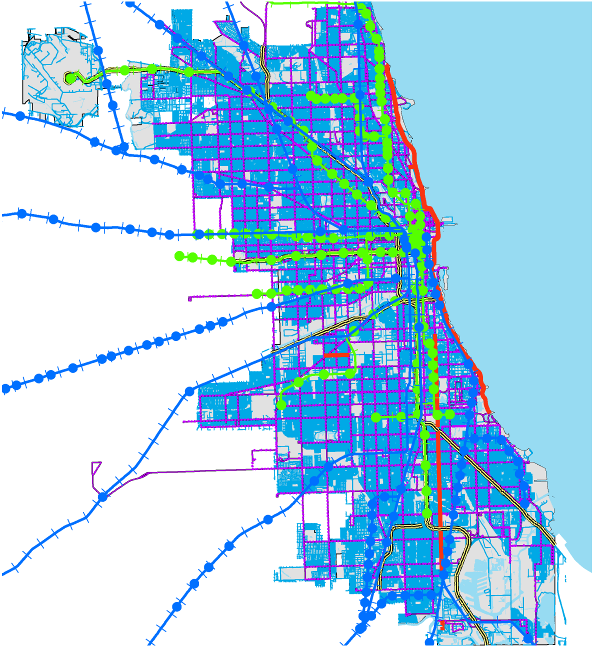
- Observe entire transportation network (subway & stops, commuter rail & stops, bus routes & stops, roads)
  - Use FMM to calculate travel time between any two census block groups by either private or public transportation (cross-check with Google Maps).

Transportation infrastructure



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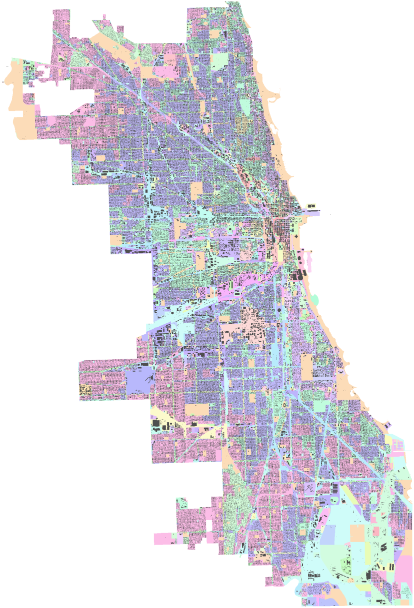
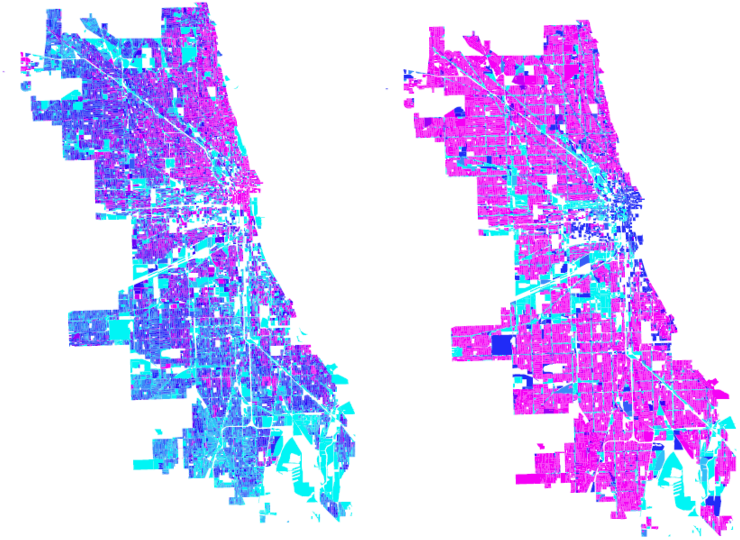
- Observe entire transportation network (subway & stops, commuter rail & stops, bus routes & stops, roads)
  - Use FMM to calculate travel time between any two census block groups by either private or public transportation (cross-check with Google Maps).
- For all ∼820,000 buildings:
  - Zoning of building.
  - Square footage / # of stories.
  - Can construct H_{Fi} and H_{Ri}.

