A granular spatial model*

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Abstract

We develop a granular spatial model (GSM) which introduces indivisible workers and firms into the canonical quantitative urban model. Assortative matching between heterogeneous employers and employees leads to the formation of large granular firms, which generates realistic agglomeration patterns with many empty locations and a few extremely dense ones, even with flat location fundamentals. This feature makes the GSM particularly suitable for the study of multiple equilibria and the long-run effects of temporary spatial shocks such as natural disasters or place-based policies. As almost all firms are inframarginal in the GSM, especially the most productive ones in the most dense locations, place-based policies become 'place-based lotteries': their expected payoff critically hinges on the probability to attract a few large firms. We illustrate these insights using as an example the spectacular recent rise of Chicago's Fulton Market district west of the Loop.

Keywords. Internal city structure; granular spatial model; multiple equilibria; place-based policies.

JEL classification. R38, R52, R58.

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1 Introduction

Countless place-based policies are built on the idea that a temporary local subsidy may have long-run effects.[1] The birth of new business centers such as La Défense in Paris and Canary Wharf in London suggests that such policies can work. But there are also seemingly "accidental" transformations of neighbourhoods—such as Fulton Market in Chicago—that occur for reasons that are hard to pin down and whose speed and magnitude are not well understood; and—more often than not—cases in which the policies simply fail to deliver any results.[2] Although we know little about the factors that make place-based policies successful, the view that attracting some large firms is a necessary condition to jump-start local development is widely held among practitioners and policy makers. It is also well understood that there are threshold effects: attracting a large and productive firm leads to a discrete jump in local employment and a potentially substantial change in local economic conditions, but relocation will only occur if the incentive package exceeds some threshold. A corollary is that too small incentive packages are either ineffective or likely to 'pick losers.' Finally, what mix of more permanent subsidies and investments—e.g., infrastructure—is required to retain the firms in the long run once temporary subsidies expire, and whether incumbents will ultimately benefit from or be hurt by the changes triggered by the place-based policy, are open questions we know little about.[3,4]

Given the huge costs of place-based policies, understanding what makes them potential success stories is important. It is, however, also a difficult endeavor. While there is an abundant reduced-form econometric literature on policy evaluation, the theoretical literature is much sparser.[5] One of the key reasons for this is, in our opinion, that models suitable

[1]See, e.g., the US Empowerment Zones (Busso et al., 2013), French Enterprise zones (Givord et al., 2013; Mayer et al., 2017; Givord et al., 2018), British Regional Selective Assistance (Devereux et al., 2007; Criscuolo et al., 2019), or Local Enterprise Growth Initiative (Einiö and Overman, 2020). Neumark and Simpson (2015) provide an extensive recent survey.

[2]A notorious example is, e.g., the Yujiapu Financial District in China: *"[it] promotes itself as China's Manhattan, but may better be seen as a monument to the breakdown of the Chinese growth model. Four-fifths of the office space stands empty. Construction on other buildings has stopped, leaving skeletons in the sky. A sprawling mall has few shoppers. Inside, a pet store has no animals."* (New York Times, April 10, 2019).

[3]Givord et al. (2018) find that firms tend to leave once subsidies become less generous. For example, in the case of the French Enterprise zones the policy had a reduced rate of tax incentives after five years. This is precisely the point where the zones start losing firms again. Okubo and Tomiura (2012) find that programs to attract manufacturing firms away from core regions in Japan selected firms with below-average productivity.

[4]Amazon's search for HQ2 provides a neat illustration of those points. First, it was anticipated that the arrival of HQ2 with *"as many as fifty thousand (50,000) new full-time jobs with an average annual compensation exceeding one hundred thousand dollars ($100,000) per employee"* would have a large local impact that could trigger substantial transformation. Second, it was clearly understood that the incentive package needed to be huge and the local economic conditions very favorable (Amazon, in its Request for Proposal, clearly enumerated conditions in terms of connectivity, infrastructure, site and buildings, incentive packages, logistics, and quality-of-life). According to the NY Times (Nov 13, 2018), Amazon was offered *"a sweeping package of $1.7 billion in incentives"* to attract HQ2 to the site in Long Island City. Last, the fierce opposition that led to the final withdrawal of Amazon from NY was at least partly motivated by the huge size of the incentive package and the perception that there would be substantial negative effects for some businesses and residents.

[5]Notable exceptions are Kline and Moretti (2014) who investigate the aggregate effects of place-based

for the evaluation of place-based policy should ideally combine features that make them difficult to work with: *heterogeneous granular firms* and *multiple equilibria*. The granular spatial model (GSM) we develop allows us to break new ground because it exhibits these two features. Indeed, our simulations of the effects of different place-based policies within the GSM confirm that the economy can be shifted between multiple spatial equilibria following temporary shocks, subject to threshold effects.

The first theoretical challenge is that, in reality, heterogeneous firms—and especially large firms—may or may not react to place-based policies. Put differently, we need to take into account that most firms are "infra-marginal" and will not react to small incentives. This is especially true for the most productive large firms located in established business cores that benefit from various kinds of agglomeration economies and are, hence, hard to attract. The presence of large indivisible firms and agglomeration rents explains why there are critical thresholds and why many policies fail to deliver the expected results.[6] These requirements stand in sharp contrast to the canonical spatial equilibrium framework in which agents are marginal and firms are absent altogether.

We tackle this problem by developing a granular spatial model (GSM) with indivisible firms and workers. The GSM we introduce in Section 2 is a blend of a quantitative spatial model (QSM) with external returns to scale (Ahlfeldt et al., 2015) and a New Economic Geography (NEG) model that emphasizes indivisibilities and fixed requirements internal to explicitly modeled firms (Fujita, 1988; Krugman, 1991). The presence of large indivisible firms generates threshold effects where the choices of a single large firm can affect the equilibrium outcome.[7] Large firms arise endogenously in the GSM due to assortative matching between heterogeneous employers and employees, which generates a fat-tailed firm distribution exhibiting large atoms.[8] The firms also generate local productivity spillovers that have been empirically documented to emerge from productive granular firms (Greenstone et al., 2010; Baum-Snow et al., 2020). The presence of a small number of large firms implies that many locations will be devoid of employment, whereas a few dense locations

policies with multiple competing locations; and Blouri and Ehrlich (2020) and Fajgelbaum and Gaubert (2020) who employ quantitative spatial models to evaluate the effect of exogenous changes in model primitives on endogenous outcomes in general equilibrium counterfactuals.

[6]The existence of infra-marginal firms due to agglomeration rents is key in models of New Economic Geography. It has been shown that agglomeration rents make firms 'sticky', i.e., firms do not react to 'small' changes in taxes and subsidies (Brülhart et al., 2012; Baldwin and Krugman, 2004; Charlot and Paty, 2007; Jofre-Monseny, 2013). Devereux et al. (2007), Criscuolo et al. (2019), and Baldwin and Okubo (2006) provide evidence suggesting this induces threshold effects in the efficacy of place-based policies.

[7]A large literature documents that much of the variation of economic activity over space and time is driven by a small number of large granular firms (Ellison and Glaeser, 1997; Gabaix, 2011; di Giovanni et al., 2014; Schoefer and Ziv, 2021). Dingel and Tintelnot (2020) introduce indivisible workers into the QSM so that idiosyncratic worker choices can affect equilibrium outcomes.

[8]This novel approach allows the GSM to account for a host of real-world phenomena such as: positive assortative matching between firms and workers (Abowd et al., 1999; Bartolucci et al., 2018); complementarity of firm productivity, worker productivity, and agglomeration economies (Combes et al., 2012; Gaubert, 2018); and decreasing returns due to span-of-control problems (Rosen, 1982; Eeckhout and Kircher, 2018).

offer significant locational rents because of agglomeration economies, thus making the firms infra-marginal. Hence, the GSM can account for the existence of threshold effects and rich patterns of firm reactions to temporary subsidies.

The second challenge is that any model in which a temporary shock—e.g., policies or disasters—may have permanent effects needs to exhibit multiple equilibria (Allen and Donaldson, 2020). Models with multiple equilibria are generally hard to work with, and recent QSMs usually disregard them by construction because they *"require assumptions prohibiting multiple equilibria"* (Thisse et al., 2021, p. 1). It is useful to recall that the canonical QSM assumes a perfectly competitive spatial equilibrium in which observed differences in economic activity across space—conditional on endogenous agglomeration and dispersion forces—are rationalized via differences in exogenous locational fundamentals (Ahlfeldt et al., 2015; Redding and Rossi-Hansberg, 2017).[9] For sparsely populated or empty areas, which naturally arise from the granularity of firms at a high spatial resolution, the inverted fundamentals are small or zero; whereas for areas with a high density of economic activity they must be very large. This has two undesirable consequences. Firstly, near-zero fundamentals in peripheral locations rule out sizable economic activity there in any counterfactual that does not alter the model's primitives. From the perspective of planners who seek to alter the fortunes of places by means of temporary policies, this is a frustrating feature: even large temporary policies will have only very small transitory effects. Secondly, the heterogeneity due to the dispersion in fundamentals makes it extremely unlikely that there will be multiple equilibria. As is known, models with multiple equilibria can be sufficiently 'convexified' using heterogeneity such that the equilibrium becomes unique.[10]

Our model features multiple equilibria which naturally arise when locational fundamentals are 'flat' enough. We believe this is a realistic feature, especially at smaller geographic scales such as cities where it is hard to understand why nearby locations should display very different fundamental productivity. We rationalize observed distributions of economic activity under flat fundamentals by inverting firm-specific moving costs instead of inverting the fundamentals as done in QSMs. Doing so allows us to avoid having arguably unrealistic (near-)zero fundamental productivity in areas sparsely populated by firms. Flat fundamentals and granular firms make the model sufficiently non-convex so that the shape of the spatial economy can change in response to shocks even if the model's primitives are held

[9] The literature using QSMs has grown very quickly in recent years. For models of internal city structure, see among others Allen et al. (2017); Tsivanidis (2019); Heblich et al. (2020); Dingel and Tintelnot (2020); Owens III et al. (2020); Miyauchi et al. (2021); Thisse et al. (2021). For QSMs concerned with the spatial distribution between cities, see among others Allen and Arkolakis (2014); Redding (2016); Ramondo et al. (2016); Caliendo et al. (2018); Fajgelbaum and Gaubert (2020). Last, there are dynamic spatial models (DSMs) that rationalize observed data in a transitory spatial equilibrium (Desmet et al., 2018; Caliendo et al., 2019; Monras, 2020).

[10] That 'convexifying problems' by adding heterogeneity in the presence of complementarities reduces the number of equilibria and may even imply uniqueness is a well-known result (see, e.g., Herrendorf et al. 2000; Morris and Shin 2006) with wide applications to areas such as global games, quantal response equilibria, or models of random matching.

constant. Therefore, shifting the spatial economy between multiple spatial equilibrium states is possible under a realistic parameterization within the GSM. This allows for the evaluation of a host of temporary spatial shocks and policies and suggests a division of labour with the QSM which is well-suited for the evaluation of policies that can be modelled as a change to the model's primitives.

Because the strength of the GSM is to facilitate transitions between multiple equilibria holding the model's primitives constant, we are primarily interested in the long-run effects of a temporary local subsidy in the spirit of US Empowerment Zones, French Enterprise zones, the British Regional Selective Assistance, or Local Enterprise Growth Initiative, among others. More concretely, within the realistic geography of Chicago—which is the US stereotype of a monocentric city—we simulate the effects of different place-based policies in a series of runs in which we randomize worker productivities, resulting in commuting pattern and goods and factor prices that resemble, but do not exactly match, Chicago. This allows us to gain more general insights into likely effects of place-based policies across contexts. Upon inversion of moving costs conditional on the actual distribution of workers, firms and goods and factor prices, the procedure could also be replicated for a specific policy in a specific city.

In each run, we start from an initial equilibrium, pay a subsidy that corresponds to varying shares of profits to all firms located in some targeted area, and solve for a temporary equilibrium. We then discontinue the subsidy and solve for the final equilibrium. Depending on the attraction of firms in the temporary equilibrium, and the agglomeration economies they generate, we may observe more firms in the final equilibrium than in the initial equilibrium. To gain insights into the effects of the policy on firm sorting, we distinguish between knowledge-based tradable services firms—*prime services*—which derive higher productivity gains from agglomeration and other firms. Policy makers may be interested in synergies between temporary subsidies and other place-based policies. In a random subset of runs, we therefore allow for a subway station to open in the targeted area in the temporary and final equilibria. Similarly, we allow for a randomized fundamental improvement that resembles the effects of an urban design improvement whose success is uncertain.

Our simulations provide several novel insights. First, a temporary subsidy can lift an area to a permanently higher level of economic activity. However, there are thresholds that must be crossed to attract firms that are not ex-ante indifferent between locations. These thresholds are naturally lower when temporary subsidies are coupled with other place-based policies that improve connectivity or fundamental productivity. Second, firms that rely most heavily on external returns are those that are most difficult to move because they are ex-ante concentrated in core locations whose agglomeration-induced productivity gains are not easily left behind. This makes the formation of new business districts in which prime services firms mutually benefit from agglomeration economies a particularly challenging undertaking. Third, we uncover a risk-return trade-off in the implementation of temporary place-based policies. At low subsidy rates, the policy can generate high returns if it succeeds in attracting firms. But the chance of success is low. At higher subsidies, the chance is much greater, but so are the costs, resulting in smaller expected social returns.

Our theoretical and empirical contributions connect to a vast literature that has analysed the internal structure of cities theoretically and empirically (Brueckner, 1987; Anas et al., 1998; Duranton and Puga, 2015). The GSM and our policy experiments also complement a companion paper in which we show emprically that *prime locations*—ultra-dense clusters of prime services—show a greater degree of persistence in historically large cities with well-developed public transport networks (Ahlfeldt et al., 2022). In that paper, we employ a variant of the GSM developed in this paper to establish that endogenous transport networks and agglomeration economies make historically grown prime locations more resilient to temporary exogenous shocks. Together, both papers show that promoting the emergence of new prime locations in historically large cities with well-established central business districts is a particularly ambitious mission on which planners can only embark with a certain degree of confidence if they are willing to commit sizable resources.

To implement the GSM, we draw from recent advances in computational economics. A growing literature in macroeconomics (Dawid and Delli Gatti, 2018) and quantitative finance (Bouchaud, 2018) relies on agent-based models (ABMs) to account for realistic heterogeneity in individual behaviour. Outside economics, a large literature reviewed by Huang et al. (2014) uses ABMs to study questions related to urban form and residential sorting.[11] The potential of the ABM as a tool in urban economics has been recognized, in principle, but extant applications do not invoke the principles of optimization and market clearing of standard models (Irwin, 2010; Kuminoff et al., 2013). Our methodological contribution is to develop a model that injects the rich individual heterogeneity of indivisible workers and firms from the ABMs into a canonical hybrid between a QSM and a NEG model that allows for rich geographical heterogeneity, optimization, and market clearing.[12]

2 A granular spatial model

The basic building blocks of our granular spatial model are locations and economic agents. There are two broad categories of agents: firms and workers. Let $N_F \in \mathbb{N}$ and $N_W \in \mathbb{N}$ denote the number of firms and of workers in the city, respectively. Firms and workers are modeled as indivisible decision-making units. They have a unique location $\ell = 1, 2, \ldots, \mathcal{L}$ in the city, which is represented by its geographic coordinates, land area, and other features

[11] Recent examples include Olner et al. (2015) and Lemoy et al. (2017).

[12] The empirical validation also remains a problem of AMBs (Lux and Zwinkels, 2018). In implementing the GSM, we rely on functional forms and parameter values that have empirical support in the literature. We also show that model outcomes correlate well with non-targeted data moments.

that we explain later.

2.1 Technology

We index firms by φ and workers by ω. Firms and workers match to produce output. The production technology is such that a firm-worker match between firm φ and worker ω in location ℓ produces output with value

$$\mu_{\omega,\varphi,\ell} = A_{\ell,\varphi} \times \theta_\varphi \times \theta_\omega, \tag{1}$$

where $\theta_\varphi > 0$ and $\theta_\omega > 0$ are the firm's and the worker's underlying productivity; and $A_{\ell,\varphi} = f(a_\ell, Y_{\ell,\varphi})$ denotes a firm-specific productivity shifter for location ℓ. We assume that the latter depends in a separable way on a location-specific part, a_ℓ, which we call the fundamental underlying location productivity; and a firm-location-specific shifter, $Y_{\ell,\varphi}$. Let E_j denote the number of employees working in firms located in j, $E_{\ell,-\varphi}$ the number of employees working in firms in ℓ (but excluding firm φ itself), Θ_f the vector of productivities of all firms, and $\mathcal{N}(\ell)$ a neighborhood of block ℓ. We assume that

$$A_{\ell,\varphi} = a_\ell \times Y_{\ell,\varphi} \quad \text{and} \quad Y_{\ell,\varphi} = f\left(a_{\ell,\varphi},\ E_{\ell,-\varphi},\ \sum_{j\in\mathcal{N}(\ell)} E_j,\ g\Big(\Theta_{f,-\varphi} \cap \{\ell \cup \mathcal{N}(\ell)\}\Big)\right). \tag{2}$$

In words, $Y_{\ell,\omega}$ consists of an idiosyncratic productivity term in location ℓ for firm φ (the term $a_{\ell,\varphi}$); a production externality stemming from local and neighborhood employment; and some combination $g(\cdot)$ of the productivity of the other firms located in ℓ and its neighborhood. Observe that our specification (2) allows for standard employment (density) based agglomeration effects (Combes and Gobillon, 2015) but also agglomeration effects that are solely channeled through firms' productivity (Baum-Snow et al., 2020), which is important for understanding sorting. Whatever the source of the agglomeration externalities is, firms take $A_{\ell,\varphi}$—which aggregates location fundamentals, location-firm productivity shifters, and external effects—as given.

2.2 Matching, wages, and profits

Workers and firms match to produce output. Firms are subject to span-of-control (SOC) costs: managing a larger number of workers generates decreasing returns to scale beyond some threshold (see Rosen, 1982, for a classic reference). We assume firm φ has no span-of-control problems if it hires less than $\overline{R}_\varphi$ workers. Put differently, there is no productivity penalty for the first $\overline{R}_\varphi$ workers since they are easy to manage; yet beyond $\overline{R}_\varphi$ workers, each extra worker ω adds progressively less output because of decreasing returns to scale due to inceased management costs.

There are two monetary costs associated with workers. First, each worker hired by firm

φ requires a fixed amount f_φ of office space in order to produce.[13] Letting r_ℓ denote the unit price of office space in location ℓ, a firm with N_φ workers pays $f_\varphi N_\varphi r_\ell$ for its consumption of office space. Second, the firm pays workers a wage, which is determined by a split of the gross profit (i.e., revenue minus land rent) between the firm and its workers. The gross profit is given by

$$\pi_\varphi^{\text{gross}} = A_{\ell,\varphi}\theta_\varphi \sum_{\omega\in\varphi} \theta_\omega - \text{SOC}(N_\varphi) - f_\varphi N_\varphi r_\ell \tag{3}$$

where we use the notation $\omega \in \varphi$ as a short-cut to indicate the set of employees of firm φ; and where we assume, without loss of generality, that the price of the firm's output is normalized to one.[14] In equation (3), N_φ denotes the number of workers and

$$\text{SOC}(N_\varphi) = \begin{cases} 0 & \text{if} \quad N_\varphi \leq \overline{R}_\varphi \\ N_\varphi^{\gamma_\varphi} - \overline{R}_\varphi^{\gamma_\varphi} & \text{if} \quad N_\varphi > \overline{R}_\varphi \end{cases} \tag{4}$$

is the output loss due to span-of-control. Hence, in (3), the first term is the total revenue generated by the matches between the firm and its workers; the second term is the revenue lost due to span-of-control problems if the firm starts having too many workers; and the third term is the total cost to supply the N_φ workers with office space in location ℓ. As shown by equations (3) and (4), there are four key technology parameters: (i) the span-of-control rank threshold $\overline{R}_\varphi$; (ii) the span-of-control elasticity, γ_φ; (iii) the productivity parameter, θ_φ; and (iv) the amount of land required per worker, f_φ. Equation (3) further shows that there are complementarities between worker productivity, firm productivity, and agglomeration economies. In other words, the most productive firms and workers will have a tendency to match and to be close together in space.

Wage determination. Specification (4) implies that adding workers to the firm progressively reduces their contribution to gross profits. Stated differently, beyond the threshold $\overline{R}_\varphi$, each worker successively becomes less valuable to the firm. This implies that the wages paid by the firm decrease with worker ranks. There are two ways to approach the problem. First, we can assume that when adding an additional worker the wages of all workers are revised accordingly. Second, we can assume that the wages of the workers already at the firm do not change and that the new worker bears all the costs generated by the span-of-control. We believe this second approach is more realistic: hiring a new worker does not affect the productivity and the wage of incumbent workers. To implement this approach, we thus need to consider that workers' wages depend on their *rank* in the firm. Workers hired earlier—i.e.,

[13] Using Canadian manufacturing data, Behrens et al. (2022b) find that square footage per worker is largely constant across space within industries. This suggests that—at least within manufacturing—there is limited scope for labor-land substitution.

[14] We assume that each firm produces a nationally traded good. We could allow for firm-specific prices, but those would just correspond to a shift in the firm-specific productivity parameter and would thus not be separately identified.

workers higher up in the hierarchy with lower rank in the firm—generate more gross output for the firm because they generate less output loss due to SOC problems. We thus need to keep track of each worker's rank in the firm to determine the wage.

As explained above, a worker ω with rank $R_\omega \leq \overline{R}_\varphi$ generates value

$$A_{\ell,\varphi}\theta_\omega\theta_\varphi - f_\varphi r_\ell \tag{5}$$

for firm φ. This gross profit (surplus) is split between the worker and the firm. We use the simplest possible approach and assume this occurs via Nash bargaining. Letting ν_φ denote firm φ's bargaining power, a share $1-\nu_\varphi$ of (5) is paid as gross wages:

$$w^{\text{gross}}_{\omega(\varphi)} = (1-\nu_\varphi)\left[A_{\ell,\varphi}\theta_\omega\theta_\varphi - f_\varphi r_\ell\right], \quad R_\omega \leq \overline{R}_\varphi, \tag{6}$$

where $\omega(\varphi)$ denotes the matching of worker ω with firm φ. A worker with rank R_ω above the SOC threshold generates less surplus and receives, therefore, a lower wage:[15]

$$w^{\text{gross}}_{\omega(\varphi)} = (1-\nu_\varphi)\Big\{A_{\ell,\varphi}\theta_\omega\theta_\varphi - f_\varphi r_\ell - \left[R_\omega^{\gamma_\varphi} - (R_\omega - 1)^{\gamma_\varphi}\right]\Big\}, \quad R_\omega > \overline{R}_\varphi. \tag{7}$$

Observe that rank-dependent wages create inertia in the movement of workers across firms. Indeed, a worker who leaves her current firm and moves to another firm will join the new firm at the lowest rank, and will only be able to move up ranks when workers above her leave the firm. When a worker leaves a firm, all workers below that worker shift up in rank and, therefore, see their wages increase. Note that rank-dependency makes workers infra-marginal, a point we will return to later.

