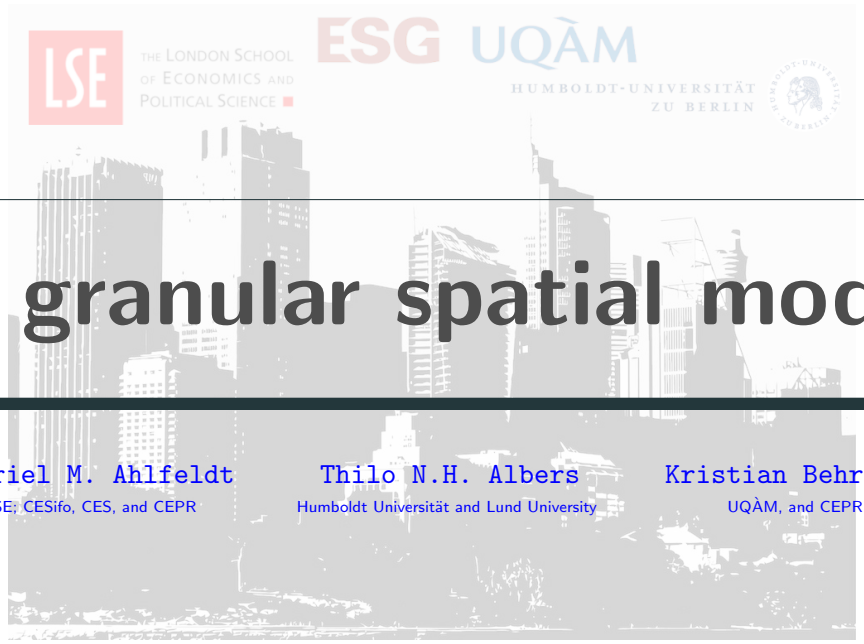

A granular spatial model

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UQÀM, and CEPR

Introduction

- Arrival of *large granular* firms can bring about substantial local change
  - 'Million Dollar' plants and TFP gains for incumbents (Greenstone et al., 2010)
  - 'Million Rouble' plants (China 1950s) and local development (Heblich et al., 2022)
  - effect of large high-skilled firms on incumbent residents (Qian and Tan, 2021)
  - change of the Mile-End in Montreal following Ubisoft's arrival in 1997
- Agglomeration economies generated by the arrival of large granular firms can jump-start a process of "cumulative causation"
  - old idea from "new economic geography" (Krugman, 1991; Fujita et al., 1999)
  - implicitly or explicitly underlies place-based developement policies
- ... but large granular firms are hard to attract
  - few, highly sought-after, require large incentive packages (e.g., Amazon's HQ2)
  - likely to already be in very good places, i.e., they are *inframarginal*

Local effects of 'superstar' firms

Take Google's location choices as an example:

- Here: 28 US office openings
- 5-year before-after comparison of employment and # establishments at ZCTA-level
- Compare openings of large offices vs. small offices (<200 employees)

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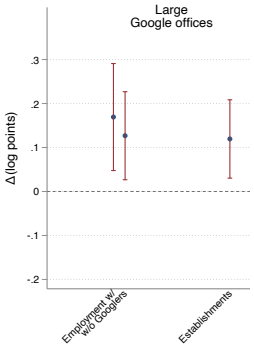
- EZ-like effects for large offices (Busso et al., 2013): 13-19% employment growth



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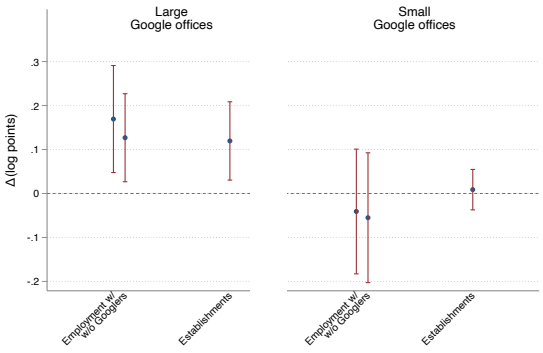

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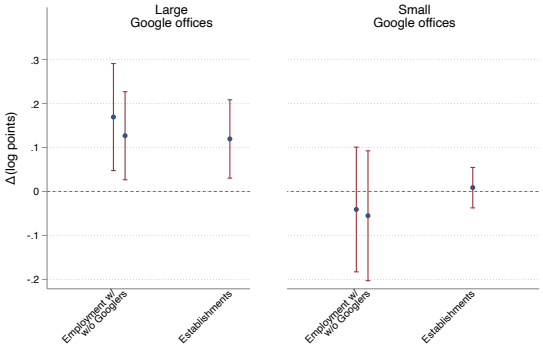

It's not 'just Google'. Size seems to matter for local outcomes.