Buildings and Zoning

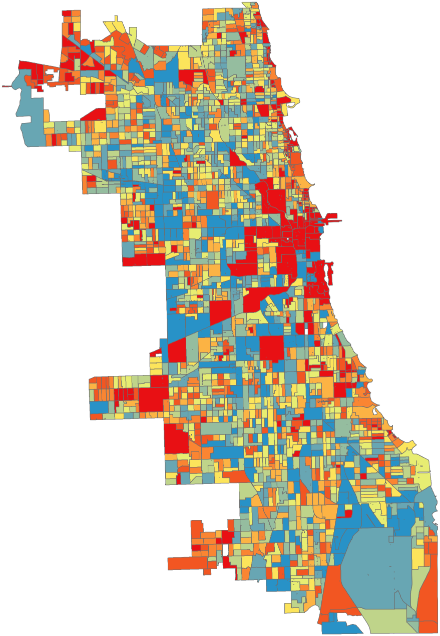


Buildings and Zoning (CBD)

Buildings m^2 and Fraction Residential



Estimated composite productivities (A_i) and amenities (u_i)



Optimal City Structure in Chicago

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  - Current results preliminary based on different rent redistribution (proportional to wage)

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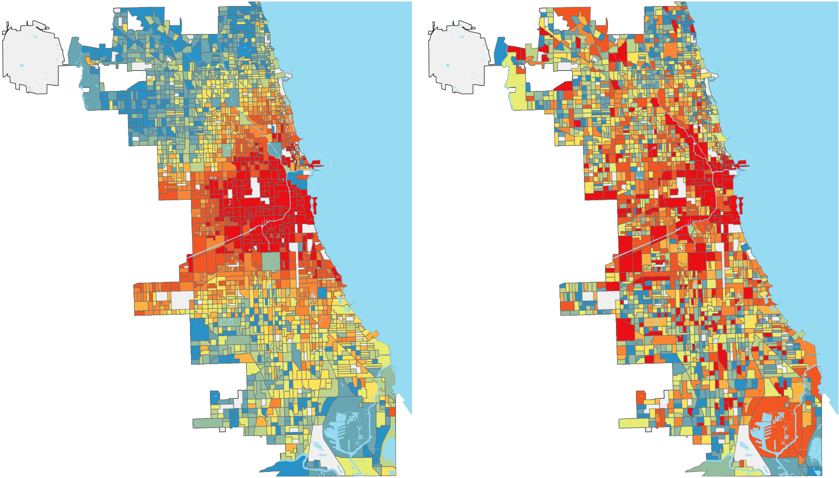
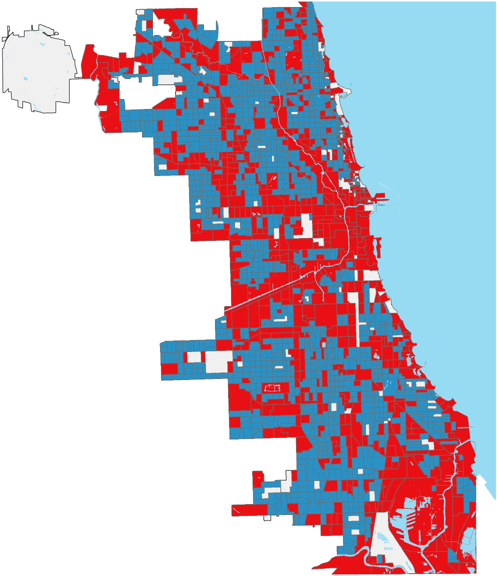
- Two exercises (effect of implementing policy on i for W):
  - Relax building regulations: calculate elasticity of welfare to increasing total area by increasing commercial ($\frac{d \ln W}{d \ln H_{Fi}}$) or residential area ($\frac{d \ln W}{d \ln H_{Ri}}$) using part (ii) of Proposition 1.
  - Reallocate zoning: reallocate more area to residential (which occurs $\iff$ $\frac{d \ln W}{d \ln H_{Ri}} \frac{1}{H_{Ri}} > \frac{\partial \ln W}{\partial \ln H_{Fi}} \frac{1}{H_{Fi}}$).

Estimated elasticity of city welfare to increasing commercial ($\frac{\partial \ln W}{\partial \ln H_{Fi}}$) and residential area ($\frac{d \ln W}{d \ln H_{Ri}}$)



Reallocate area: residential (red) or commercial (blue)?



Outline of the Talk

Conclusion

- Understand “place-based” policies in the presence of externalities:
  - Incorporate a number of the spatial linkages present in cities.
  - Characterize properties of the model and derive analytical solutions for how changing zoning affects welfare
  - Framework sufficiently flexible to take to readily available micro-data.

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  - Incorporate a number of the spatial linkages present in cities.
  - Characterize properties of the model and derive analytical solutions for how changing zoning affects welfare
  - Framework sufficiently flexible to take to readily available micro-data.
- Broader scheme of things:
  - Develop a set of mathematical tools to characterize properties of GE models with spatial interactions.