Summing up, gross profits, net profits, and the wage bill W_φ of firm φ are given by

$$\begin{aligned}
\pi^{\text{gross}}_\varphi &= A_{\ell,\varphi}\theta_\varphi \sum_{\omega\in\varphi}\theta_\omega - \left(N_\varphi^{\gamma_\varphi} - \overline{R}_\varphi^{\gamma_\varphi}\right) - N_\varphi f_\varphi r_\ell \\
\pi^{\text{net}}_\varphi &= \nu_\varphi \pi^{\text{gross}}_\varphi \\
W_\varphi &= (1-\nu_\varphi)\pi^{\text{gross}}_\varphi = \sum_{\omega\in\varphi} w^{\text{gross}}_{\omega(\varphi)},
\end{aligned}$$

where the wages $w^{\text{gross}}_{\omega(\varphi)}$ paid under the employer-employee matching $\omega(\varphi)$ are given by (6)

[15]Summing (6) and (7) across all workers in the firm, we have (suppressing the constant term $1-\nu_\varphi$ in what follows to alleviate notation):

$$\begin{aligned}
\pi^{\text{gross}}_\varphi &= \sum_{R_\omega \leq \overline{R}_\varphi}\left(A_{\ell,\varphi}\theta_\omega\theta_\varphi - f_\varphi r_\ell\right) + \sum_{R_\omega > \overline{R}_\varphi}\left[A_{\ell,\varphi}\theta_\omega\theta_\varphi - f_\varphi r_\ell - \left(R_\omega^{\gamma_\varphi} - (R_\omega-1)^{\gamma_\varphi}\right)\right] \\
&= \sum_{\omega\in\varphi}\left(A_{\ell,\varphi}\theta_\omega\theta_\varphi - f_\varphi r_\ell\right) - \sum_{R_\omega > \overline{R}_\varphi}\left[R_\omega^{\gamma_\varphi} - (R_\omega-1)^{\gamma_\varphi}\right] \\
&= \sum_{\omega\in\varphi}\left(A_{\ell,\varphi}\theta_\omega\theta_\varphi - f_\varphi r_\ell\right) - \left(R_{\max}^{\gamma_\varphi} - \overline{R}_\varphi^{\gamma_\varphi}\right) = A_{\ell,\varphi}\theta_\varphi\sum_{\omega\in\varphi}\theta_\omega - \left(N_\varphi^{\gamma_\varphi} - \overline{R}_\varphi^{\gamma_\varphi}\right) - N_\varphi f_\varphi r_\ell,
\end{aligned}$$

where $R_{\max} = N_\varphi$ is the maximum rank of a worker in the firm (which is also equal to the size of the firm in terms of workers). Clearly, this expression is the same as (3), up to the constant term $1-\nu_\varphi$.

and (7), respectively.

Observe that workers' and firms' incentives are aligned since they split the surplus generated by the match. Hence, it is rational for a firm to hire workers that produce positive match values and to reject matches that produce negative match values. We assume that firms accept all workers who add a positive amount of profit and reject workers who do not add positive profit. Assuming that there is an outside option with value zero, workers do not accept a job that does not pay positive wage. Since wage is a share ν_φ of profit, it is enough to check whether a match is acceptable for either the firm or the worker.

2.3 Preferences

Each worker ω in location ℓ has Cobb-Douglas preferences

$$U_{\omega,\ell}(h,g) = \frac{B_{\ell,\omega}}{\alpha_\omega^{\alpha_\omega}(1-\alpha_\omega)^{1-\alpha_\omega}} h^{\alpha_\omega} g^{1-\alpha_\omega} \tag{8}$$

where $\alpha_\omega \in (0,1)$ denotes the expenditure share for housing; and h and g denote the consumption of housing and of a bundle of other goods, respectively. The parameter $B_{\ell,\omega} = f(b_\ell, X_{\ell,\omega})$ denotes a consumer-specific preference for location ℓ. We assume the latter depends in a separable way on a location-specific part, b_ℓ, which we call the residential location fundamental; and a consumer-location specific part, $X_{\ell,\omega}$. Let R_j denote the number of workers living in location j, $R_{\ell,-\omega}$ the number of workers living in ℓ (but excluding ω), and Θ_w the vector of worker productivities. We assume that

$$B_{\ell,\omega} = b_\ell \times X_{\ell,\omega} \quad \text{and} \quad X_{\ell,\omega} = f\left(b_{\ell,\omega},\ R_{\ell,-\omega},\ \sum_{j\in\mathcal{N}(\ell)} R_j,\ g\Big(\Theta_w \cap \{\ell \cup \mathcal{N}(\ell)\}\Big)\right). \tag{9}$$

Hence, $X_{\ell,\omega}$ consists of an idiosyncratic preference for location ℓ by worker ω (the term $b_{\ell,\omega}$); a residential externality that operates locally and in the neighborhood of ℓ; and a combination of the other workers' productivity in ℓ and its neighborhood. Observe that our specification includes standard residential externalities channeled through neighborhood population size (Ahlfeldt et al., 2015) but also externalities that depend on, e.g., educational attainment as proxied by productivity (Couture et al., 2019), which is important for understanding sorting.

Let r_ℓ denote the price of housing (the rent) in location ℓ, and let $\overline{p}$ denote the common price of the bundle of consumption goods in the city. We assume, without loss of generality, that $\overline{p} \equiv 1$. Conditional on living in location ℓ, consumer ω solves the following optimization problem:

$$\max_{h,g} \quad U_{\omega,\ell}(h,g) = \frac{B_{\ell,\omega}}{\alpha_\omega^{\alpha_\omega}(1-\alpha_\omega)^{1-\alpha_\omega}} h^{\alpha_\omega} g^{1-\alpha_\omega} \quad \text{s.t.} \quad r_\ell h + g = w_\omega^{\text{net}}(\theta_\omega), \tag{10}$$

where $w_\omega^{\text{net}}(\theta_\omega)$ denotes the consumer's net income (i.e., income after paying for commuting costs), which is a function of the worker's underlying productivity θ_ω. Workers take $B_{\ell,\omega}$ (which aggregates location fundamentals, location preferences, and the external effect) as given. The solution to the consumer's problem (10) is such that

$$h^* = \frac{\alpha_\omega w_\omega^{\text{net}}(\theta_\omega)}{r_\ell} \equiv h^*_{\omega,\ell} \quad \text{and} \quad g^* = (1-\alpha_\omega) w_\omega^{\text{net}}(\theta_\omega) \equiv g^*_\omega. \tag{11}$$

Thus, the indirect utility is given by

$$U^*_{\omega,\ell} = \frac{B_{\ell,\omega}}{\alpha_\omega^{\alpha_\omega}(1-\alpha_\omega)^{1-\alpha_\omega}} \left(\frac{\alpha_\omega w_\omega^{\text{net}}(\theta_\omega)}{r_\ell}\right)^{\alpha_\omega} \left[(1-\alpha_\omega) w_\omega^{\text{net}}(\theta_\omega)\right]^{1-\alpha_\omega} = B_{\ell,\omega} w_\omega^{\text{net}}(\theta_\omega) r_\ell^{-\alpha_\omega}. \tag{12}$$

In what follows, the aggregate demand for real estate emanating from workers will be important. Using (11), it can be expressed as follows:

$$H_\ell^{\text{worker}} = \sum_{\omega\in\ell} h^*_{\ell,\omega} = \frac{1}{r_\ell} \sum_{\omega\in\ell} \alpha_\omega w_\omega^{\text{net}}(\theta_\omega),$$

where we use the notation $\omega \in \ell$ as a short-cut to indicate the set of workers located in ℓ.

2.4 Commuting

Workers may live and work in different locations. They have to pay commuting costs to access their workplace. Let $d_{\ell,\kappa}$ denote the 'distance' between locations ℓ and κ. If worker $\omega \in \ell$ works for firm $\varphi \in \kappa$, the wage net of commuting costs she receives is given by

$$w^{\text{net}}_{\omega(\varphi)} = w^{\text{gross}}_{\omega(\varphi)} \mathrm{e}^{-\xi_\omega d_{\ell,\kappa}}, \tag{13}$$

where $\xi_\omega > 0$ is a worker-specific commuting decay parameter and where $w^{\text{gross}}_{\omega(\varphi)}$ is the gross wage generated by the worker-firm match. We explain later how we model transport costs via the distance term $d_{\ell,\kappa}$.

2.5 Locations and supply of floorspace

There is a finite set of locations $\ell = 1, 2, \ldots, \mathcal{L}$. Each location is characterized by its given land surface, geographic centroid, and parameters linked to the supply of real estate. Locations supply land, which a construction sector turns into floorspace. More precisely, we assume there is a competitive construction sector that combines land, L, and capital, K, to produce floorspace that can be used for either housing or offices.[16] To keep the analysis simple, we assume perfect substitutability between residential housing and commercial real estate.

Denote by $\overline{L}_\ell$ the fixed supply of land in location ℓ. The production function for floorspace

[16] Gyourko and Molloy (2015) argue there is no evidence of market power in the residential construction market. Indeed, there are more than 100K companies in the single family construction business in the US. Combes et al. (2019) report similar findings and numbers for France.

exhibits constant returns to scale and is given by

$$H_\ell = \frac{D_\ell}{\beta_\ell^{\beta_\ell}(1-\beta_\ell)^{1-\beta_\ell}} L_\ell^{\beta_\ell} K_\ell^{1-\beta_\ell}, \tag{14}$$

where D_ℓ is a location-specific productivity shifter related to the fundamental conditions (e.g., soil type, slope) for building in that location. Floorspace is sold at price r_ℓ per unit to both residents and firms. We follow standard practice and assume that capital can be raised in a national market and normalize its price to one. Profit maximization implies

$$\max_{L_\ell, K_\ell} \quad \pi_\ell = r_\ell \frac{D_\ell}{\beta_\ell^{\beta_\ell}(1-\beta_\ell)^{1-\beta_\ell}} L_\ell^{\beta_\ell} K_\ell^{1-\beta_\ell} - \rho_\ell L_\ell - K_\ell, \tag{15}$$

where ρ_ℓ denotes the price of land (the land rent). The first-order conditions of (15) are:

$$\beta_\ell r_\ell \frac{D_\ell}{\beta_\ell^{\beta_\ell}(1-\beta_\ell)^{1-\beta_\ell}} L_\ell^{\beta_\ell - 1} K_\ell^{1-\beta_\ell} = \rho_\ell \quad \text{and} \quad (1-\beta_\ell) r_\ell \frac{D_\ell}{\beta_\ell^{\beta_\ell}(1-\beta_\ell)^{1-\beta_\ell}} L_i^{\beta_\ell} K_\ell^{-\beta_\ell} = 1,$$

which implies that $\frac{K_\ell}{L_\ell} = \rho_\ell \frac{1-\beta_\ell}{\beta_\ell}$, so that $L_\ell = \frac{1}{\rho_\ell}\frac{\beta_\ell}{1-\beta_\ell} K_\ell$. This allows us to derive the unit factor demands from the following condition:

$$\frac{D_\ell}{\beta_\ell^{\beta_\ell}(1-\beta_\ell)^{1-\beta_\ell}} \left(\frac{1}{\rho_\ell} \frac{\beta_\ell}{1-\beta_\ell} K_\ell \right)^{\beta_\ell} K_\ell^{1-\beta_\ell} = 1,$$

which yields

$$K_\ell^{\text{unit}} = \frac{1-\beta_\ell}{D_\ell} \rho_\ell^{\beta_\ell} \quad \text{and} \quad L_\ell^{\text{unit}} = \frac{\beta_\ell}{D_\ell} \rho_\ell^{\beta_\ell - 1}. \tag{16}$$

Assume that supply is given by $\xi_\ell \overline{L}_\ell$, where $\overline{L}_\ell$ is the available surface and $\xi_\ell \in [0,1]$ the share that is developpable. In equilibrium, land supply equals land demand so that

$$H^d(r_\ell) L_\ell^{\text{unit}} = H^d(r_\ell) \frac{\beta_\ell}{D_\ell} \rho^{\beta_\ell - 1} = \xi_\ell \overline{L}_\ell,$$

which yields the equilibrium price of land as follows:

$$\rho_\ell^{\beta_\ell - 1} = \frac{1}{H^d(r_\ell)} \overline{L}_\ell \frac{\xi_\ell D_\ell}{\beta_\ell}. \tag{17}$$

The unit cost function for building housing is given by

$$c(\rho_\ell) = \rho_\ell L_\ell^{\text{unit}} + K_\ell^{\text{unit}} = \rho_\ell \frac{\beta_\ell}{D_\ell} \rho_\ell^{\beta_\ell - 1} + \frac{1-\beta_\ell}{D_\ell} \rho_\ell^{\beta_\ell} = \frac{\rho_\ell^{\beta}}{D_\ell}$$

which in equilibrium equals the unit price of housing, r_ℓ, because of zero profits in the perfectly competitive building sector:

$$r_\ell = c(\rho_\ell) \quad \Rightarrow \quad r_\ell = \frac{\rho_\ell^{\beta_\ell}}{D_\ell} \quad \Rightarrow \quad \rho_\ell = (D_\ell r_\ell)^{1/\beta_\ell}. \tag{18}$$

2.6 Equilibrium

This section discusses the different equilibrium conditions of the model in general terms. We relegate implementation details to Section 2.7.

2.6.1 Housing market

We first discuss equilibrium in the housing market. We consider both a long run equilibrium, where the housing market clears across the whole city, and a short run equilibrium, where the housing market reacts locally only to the move of individual firms.

Long run. Combining (17) and (18), the equalization of supply and demand in location ℓ requires:

$$r_\ell^{\frac{\beta_\ell - 1}{\beta_\ell}} = \frac{1}{H^d(r_\ell)} \overline{L}_\ell \frac{\xi_\ell D_\ell^{\frac{1}{\beta_\ell}}}{\beta_\ell} \quad \Rightarrow \quad H^d(r_\ell) = \overline{L}_\ell \frac{\xi_\ell D_\ell^{\frac{1}{\beta_\ell}}}{\beta_\ell} r_\ell^{\frac{1-\beta_\ell}{\beta_\ell}} \equiv \overline{L}_\ell \widetilde{D_\ell} r_\ell^{\frac{1-\beta_\ell}{\beta_\ell}},$$

where we use the following normalization for the 'composite productivity parameter' in the supply of floorspace: $\widetilde{D_\ell} \equiv (\xi_\ell / \beta_\ell) D_\ell^{1/\beta_\ell} > 0$. Aggregate demand for floorspace in location ℓ is given by

$$H^d(r_\ell) = \sum_{\omega \in \ell} \frac{\alpha_\omega w^{\text{net}}_{\omega(\varphi)}(\theta_\omega)}{r_\ell} + \sum_{\varphi \in \ell} f_\varphi N_\varphi, \tag{19}$$

where the first term is demand of floorspace by workers who live in ℓ and the second term is the demand for office floorspace by firms that produce in ℓ. Note that the latter depends on the land rent via firms' choices to hire workers: a larger rent reduces the match value with less productive workers, thus leading to a reduction in N_φ. Generally, the wage, $w^{\text{net}}_{\omega(\varphi)} \equiv w^{\text{net}}_{\omega(\varphi)}(\mathbf{r})$ and the firm size $N_\varphi \equiv N_\varphi(\mathbf{r})$ both depend on the vector $\mathbf{r} = (r_1, r_2, \ldots, r_{\mathcal{L}})$ of rents across all locations $\ell = 1, 2, \ldots, \mathcal{L}$ in the city. The equilibrium in the housing market is hence determined from a system of non-linear equations and solves:

$$\sum_{\omega \in \ell} \frac{\alpha_\omega w^{\text{net}}_{\omega(\varphi)}(\theta_\omega, \mathbf{r})}{r_\ell} + \sum_{\varphi \in \ell} f_\varphi N_\varphi(\mathbf{r}) = \overline{L}_\ell \widetilde{D_\ell} r_\ell^{\frac{1-\beta_\ell}{\beta_\ell}}, \quad \forall \ell = 1, 2, \ldots \mathcal{L}. \tag{20}$$

For computational purposes, we solve (20) holding the assignment of workers to firms fixed (i.e., N_φ does not change, and neither does the mapping $\omega(\varphi)$). We then reoptimise the assignment of workers across firms and allow firms to move, and iterate until: (i) no firm wants to move; (ii) no worker wants to rematch; and (iii) the housing market (20) clears. We explain the procedure for solving the model in more detail later.

Short run. As explained above, (20) determines the city-wide market equilibrium for floorspace. Ideally, we could solve it whenever an economic agent changes location or whenever a worker changes employer. This is, however, technically infeasible. We hence consider a 'short run' version where the movement of an agent across locations only affects rents in the origin- and destination locations. Assume, e.g., that firm φ moves from ℓ to κ. In the short run (subscript sr), we solve sequentially the two equations

$$H^d_{\text{sr}}(r_\ell) = \sum_{\omega\in\ell} \frac{\alpha_\omega w^{\text{net}}_{\omega(\varphi)}(\theta_\omega, r_\ell)}{r_\ell} + \sum_{\varphi\in\ell} f_\varphi N_\varphi, \quad H^d_{\text{sr}}(r_\kappa) = \sum_{\omega\in\kappa} \frac{\alpha_\omega w^{\text{net}}_{\omega(\varphi)}(\theta_\omega, r_\kappa)}{r_\kappa} + \sum_{\varphi\in\kappa} f_\varphi N_\varphi, \tag{21}$$

to pin down the new values of r_ℓ (which increases) and r_κ (which decreases). We also consider it reasonable to assume that the supply elasticity of housing, $\frac{1-\beta_\ell}{\beta_\ell}$, is lower in the short run than in the long run. We model the housing supply in the short run as follows:

$$H^d_{\text{sr}}(r'_\ell) = H^d(r_\ell)\left(\frac{r'_\ell}{r_\ell}\right)^{\frac{1-\beta^{\text{sr}}_\ell}{\beta^{\text{sr}}_\ell}}, \tag{22}$$

where r'_ℓ is the short-run price and where r_ℓ is the intial price in the location. The parameter $\beta^{\text{sr}}_\ell > \beta_\ell$ captures the fact that, in the short run, supply is less elastic with respect to prices than in the long run.

2.6.2 Labor market equilibrium

As explained in Section 2.2, workers and firms match to generate output. There is a potentially very large number of possible matches between firms and workers. The realized matching pattern depends, in particular, on the order in which workers search across firms. To reduce the number of matching patterns, we focus on 'efficient patterns': *positive assortative* ones. To this end, we start with an empty assignment and proceed sequentially in decreasing order of workers' and firms' productivities. In other words, the most productive workers search first and start by searching over the most productive firms. This produces matches with high aggregate match values that are 'efficient'. We will provide more details in the implementation part later on.

Formally, worker ω in location ℓ searches over all firms φ to maximize her income net of commuting costs:

$$\max_\varphi\ w^{\text{net}}_{\omega(\varphi)} = \max_\varphi\ w^{\text{gross}}_{\omega(\varphi)} \mathrm{e}^{-\xi_\omega d_{\ell,\kappa(\varphi)}}, \tag{23}$$

where $\kappa(\varphi)$ denotes the location κ of firm φ. For technical reasons, to avoid that workers switch employers when there are very small differences in wages, we introduce worker-specific matching frictions μ_ω. This implies that a worker will switch from her current employer φ to another employer φ' only if

$$\max_{\varphi'} \; w^{\text{gross}}_{\omega(\varphi')} \mathrm{e}^{-\xi_\omega d_{\ell,\kappa(\varphi')}} - w^{\text{gross}}_{\omega(\varphi)} \mathrm{e}^{-\xi_\omega d_{\ell,\kappa(\varphi)}} \leq \mu_\omega. \tag{24}$$

As explained before, a worker joins the new firm at the lowest rank, whereas all workers of rank below the one in the current firm move up in the hierarchy once the worker leaves.

Equilibrium in the labor market is defined by a *stable matching*, i.e., a matching pattern where: (i) all worker-firm matches produce positive value; and (ii) no worker can find a better match than the one he is currently in. We explain in Appendix A.1 that there are no incentives for firms to switch the ranks of workers within the firm and that there is only limited scope for reoptimization across firms. The latter would require some side payments mechanism, something we abstract from in the model to keep it tractable.[17]

Observe that in the GSM workers may optimally choose to not be in the labor market. This may happen when they cannot match with any employer to produce positive revenue for the firm (which occurs especially for low-productivity workers). In that case, neither the firm nor the worker want to match and the worker will not supply any labor and earn zero income (equal to the outside option).

Two comments are in order. First, even when some workers are not matched our labor market clears in the sense that all workers who want to work are effectively hired by some firm. Second, our aggregate labor supply is not inelastic: workers can choose to work (supply one unit of labor), or not to work (supply zero units of labor). The important thing is that there is no voluntary unemployment since all workers who find it profitable to work will work: since firms' and workers' incentives are aligned, mutually beneficial matches occur.

2.6.3 Spatial equilibrium

Firms are free to move between locations. Moving between locations entails firm-specific moving costs $\eta_\varphi \geq 0$. When firms move between locations they (temporarily) maintain their employees. Stated differently, the firm evaluates what its profit would be in the new location conditional on its current sets of employees. The firm is able to evaluate which employees would eventually end up being unprofitable in the new location (and would hence be laid off), but the firm anticipates that it will keep the remaining employees who will be paid new wages that depend on the agglomeration economies and office prices in the new location. Of course, employees are free to rematch with other employers following the relocation if that is optimal for them, and this the firm does not know before making the move.

Each firm searches over all locations to find the location that maximizes its profit condi-

[17] We rule out poaching by firms by excluding side payments: a firm cannot poach workers from another firm by splitting the surplus generated by that poaching. While interesting, allowing for the possibility complicates the numerical simulation of the model substantially. Appendix A.1 discusses this point in more details.

tional on its current workforce. From expression (3), we know that

$$\pi_{\varphi,\ell}^{\text{gross}} = A_{\ell,\varphi}\theta_\varphi \sum_{\omega\in\varphi} \theta_\omega - \text{SOC}(N_\varphi) - f_\varphi N_\varphi r_\ell.$$

The firm observes $A_{\ell,\varphi}$ and r_ℓ in each location and integrates them into its decision.[18] Put differently, the firm knows: (i) the location-specific productivity shifters $A_{\ell,\varphi}$; (ii) the rents r_ℓ; and (iii) which employees it will eventually shed when moving to the new location since they are no longer productive enough. Of course, once a firm makes a move, rents and its set of employees may change in response to that move and what other firms do. This in turn may lead to subsequent adjustments.