Place-based policies: Importance of large firms

Place-based policies:

- Evidence on their effectiveness is mixed (Neumark and Simpson, 2015)
- Economists typically interested in the average effect
- Policy makers typically interested in the right tail (winners)
- What about variation around average effect *among those treated*?

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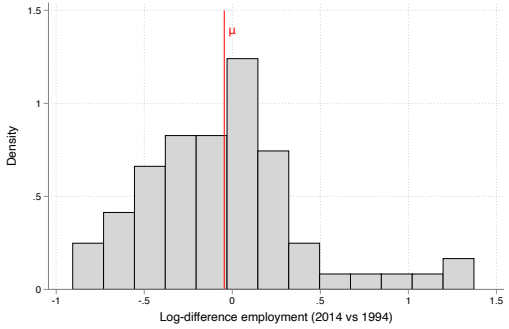

Employment outcomes for Round I Empowerment Zones after 20 years

What can we learn from looking at the right tail (winners)?

Place-based policies: Importance of large firms

'Catching a big fish' early matters:

- within first 5 years of program, firm with > 250 employees
- infer arrival of large firm from employment size distributions of CBP (delete ambiguous cases)
- deduce size of attracted large firm
- $g_{t/1994} = \alpha + \beta BIGFISH + \gamma + \epsilon$
- γ city-wide growth (6 cities)

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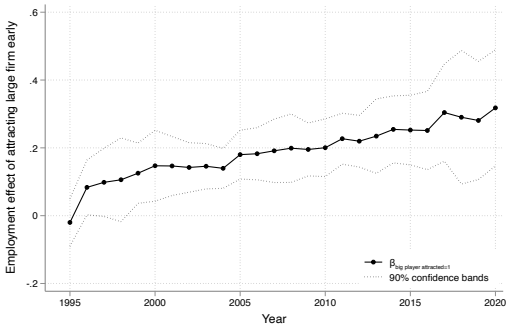


Employment growth relative to 1994 (based on ZCTA-level County Business Pattern data; 69 ZCTAs)

Weak average effects of place-based policies vs success stories in the right tail (e.g., 'Million dollar' plants; Greenstone et al., 2010) are not contradictory

Place-based 'lotteries'

- More likely to win if you attract early a large firms, but they are hard to move.
- Larger incentives increase probability of getting a big fish, but thresholds likely depend on initial conditions.
- Firms may not stay, effects may or may not outlast the lifetime of the program (Kline and Moretti, 2014; Givord et al., 2018)

1. Size matters. 2. Threshold effects and role for initial conditions. 3. Temporary changes can have persistent effects.

We develop a new quantitative model that has these features.

Back to the future? New Economic Geography

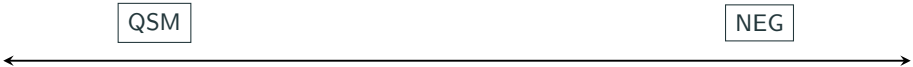
- NEG models developed in 1990s already had those features
  - Allowed us to think about a host of important policy questions
  - Were very popular in policy-oriented circles
- ... yet, NEG's traction in applied work quickly disappeared
  - Hard to extend to multiple locations, very hard to quantify structurally. Little to no structural work (Redding and Rossi-Hansberg, 2009)
  - Complex models, not well-suited to deal with computationally (inequalities become important but are hard to handle using marginal analysis)

Enter the Quantitative Spatial Models

- Quantitative spatial models (QSM) have filled the structural/computational void
  - Rationalize observed outcomes through endogenous forces and primitives
  - Mapping from primitives to endogenous outcomes facilitates nice counterfactuals
  - Tractable tool for policy analysis (modelled via permanent changes in primitives)
- Important role for exogenous local characteristics (fundamentals)