Given the presence of moving costs, a firm will move only if $\max_{\ell'\in\mathcal{L}} \pi_{\ell',\varphi}^{\text{gross}} - \pi_{\ell,\varphi}^{\text{gross}} > \eta_\varphi$, i.e., the gain from relocating exceeds the moving costs. Formally, a spatial equilibrium is such that

$$\max_{\ell'\in\mathcal{L}} \pi_{\ell',\varphi}^{\text{gross}} - \pi_{\ell,\varphi}^{\text{gross}} \leq \eta_\varphi, \quad \forall\varphi. \tag{25}$$

In a spatial equilibrium, no firm has an incentive to change location conditional on the distribution of the other firms. As (25) shows, a spatial equilibrium is generally defined by inequalities. Put differently, firms are usually infra-marginal in the sense that they are *not indifferent* between their current location and the next best. We return to this point in our application later and show that this is important to understand when a policy can attract firms and which firms are likely to come.

2.7 Implementation details

The GSM is a rich model that allows for indivisibilities and many dimensions of heterogeneity. We now discuss how we implement it and solve it from a computational perspective. The algorithm we use for computing a spatial equilibrium is presented in Appendix A.2 in form of pseudocode (`Algorithm 1: Spatial equilibrium`). Its workings—which is very similar to a standard fixed-point algorithm—can be summarized in plain language as follows.

First, we select the number of firms, workers, and locations, and set all parameter values (productivities, span-of-control, housing parameters, preferences etc). We also choose an initial spatial allocation of firms and workers by assigning them to locations. The initial allocation can be either arbitrary, or it can be based on observed distributions of workers and firms across space as we do in our application in Section 4. We also set, without loss of generality, initial values for land rents as $r_\ell = 1$ for all locations.

Second, we determine an initial assignment of workers to firms. As explained in Section 2.2, we start with an assignment that exhibits positive assortative matching. To this end, we sort workers and firms by decreasing order of productivity and then start by assigning

[18]The aggregate matching value $\theta_\varphi \sum_{\omega\in\varphi} \theta_\omega$ and the SOC costs $\text{SOC}(N_\varphi)$ are independent of the location conditional on the firms set of workers.

the most productive worker (who will pick the most productive firm). We then assign the second most productive worker and so on. This gives us an *initial matching* of workers with firms. This initial matching is of course not a stable equilibrium matching as it disregards commuting costs and externalities (and is not based on equilibrium housing prices), but it provides a very good starting point.

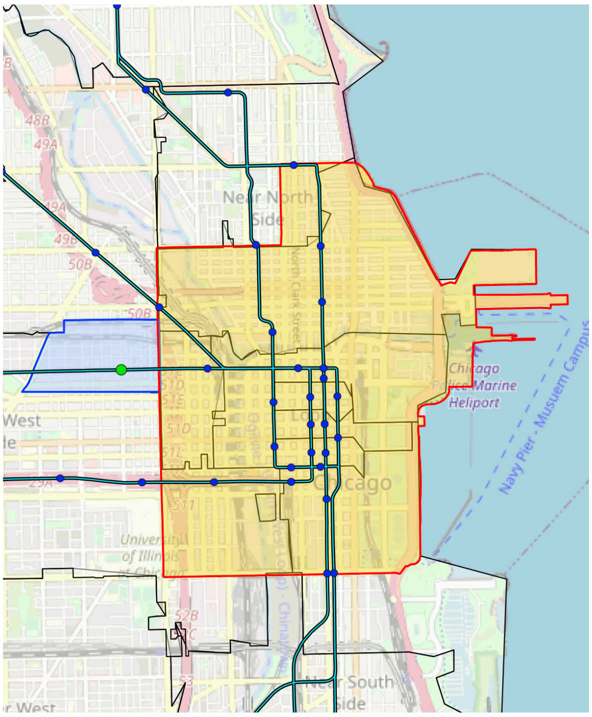
Third, given the initial spatial allocation and the initial matching, we determine a spatial equilibrium as follows. As a first step, we compute the wages for the current matching using (6) and (7). From these gross wages, we compute the wages net of commuting costs, which allows us to solve for the land rents using the system of equations (20). As a second step, we iterate over all firms to determine their incentives to relocate. More precisely, we sequentially go over all firms and evaluate their prospective profit in all locations. If the firm can profitably move to a different location, it does so. In that case, we adjust the rents r_ℓ in the origin and the destination location using (21) in the short run. We also adjust the $A_{\ell,\varphi}$ terms in these locations. As a third step, we then allow the workers to rematch. To this end, each worker searches over all firms to determine the employer that offers a wage such that the worker's net wage is maximized. If such an employer is found and different from the current employer, the worker leaves her current employer and moves to the new one. The ranks of the workers in the firms are updated. We iterate until no worker can find a better match than the one she is currently in. We then solve for the new equilibrium rents given the new locations and the new assignment and allow for firms to move again (and for workers to rematch afterwards). We continue to iterate this fixed-point procedure until: (i) no firm wants to relocated; and (ii) no worker wants to rematch. By construction, this corresponds to a spatial equilibrium where every agent (firms and workers) optimizes and where the labor market and the market for floorspace clear.

3 A real-world example of urban transformation

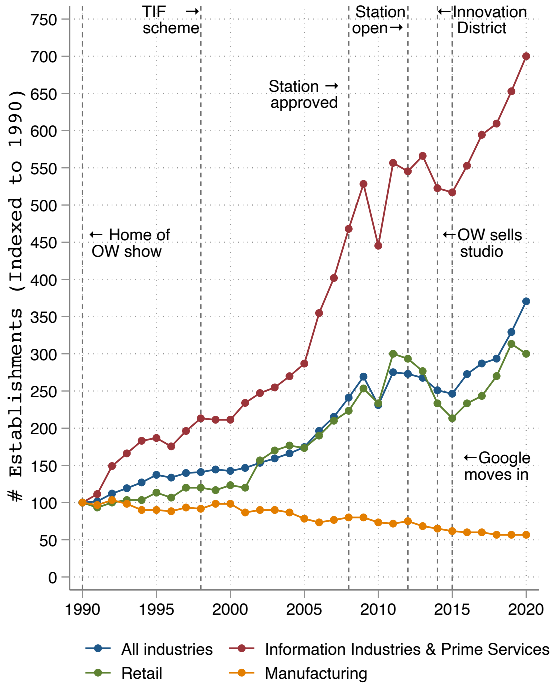
The GSM allows to model a world in which the transformation of neighbourhoods happens without a large apparent changes in fundamentals. In the real world, such neighbourhood changes happen frequently, although few cases are systematically documented. Easterly et al. (2016) provide a fascinating case study of SoHo in New York City that spans several centuries, revealing several tipping points at which the block suddenly specialized in industries as diverse as sex work, textiles, or arts. For a more recent case in point, we zoom into Fulton Market, a now burgeoning district in Chicago's West Loop (Figure 1a).

Fulton Market had been Chicago's meatpacking district in the late 19th and early 20th century. It started to face urban decline from the 1960s onward (Fitzgerald, 2020). In the early 1990s, however, the neighbourhood experienced a slight upward trend, which accelerated in the mid-2000s as documented by a growing number of establishments (Figure 1b). Media companies, and tech- and information industries, were driving much of this upward

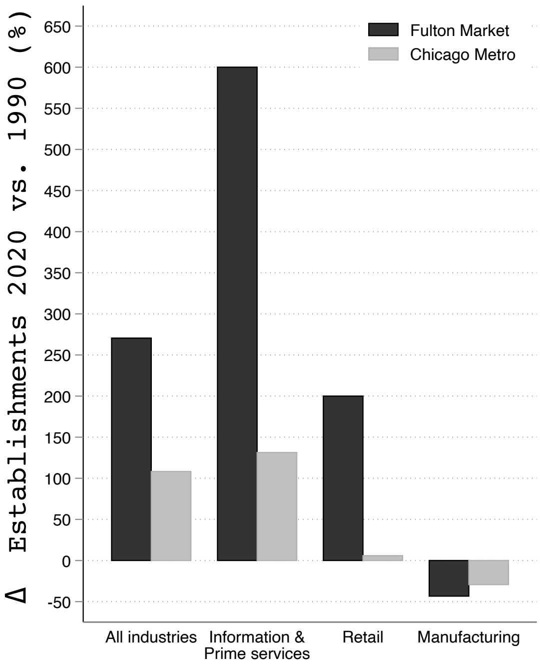
Figure 1: Fulton Market - location & growth



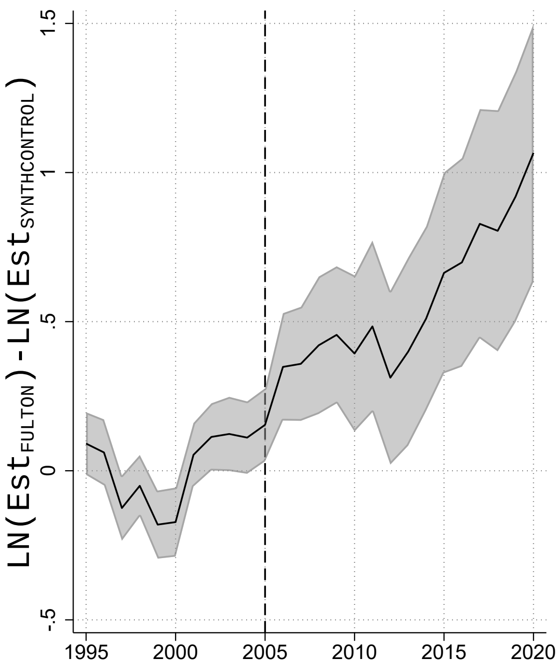
(a) Fulton Market's location (in blue)



(b) Establishment growth



(c) Fulton Market vs. Chicago Metro



(d) Fulton Market vs. synthetic control

Notes: a) Map of central Chicago. The red outline delimits the CBD as defined by the City of Chicago. The blue area is the Fulton Market Innovation District. The large green dot corresponds to Morgan Station, whereas the small blue dots and the blue lines depict the subway network and the other stations. b-d) Underlying data: establishments according to NETS (see Appendix B.1 for details). d) Prime service and information industry establishments only. The shaded areas correspond to 95% confidence bands (see Appendix B.2 for details).

trend, replacing manufacturing firms. Growth accelerated further in the 2010s, especially after Google opened its Midwest HQ in a former cold storage facility in 2015 (City of Chicago, 2014). The neighbourhood now attracted other well-known companies to open branches, among them the VC firm Sandbox Industries and the online portal Glassdoor. It even made McDonald's to move its global HQ back from suburban Chicago to Fulton market in 2018 (City of Chicago, 2021). However, Fulton Market is not just an extension of the CBD. It is replete with amenities, among them 5 of 24 Chicago's Michelin star restaurants (Waxman, 2021). In essence, Fulton Market went from 'skid row' to a vibrant neighbourhood attracting Fortune-500 companies in 15–20 years (Fitzgerald, 2020).

To what extent do these trends in Fulton Market reflect those of Chicago or similar neighborhoods? Figure 1c highlights that, compared to the rest of the metropolitan area, the neighbourhood's establishment growth was exceptionally strong, in particular in retail and the information and prime services sectors. Figure 1d takes the comparison to the rest of the metropolitan area a step further, employing Abadie et al.'s (2010) synthetic control approach. As predictors for the synthetic control group, we employ the average log-number of establishment over 1995–2005, their average growth rate during the same period, population, distance to the CBD, and area. Even when compared to this synthetic neighbourhood—which matches Fulton Market's dynamics until 2005—the area's takeoff is remarkable. As a reference point, Fulton Market had 371 establishments in the prime service and information industry at the beginning of 2020. A .5(1) log points difference implies that the synthetic control group reached a level of only 225(136) establishments. By any metric, Fulton Market has become a growth hub compared with other places in the Chicago metro area.

It is, however, far less clear what caused the revitalization of the Fulton Market area. Figure 1b highlights some of the narratives. Many accounts of the area's re-emergence begin with the importance of Oprah Winfrey's Harpo studios, which aired her famous show from 1990 until 2015 (Bomkamp, 2016; Konkol, 2020). Harpo created local employment, attracted visitors to the neighborhood, and generated demand for restaurants (CBS Chicago, 2015). Surely, Harpo's presence contributed to Randolph Street's rise as 'restaurant row'. And yet, while Harpo studios and the nearby-held Democratic National Convention in 1996 attracted some investment to the area, it was still in poor shape at the end of the decade (Fitzgerald, 2020). It was precisely this 'bad shape' that allowed it to become part of a Tax Increment Financing area in 1998.[19] The associated funds allowed the district to finance improvement- and infrastructure projects, culminating in paying the lion's share of the new Morgan Subway Station (Dickert, 2012).

Opened in 2012, the station gave additional growth impetus. Chicago's Google office head said that the combination of two neighborhood amenities, the new station stop and

[19]The Tax Increment Financing (TIF) plan for the Kinzie Industrial Corridor, encapsulating the Fulton Market area, states that the *"area as a whole has not been subject to growth and development"* and properties experienced *"deterioration and investment and may soon become blighted"* (City of Chicago, 1998, p. 3).

the presence of restaurants, drove Google's 2013 decision to open its Midwest HQ in the area (Harris, 2014). According to many, it was Google's advent that then opened the 'real floodgates' for redevelopments (e.g. Smith, 2019). Just before Google actually arrived, the city council had made the area the 'Fulton Market Innovation District' (FMID). The proclamation entailed a new land-use plan and urban design improvements aiming to replicate the success of other innovation districts in the US (City of Chicago, 2014, p. 5). The beginning of the station's operations, the FMID, and the advent of Google coincide with the latest phase of the Fulton Market boom. This phase, ironically, replaced the building of Oprah's Harpo studios—arguably Fulton's initial pioneer—with McDonald's global HQ (Bomkamp, 2016).

Was Fulton Market's transformation a result of any one policy or predictable ex ante? From stopping its decline in the 1990s, to its growth spurt in the mid-2000s, to the latest boom phase, it is hard to point to any one specific factor as the cause of Fulton Market's success. The decline of the meatpacking industry freed up an architecturally interesting housing stock and Oprah's presence drew attention, creative industries, and people to the area. Policy aimed to improve urban design and infrastructure through TIF. However, the neighborhood already exhibited significant growth by the time Morgan station went into operation and the city declared Fulton Market an 'innovation district'. Among all these factors, building Morgan station comes closest to changing the fundamentals. However, neither the timing of Fulton Market's rise nor the fact that Google wanted to move into a 'trendy' neighborhood support the view that it kicked off the neighborhood's growth alone. Instead, Fulton Market's emergence as an economic powerhouse appears to be best understood on the backdrop of 'historical accidents', policy efforts, and cumulative causation. The station interacted with these changes, but would not have been able to set them in motion by itself.

4 Model-based quantitative analysis

This section shows how the GSM can be used for the quantitative evaluation of spatial shocks and policies. In doing so, we provide an application that connects to the scenario introduced in Section 3. However, our application explores how placed-based policies can shift the spatial distribution of economics activity in ways that are transferable across institutional and geographic contexts. We do not intend to present a quantification of the effects of any specific policy. In other words, we do not ask the question which policy—if any—has led to the development of Fulton Market. Instead, we ask what policies—in Chicago and elsewhere—could cause a transformation similar to the one in Fulton Market. To this end, we build a city that resembles Chicago—the US stereotype of a monocentric city—but we do not match observed data exactly in the initial equilibrium. To the contrary, we introduce an element of randomness to the initial equilibrium and conduct our simulations in thousands of runs to ensure some external validity.

We proceed as follows. First, we introduce the general procedure for the evaluation of spatial shocks and polices. Second, we quantify the model and show how under a canonical parametrization the model generates a spatial distribution of economic activity that resembles our reference, Chicago. Third, we simulate the effects of various place-based policies that create incentives for prime services companies to relocate to a targeted neighbourhood. Throughout this section, we adopt methods that are conventional in empirical research, but we apply them to synthetic data generated by our model instead of real-world outcomes.

4.1 Quantification and simulation

The quantitative analysis within the model, in general terms, consists of the usual steps in quantitative urban models. First, we set all structural parameters in Section 4.1.1. Second, we use the set of parameters and observed data to invert unobserved firm moving costs in Section 4.1.2. Third, we conduct counterfactual exercises as described in Section 4.1.3.

4.1.1 Parametrization

The GSM allows for arbitrary heterogeneity and thus offers a large range of parametrizations. We therefore need to make choices as to which dimensions we think are the most relevant to the problem we are looking at.

In what follows, we make the following choices. First, starting with locations ℓ, we use the real-world example of Chicago. We consider 115 ZIP Code Tabulation Areas (ZCTAs). We carve out the Fulton Market area from the existing ZCTAs so that we have a total of 116 locations. For each location, we know the land area $\overline{L}_\ell$ and the share of built area ξ_ℓ (see Appendix Section C.1), which allows us to determine the total land supply. We fix the location-specific housing technology parameters $\beta_\ell = 0.3$, which maps into an empirically plausible floorspace supply elasticity of 2.1 (Saiz, 2010). The short-run elasticity we choose is much lower at 0.25 (Mayer and Somerville, 2000). Last, we let $\widetilde{D}_\ell = 0.2$ for all locations, which generates a plausible distribution of equilibrium rents.

Second, turning to preferences, we do not think that heterogeneity is crucial for place-based policies that target firms. Hence, we let $\alpha_\omega = \alpha$ for all workers ω. We also shut down residential amenities by letting $B_{\ell,\omega} \equiv 1$ for all ω and ℓ. Since α is the income share for housing, we choose $\alpha = 0.3$ (Combes et al., 2019). Concerning commuting, we set $\xi_\omega = 0.01$ for all workers (Ahlfeldt et al., 2015).

Third, turning to technology, we assume that workers and firms are heterogeneous in productivity. We use sales per employee from the NETS data to proxy productivity for prime services and non-prime services. Our baseline productivity for a firm in industry s located initially in ZCTA $\overline{\ell}$ is constructed as follows:

$$\theta_{\varphi(\overline{\ell},s)} = \frac{\text{sales/employee}_{\overline{\ell},s}}{\text{sales/employee}_{Chicago,s}} \times \frac{\text{sales/employee}_{Chicago,PS}}{\text{sales/employee}_{Chicago,non-PS}} \times \widetilde{\theta} \tag{26}$$

where $\widetilde{\theta} = 7.5$ is a level of productivity that generates a plausible share of expenditure on floor space. The other three technology parameters are: (i) the SOC rank parameter $\overline{R}_\varphi$, which is a random integer between 2 and 4; (ii) the SOC cost elasticity $\gamma_\varphi = 1.4$; and the fixed amount of floorspace per worker f_φ which is a uniformly distributed random number between $[1.89, 2.31]$. Last, we assume that firms' share in gross profits is $\nu_\varphi = 0.33$, which yields the canonical labor share of two-thirds. For workers, we draw their fundamental productivity θ_ω from a uniform distribution on $[0.05, 5]$. When taken together, our choices on firms' and workers' technology result in a plausible granular distribution of firm sizes with fat tails and large atoms.

Finally, we need to specify how we model agglomeration economies. Following a long tradition, we assume that agglomeration economies are a function of the underlying employment density in a location (Ciccone and Hall, 1996; Combes and Gobillon, 2015). We assume that each firm in industry s benefits from the externalities generated by other firms in industry s in its own location and in the neighboring locations. More specifically, we parametrize equation (2) as follows:

$$Y_{\ell,\varphi,s} = a_{\ell,\varphi} \times \left[\frac{1}{2} (1 + E_{\ell,s,-\varphi})^{\epsilon^\varphi_{p,s}} + \frac{1}{2} \left(1 + \sum_{j \in \mathcal{N}(\ell)} E_{j,s} \right)^{\widetilde{\epsilon}^\varphi_{p,s}} \right]. \tag{27}$$

where $\epsilon^\varphi_{p,s} \geq 0$ denotes the strength of the production externality affecting firm φ of industry s in term of local employment, whereas $\widetilde{\epsilon}^\varphi_{p,s} \geq 0$ is the strength of the externality coming from employment in neighborhood $\mathcal{N}(\ell)$. In line with empirical estimates, we assume that $\epsilon^\varphi_{p,PS} = 0.04$ for prime services and that there is a distance decay: $\widetilde{\epsilon}^\varphi_{p,PS} = 0.02$. For non-prime services, we assume the agglomeration externalities are lower at $\epsilon^\varphi_{p,non-PS} = 0.02$ and at $\widetilde{\epsilon}^\varphi_{p,non-PS} = 0.01$ for the neighborhood (Combes and Gobillon, 2015).

We define the neighboorhood $\mathcal{N}(\ell)$ based on distance to location ℓ. We model distance $d_{\ell,\kappa}$ in two different ways. First, we consider the straight line distance between the two centroids of the ZCTAs, which we view as an approximation for travel by car and foot. Second, we explicitly model the subway network of Chicago by using the geographic coordinates of the 153 subway stops and by computing the network distance between any two stations as the shortest path on the network. We assume that getting to and from the network is done in a straight line, i.e., by foot or car.[20]

We allow for modal choice, i.e., agents optimize by choosing whether to use the car or use the public transport network. Let $d_{\ell,\kappa}$ denote the distance between locations ℓ and κ, and let N denote the set of stations. We model the distance between the two locations using

[20]We use a slightly simplified network geometry by assuming that the connection between two neighboring stations is a straight line, thus excluding any bends in the subway line.

the network N as follows:

$$d^N_{\ell,\kappa} = \zeta_I \times \left[\min_{n_1 \in N} d_{\ell,n_1} + \min_{n_2 \in N} d_{n_2,\kappa} \right] + \zeta_S \times \text{shortest path}(n_1, n_2), \tag{28}$$

where shortest path(n_1, n_2) denotes the shortest path between stations n_1 and n_2; and where $\zeta_I = 3$ and $\zeta_S = 0.3$ are an inflate- and a shrink factor capturing the extra cost of walking to and from the station, and the extra gain in terms of speed once on the network. In specification (28), access to and from the network is straight-line and more costly than car, and then there is a gain from moving along the network (distance on the network is equivalent to only ζ_S times distance off the network). Of course, since there is modal choice, agents choose the network if and only if $d^N_{\ell,\kappa} < d_{\ell,\kappa}$, and they travel off the network otherwise.

Last, before proceeding, it is important to point out that there will be frictions to the movement of agents in our model. More precisely, we assume that matching between workers and firms is costly, i.e., there are matching frictions. We also assume that relocation is costly, i.e., there are moving frictions. Having these frictions is both realistic and required numerically because of the presence of indivisibilities in the model.[21]

4.1.2 Model inversion

For each of the 116 locations (115 ZCTAs plus Fulton Market), we compute the population shares and the shares of PS and non-PS firms in 2010 using Census data and the National Establishment Time Series (NETS). We use these shares to apportion workers and firms in the initial equilibrium to the different locations. We split the total number of firms in our model between PS and non-PS firms in proportion to the observed shares of establishments in Chicago: 24.55% prime services, and the rest non-PS. Of course, there is no reason why that initial allocation should be an equilibrium. Hence, to apply our model to real-world data, we proceed in a way that is conceptually very similar to what is done in QSMs. The idea is to rely on *model inversion* to fit the initial equilibrium of the model to the observed spatial distribution. The algorithm we use for model inversion is presented in Appendix A.2 in form of pseudo-code (`Algorithm 2: Model inversion`).

In plain language, the model inversion works as follows. First, without loss of generality, we set the initial value for land rents to $r_\ell = 1$ in all locations. We then determine the assignment of workers to firms using the observed initial distributions and solve for both workers' wages and the equilibrium prices of floorspace, holding the locations of all agents constant. To rationalize this observed distribution as a spatial equilibrium given the initial land prices and wages, we need to make sure that agents have no incentives to move. While

[21] This is different from the QSM where we can—in principle—solve exactly a system of nonlinear equations. As we show in Appendix Section C.6, in our model with indivisibilities, almost all agents are inframarginal, which implies that we have inequalities. Furthermore, since agents are granular—and some firms are very large—the presence of some frictions avoids agents moving to arbitrage away tiny profit differences, thereby leading to cycles and slow (or no) convergence.

this is done using the location fundamentals in the QSM, we instead rely on firm-specific moving costs to rationalize the observed distribution as a spatial equilibrium.

Formally, we iterate over all firms and compute for each one the profit it makes in the initial allocation, as well as the profit it would make in the best location. Moving costs then must equal at least the difference between the two, else the firm would have an incentive to move to the a priori better location. This procedure allows us to retrieve firm-specific moving costs that support the observed distribution as a spatial equilibrium.

Note that we do not need to assume there is substantial heterogeneity in location fundamentals to do so. Indeed, even fairly flat fundamentals may serve to rationalize the observed distribution, which is very different from the QSM where everything is loaded onto the heterogeneous fundamentals. A benefit of having flat—or fairly flat—fundamentals is that multiple equilibria are more likely to arise. As explained before, this is important when thinking about the possible effects of place-based policies since multiple equilibria are necessary for transitory shocks to have permanent effects. In what follows, we assume that the Chicago CBD has a fundamental productivity of $a_C = 1.05$ and that productivity in other places decays following a negative exponential gradient with parameter -0.01 in distance to the CBD: $a_\ell = a_C e^{-0.01 d_{c,\ell}}$. This implies that the ex-ante most attractive location, the CBD, has a fundamental productivity advantage of 15% over the average location, thus showing that we work with very flat fundamentals compared to the standard QSMs.[22]

4.1.3 Simulating the GSM

We run a series of Monte Carlo experiments—within the realistic geography of Chicago—to explore the effects of a place-based policy targeting Fulton Market. We simulate the model in the following three steps. First, as explained above, we invert the model using Algorithm 1 (see Appendix A.2) to rationalize the observed distribution of population and firms in 2010 as our initial equilibrium. Second, we implement a mix of temporary and permanent place-based policies in Fulton market and compute the resulting equilibrium using Algorithm 1 (see Appendix A.2). Last, we switch off the temporary parts of the subsidy mix and find the new long-run equilibrium of the model using, again, Algorithm 1.

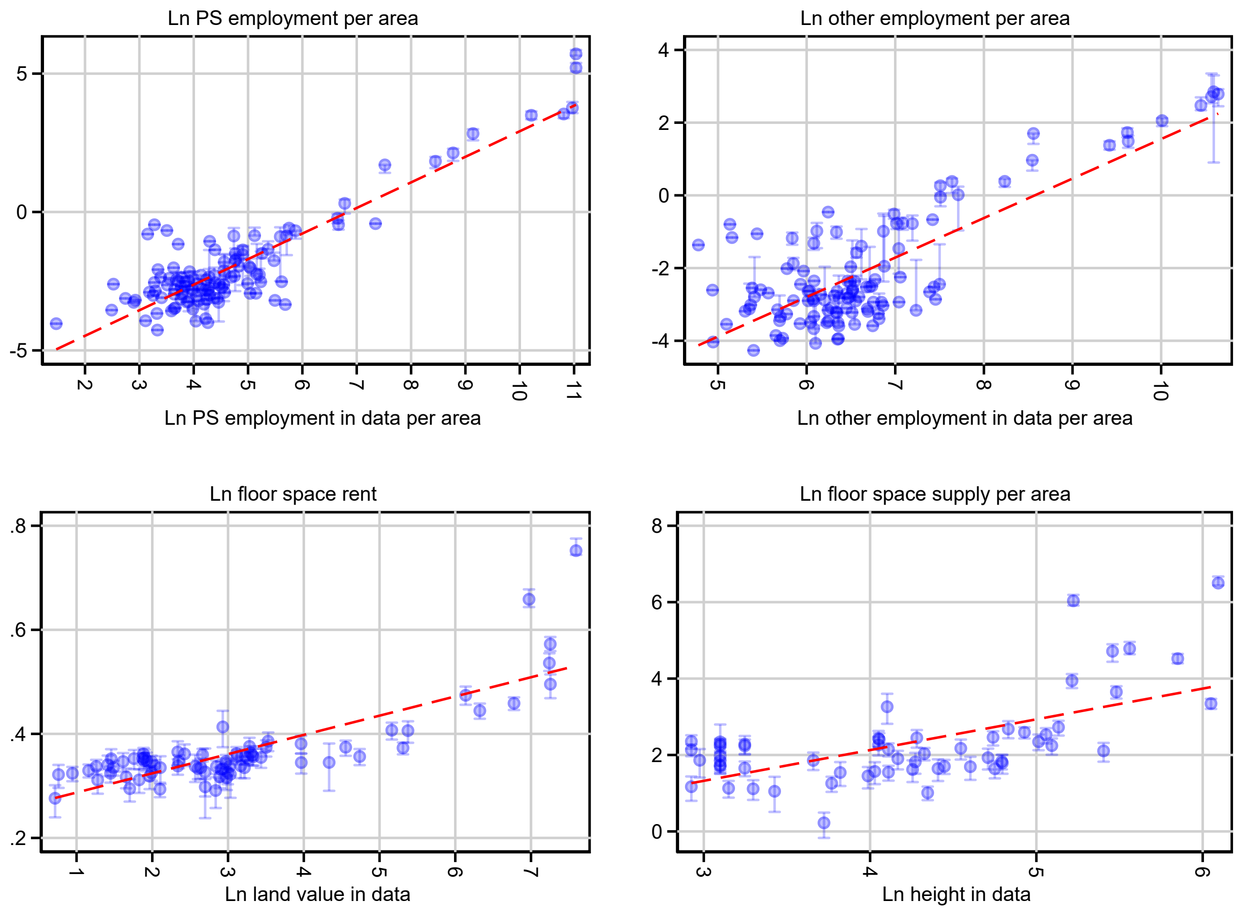
4.2 The initial equilibrium

As discussed above, we match the observed shares of ZCTAs in the total population of workers (at residence) and firms, as well as productivity at the ZCTA-sector level. To allow for some variation in the spatial structure of the city across runs, we randomize worker productivity, SOC thresholds, and the per-worker floor space input at the firm level when we initialize the model. Figure 2 shows how our synthetic versions of Chicago compare to

[22] Another desirable feature is that there is positive spatial correlation in our fundamentals, i.e., two close-by locations have similar fundamental productivity. This strikes us as plausible.

real-world Chicago along various dimensions. Since none of the outcomes has been targeted in the initialization of the model, the positive correlations reveal that the model generates realistic distributions of rents and densities through its endogenous mechanisms. The slope of less than one in the bottom-left panel is, e.g., consistent with land rents (observed in data) scaling more than proportionately in floor space rents (solved in the model) in vertical cities (Ahlfeldt and Barr, 2022). Across all locations, the model predicts commuting cost that correspond to 5% of the gross wage, on average, which is close to the US median (Albouy and Lue, 2015).

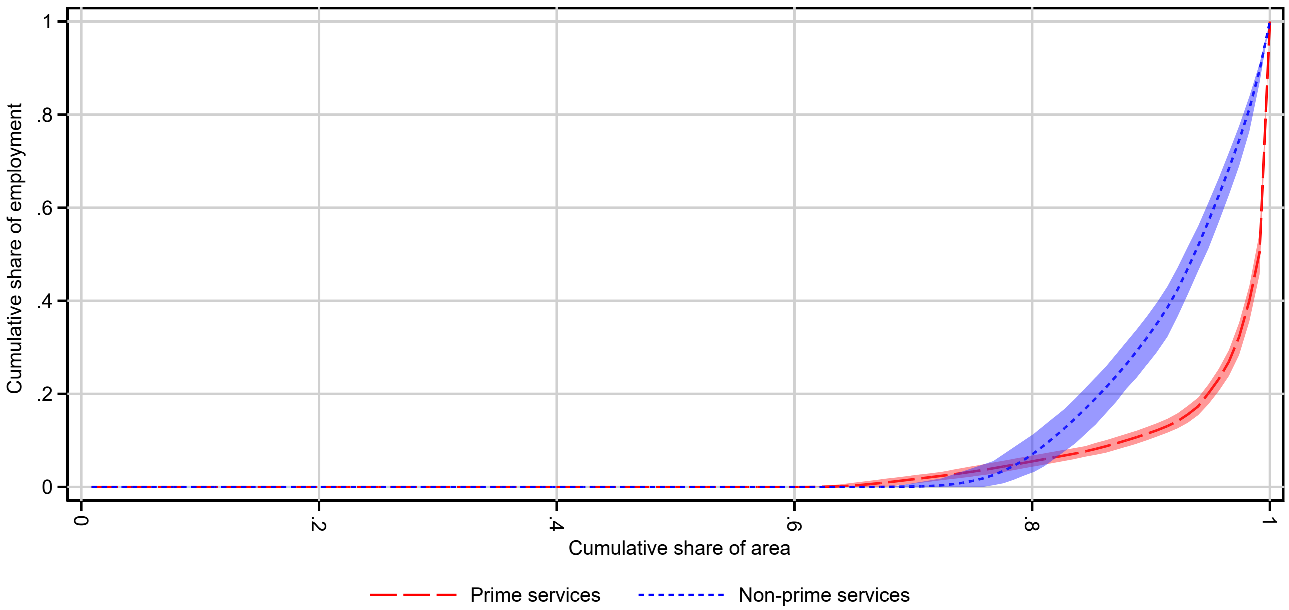
Figure 2: Model vs. data



Notes: Dots show the 50th percentile in the distribution across model-base outcome across runs within a ZTCA in the initial equilibrium. Error bars give the range between the 5th and 95th percentile. Red dashed line is the linear fit into the dots.

In general, our synthetic versions of Chicago resemble the real-world counterpart in its canonical monocentric structure. We refer to Appendix C.2 for a battery of maps and gradient estimates. We summarize the spatial distribution of employment by sector in Figure 3. The first insight is that, given our parametrization, more than 60% of ZCTAs have zero employment in one of the two sectors in the initial equilibrium. In the canonical quantitative model, these zeros would be rationalized with a zero fundamental productivity, ruling out any employment effects in those locations in any counterfactual. It is a feature of the GSM that zeros arise naturally from the indivisibility of workers and firms under flat fundamentals. Therefore, locations that are empty in the initial equilibrium can be populated in counterfactuals. The second important insight from Figure 3 is that prime services firms are much more spatially concentrated in the initial equilibrium. The reason is that they benefit more from external returns to scale, which creates an incentive for them to agglomerate in prime locations; and that the complementarity between worker- and firm productivity, and externalities amplifies this by making prime services firms much larger. In fact, the degree of concentration in the central prime location is quite striking as in the average run almost 50% of prime services employment is within a single ZCTA. In contrast, no ZCTA contains more than 10% of non-prime services employment in the average run (see Appendix C.3).

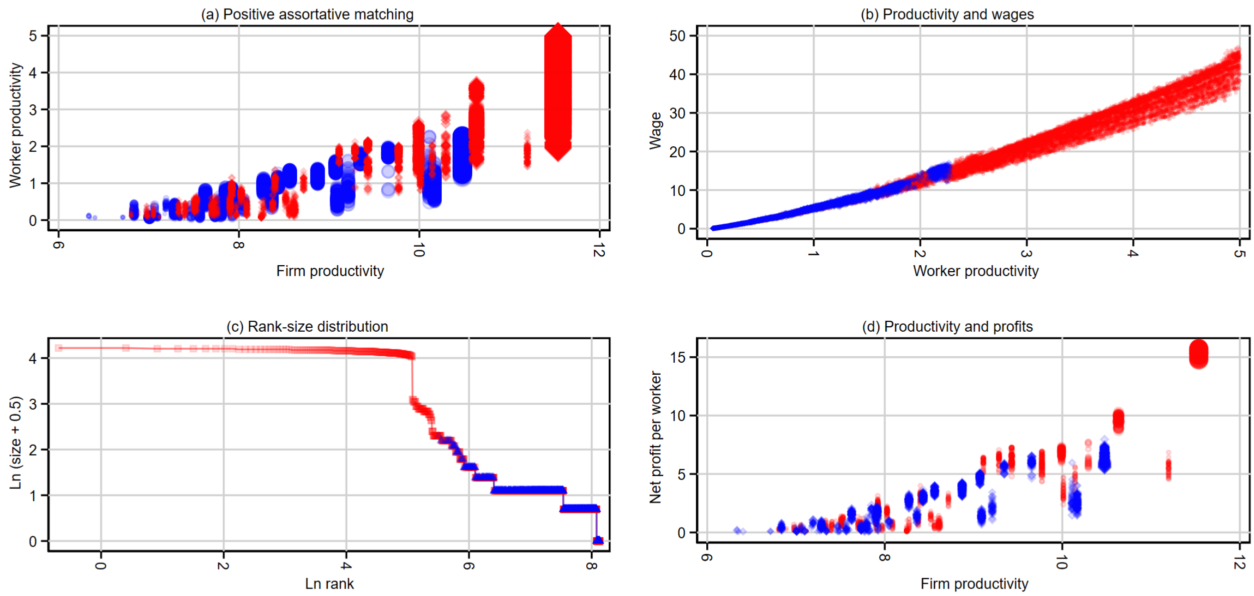
Figure 3: Lorenz curve of spatial employment distribution by sector



Notes: Lorenz curves depict the distribution of employment across ZCTAs in the initial equilibrium. We calculate one Lorenz curve for sector and run. Dashed lines are mean values across runs for a given cumulative share of ZCTAs. The shaded lines areas are between the 5^{th} and 95^{th} percentiles.

A distinctive feature of the GSM is that indivisible workers are matched to indivisible firms. As we show in Figure 4, there is positive assortative matching (Abowd et al., 1999; Bartolucci et al., 2018), i.e. more productive workers tend to work for more productive firms, which tend to be prime services firms (panel a). In keeping with intuition, productive prime services firms pay high wages to productive workers (panel b), tend to grow large (panel c), and make high profits, even in per-worker terms (panel d). This variation in profits is another realistic feature that sets the GSM apart from the canonical QSM. In the standard model, firms are divisible, perfectly mobile, and homogeneous and, therefore, profits are equalized via a competitive bidding process on the real estate market. In contrast, firms are indivisible, imperfectly mobile, and heterogeneous in the GSM. Thus, there are are three reasons why profits are *not* equalized across space.

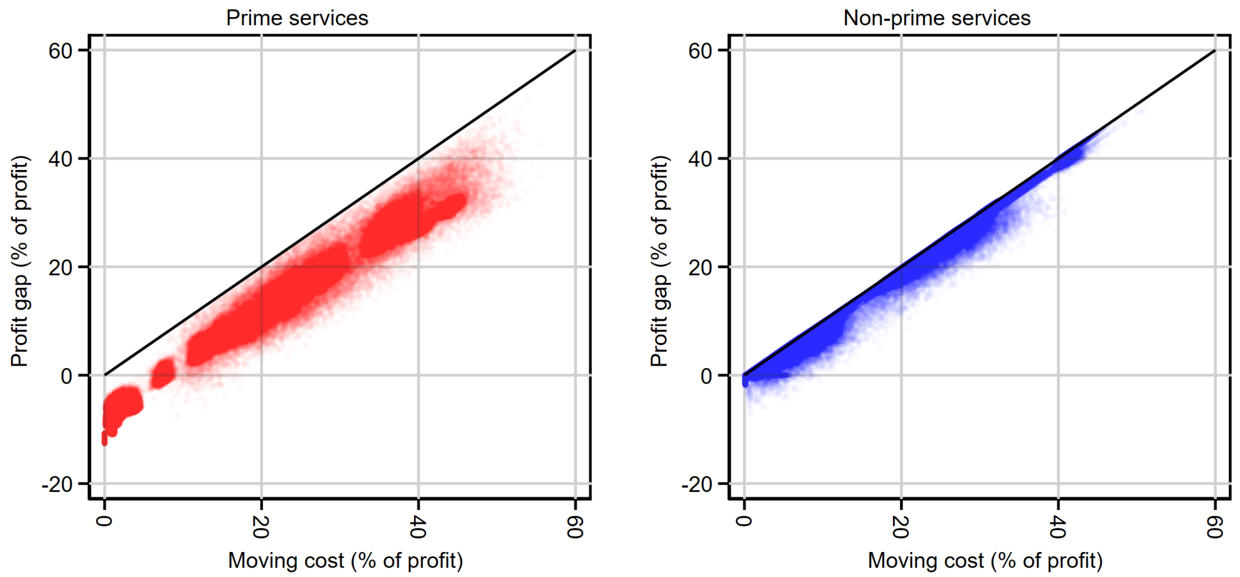
Figure 4: Worker and firm productivities



Notes: Red dots are prime services firms. Black dots are other firms. Marker size in (a) and (d) is proportionate to firm size (employment). All outcomes are observed in the initial equilibrium. We pool firms and workers over 10 random runs.

As a result, there is not necessarily a marginal firm that is indifferent between a pair of locations. Figure 5 illustrates this feature of the GSM taking firm's incentives to relocate to Fulton Market in the initial equilibrium as a case in point. Any firm on the 45-degree line would be indifferent between staying at their current location and moving to Fulton Market because the increase in profit would exactly offset for the moving cost. However, few non-prime services firms and hardy any prime services firms are close to the 45-degree line. Prime services firms, in particular, are inframarginal in the sense that small incentives will not cause them to move to Fulton Market. This is not just because they have high moving costs. If anything, those prime services for which we invert low moving costs are even further from the line of indifference. The reason is that, as shown in Figure 3, prime services firms are spatially concentrated in a few locations that generate great external returns, high productivity, and profits. Indeed, prime services firms facing the largest barriers to migration are located in places that offer the greatest return to agglomeration (see Appendix C.5). Notice that workers are similarly infra-marginal with respect to the choice of their employer, which is why firms tend to take their workers with them when they change location (see Appendix Section C.6).

Figure 5: Inframarginal firms



Notes: Unit of observation is firm-run in the initial equilibrium. Profit gap is relative change in profit a firm would experience when moving to Fulton Market.

4.3 Counterfactuals

We now use the procedure outlined in Section 4.1.3 to evaluate the conditions under which place-based policies can trigger a development in Fulton Market that resembles that seemingly accidental transformation of the area described in Section 3. We consider three policies: (i) the opening of Morgan Station on the Purple and Green lines that enhances access to labour supply and agglomeration economies; (ii) a temporary subsidy of gross profits which resembles a mix of wage subsidy and corporate tax discount; and (iii) an increase in production amenity that captures a fundamental improvement in the attractiveness of location, e.g. due to better urban design.

We conduct 2,000 experiments (runs) in which each policy is enacted with a 50-percent probability. Conditional on being enacted, the intensity of the subsidy and the fundamental improvement are randomly drawn. In addition, we run 500 placebo experiments in which there is variation in initial conditions, but no policy is enacted. The subsidy can range from zero to a share of 15% of firms' gross profits (wages plus net profits). The fundamental improvement enters as a multiplicative shifter of a location's production fundamental a_ℓ that can range from 1 to 1.1, a 10% improvement. For comparison, as mentioned before the CBD has a fundamental productivity advantage of 15% over the average location. All distributions used for the randomization are independent. This setting ensures that we obtain exogenous variation at the extensive and intensive margins across runs. In each run, we first solve for the temporary equilibrium during which the temporary policy is enabled before we solve for the final equilibrium in which the temporary subsidy is disabled. This way, we can evaluate the permanent effect of the temporary policy in isolation and in interaction with complementary permanent policy components.