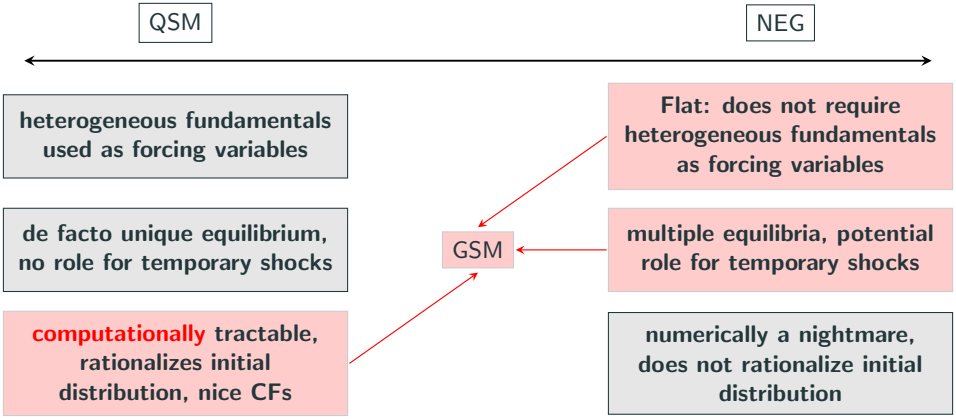
"Agglomeration in these models is simply the result of exogenous local characteristics augmented by endogenous economic mechanisms."
(Redding and Rossi-Hansberg, 2009, p.22)

Motivating the Granular Spatial Model



QSM	NEG
heterogeneous fundamentals used as forcing variables	Flat: does not require heterogeneous fundamentals as forcing variables
de facto unique equilibrium, no role for temporary shocks	multiple equilibria, potential role for temporary shocks
numerically tractable, rationalizes initial distribution, nice CFs	numerically a nightmare, does not rationalize initial distribution

Motivating the Granular Spatial Model



Motivating the GSM

We leverage what we have learned from the QSM and blend it with elements of NEG to revisit issues of agglomeration with granular firms

- GSM features agglomeration and dispersion forces known from the QSM, but there are important differences
  - Large indivisible firms account for a substantial share of spatial employment concentration (Ellison and Glaeser, 1997)
  - Potentially all firms and workers are inframarginal
  - Requires different tools than either QSM or NEG on the production side
- Discrete nature of the model
  - allows for arbitrary heterogeneity at the location, worker, and firm level
  - algorithmic approach makes it amenable systematic simulation work

GSM: Model roadmap

- Preferences
- Technology
- Worker-firm matching and ranks within firms
- Production of floorspace
- Equilibrium for floorspace
- Worker search
- Firm relocation
- Spatial equilibrium

GSM: Basic building blocks

- The GSM has three basic building blocks:
  - $N_W \in \mathbb{N}$ workers, subscript ω
  - $N_F \in \mathbb{N}$ firms, subscript φ
  - $\mathcal{L} \in \mathbb{N}$ locations, subscript ℓ
- Workers and firms are indivisible and (potentially arbitrarily) heterogeneous; in particular, heterogeneous productivities θ_ω and θ_φ
- Workers and firms have at most one address (location).

We solve for static equilibria and conduct counterfactual analysis to evaluate transitory and persistent effects of shocks.

GSM: Preferences

- Worker ω in location ℓ solves the following problem:

$$\max_{h,g} \quad U_{\omega,\ell}(h,g) = \frac{B_{\ell,\omega}}{\alpha_\omega^{\alpha_\omega}(1-\alpha_\omega)^{1-\alpha_\omega}} h^{\alpha_\omega} g^{1-\alpha_\omega} \quad \text{s.t.} \quad r_\ell h + g = w_\omega^{\text{net}}(\theta_\omega)$$

  where h and g are consumption of housing and a bundle of goods; and $B_{\ell,\omega}$ is a location-specific shifter (with possibly an endogenous residential externality).

- Income net of commuting $w_\omega^{\text{net}}(\theta_\omega) = w_\omega^{\text{gross}}(\theta_\omega) \mathrm{e}^{-\xi_\omega d_{\ell,\kappa(\varphi)}}$ depends on θ_ω; $\xi_\omega > 0$ is commuting decay

- Housing demand and indirect utility are:

$$h_{\omega,\ell}^* = \frac{\alpha_\omega w_\omega^{\text{net}}(\theta_\omega)}{r_\ell} \quad \text{and} \quad U_{\omega,\ell}^* = B_{\ell,\omega} w_\omega^{\text{net}}(\theta_\omega) r_\ell^{-\alpha_\omega}.$$

GSM: Technology

- If worker ω and firm φ match in location ℓ they produce output

$$\mu_{\omega,\varphi,\ell} = A_{\ell,\varphi} \times \theta_{\varphi} \times \theta_{\omega}$$

  where θ_{φ} and θ_{ω} are productivities, and $A_{\ell,\varphi}$ a location-specific shifter.

- We use a 'standard' specification for agglomeration economies:

$$A_{\ell,\varphi} = a_{\ell} \times \underbrace{g\left(E_{\ell,-\varphi}, \sum_{j \in \mathcal{N}(\ell)} E_j\right)}_{\text{agglomeration externalities}}$$

  where E_j is employment in location $j \in \mathcal{L}$ and $\mathcal{N}(\ell)$ is the neighborhood of ℓ.