4.3.1 The ripple effect

To quantify the spatial effects of the simulated place-based policy measures, we regress an outcome $Y_{i,r,t}$ computed for ZCTA $\ell \in \mathcal{L}$, in an equilibrium stage $t \in \{1,2,3\}$ in run $\rho \in R$ against ZCTA-run effects $\alpha_{\ell,\rho}$ as well as two sets of dummy variables that denote combinations of distance-from-Fulton-Market-bins and equilibrium stages:

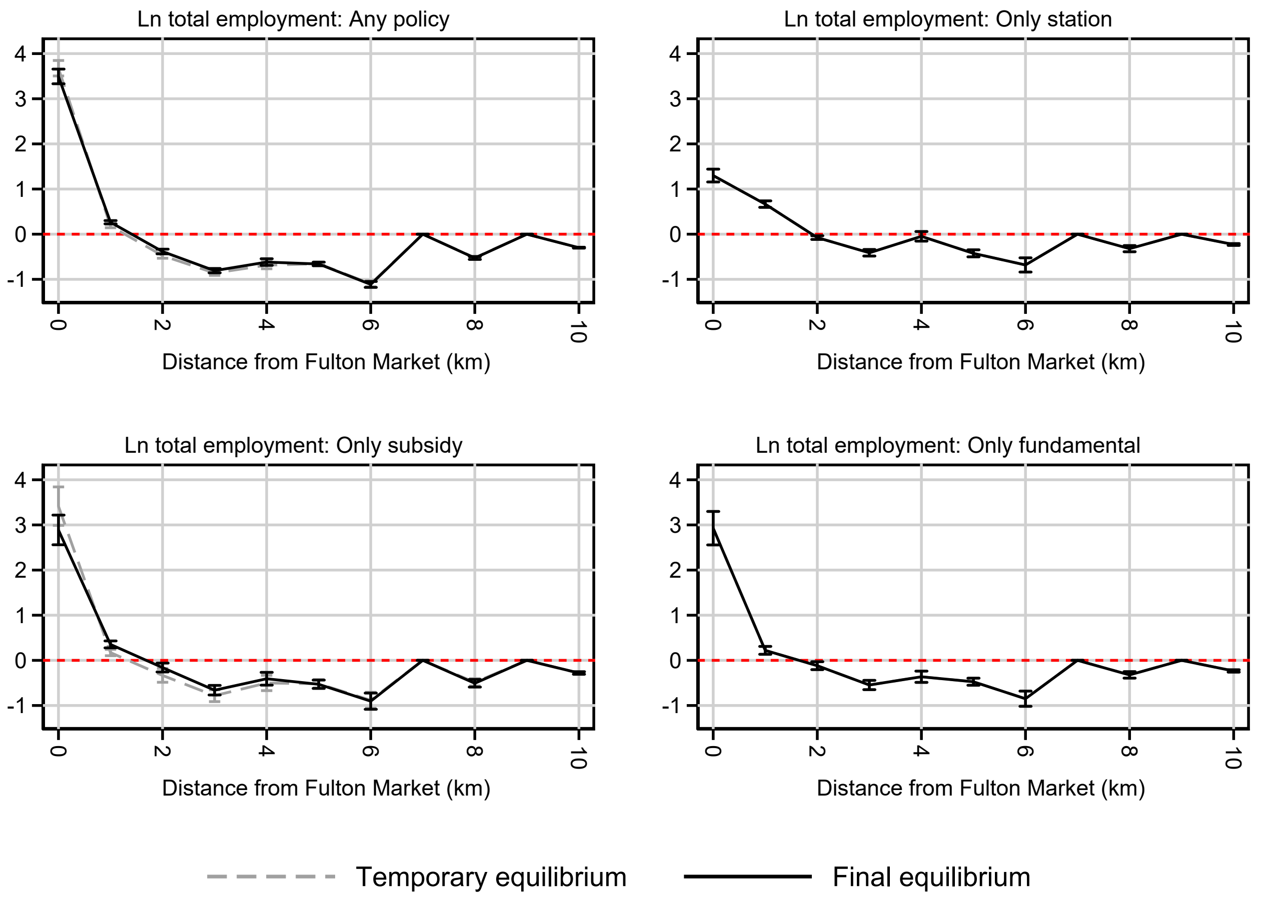
$$\ln Y_{\ell,\rho,b(\ell),t} = \alpha_{\ell,\rho} + \sum_{b=0}^{10} \sum_{z=2}^{3} \beta_{b,z} B_b \times \mathbb{I}(t = z) + \varepsilon_{\ell,\rho,t}, \tag{29}$$

where $B_{b=0}$ indicates ZCTAs within 0.5km of Fulton Market, $B_{b=1}$, $B_{b=2}$,...,$B_{b=9}$ indicate ZCTAs at distances $(b - 0.5, b + 0.5]$, and $B_{b=10}$ indicates ZCTAs at distances $(9.5, \infty]$. Notice that we denote the initial equilibrium by $t = 1$, the temporary equilibrium by $t = 2$, and the final equilibrium by $t = 3$. $\beta_{b,z}$ then provides an estimate of the policy effect at a specific distance and equilibrium stage. Unlike in a conventional difference-in-difference specification, we do not control for policy-independent period effects, so that $\beta_{b,z}$ captures the full general-equilibrium effect of the policy predicted by the model.

We plot the estimated point estimates and confidence intervals from regressions where we use employment density as an outcome in Figure 6. In the first panel, we use all runs where any of the three policy effects is implemented. The subsequent panels use mutually exclusive sets of runs in which only one of the policies is implemented. Placebo runs (no policy) are not included in any panel. Evidently, all policies succeed in promoting economic development in the targeted area in the average run. Fulton Market's employment gain, however, comes at the expense of the surrounding ZTCAs. This is intuitive given that firm relocations over short distances trigger a smaller disruption to established worker commuting paths, reducing the risk of worker-firm separations at the new location. This negative spillover effect to nearby areas resembles an "agglomeration shadow", i.e., the idea that it can be difficult to flourish in close proximity to a major agglomeration (Fujita et al., 1999; Bosker and Buringh, 2017). With the reduction in employment comes a loss of agglomeration economies and an incentive for firms in the agglomeration shadow to search for more attractive locations nearby. The result is a ripple effect in the propagation of the spatial shock, which, to our knowledge, is new to the theoretical literature concerned with the internal structure of cities. We also find this ripple effect in other outcomes such as the the number of firms, rents, and floor space supply (see Appendix Section C.7).

Last, we see that in case of only a temporary subsidy (bottom left panel) there is quite naturally a stronger employment reaction in the temporary equilibrium than in the final equilibrium: some firms leave again or downsize once the policy is discontinued.

Figure 6: Treatment effects in model by policy



Notes: Treatment effects in log scale estimated from panel difference-in-difference models controlling for run-block effects, with standard errors clustered on runs. Each treatment effect is from an interaction of a distance-bin dummy and either a dummy indexing the temporary or the final equilibrium.

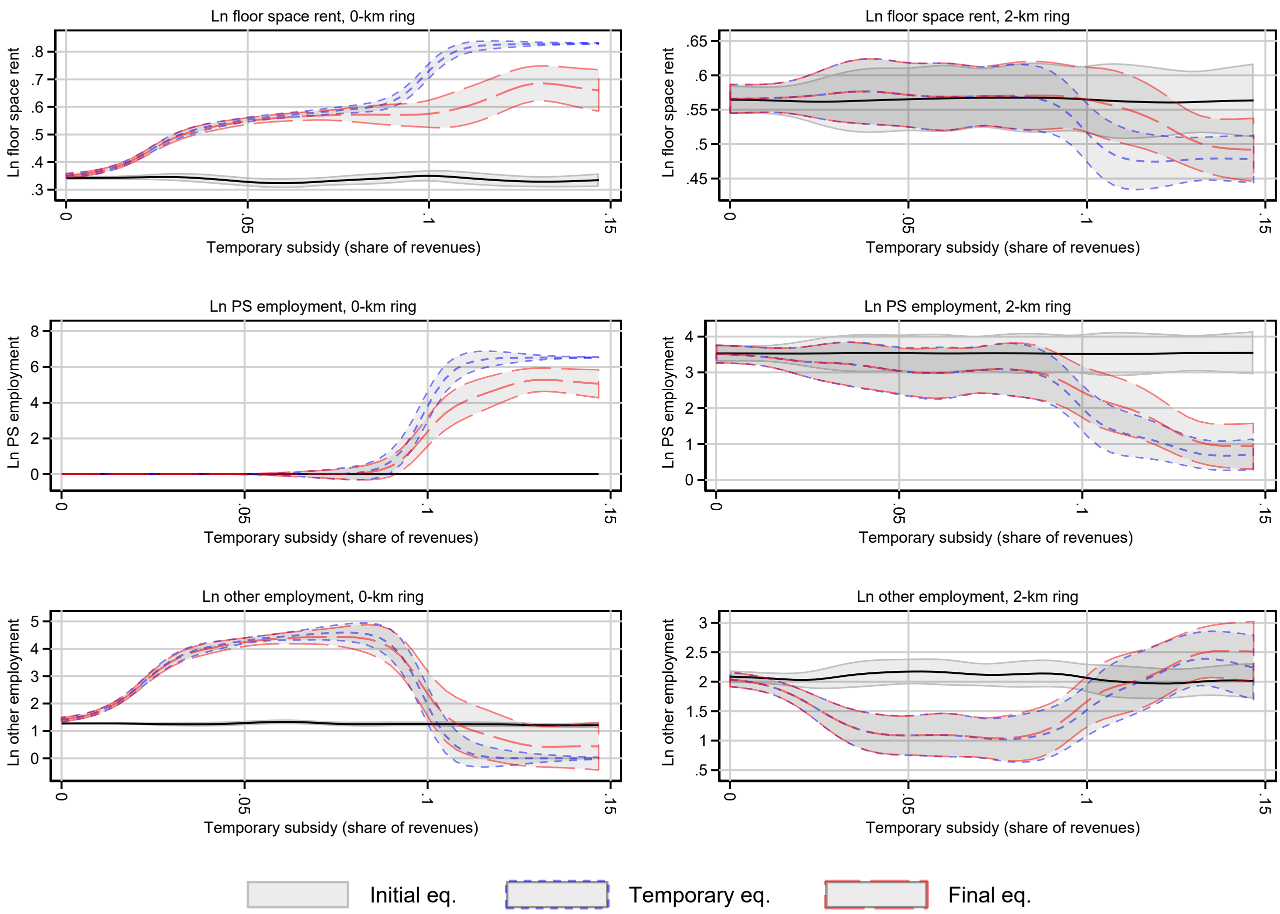
4.3.2 Multiple equilibria

The positive employment effects in Fulton Market associated with a station opening and a fundamental improvement in Figure 6 echoe previous analyses of the effects of transport improvements and other permanent shocks (Ahlfeldt et al., 2015; Tsivanidis, 2019; Heblich et al., 2020; Zárate, 2022). Yet, the bottom-left of panel of Figure 6 also shows that a temporary subsidy can have permanent effects. This is a novel result in the context of quantitative models of internal city structure. It speaks to the conventional notion in the new economic geography literature that agglomeration economies give rise to multiple equilibria in the spatial distribution of economic activity (Fujita and Ogawa, 1982; Krugman, 1991; Thisse et al., 2021).

The motivation for many place-based policies is the idea that a temporary policy can shift the economy to a different spatial steady state and, thus, have permanent effects. In

Figure 7, we zoom into selected distance-from-Fulton-Market bins and illustrate conditional means of selected outcomes across runs as a function of the intensity of the temporary subsidy. We estimate the conditional means and the associated confidence bands separately for the initial, temporary, and final equilibria using local polynomial regressions. The panels to the left illustrate outcomes in Fulton Market, the only location within the 0-km distance bin. The panels to the right do the same for ZCTAs whose centroids are within a distance from 1.5 to 2.5 km in the agglomeration shadow.

Figure 7: Temporary vs. final equilibrium



Notes: Graphs show estimates of the conditional means of a model-based outcome within a group of ZCTAs across runs as a function of the run-specific level of the subsidy in the different equilibrium. The subsidy is paid as a share of firm revenues in the temporary equilibrium, exclusively. the subsidy is the only policy implemented (Morgang station does not open; there is no fundamental improvement). The 0km ring contains Fulton Market. The 2-km ring contains all ZCTAs whose centroids fall within 1.5 and 2.5 km distance from the Fulton Market centroid. Point estimates and confidence bands are from are from local polynomial regressions using a Gaussian kernel and a bandwidth 0.1.

The floor space rent is an intuitive summary statistic that scales in economic activity in a broad sense since all potential users eventually compete on the same local real estate market. In keeping with intuition, the upper left panel reveals that higher subsidies attract more firms, leading to higher rents. However, the effect is double-s-shaped. If the subsidy amounts to less than 1% of a firm's gross profit, the probability of attracting firms is marginal. This is intuitive since firms are not ex-ante indifferent between locations. In fact, the subsidy must amount to the difference between the profit gap and the moving cost for a firm to consider moving to Fulton Market (see Figure 5). At about 5%, the effect of the subsidy flattens out. This is also intuitive given that firms in our model are heterogeneous. Naturally, the subsidy will first attract firms that are closer to the line of indifference in Figure 5. With each attracted firm, the marginal firm is less inclined to move into the target area, reducing the marginal effect of the subsidy. At around 10%, there is another step, with the marginal effect of the subsidy first increasing and then decreasing. The middle-left and bottom-left panels reveal that the two shifts in rent in the temporary equilibrium around 5% and 10% are driven by sorting. The first shift is driven by non-prime-services firms that are less averse to moving into Fulton Market (they are generally close to the 45-degree line in Figure 5). The second shift is driven by prime services firms which require high subsidies before considering leaving the highly agglomerated and productive locations they have sorted into in the initial equilibrium (they are far from the 45-degree line in Figure 5). That there are critical thresholds in subsidy levels that must be crossed to attract different types of firms is a novel and policy-relevant finding that highlights the merits of a GSM featuring heterogeneous, infra-marginal firms.

Yet, the perhaps most important insight from a policy perspective is that the attracted firms do not necessarily leave the area after the subsidy ends. For intermediate subsidy levels, at which primarily non-prime services firms are attracted by the subsidy, the final equilibrium is almost identical to the temporary equilibrium. Although the targeted area loses some of its appeal when the subsidy ends, firms choose to stay, resulting in a sustainable shift in the spatial distribution of economic activity caused by a temporary shock. For one thing, moving cost which constituted a barrier to entering Fulton Market in the initial equilibrium also constitute a barrier to leaving Fulton market in the temporary equilibrium. For another, the legacy of the temporary shock is caused by the agglomeration economies generated by the newcomers which help establishing an alternative equilibrium distribution of economic activity.

For high subsidy levels, there is some reversion in rents from the temporary to the final equilibrium. But rents remains higher than in the initial equilibrium which is, again, consistent with a shift between multiple equilibria. While some of the prime services firms attracted in the temporary equilibrium leave the area in search of cheaper real estate when the subsidy ends, the majority stays (middle-left panel).

Another noteworthy impact of high temporary subsidies is the crowding out of the incumbent non-prime services firms. The firms moving to Fulton Market bring with them agglomeration economies, from which prime services firms benefit more than non-prime services firms. Therefore, the latter are priced out of the market, a firm displacement effect (Mayer et al., 2017; Givord et al., 2013; Einiö and Overman, 2020) that resembles displacement of incumbent residents known from a growing literature on residential sorting (Diamond, 2016; Almagro and Domínguez-Iino, 2020) and gentrification (Guerrieri et al., 2013; Couture and Handbury, 2020; Behrens et al., 2022a).

In keeping with intuition, the effects in the agglomeration shadow generally point into the opposite direction of what we observe in the targeted area. At intermediate subsidy levels, ZCTAs in the 2-km distance ring lose non-prime services companies to the targeted area (bottom right panel). At high subsidy levels, they lose prime services firms and attract non-prime services firms crowded out of the targeted area. Only the loss of the highly productive and agglomeration-economy-dependent prime services firms is associated with a significant reduction in rent because the 2-km ring is ex-ante specialized in prime services. As with the direct policy effect in the targeted area, the indirect policy effect persists in the final equilibrium, once more confirming a sustainable shift to an alternative spatial equilibrium following a temporary shock.

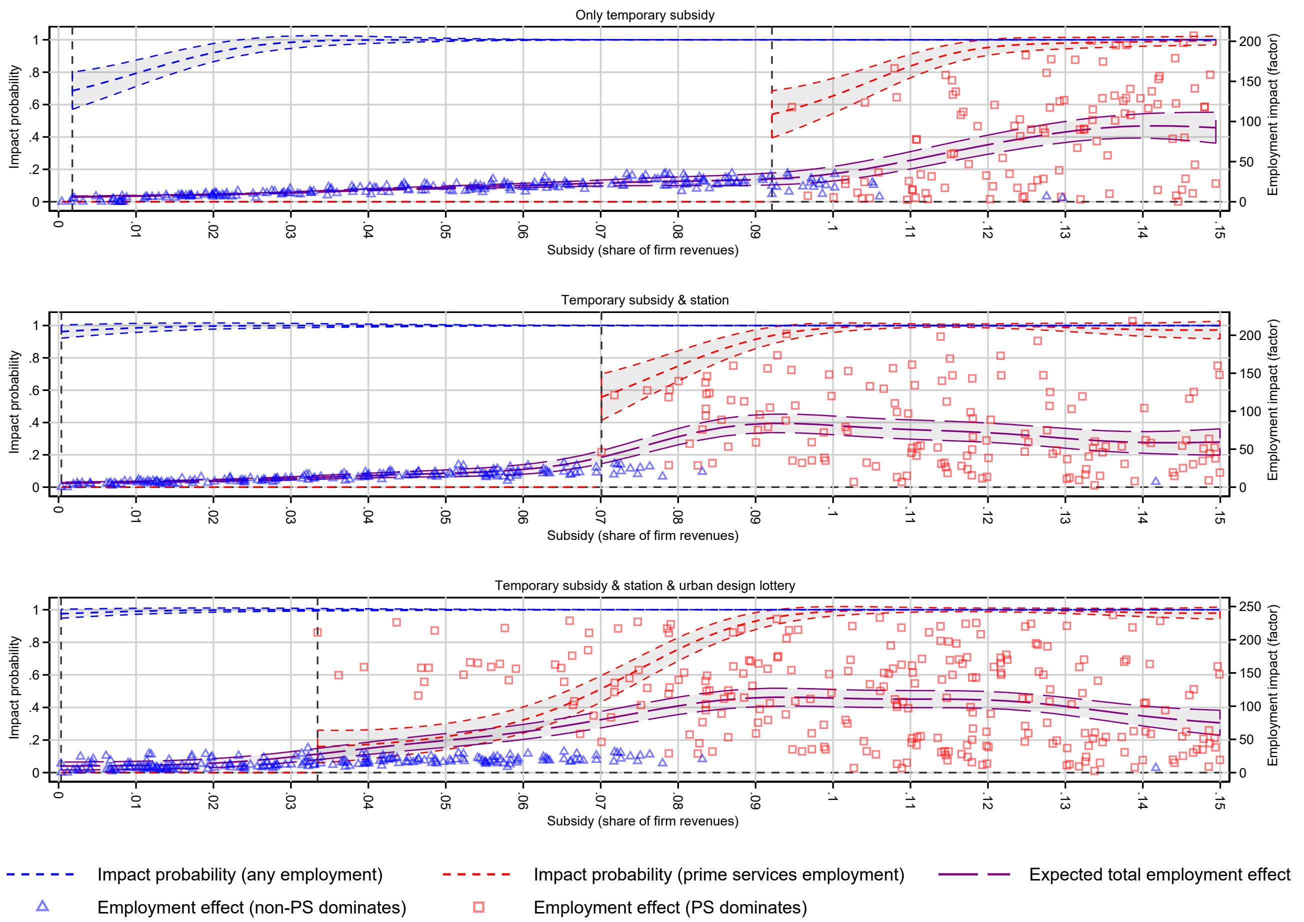
These results are encouraging from a policy perspective, but they come with a caveat. External returns imply that temporary policies can permanently change the internal organization of cities to potentially more desirable configurations. Ironically, however, firms that rely more on external returns are more difficult to relocate. This is because they naturally concentrate in dense clusters that generate great agglomeration economies (see Appendix Section C.5). To make an ex-ante non-agglomerated area a viable substitute for a prime location, a subsidy must be sizable. Under our parametrization, we require subsidies to the equivalent of the present value of 10% of firms' gross profits, which—when paid to multiple large prime services companies—can easily amount to a vast sum. More generally, the illustrative application introduced here reveals a strength of the GSM that makes it particularly suitable for the study of potentially persistent effects of a host of temporary shocks such as natural disasters, war destruction, or pandemics (see Ahlfeldt et al. 2022).

4.3.3 Threshold effects

Urban planners frequently wish to promote the emergence of new business centers to curb congestion in established cores and to revitalize economically struggling areas. Anecdotally, their track record is mixed at best. La Défense in Paris—Europe's largest purpose-built business district—stands out as a prominent success. Canary Wharf in London has done well recently, but failed in the first attempt, resulting in the main developer going into administration. In China, ghost towns and new ghost business centers—such as the Yujiapu Financial District— increasingly litter the landscape. This suggests there is significant risk of failure associated with ambitious policies that seek to transform ordinary places into prime locations. The GSM is well-suited to capture this risk. Because firms are generally inframarginal when making location decisions, some thresholds must be crossed before the forces of cumulative causation (Krugman, 1991) take over in promoting sustainable development.

We illustrate the presence of such thresholds in Figure 8. In the top panel, we consider the effects of a temporary subsidy as the sole policy measure implemented with the intention to turn Fulton Market into an employment centre or even prime location. The first insight is that that there is a threshold below which the subsidy has no effect whatsoever. At 0.8% of a firm's gross profit, this threshold is relatively low. However, even if the threshold is crossed, the policy does not deliver any sustainable effect in about 33% of the runs. If the subsidy has an impact, the policy will be cost-effective in the sense that there will be sustainable development at a low price tag. But the risk of failure is large. This changes at higher subsidy levels. At 3% or more, some positive impact on employment occurs with near certainty. Over a relatively wide band, the employment effect scales more or less proportionately in the subsidy level, suggesting that planners have control over urban transformations at the extensive and intensive margins.

Figure 8: Local employment effect of temporary subsidy



Notes: Each dot represents a relative employment change in Fulton Market from the initial to the final equilibrium in one run. The relative change in employment is computed as the ratio of 1+employment in the final over 1+employment in the initial equilibrium. Expected total employment and impact probabilities (shaded areas are 95% confidence bands) are computed using local polynomial regressions of degree zero with a Gaussian kernel and a bandwidth of 0.1. Opening station is Morgan station. Design lottery is a premium to the fundamental productivity drawn from a uniform distribution between ranging from zero to five percent..

Once the subsidy level exceeds a little more than 9% of gross profits, there is another threshold for a disruptive urban transformation. At this point, the subsidy is high enough to incentivize some prime services firms to move to Fulton Market and leave the agglomeration economies in their original locations behind. However, even at this high level of subsidy, the transformation of Fulton Market into a prime location is far from guaranteed. In fact, once the threshold is crossed, there is an about 50-50 chance that some prime services employment will settle in the area. To have near certainty that some prime services settle in the area, subsidies need to exceed 12% of gross profits. In return, planners can expect a much larger local employment increase, on average. This is intuitive given that the presence of prime services firms that emit and benefit from agglomeration economies may result in the high levels of density and productivity that are characteristic for prime locations. However, even conditional on attracting some prime services employment, the fortunes of Fulton Market are far from clear, even at very high subsidy levels. Depending on the run, Fulton Market can host a hand-full of prime services workers or become the city's largest prime location. This suggests that there is an element of chance associated with a policy attempt to develop a prime location, subject to forces that are beyond the control of a planner.

Of course, the planner can adopt additional policies to increase the odds of success.[23] In the middle panel, we replicate the simulation with Morgan Station opening in the temporary equilibrium and remaining open in the final equilibrium. Notice that the effect of Morgan Station on firms locating in Fulton Market is twofold. First, it increases a firm's access to labour supply and the likelihood of attracting productive workers. Second, it facilitates some access to agglomeration economies form the established prime location which travel through the network. These benefits increase the impact probability at low subsidy levels. Since Fulton Market is already specialized in non-prime services, the subway station alone makes Fulton Market attractive to other non-prime services firms. Equally important, the station also shifts the critical threshold for the attraction of prime services to the left. Having a subway station significantly reduces the hurdle for prime services firms to move into a would-be prime location. This is very much in line with anecdotal evidence from Canary Wharf in London. After it its initial failure, the former Docklands were connected to the subway network via the extension of the Jubilee line. A large firm—HSBC—moved in, and the process of cumulative causation that led to the transformation into a prime services centre was triggered.

It is natural to believe that good urban design can also make a difference. We argue that it is one of the key strengths of the GSM that it can rationalize given spatial distributions under flat fundamentals. And yet, we acknowledge that, just like in many other cities, the historic centre of Chicago is characterised by a unique combination of natural amenities (Lake Michigan and Chicago River), signature buildings (historic landmarks and iconic skyscrapers), and ambitious urban design (parks, plazas and boulevard). Since these fea-

[23] Likewise, as we show in Appendix C.8, the planner can use a temporary subsidy to enhance the impact of other permanent policies.

tures, together, arguably create a sense of place (Bloom, 1990) that may be valued by workers and their employers, we allow for a fundamental productivity advantage in the centre that peaks at 5%. It is, of course, far from certain that the planner will succeed in creating a sense of place that matches the historically grown city center. To account for the associated risk in the success of the urban design, we model the fundamental design effect as a lottery that returns an 0-5% premium with uniform probability. The bottom panel reveals that with such a design lottery, there is a chance that a successful prime location emerges even at relatively low subsidies, but the probability is fairly low. It may be tempting—especially for a confident planner—to bet on a successful design and hope for a successful transformation without giving major financial incentives, but the chances that the targeted area does not live up to higher hopes is relatively high.

To conclude, the GSM rationalizes why real-world attempts of developing prime locations frequently fail. Even with high temporary subsidies, a good transport connection, and successful urban design, there is no guarantee that a transformation succeeds because firms are infra-marginal with respect to their location decisions. The attraction of multiple firms that together can replicate the agglomeration economies that are characteristic for prime locations involves an element of chance that constitutes a necessary condition for success. The threshold effects derived here, potentially generalize to other settings and explain why spatial distributions tend to show a remarkable degree of persistence, within and between cities.

4.4 Some simple welfare calculations

So far, we have focused on the positive question of whether the transformation of an ordinary neighbourhood into a prime location is realistically achievable. Of course, there is also the normative question of whether such a transformation is desirable. Since our GSM is a general equilibrium closed-city model, the utility of workers is endogenous. We use it as a basis for a back-of-the-envelope evaluation of the net present value (NPV) in the spirit of a social cost-benefit analysis. Since, the purpose of this exercises is to illustrate the trade-offs that arise from the thresholds introduced in Section 4.3.3 and not to provide a complete evaluation of a concrete policy, we take a couple of short-cuts to keep this section concise. First, we assume owners of capital and land to be absent and focus on the welfare of workers. Second, we assume that the workers and firms receive the welfare gains and the subsidy in perpetuity. Third, we assume that the planner has no direct preferences over the spatial distribution of economic activity. Fourth, we abstract from costs associated with the transport improvement or a participation in a design lottery.[24] Fifth, we evaluate the welfare

[24]While opening Morgan Station on an existing line was relatively cheap, other settings where a new line has to be built may require more sizable investments. Participation in the design lottery can lead to extra cost for more prominent architects, expensive materials, or sophisticated structural engineering, but the success of the design will remain uncertain.

case for an average worker who earns the average net wage and pays the average rent and abstract from spatial variation in the welfare effect across locations in the city.

We start from the equivalent variation for worker ω in ℓ in run ρ, given by

$$EV_{\rho}^{\omega,\ell} = e(r_{\rho,t=1}^{\omega,\ell}, U_{\rho,t=3}^{\omega,\ell}) - e(r_{\rho,t=1}^{\omega,\ell}, U_{\rho,t=1}^{\omega,\ell}) = \left(\frac{r_{\rho,t=1}^{\omega,\ell}}{r_{\rho,t=3}^{\omega,\ell}}\right)^{\alpha} w_{\rho,t=3}^{\text{net},\omega,\ell} - w_{\rho,t=1}^{\text{net},\omega,\ell} \tag{30}$$

where, as before, subscript $t=1$ denotes the initial equilibrium and subscript $t=3$ denotes the final equilibrium. $EV_{\rho}^{\omega,\ell}$ provides a measure of the monetary equivalent to the experienced utility gain—measured at initial prices—which depends on a change in housing rent and net wage, which itself depends on changes in the gross wage and commuting cost. Concretely, we evaluate an equivalent variation $\overline{EV}_{\rho} = \xi EV_{\rho}^{\omega=\overline{\omega},\ell=\overline{\ell}}$ for the average worker $\overline{\omega}$ in the average location $\overline{\ell}$, where ξ is a scalar that scales prices to 2020 levels.[25] This way we obtain a welfare measure in intuitive units.

Naturally, any place-based policy comes at a cost. Here, we focus on the cost of the temporary subsidy to firms' gross profits, which is isomorphic to a combined same-rate discount on the corporate tax and a wage subsidy. We express the cost of the subsidy in per-worker terms:

$$\mathcal{C}_{\rho} = s_{\rho} \times \frac{(\xi/\delta^F)}{N_w} \times \sum_{\varphi} \left(\pi_{\varphi,\rho|\ell=FM,t=2}^{\text{gross}}\right), \tag{31}$$

where s_{ρ} is the rate of the subsidy paid to firms in Fulton Market in the temporary equilibrium and $(1/\delta^F)$ is a multiplier that depends on firm's internal rate of return δ^F and converts the flow of per-period subsidy (the lasst term in Eq. (31)) into a present value.[26] It is straightforward to combine the equivalent variation and the present value of the subsidy in (30) and (31) to obtain the net present value in per worker terms:

$$NPV_{\rho} = \frac{\overline{EV}_{\rho}}{\delta^S} - \mathcal{C}_{\rho}, \tag{32}$$

where δ^S is the social discount rate. Since the social planner should place a higher value on future generations than the private sector, we choose a smaller value for the social discount rate $\delta^S = 0.05$ than for the internal rate of return which we set to $\delta^F = 0.1$.

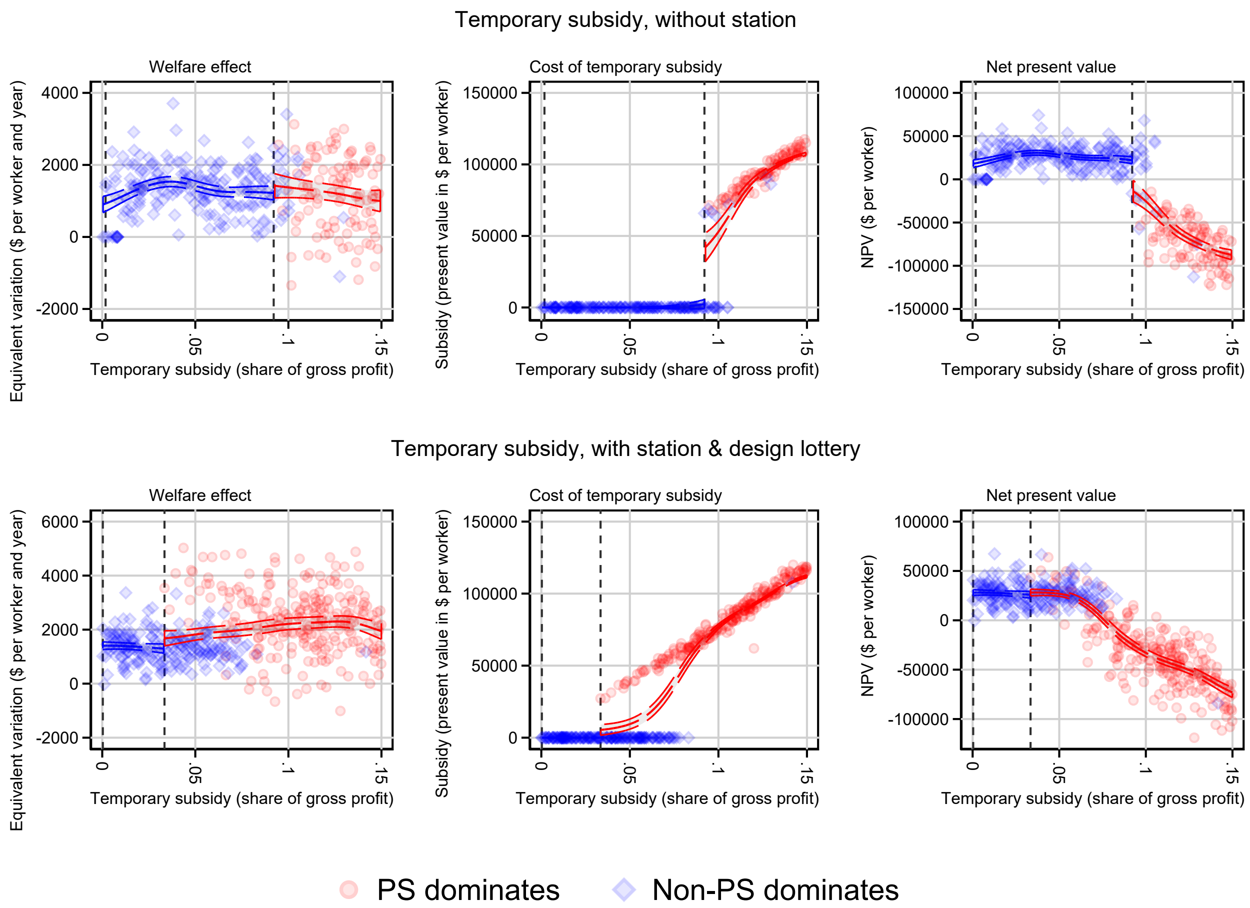
We present the outcomes defined in (30), (31), and (32) in Figure 9. The reallocation of workplaces to Fulton Market can affect welfare through exposure to agglomeration and productivity, a change in commuting costs, as well as general equilibrium effects on rents. In general, a more dispersed distribution of employment will be associated with lower commuting costs and lower exposure to agglomeration, so the expected effect is theoretically

[25] We chose ξ such that the mean gross wage in the model equates to the May 2020 average wage of Chicago of $60,340 observed in the *Occupational Employment and Wage Statistics*.

[26] In computing the present value, we treat the subsidy as a perpetuity, assuming that the subsidy is in place for a long time.

ambiguous. The left panels of Figure 9 show that the net effect is positive in most runs. If the subsidy is implemented in isolation, welfare increases by the equivalent of about $1,200 per worker and year, on average. There is no clear trend with respect to the subsidy level. If anything, there are more runs which deliver negative welfare effects at high subsidy levels when more prime services employment is attracted. Coupled with the new station and a design lottery that may increase fundamental productivity, the expected welfare effect, at about $1,400 per worker and year, is a bit higher at low subsidy levels. Once the threshold for attracting some prime services is crossed, the welfare effect increases quite steadily to beyond $2,000 per worker and year. Yet, there remains significant dispersion of the welfare effect, suggesting that initial conditions matter.

Figure 9: Welfare effect of temporary subsidy



Notes: Welfare is measured in per-worker terms and accounts for gross wages, commuting costs, and rents. The cost of the subsidy is computed as the present value of of a infinite annuity, discounted at an internal rate of return of 10% and expressed in per-worker terms. The annuity is the sum over the product of the subsidy share (on the x-axis) and the profits of all firms in Fulton Market in the temporary equilibrium. The net present value is the present value (at a 5% social discount rate) of the welfare effect, minus the present value of the subsidy, again in per-worker terms. Opening station is Morgan station. Design lottery is a premium to the fundamental productivity drawn from a uniform distribution between ranging from zero to five percent. The station opening and the design lottery come at no additional cost (Morgan Station was opened on an existing line). Dashed lines are conditional means and 95% confidence bands computed using local polynomial regressions of degree zero with a Gaussian kernel and a bandwidth of 0.1.

The middle panels of Figure 9 illustrate how the total cost of the temporary subsidy increases in the subsidy rate. For one thing, a higher subsidy rate mechanically increases the total cost, ceteris paribus. For another, higher rates imply a greater chance of success as shown in Figure 8. And with greater gross profits in Fulton Market, the total cost increases further. Evidently, the cost increases substantially if the policy succeeds in attracting prime services firms because primes services are generally large and profitable (see Figure 4). They will only move to Fulton Market if they expect to make sizable profits, resulting in sizable subsidies. Adding the station and the design lottery, lowers the threshold for attracting prime services with some probability. As a result, there is a band of subsidy rates from about 0.04 to about 0.09 where the expected cost is relatively low. However, there is some chance the total cost could go through the roof in case prime services are attracted.

Summing over the present value of the welfare effect and the cost of the subsidy, we obtain the net present value of the policy in the right panels of Figure 9. Given that the welfare effect is relatively flat in the subsidy rate whereas the cost increases steeply, it is no surprise that high subsidy rates do not pass the cost-benefit test.[27] It turns out that transforming Fulton Market into a prime location does not increase welfare substantially compared to the alternative of developing a more modest cluster specialized in other industries. But it is significantly more costly. If the policy objective is to create a prime location, perhaps for reasons related to prestige or because significant urban growth is anticipated in the long run, planners may still wish to go ahead with a high subsidy level in order to maximize the chance of a successful urban transformation.

At this stage, we wish to remind the reader that we are not evaluating a specific policy. We also do not wish to make a statement about the desirability of turning ordinary neighbourhoods into prime locations. Instead, we wish to draw the attention to the possibility that such a transformation is theoretical achievable with a temporary subsidy alone, but the likelihood of success, the welfare effect, and the cost are subject to threshold effects and associated with significant risk. These are generalizable insights that illustrate how the GSM can complement the canonical quantitative urban model in policy analysis.

5 Conclusion

We develop a quantitative model with many locations and indivisible workers and firms. This granular spatial model (GSM) rationalizes observed distributions via moving costs instead of differences in fundamentals. As a result, the bar for shifts between multiple spatial equilibria is much lower than in the canonical quantitative urban models. This makes the GSM suitable for the evaluation of temporary place-based policies. We illustrate the model's potential using policies that seek to transform ordinary neighbourhoods into prime locations

[27] One caveat is that we assume the subsidy is a perpetuity. Clearly, this provides an upper bound for the cost of the subsidy. In future work, the horizon over which the subsidy is in place needs to be modeled in more detail.

as a case in point. There are three important insights that are new to the literature using quantitative models to evaluate place-based policies.

First, temporary policies can, indeed, shift the spatial economy between multiple spatial steady states and create dense clusters of economic activity that sustain high endogenous productivity levels owing to external returns to scale. However, a policy-induced shift between multiple steady states is a challenging undertaking. Since there is no such thing as a marginal firm that is indifferent between locations, thresholds must be crossed for firms to move into a targeted area and the thresholds for reaching external returns that sustain a would-be prime location via agglomeration economies—by attracting large and productive firms—are particularly high.

Second, sorting matters on the firm side as much as on the worker side. External returns are key to multiple equilibria. Ironically, shifting those firms that are most dependent on external returns is the most challenging. The reason is that these firms are ex-ante sorted into dense clusters generating large agglomeration economies and any move to a location that does not offer similar external returns will result in a significant profit cut. If the transition to a prime location succeeds, prime services firms are likely to outbid incumbent firms from other sectors that derive lower external returns to scale. The result may be viewed as the firm analog to the well-known residential gentrification process (Behrens et al., 2022a).

Third, the simulations within our granular spatial model bring to light a risk-return trade-off that planners face when implementing temporary place-based policies. Low subsidies to targeted areas may turn out to be cost-effective, but the risk of failure is high, for reasons that can be beyond the control of the planner. Initial conditions and chance matter. In keeping with intuition, higher subsidies increase the chances of inducing disruptive spatial transformations, but costs can quickly escalate to levels that put the social desirability of the policy into question. This risk-return trade-off may explain why successes—such as La Défense in Paris—and failures—such as the Yujiapu Financial District—exist side by side in the real world. A place-based policy is partly a "place-based lottery."

More generally, our results highlight the potential of the granular spatial model to complement the canonical quantitative urban model when it comes to the evaluation of shocks that do not affect the primitives of the model and in settings where large granular firms matter. Examples are countless and include other placed-based policies that create incentives for residents to moves, natural disasters such as floods or fires that temporarily devastate neighbourhoods, or the legacy effects of a pandemic that temporarily restricts the way we move and interact in space.

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A Appendix I: Model

This appendix section complements Section 2 in the main paper.

A.1 Stable matching

In this appendix, we establish a number of properties of the stable matching between firms and workers.

With firms. We first show that there is no scope for re-optimization of the worker assignment within firms. To see that this type of reoptimization is never profitable to workers or firms, irrespective of the existence of possible side payments (transfers between workers), consider two workers ω and ω' in firm φ, with ranks $R_\omega < R_{\omega'}$. Switching the ranks of the workers leaves the total surplus generate for the firm unchanged, i.e., there are no incentives for the firm to switch workers' positions. On the worker side, the match value is independent of the rank, whereas higher rank implies non-increasing wage (constant match value but higher SOC costs). Hence, if $\omega \neq \omega'$, at least one of the worker looses from the switch. Since the sum of workers' wages remains unchanged, there is no possible side payment to make this change mutually beneficial to the workers and the firm.

Between firms. There is also no scope for re-optimization between firms by switching workers. Consider two workers ω and ω' in firms φ and φ', with ranks $R_{\omega(\varphi)} < R_{\omega'(\varphi')}$. Assume first that there are no side payments. In that case, the profit of firm φ changes by $\Delta\pi_\varphi = A_{\ell,\varphi}(\theta_{\omega'} - \theta_\omega)\theta_\varphi$, whereas the profit of firm φ' changes by $\Delta\pi_{\varphi'} = A_{\ell',\varphi'}(\theta_\omega - \theta_{\omega'})\theta_{\varphi'}$. Hence, the only mutually acceptable match, $\Delta\pi_{\varphi'} \geq 0$ and $\Delta\pi_\varphi \geq 0$, is such that $\theta_\omega = \theta_{\omega'}$, which will never occur since there is nothing to be gained for the firm (recall that workers bear the commuting costs, and that the firms' size remains unchanged by the switch, i.e., it pays the same SOC cost and total land rent).

Asssume now that side payments are possible. In that case, the gains to the two firms from the switch is $\Delta\pi = (\theta_{\omega'} - \theta_\omega)(A_{\ell,\varphi}\theta_\varphi - A_{\ell',\varphi'}\theta_{\varphi'})$. This is positive if and only if the switch is 'assortative', i.e., the switch is a reallocation of a more productive worker to a more productive firm, where productivity subsumes the firms fundamental productivity θ_ω and its 'location productivity' $A_{\ell,\varphi}$. Assume that $\Delta\pi > 0$. In that case, firms could potentially bargain over the surplus $\Delta\pi$ and split it with bargaining coefficient $\zeta \in (0,1)$ such that $\widetilde{\Delta}\pi_\varphi = \Delta\pi_\varphi + \zeta\Delta\pi > 0$ and $\widetilde{\Delta}\pi_{\varphi'} = \Delta\pi_{\varphi'} + \zeta\Delta\pi > 0$ after the switch. This would be potentially beneficial to both firms, so they would agree on this. It would also be beneficial to workers since their incentives are aligned with those of the firms.

To keep the model tractable, we abstract from these side payments. Since we focus on an initial matching that is positive assortative, and since the rank-dependence of wages induces inertia in workers decisions to rematch, there would not be much to be gained of having side payments in the model.

A.2 Algorithms

This appendix provides a succinct description in pseudo-code of the general workflow of the algorithms we use. Algorithm 1 describes the determination of a spatial equilibrium conditional on a given set of parameter values and initial conditions. Algorithm 2 describes one specific way of initializing the model and of rationalizing an observed distribution as an initial equilibrium using a technique called 'model inversion' in the quantitative spatial literature.

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.

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 betweem 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 the firm-specific moving costs such that the firms' current locations yield the highest profit.

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

In concrete terms, we implement these algorithms to solve the model using code written entirely in C++11. Our code is completely customized and developed from scratch, safe for the use of non-linear root-finding algorithms from the GNU Scientific Library (see `https://www.gnu.org/software/gsl/doc/latex/gsl-ref.pdf` for additional details.)

B Appendix II: Fulton Market

This appendix section complements Section 3 in the main paper.

B.1 Data

Source: National Establishment Time Series (NETS) data The dataset is proprietary and provided by Walls & Associates. The big advantage of the data is that it is point-based, i.e. it provides data on single establishments at distinct geographic locations. For this project, we acquired the Chicago data for 1990-2020. The snapshots are always taken in January of the year. Hence, all data predate the Covid-19 pandemic.

In addition to the current company location, Walls & Associates provides a 'moves' file, which contains all moves of a given establishment/firm. For the 30 years in our sample, we thus can locate each firm in any given year.

We assign each unique establishment location to a 'Zip Code Tabulation Area' (ZCTA) for the wider Chicago area, including a special pseudo-ZCTA that we created for the 'Fulton Market Innovation District' (see Appendix C.1). For the graphs in the main text, we sum the establishments by year and ZCTA. We also make use of the industry classification (NAICS) for the establishments provided by Walls & Associate.

B.2 Synthetic control approach

To gauge the extent of Fulton Market's take-off relative to other neighborhoods, we employ the synthetic control approach by Abadie et al. (2010). As a treatment year, we choose 2005. Our outcome variable is the log-number of establishments. The predictors and their values for Fulton Market and for the control group are the shown in the right panel of Table A 1. The control group consists of 5 neighbourhoods (left panel of Table A 1).

Table A 1: Synthetic control group - summary

Control group composition		Fulton Market vs. synthetic control group		
ZCTA	Weight	Predictor	Treated	Control
60141	25%	LN (Establishments)	4.75	4.75
60456	19%	Growth #establishments	0.04	0.04
60601	20%	LN(dist) to CBD	0.81	0.87
60602	11%	LN(population)	8.16	8.13
60605	26%	Area	1,522,074	3,713,854

Notes: Synthetic control approach using synth algorithm by Abadie et al. (2010). We only include prime service and information industry establishments.

To assess the significance of our estimate, we compute confidence bands. We follow the logic by Abadie et al. (2010), who compare the estimated treatment effect for the actually treated unit against treatment effects estimated in placebo studies. Analogously to their approach, we run placebo studies for each of the other 115 ZCTAs from the 'donor pool' using the same predictor variables. We drop two ZCTAs for which the pre-2005 MSPE is twice as high as that for Fulton Market. Instead of plotting the 114 (113 placebo +1 actually treated) lines (as in Abadie et al., 2010), we calculate the treatment effects' standard deviation $\sigma_{Placebo}$ at any given point in time in the post-treatment period. $1.96 \times \sigma_{Placebo}$ provides us with (symmetric) 95% confidence bands for the treatment effect for Fulton Market.