- Alternatively: pure function of productivity θ_{φ} (Baum-Snow et al., 2021).

GSM: Worker-firm matching

- There is many-to-one matching between workers and firms.
- Firms have two fundamental productivity parameters: usual productivity (θ_φ) and managerial productivity (span-of-control, SOC; Lucas, 1978; Rosen, 1982).
- Firm φ can manage at no extra costs up to $\overline{R}_\varphi \in \mathbb{N}$ workers. Beyond that, increasing costs to manage more workers.
- Firms are heterogeneous in both productivities. No assumptions required on the correlation between $\overline{R}_\varphi$ and θ_φ.
- Each worker uses a fixed amount f_φ of office space (we could allow for substitutability here, but good starting point).

GSM: Ranks within firms

- Need to think about firm sizes and worker 'ranks'. We specify SOC costs as follows:

$$\text{soc}_\omega = \begin{cases} 0 & \text{if} \quad R_\omega \leq \overline{R}_\varphi \\ R_\omega^{\gamma_\varphi} - (R_\omega - 1)^{\gamma_\varphi} & \text{if} \quad R_\omega > \overline{R}_\varphi \end{cases}$$

  where $R_\omega \in \{1, 2, \ldots N_\varphi\}$ is the worker's rank in the firm of size N_φ.

- The first worker to arrive has rank 1, the second rank 2, ...
- If a worker joins a firm of size N_φ, she joins at rank $N_\varphi + 1$. Workers always arrive at the bottom.
- If a worker with rank k leaves a firm, all workers of rank $> k$ in that firm move up. A worker of any rank can leave a firm.

GSM: Ranks within firms

- Let $\omega(\varphi)$ denote the worker-firm matching. Net match value $\mathrm{mv}_{\omega(\varphi)} \geq 0$ is

$$\mathrm{mv}_{\omega(\varphi)} = \begin{cases} A_{\ell,\varphi}\theta_\omega\theta_\varphi - f_\varphi r_\ell & \text{if} \quad R_\omega \leq \overline{R}_\varphi \\ A_{\ell,\varphi}\theta_\omega\theta_\varphi - f_\varphi r_\ell - [R_\omega^{\gamma_\varphi} - (R_\omega - 1)^{\gamma_\varphi}] & \text{if} \quad R_\omega > \overline{R}_\varphi \end{cases}$$

- Joining a firm does not affect others' wages since the SOC costs are *private costs* (alternatively, think about this as training costs)
- Leaving a firm does not affect wages above her; but leads to wage increases below her beyond rank $\overline{R}_\varphi$ as others move up.
- Technically important feature, since a worker leaving a firm does not change incentives of others (no 're-matching cascades'). But need to keep track of ranks.

GSM: Match values, profits, and wages

- Let $\Omega_\varphi = \{\omega \,|\, \omega(\varphi)\}$ be the set of workers matched with φ. Aggregating to the firm level, we have total SOC:

$$\mathrm{SOC}(N_\varphi) = \sum_{\omega \in \Omega_\varphi} \mathrm{soc}_\omega = \begin{cases} 0 & \text{if} \quad N_\varphi \leq \overline{R}_\varphi \\ N_\varphi^{\gamma_\varphi} - \overline{R}_\varphi^{\gamma_\varphi} & \text{if} \quad N_\varphi > \overline{R}_\varphi \end{cases}$$

- The gross profit that the firm and the workers can split is:

$$\pi_\varphi^{\mathrm{gross}} = \mathrm{MV}_{\omega(\varphi)} = \sum_{\omega \in \Omega_\varphi} \mathrm{mv}_{\omega(\varphi)} = A_{\ell,\varphi}\theta_\varphi \sum_{\omega \in \Omega_\varphi} \theta_\omega - \mathrm{SOC}(N_\varphi) - f_\varphi N_\varphi r_\ell$$

- Nash bargaining with share ν_φ to split match values:

$$w_{\omega(\varphi)}^{\mathrm{gross}} = (1 - \nu_\varphi)\mathrm{mv}_{\omega(\varphi)}, \quad \pi_\varphi^{\mathrm{net}} = \nu_\varphi \mathrm{MV}_{\omega(\varphi)}$$

GSM: Production of floor space

- Competitive construction sector, combines land, L, and capital, K, to produce floorspace. Capital raised in a national market at constant (normalized) price.
- CRS production function for floorspace:

$$H_\ell = \frac{D_\ell}{\beta_\ell^{\beta_\ell}(1-\beta_\ell)^{1-\beta_\ell}} L_\ell^{\beta_\ell} K_\ell^{1-\beta_\ell},$$

  where D_ℓ is a location-specific housing productivity shifter related to fundamentals (e.g., soil type, slope).
- Locations are heterogeneous. Land supply is $\xi_\ell \overline{L}_\ell$, where $\overline{L}_\ell$ and $\xi_\ell \in [0,1]$ are the available surface and the developable share.