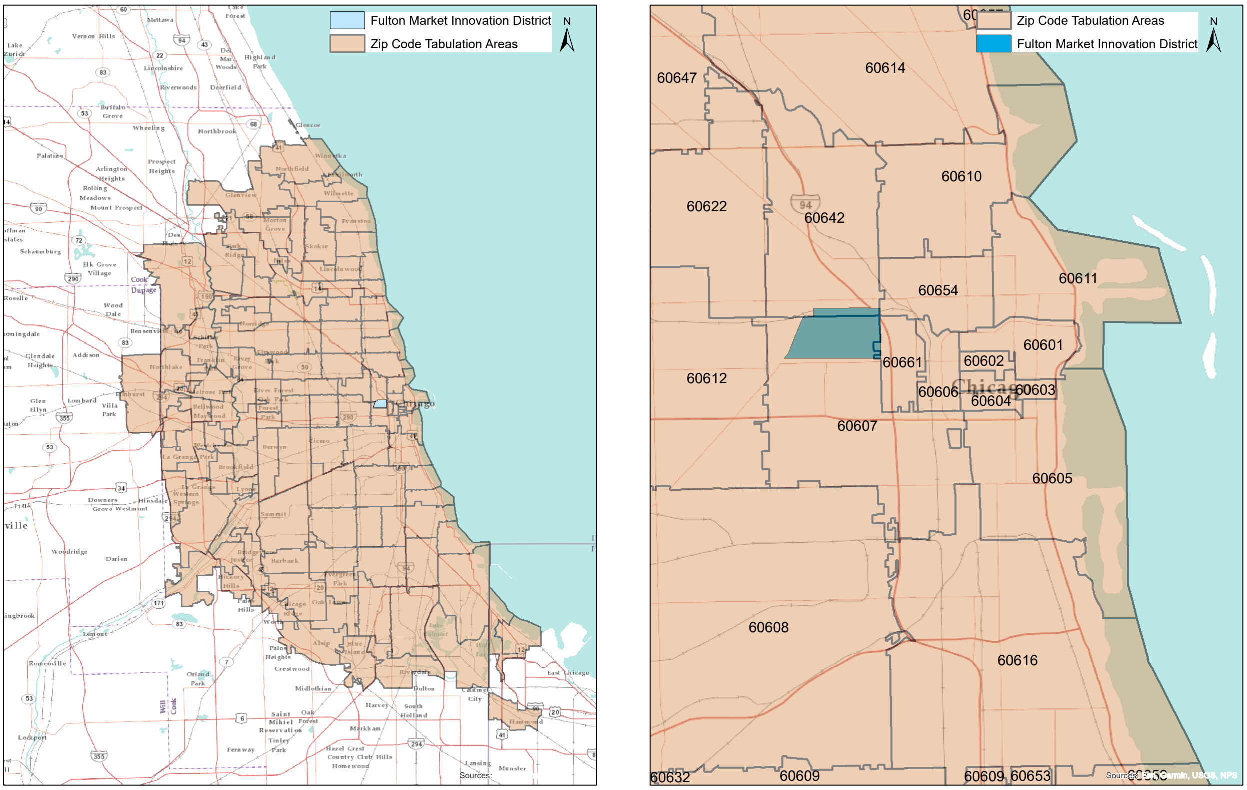
C Appendix III: Application

This appendix section complements Section 4 in the main paper.

C.1 The Chicago geography & underlying data

The geography We employ the official TIGER files for the delineation of the ZIP Code Tabulation Areas (ZCTA).[28] Our definition of the Chicago metro area is shown in Figure A1a. It includes 115 ZCTAs. Two of them, constituting East Chicago, lie in Indiana. Since we want to study a smaller neighbourhood, we have to carve out the Fulton Market Innovation District. Its official delineation is reported in City of Chicago (2014). Naturally, we adjust the size of the three affected ZCTAs accordingly (Figure A1b). This leaves us with a total of 116 non-overlapping geographical units. We simply refer to them as ZCTAs.

Figure A1: Model Geography - Chicago



(a) Study area

(b) Fulton Market Innovation District

Notes: The Fulton Market Innovation District is carved out from three ZIP Code Tabulation Areas (60607,60642, 60661).

Population For the model, we require population data for each ZCTA. The population data for 2010 are provided in the official Gazetteer files by the Census Bureau (here). They correspond exactly to the ZCTA boundaries in the TIGER files. To calculate the population data for the 'additional' Fulton Market ZCTA and adjust the figures for those ZCTAs that it consists of, we apply simple area weights.

[28] Data are provided by the Census Bureau. The official name is: 'TIGER/Line Shapefile, 2019, 2010 nation, U.S., 2010 Census 5-Digit ZIP Code Tabulation Area (ZCTA5) National'. More details can be found here.

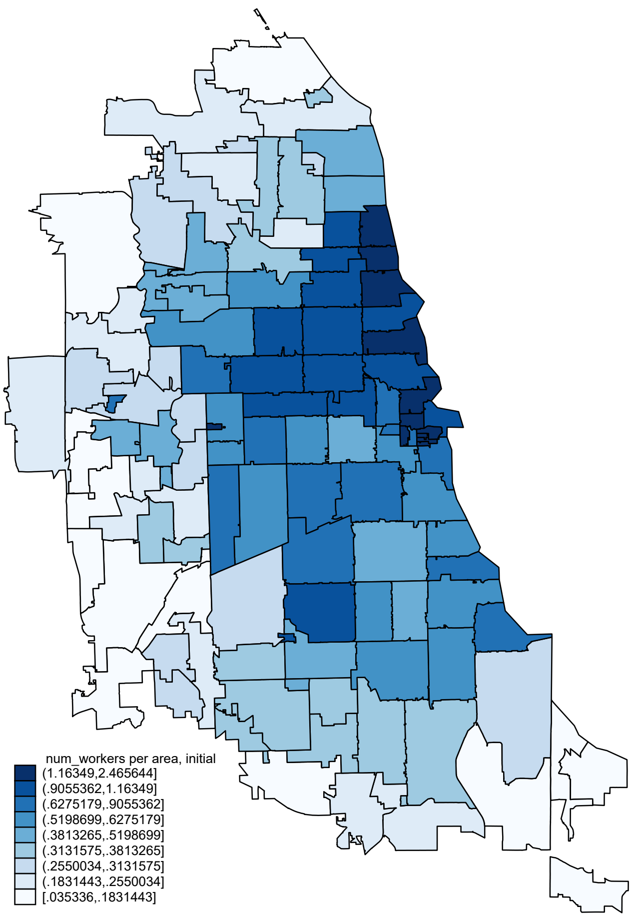
Built area We require the actual built area in each of the ZCTA in the model, not least because some ZCTAs encapsulate large parks or water bodies. Microsoft's publicized its building footprints data. These have been converted to shapefiles by Illinois floodmaps/University of Illinois Board of Trustees for Illinois (here) and by the University of Indiana (here) for Indiana. We employ these shapefiles to calculate the total built area in each of our 116 ZCTAs.

Firms, employment, and productivity We calculate the number of firms, employment, and productivity based on on the National Establishment Time Series (NETS) data (see Appendix B.1 above for a short description of the data). Note that the NETS data are point data such that we can simply extract counts and ratios for the corresponding ZCTA's using the shapefiles described above.

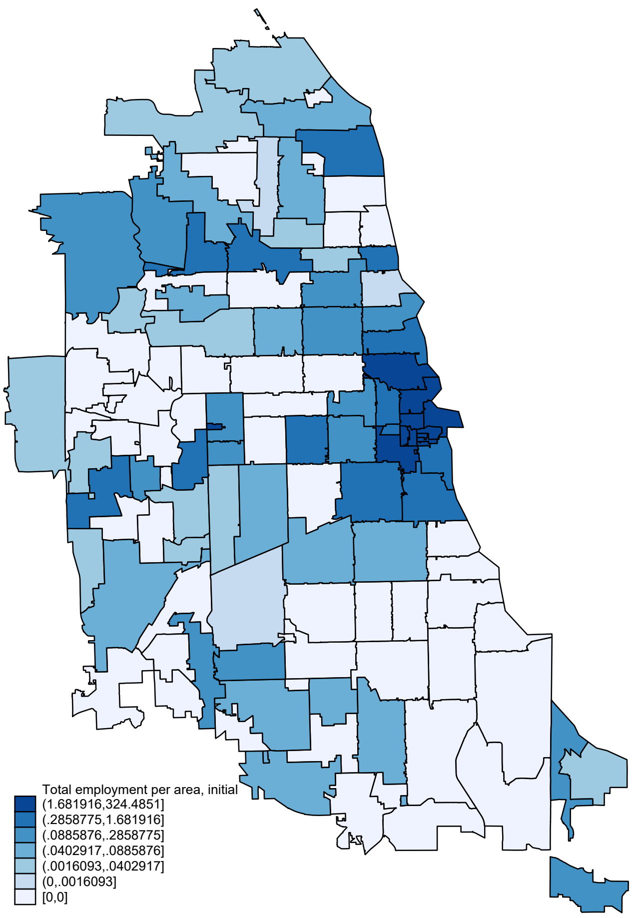
C.2 Initial equilibrium

Figure A2 provides an intuitive illustration of our stylized version of Chicago. It maps the distribution of worker densities at the residence and workplace across ZCTAs in the initial equilibrium. We plot the mean densities across all runs since the allocation changes across runs due to the randomization. In keeping with the canonical urban model, densities decrease as one moves away from the city center, with some fuzziness.

Figure A2: Worker density in initial equilibrium



(a) At residence

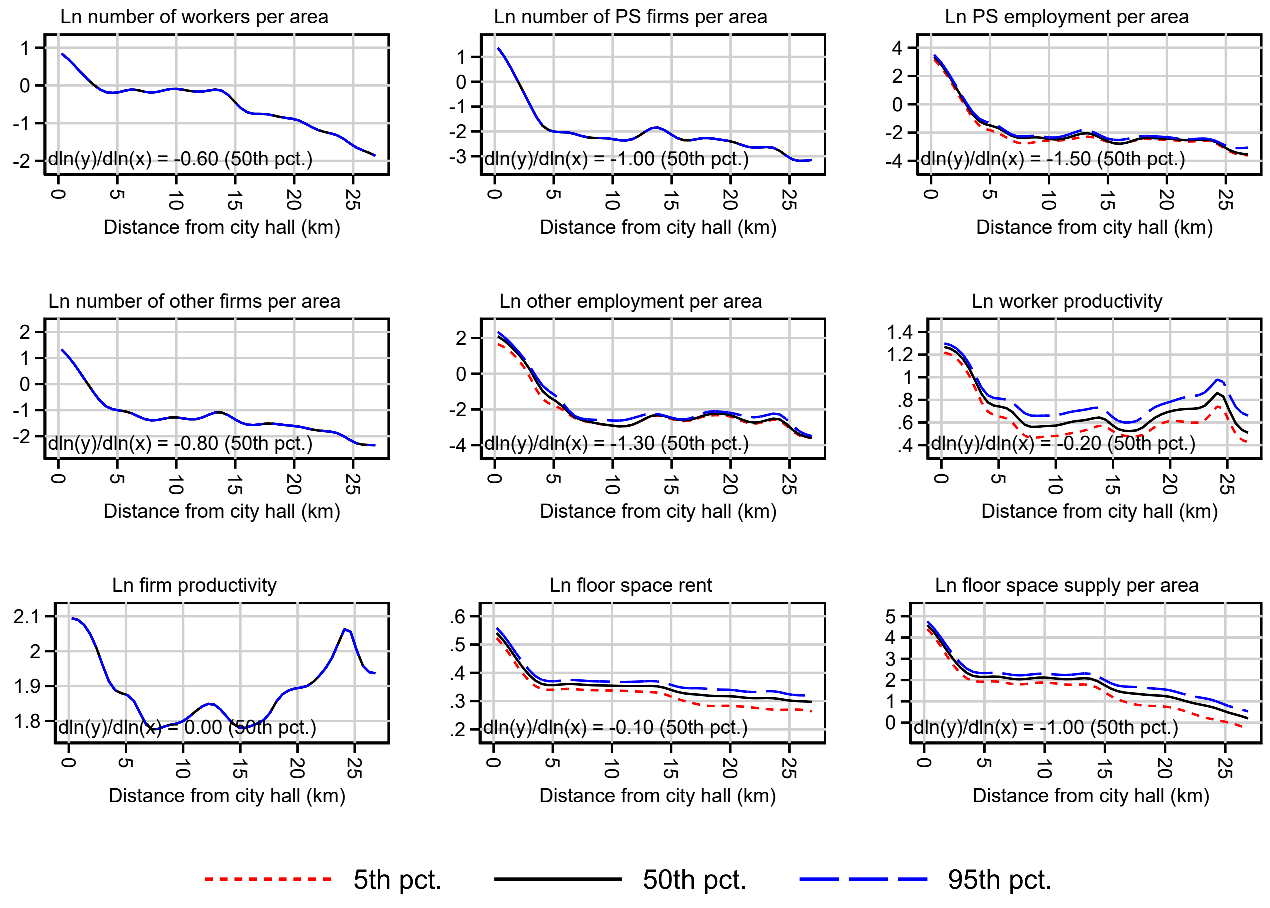


(b) At workplace

Notes: Unit of observation is ZCTA. We plot the means in the distribution of initial values across all runs.

Figure A3 summarizes the spatial distribution of economic activity in the initial equilibrium for a broader set of outcomes. Consistent with the real-world geography of monocentric cities like Chicago the density of firms and workers declines in distance from the city center, here approximated by the city hall. Since larger, more productive firms generally locate closer to the city center, the employment density gradient is steeper than the firm density gradient. The density of workers measured at the workplace declines much faster near the the center than the density of workers measured at the residence, which is consistent with the standard urban land use pattern. The firm and worker productivity gradients show a u-shaped pattern, with the peripheral peak representing a sub-center near O'Hare airport. To accommodate high worker densities near the center, buildings have to be tall. Tall buildings, in turn, require high floor space rents given construction costs that are convex in height. Even with relatively flat fundamentals, high floor space rents are sustainable, owing to due to agglomeration-induced productivity in the city center.

Figure A3: Distance gradients in initial equilibrium

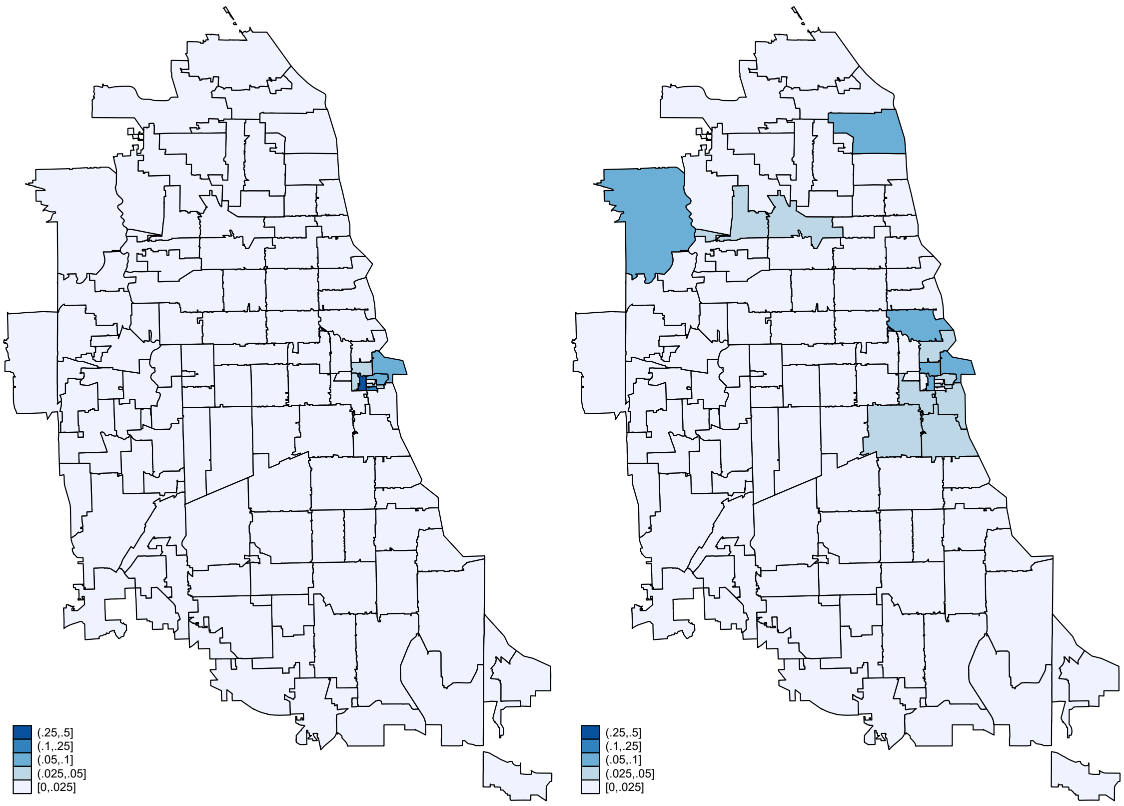


Notes: All panels show predicted values from local polynomial regressions of a model-based grid-run outcome against distance from the CBD in the initial equilibrium. The percentile refers to the distribution distribution of outcomes across run within a ZCTA.

C.3 Ex-ante firm sorting

Figure A4 shows the mean of the share of a ZCTA at total employment within a sector across all runs. Nearly 50% of prime services employment concentrated in a single ZCTA in the average run. In contrast, no ZCTA contains more than 10% of non-prime services.

Figure A4: Share of employment initial equilibrium

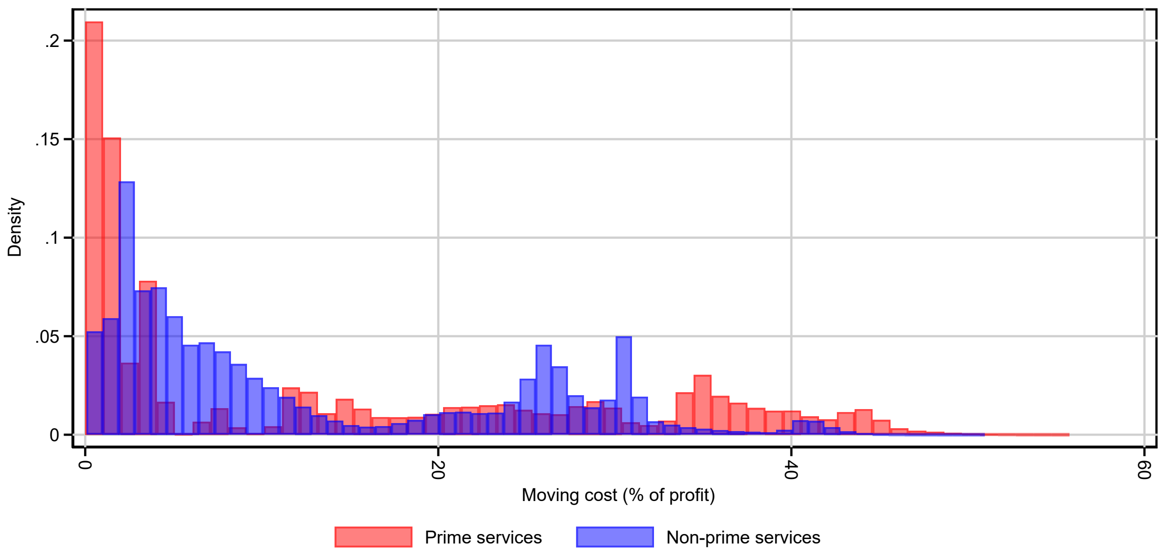


(a) Prime services (b) Non-prime services

Notes: Unit of observation is ZCTA. We plot the means in the distribution of initial values across all runs.

C.4 Moving cost

Figure A5: Local employment effect of temporary subsidy



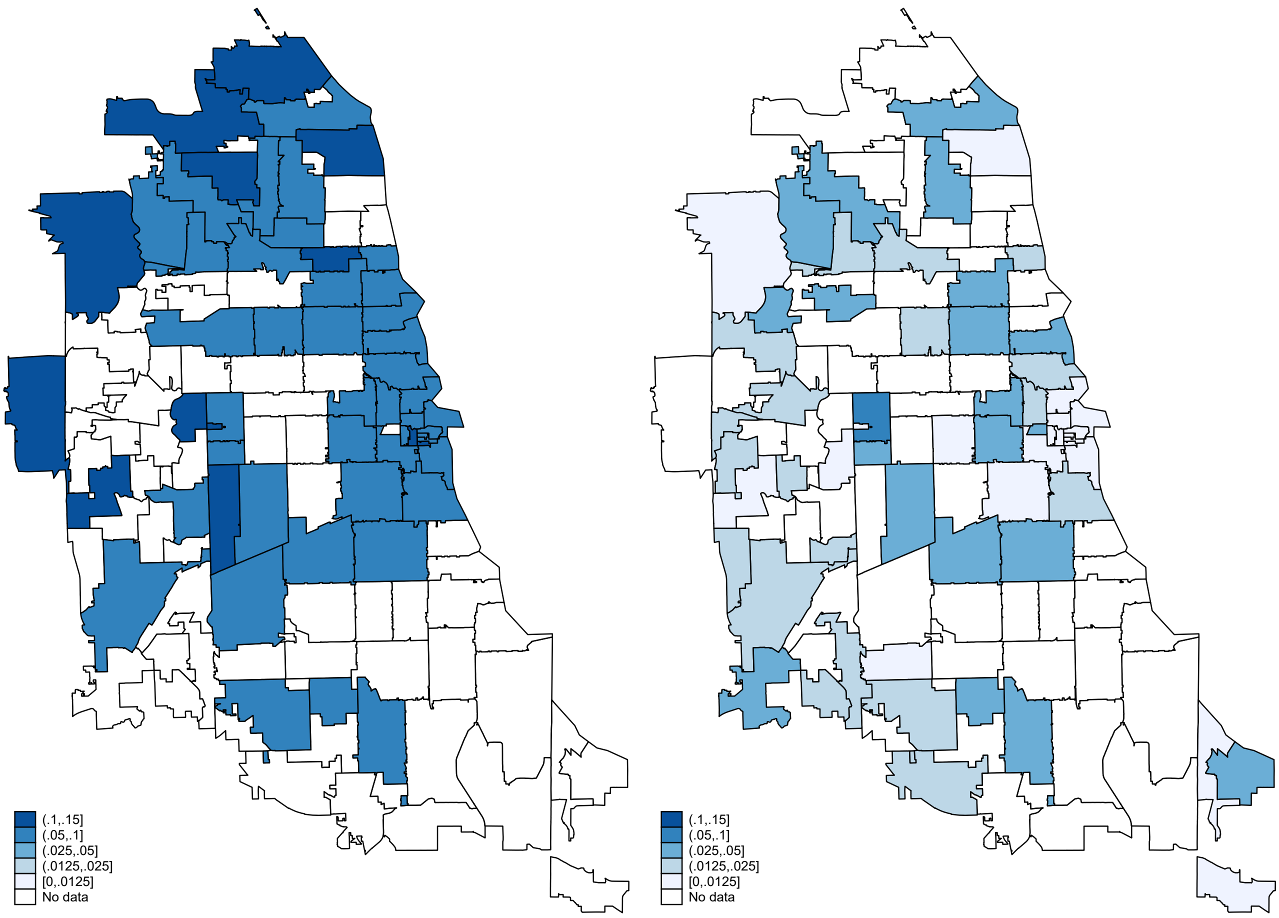
Notes: Moving cost are inverted such that each firm is indifferent between its current and best (in terms of profits) location..

Figure A5 shows the distribution of inverted moving cost by firm type. Some firms have zero moving cost because they are in the best location. Thus, they are infra-marginal with respect to the choice of the second-best location.

C.5 Infra-marginal firms

In Figure A6, we illustrate firm's barriers to moving by sector and ZCTA. We compute the barrier to moving as the difference between the the moving cost and the profit gap illustrate in Figure 5 (the vertical distance from the 45-degree line). We then compute the mean of the distribution across all firms and all runs within a ZCTA and sector. A6 confirms Figure 5 in that prime service firms have much greater barriers to moving, on average. There is, however, no strong spatial pattern in barriers to movement, although prime services in relatively cheap suburban areas in the north and west appear particularly difficult to move. A closer inspection in Figure A7 reveal that prime services firms with the greatest barriers to moving are those that benefit the most from agglomeration externalities. Fro non-prime services firms, which depend less on external returns, the relationship is the opposite.

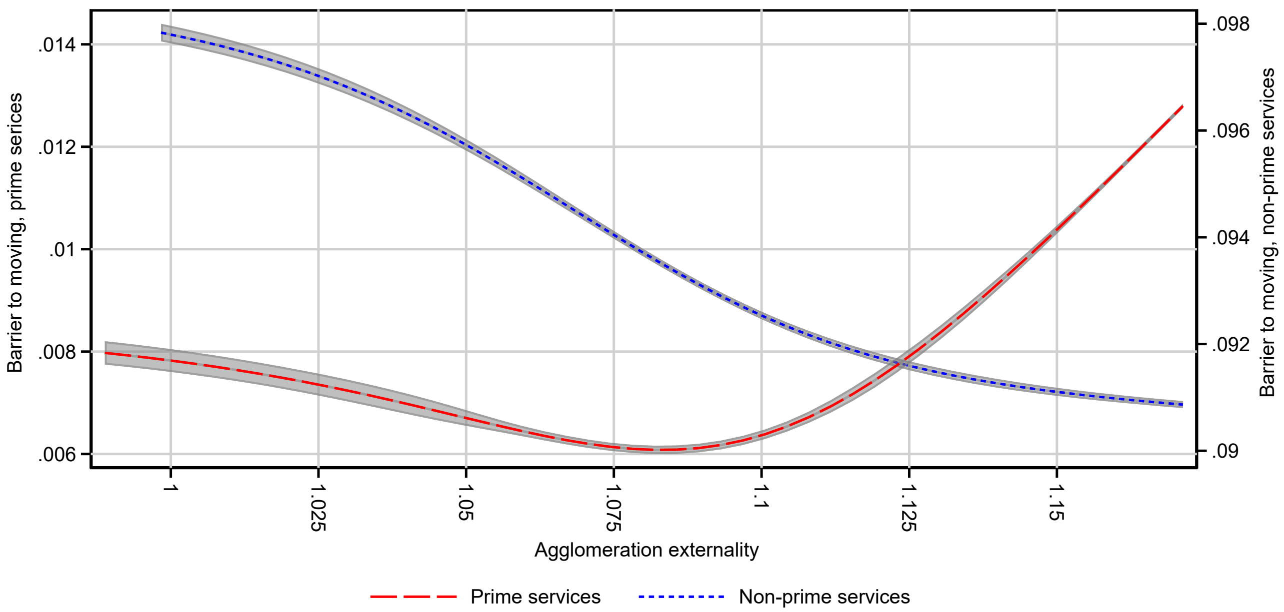
Figure A6: Barriers to moving



(a) Prime services (b) Non-prime services

Notes: Unit of observation is ZCTA. Barrier to moving is moving cost minus change in profit associated with a move to Fulton market, normalized by firms profits in the initial equilibrium. We plot the means in the distribution across all firms and all runs within a ZCTA-sector cell.

Figure A7: Barriers to moving vs. agglomeration externalities

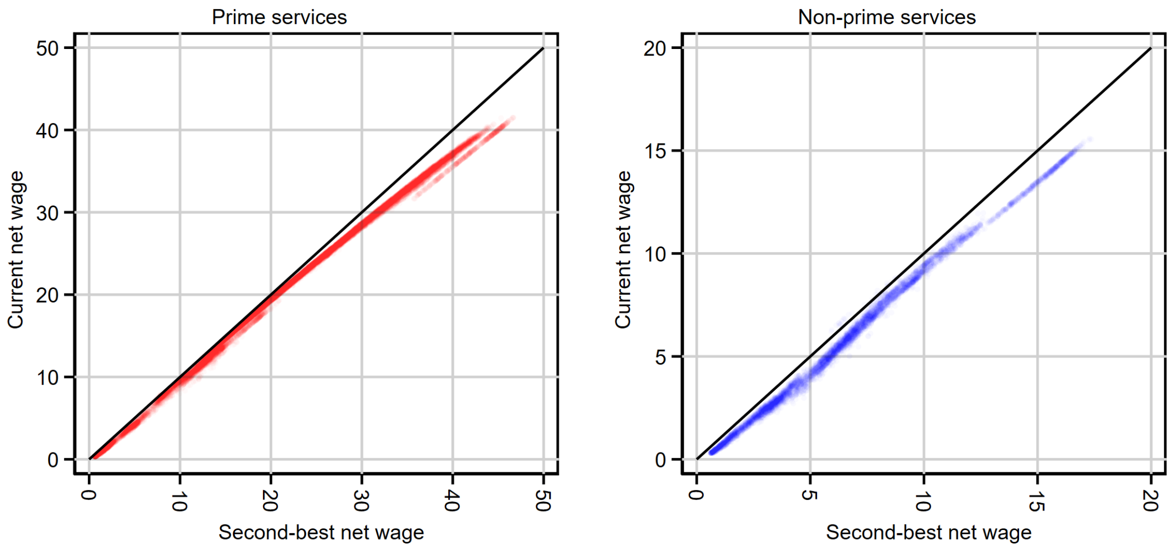


Notes: Barrier to moving is moving cost minus change in profit associated with a move to Fulton market, normalized by firms profits in the initial equilibrium. Agglomeration externality is the productivity gain derived from nearby firms. We use local polynomial regressions and a Gaussian kernel with a bandwidth of 0.05 to fit the relationship at the ZCTA-run level.

C.6 Infra-marginal workers

Figure A8 compares the net (of commuting cost) wage workers obtain in their best match to the best alternative firm. A marginal worker would be exactly on the 45-degree line. However, workers for prime services and manufacturing firms are below the 45-degree line, implying that they are infra-marginal with respect to the firm choice.

Figure A8: Inframarginal workers

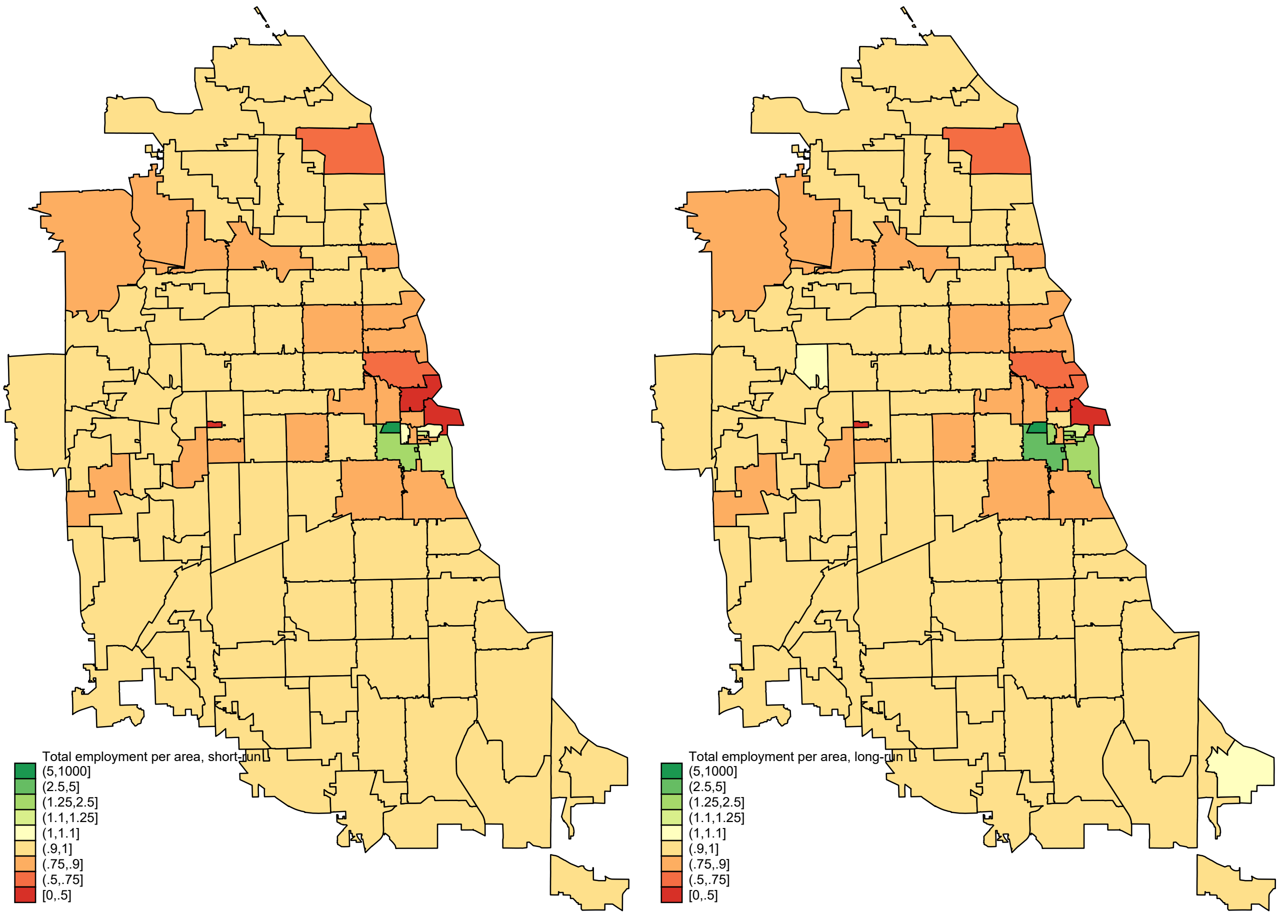


Notes: Unit of observation is worker-run in the initial equilibrium (across 25 random runs). Current net wage is the net (of commuting cost) wage plus the matching friction at the first-best firm. Second-best net wage is the net wage at the best alternative.

C.7 The ripple effect

In Figure A9, we illustrate how the distribution of employment (measured at the workplace) changes from the initial to the temporary and the final equilibrium based on all runs where a temporary subsidy, but no other policy, is implemented. Evidently, there is a relocation of employment towards Fulton Market. There are some positive spillovers to nearby areas within the range of agglomeration spillovers. Beyond the immediate surroundings, there appears to be a doughnut of areas that lose employment, suggesting that jobs relocate from nearby areas just outside the sphere of agglomeration spillovers.

Figure A9: Relative employment change from initial equilibrium

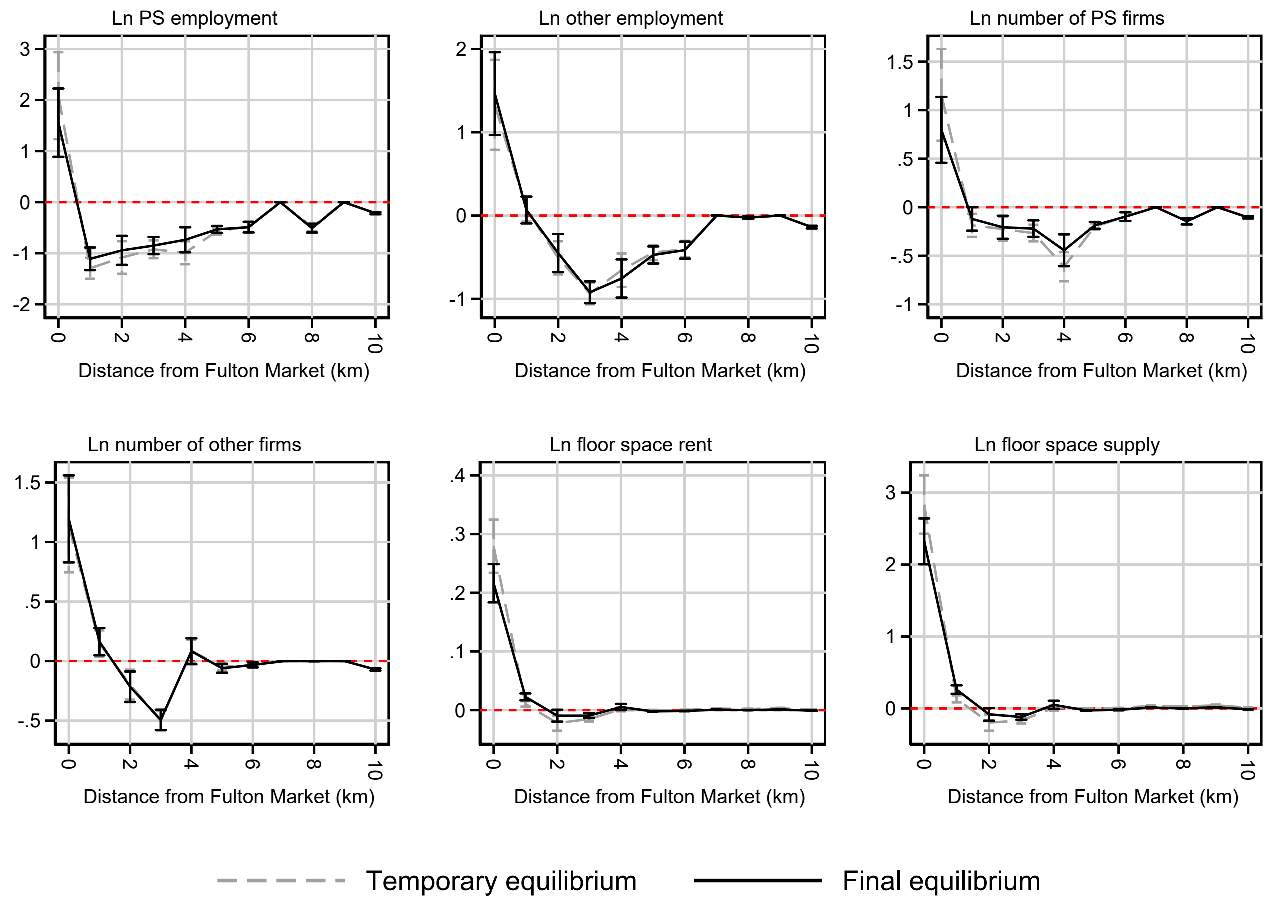


(a) To temporary equilibrium (b) To final equilibrium

Notes: Unit of observation is ZCTA. We show the ratio of 1+total employment in the temporary or final equilibrium over the same outcome in the initial equilibrium. We plot the means in the distribution of changes across all runs in which at least on of the policies is in place.

Figure A10 reveals that the ripple effect exists for prime services employment and other employment. The agglomeration shadow effect is somewhat stronger at short distances for prime services employment, likely because of the ex-ante specialization in prime services of nearby areas. Importantly, we find that for both firm types, there is also a ripple effect in the number of firms. This reveals that a fraction of the employment effect is driven by firm relocations. Figure A10 also shows that the ripple effect shows up in floor space rents and floor space supply. This is the expected result given that we rule out telecommuting and there is a fixed land supply.

Figure A10: Treatment effects in model by outcome



Notes: Treatment effects in log scale estimated from panel difference-in-difference models controlling for run-block effects, with standard errors clustered on runs. Each treatment effect is from an interaction of a distance-bin dummy and either a dummy indexing the temporary or the final equilibrium.

C.8 Complementarities

Our model simulations reveal that place-based policies can have significant effects. However, planners, in reality, operate under tight budget constraints. And even if they did not, major expenditures would have to be justifiable in social cost benefit analyses. Exploiting complementarities between different spatial policies may be key to cost efficiency. Indeed, place-based programmes often combine improvements in transport infrastructure, subsidies and some form of neighbourhood improvements as discussed in Section 3.

Investments into durable capital such as transport infrastructure, high-speed broadband, or a better urban design are particularly expensive. Given the encouraging result in Section 4.3.2, it appears worth asking the question if an accompanying temporary subsidy can significantly increase the impact of a durable investment. To answer this question, we estimate how the marginal effect of a new station and a fundamental improvement in the *final equilibrium* vary in in the level of a temporary subsidy paid in the *temporary equilibrium*. Since interaction effects can be non-linear, we estimate the marginal effects using locally-weighted regressions (Cleveland and Devlin, 1988).

$$\Delta \ln Y_{r,i=Fulton} = \gamma_s X_r + \varepsilon_r, \tag{33}$$

where Δ indicates the long-difference from the initial to the final equilibrium, $Y_{r,i=Fulton}$ is a simulated outcome for Fulton Market in run r, γ_s is an estimated marginal effect that is specific to a subsidy level V_s paid in a run $s \in R$. We estimate (33) in R locally weighted regressions in which we weigh observations observations r using the following Gaussian kernel weights:

$$w_{r,s} = \frac{1}{\kappa\sqrt{\pi}} \exp\left[-\frac{1}{2}\left(\frac{V_r - V_s}{\kappa}\right)^2\right],$$

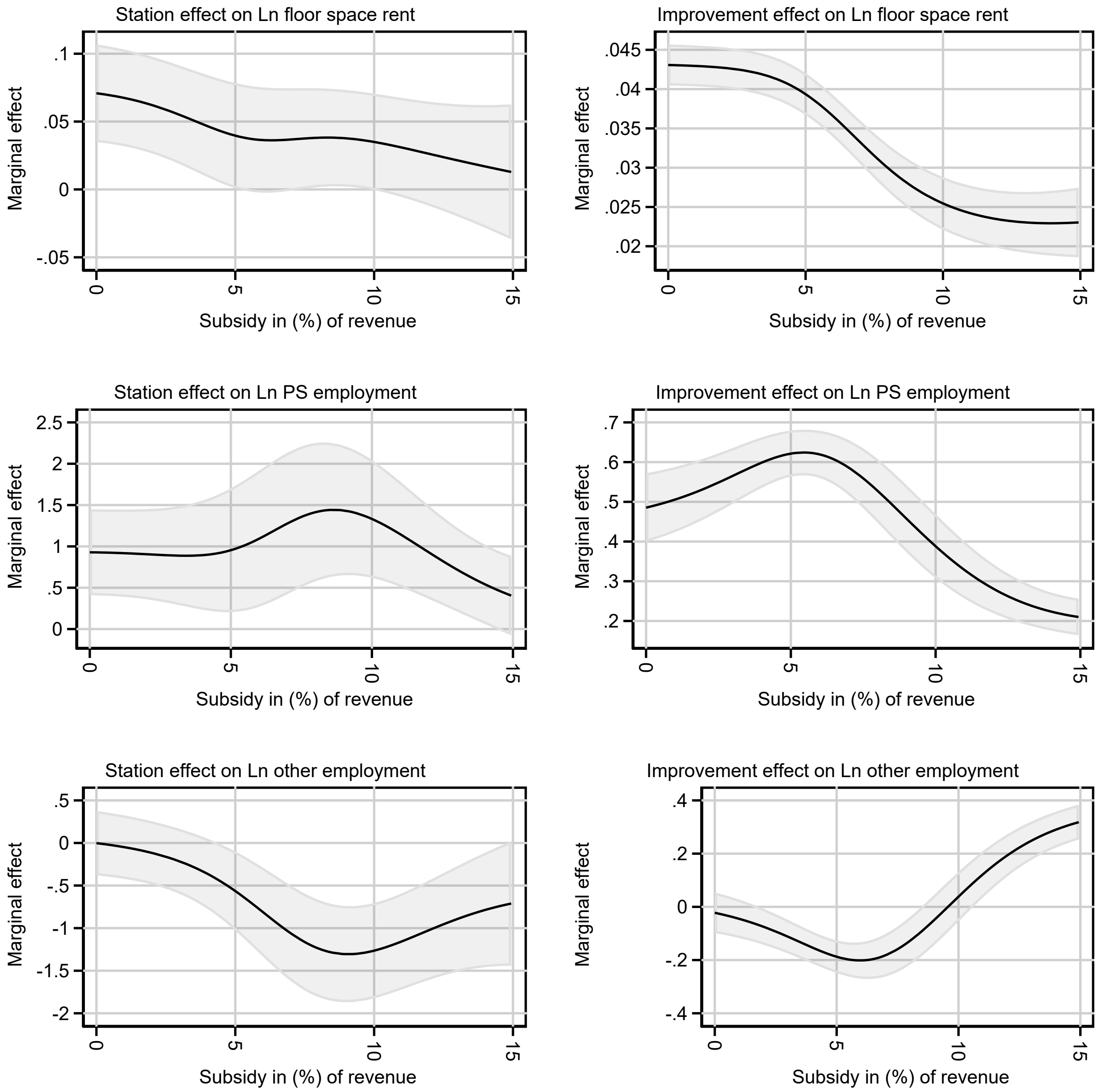
where κ is a bandwidth, which we set to twice the Siverman rule-of-thumb value since non-parametric estimates of derivatives require more smoothing.

We plot our estimates of γ_s in Figure A11. Using, once again, rent as a proxy for the level of economic activity in Fulton Market, we find that there is no complimentary between a temporary subsidy and the impact of a new station or a fundamental improvement (upper panels). While each policy has its independent positive impact, there is, if anything some cannibalization if they are implemented jointly.

If we we consider prime services specifically, however, the picture changes (middle panels). As discussed in Section 4.3.2, prime services are ex-ante concentrated in prime locations that generate external returns from which they derive sizable productivity gains. Therefore, they are difficult to move to places that do not offer similar external returns. Figure A11 suggests that a temporary subsidy, when coupled with durable capital investments, can have a synergistic impact on the emergence of a prime location. However, the choice of the subsidy level matters. For the synergies to play out, the subsidy must correspond at least to 5% of the present value of of firm revenues in order to have a positive interaction effect with a station. Beyond 10%, the complementary vanishes. At very high levels, the effect of the subsidy dominates to the point that it reduces the station effect. The interaction with a fundamental improvement follows a similar pattern, but the synergies are maximized at a lower subsidy level of slightly more than 5%. Unsurprisingly, the joint effort of kick-starting a transformation into a prime location via two complementary policies will come at the expense crowding out employment in other sectors (bottom panels).

The result in this section illustrate how policy-makers can use temporary policies to enhance the impact of policies that permanently alter locations. The main takeaway is that temporary subsidies can amplify the effects of durable investments into infrastructure and urban design when it comes to attracting firms that are otherwise difficult to move because they enjoy agglomeration economies in the laces they are rooted.

Figure A11: Interaction effects



Notes: We estimate the marginal effect of a policy (station or fundamental improvement) as a function of the subsidy rate using locally weighted regressions. We regress an outcome against a policy variable weighting all observations by the absolute deviation of the run-specific subsidy rate from a given rate, using a Gaussian Kernel and a bandwidth that is twice the Silverman rule of thumb because we estimate a derivative. .