GSM: Floorspace market clearing

- Market clearing for floorspace in ℓ requires

$$\underbrace{\frac{\xi_\ell \overline{L}_\ell}{\beta_\ell} D_\ell^{1/\beta_\ell} r_\ell^{\frac{1-\beta_\ell}{\beta_\ell}}}_{\text{floorspace supply}} = H^d(r_\ell) = \underbrace{\sum_{\omega \in \ell} \frac{\alpha_\omega w^{\text{net}}_{\omega(\varphi)}(\theta_\omega, \mathbf{r})}{r_\ell}}_{\text{residential}} + \underbrace{\sum_{\varphi \in \ell} f_\varphi N_\varphi(\mathbf{r})}_{\text{commercial}}.$$

  where $H^d(r_\ell)$ is aggregate demand for floorspace

- In GE, changes in $\mathbf{r}$ affect wages (via changes in match values and movement across firms) and firm sizes (via the matching).
- Yields equilibrium rents for a given spatial distribution of firms and workers and a given matching $\omega(\varphi)$

GSM: Floorspace equililbrium

- Technically infeasible to solve the city-wide equilibrium whenever an agent changes location or a worker changes employer.
- Thus local ('short run') solutions after each move. Once all agents have made choices (or at fixed time steps), we clear the market city-wide.
- Assume a move from κ to ℓ. We solve locally for r_ℓ and r_κ:

$$H_t^s(r_{\ell,t}) = H_{t-1}^s \times \left(\frac{r_{\ell,t}}{r_{\ell,t-1}} \right)^{\frac{1-\beta_\ell^{\mathrm{sr}}}{\beta_\ell^{\mathrm{sr}}}},$$

where $r_{\ell,t}$ is the price after move t, and $r_{\ell,t-1}$ is the initial price; $\beta_\ell^{\mathrm{sr}} > \beta_\ell$ (short-run supply elasticity lower than in the long run).

GSM: Worker search

- Worker ω in ℓ searches over all firms φ to maximize her income net of commuting costs:

$$\max_{\varphi} \; w^{\text{net}}_{\omega(\varphi)} = \max_{\varphi} \; w^{\text{gross}}_{\omega(\varphi)} \mathrm{e}^{-\xi_{\omega} d_{\ell,\kappa(\varphi)}}$$

- For technical reasons, we introduce small matching frictions. Works do not arbitrage away ϵ-wage differentials.
- Workers may opt out of the labor force (zero value outside option, but could have a minimum wage in the model).
- Stable matching: no worker can find a better match and—if randomly reallocated—would return to her initial firm. Recall others have no incentive to change their choices following the worker's move. No 'poaching' across firms.
- Initially, most productive workers search first: leads to initial PAM. Good starting point, and fairly efficient.

GSM: Firm relocation

- Firms move across locations and moving entails firm-specific moving costs $\eta_\varphi \geq 0$. A firm leaves ℓ for ℓ' only if

$$\max_{\ell' \in \mathcal{L}} \pi^{\text{gross}}_{\ell',\varphi} - \pi^{\text{gross}}_{\ell,\varphi} > \eta_\varphi$$

- Firms search over all locations. They observe $A_{\ell,\varphi}$ and r_ℓ in each location and incorporate them into their decisions.
- Firms evaluate prospective locations *conditional on their current workforce*. Firms move with all their profitable employees (they can lay off workers).
- After a move, workers are free to rematch if that is better for them.
- Moving costs imply that firms do not arbitrage away ϵ-profit differentials.

GSM: Spatial equilibrium

- In this application, we consider residential location fixed, but we could relax that.
- No firm has an incentive to change location conditional on current distributions and prices. Formally,

$$\max_{\ell' \in \mathcal{L}} \ \pi^{\text{gross}}_{\ell',\varphi} - \pi^{\text{gross}}_{\ell,\varphi} \leq \eta_{\varphi}, \quad \forall \varphi.$$

- A spatial equilibrium is generally defined by inequalities. Firms are usually infra-marginal in the sense that they are *not indifferent* between their current location and the next best. There may not be any 'marginal firm'.
- An equilibrium is: (i) stable matching; (ii) floorspace market clearing; and (iii) spatial equilibrium.

GSM: Application roadmap

- Some implementation details
- Model inversion
- Spatial equilibrium (algorithm)
- Model inversion (algorithm)
- Hypothetical place-based policy

GSM: Some implementation details

HiVE framework

- We present a preliminary application to highlight the model's potential
- *Conceptual challenge:* Quantifying all primitives of the model. This is a full-fledged project by itself.
- *Technical challenge:* Simulating the model is very demanding, especially at scale. Standard tools are not readily applicable.
- Currently developing a higher performance custom-coded C++ simulation framework (`HiVE`) that also provides 2D/3D real-time analysis and visualization.

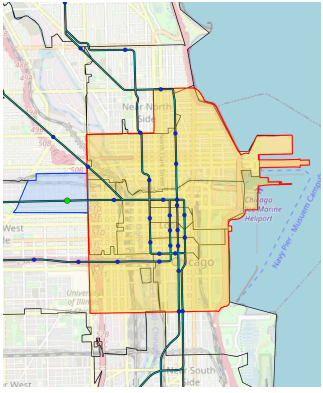
Powered by

GSM: Model inversion

- Fixed-point type algorithm to solve for a spatial equilibrium ▸ Algorithm 1
- As in standard QSM, we invert the model to match initial data.
- Recall we work with essentially flat fundamentals which we take as given. Hence, we cannot rely on them for model inversion.
- Our strategy ▸ Algorithm 2
  - We take initial distributions of workers and firms as given.
  - Given the distributions, we match workers to firms and solve for wages and rents conditional on the distributions.
  - We back out the smallest moving costs for each firm such that the firm has no relocation incentive (in our application here, workers do not move).
  - *Forcing variable:* unobserved firm-specific moving costs η_φ.

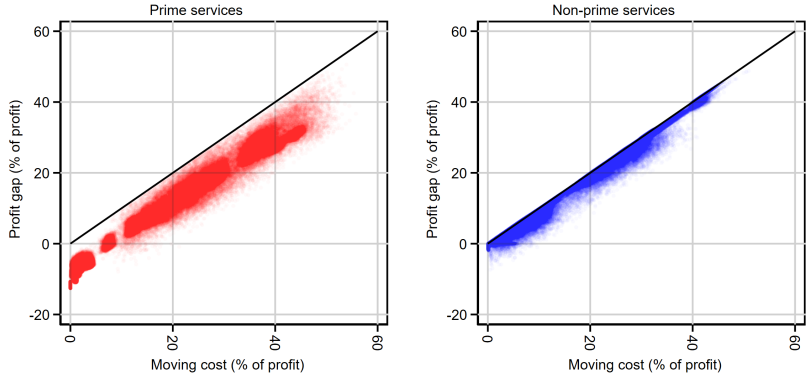
Taking the model to the city

- Attracting big fish has potentially large payoff
- Why do they come?
  - Temporary subsidies & subsidy-like benefits matter (e.g. Amazon's HQ2)
  - transport matters (e.g. Google's Fulton Market office)
  - Local productivity improvement
- Take realistic geography for model → Chicago; account for randomness in initial conditions via Monte Carlo



What (mix of) place-based policy could hypothetically generate a transformative change?

Inframarginal firms: Potential relocation to Fulton Market



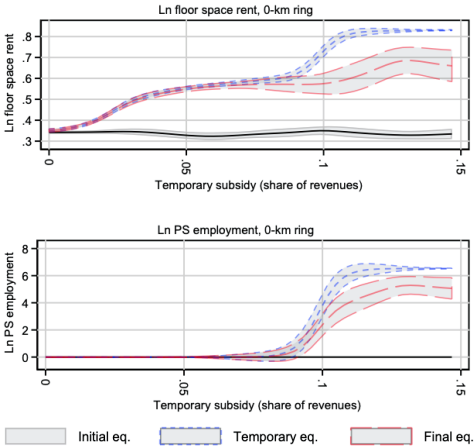
Cost of moving to Fulton Market **exceeds benefit** (in terms of profits).
Agglomeration-dependent prime service firms are especially inframarginal.

Temporary and persistent rent and employment effects

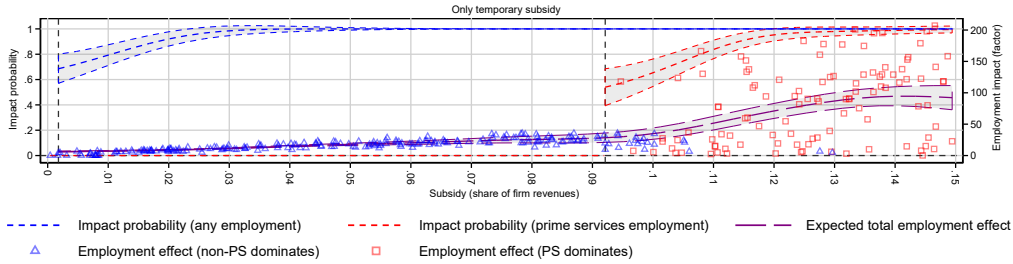
Employment

Targeting Fulton Market with a temporary subsidy (counterfactual analysis)

- Temporary equilibrium features larger changes than final equilibrium (reversion)
- Transitory shocks can have permanent changes (fundamentals are constant)
- Large variation in outcomes around average effect ('lottery'; probability and magnitude)
- Temporary effect only partially reversed in average across runs.



Place-based lotteries: Temporary subsidies and threshold effects

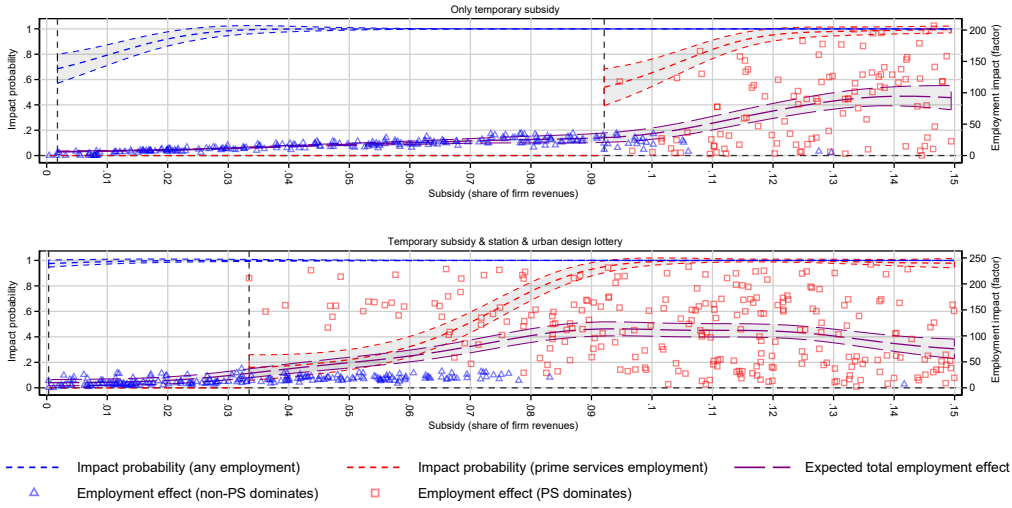


Threshold effect: Probability of attracting PS firms essentially zero below a minimum subsidy level (PS firms particularly inframarginal)

Prize effect: Attracting a PS firm results in large employment gains. Low subsidies, conditional on crossing threshold, offer high return at high risk

Place-based lotteries: Fundamental improvements lower thresholds

EZ subway



Conclusions

- New **spatial model with discrete locations, workers, and firms** that blends elements of QSM and of NEG
  - many canonical elements, but also some important departures (technology; possibility of flat fundamentals; multiple equilibria)
  - computational tractability (as in *QSM*) allows potentially for structural calibration and simulations
  - granular firms, cumulative causation, and thresholds (as in *NEG*)
- Model speaks to the **role of large firms in place-based policy making**
  - If place-based policies attract superstar firms, transformative changes are more likely to happen, but no guarantee
  - Superstar firms are difficult to attract because likely already in the best locations

Conclusions

- Empirical corollary: **Success of place-based policy may hinge on initial conditions**
  - fails more often when competing with well-established cores? (causal historical evidence from 'prime locations'; Ahlfeldt et al., 2021)
  - Regional policy in the UK (little success competing against London) vs regional policy in Germany (more success, no 'London')?
- Achieving **persistent effects with temporary place-based policies** is ambitious
  - Low subsidies are *unlikely* to have transformative effects
  - Just above the critical threshold subsidies can offer great return, but also high risk of failure since attraction of superstar firms is uncertain (*place-based lottery*)
  - Sufficiently high subsidies likely to induce transformative change, but very *expensive*
  - Transport and urban design improvements lower critical thresholds, but very *expensive* too

— SUPPLEMENTAL MATERIAL —

HiVE Framework

Return

[Still under development]

- Building block for developing better agent-based models
- Integrated simulation framework to run the GSM and other simulation applications
- Full-fledged archetype-based ECS (entity component system) and thread-safe custom data structures (flat hashmap, job queue)
- openGL ImGui 2D/3D real-time data visualization tools
- Fully thread-safe
- Job scheduling system
- C++14/17, high-performance code, should scale to run 'large problems'

GSM: Spatial equilibrium algorithm

▸ Return

Algorithm 1: Spatial equilibrium

begin
  Starting from current locations and worker-firm matching
  while *some firms want to move* **do**
    Compute wages, determine housing demand and supply, solve for r_ℓ to clear housing markets conditional on current matching and firm locations.
    for *each firm* φ **do**
      1: Go through all locations ℓ, find the one that yields the highest profit conditional on current land rents r_ℓ, externalities $A_{\ell,\varphi}$, and hired workers N_φ
      2: Move to best location. Short-run adjustment of r_ℓ in the origin and destination locations. Update externalities $A_{\ell,\varphi}$.
    Rematch workers and firms conditional on new rents and firm locations:
    while *some workers want to change employer* **do**
      for *each worker* ω **do**
        for *each firm* φ **do**
          Determine net wage of worker ω with firm φ, conditional on the current assignment and for the current r_ℓ in all locations
        Assign worker ω to the firm with highest net wage, conditional on positive net wage. If not, worker is out of labor force. Update worker ranks in firms.

Result: Spatial equilibrium with stable matching and labor- and land-market clearing.

GSM: Model inversion algorithm

Return

Algorithm 2: Model inversion

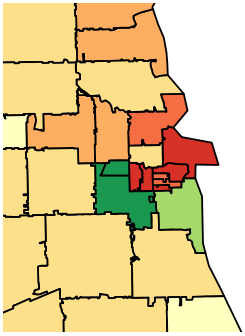
begin
- **Initialization:** Generate firms, workers, and locations; set all parameter values. Allocate workers and firms to initial locations based on observed shares in the data.
- **Initial matching:** Sort firms and workers by decreasing productivity, then
- **for** *each worker* ω **do**
  - **for** *each firm* φ **do**
    - Determine match value between worker ω and firm φ conditional on the current assignment.
  - Assign worker ω to the firm with highest match value, conditional on positive match value. If not, the worker is out of the labor force. Update worker ranks in firms.
- Holding firm locations fixed, compute wages and land rents. Rematch workers and firms conditional on rents and firm locations:
- **while** *some workers want to change employer* **do**
  - **for** *each worker* ω **do**
    - **for** *each firm* φ **do**
      - Determine net wage of worker ω with firm φ, conditional on the current assignment and for the current r_ℓ in all locations
    - Assign worker ω to the firm with highest net wage, conditional on positive net wage. If not, worker is out of labor force. Update worker ranks in firms.
- **Model inversion:** Back out minimum firm-specific moving costs such that the current locations yield the highest profit.

Result: Initial equilibrium, fitted to observed distributions of firms and workers.

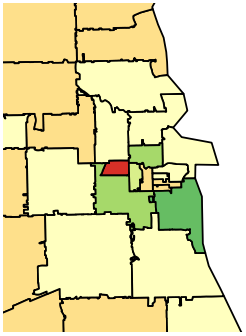
Temporary and persistent employment effects

Return

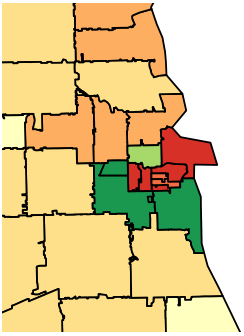
Targeting Fulton Market with a temporary subsidy (counterfactual analysis)



Enabling policy



Disabling policy



Legacy

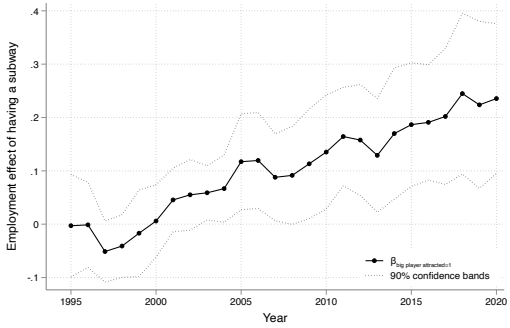
Temporary effect is only **partially reversed** in the average Monte Carlo run.

Among program participants, those with access to subways do better

Return

Access to rapid transport helps:

- Use GNT subway dataset
- ZCTA has EZ with station (Y/N)
- $g_{t/1994} = \alpha + \beta SUBWAY + \gamma + \epsilon$
- γ city-wide growth (6 cities)



Employment growth relative to 1994 (based on ZCTA-level County Business Pattern data; 69 ZCTAs)