Housing Supply Constraints and the Distribution of Economic Activity: The Case of the Twin Cities*

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Abstract

This paper analyzes the effects of city-level zoning reforms on the spatial distribution of economic activity in a metropolitan area. Using parcel-level property tax and zoning data, I use Minneapolis recent reform, which eliminated single-family zoning lots, to estimate productivity gains in the local housing development sector. Using the methodology, I find that median productivity in the housing development sector is expected to grow by 9 percent at the tract level in the city. I feed the estimated productivity gain into a quantitative spatial model of the Twin Cities, the metropolitan area which Minneapolis is a part of, to compute the effect of the reform on local wages, rents and commuting patterns. I find that housing becomes around twenty percent more affordable in Minneapolis, and rents in most other tracts fall significantly as well. As a result of people moving to Minneapolis after the zoning reform, wages in other regions of the metropolitan area increase modestly.

JEL Classification: R12, R13, R31, R52

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1 Introduction

This paper investigates general equilibrium effects across a metropolitan area when one of its cities implements a zoning reform that allows for more population density. Previous studies have shed light on the potential benefits for cities in the United States to allow more housing development when they face housing supply constraints due to zoning or other regulations. Allowing more development is expected to lower the cost of housing, attracting new residents, which in turn increases the city's workforce and output. What is usually not emphasized by the current literature is that cities in the same urban area will also be affected by the zoning reform. Here, I use theory and data on the recent zoning reform that took place in Minneapolis, MN, to quantify how the distribution of population, workplace, wages and rents rates across Twin Cities metropolitan area are impacted by the reform.

To investigate first and second order effects of a local zoning reform, I develop a quantitative spatial model of a metropolitan area. Since housing in each location are subject to different regulatory constraints, development costs vary by location. In addition, workers are exposed to location preference shocks with respect to where they want to live and work, as well as commuting cost between their residence and workplace locations. I also introduce agglomeration effects and decreasing returns to scale in the production of the consumption good.

One of the main contributions of this paper is to develop a methodology to infer productivity losses from zoning laws. I model the reform as a shifter in productivity of the housing sector. This interpretation is similar to how one can interpret changes in total factor productivity in business cycle models as changes in capacity utilization. This approach is similar to the ones found in Glaeser et al. (2005) and Herkenhoff et al. (2018), and is based on the empirical evidence such as in Albouy and Ehrlich (2018) that stricter zoning regulations inhibiting development in an area translate to higher housing costs. By allowing more population density, the reform reduces the cost of housing per unit. This is equivalent to a decrease in the marginal cost of producing housing in a location, which drives down rents.

Lower rental rates attract new residents, which move out of other locations in the metropolitan area. When they do so, due to commuting costs, this gives rise to changes in commuting patterns across the metropolitan area after the zoning reform. Not only the city experiences an influx of residents, but its share of workers with respect to the metropolitan area also increases. Since other locations in the metro area lose workers and residents, rents tend to fall in those locations and wages rise, since labor demand is downward-sloping.

I focus on the recent zoning reform that eliminated single-family housing in the city of Minneapolis and its larger impact on the Twin Cities metropolitan area. While Minneapolis is the economic center of the metro area, its population is only about ten percent of the total. Moreover, roughly twenty percent of the jobs in the Twin Cities are located in the city. Until 2019, around seventy percent of the city's residential lots were zoned as single-family units. Starting in 2020, every parcel in the city of Minneapolis admits at least three dwelling units. No the other city inside the metro area thus far has introduced a similar plan for housing reform. Because it took place recently, its effects will take some years to appear in the data. Therefore, the use of a quantitative spatial model is more suited to analyze this problem than more usual microeconometric tools in urban economics.

With the model, I back out housing productivities at the level of the Census tract before the zoning reform. These measures of housing productivity are consistent with rents imputed from data on parcel-level property values. In the model, given land and materials demanded by the housing sector, lower productivity increases the cost of supplying housing. Therefore, rezoning a location by allowing more density is equivalent to increasing the developer's productivity in that same location. Since the reform affected all the locations previously zoned as single-family in Minneapolis, productivity increases in the housing sector in many parts of the city.

To discipline this increase, I combine these measures with zoning data available at the parcel level for Minneapolis. The objective of the exercise is to quantify by how much the productivity of the housing sector changes after the restriction on single-family units is lifted across the city. I project the estimated housing productivity prior to the zoning reform on each tract's share of lots zoned as single-family units, as well as the tract's distance to the city's downtown area. Because these regressors don't vary due to endogenous choices made by the agents in the model and in the data, they are exogenous and thus can be used to inform how housing productivity will change in each location. I find that the median productivity growth is about 9 percent at the tract level.

To quantitatively assess the impact of the zoning reform, I feed the model with the counterfactual productivities and compute the new general equilibrium in the urban area. I find that the upzoning is expected to decrease the cost of housing in Minneapolis by about twenty percent, even with the additional influx of residents from other cities in the metropolitan area. Rents in most other tracts in the metro area also fall, given that part of their local population moves out to Minneapolis. The model also predicts that the policy should attract new residents and workforce to the city by five and two percent, respectively. Most of the new jobs are created in Downtown Minneapolis, which also draws workers from other tracts in the city. Because there are fewer workers in the tracts farther from the city center, downward-sloping labor demand causes wages in those locations rise. Aggregated at the city level, wages in Minneapolis fall by almost one percent.

In addition, the model predicts the second-order effects of the policy coming form the reallocation of the workforce inside the metropolitan area. Workers that move to Minneapolis come from suburban parts of the metropolitan area. Minneapolis is located in the center of the Twin Cities. This implies that the reform generates higher density in the center of the metropolitan area. Higher density is not exclusive to Minneapolis. Other tracts adjacent to Minneapolis also experience population growth. Driving this result is both the increase in wages in these locations outside Minneapolis, as well as the lower costs of commuting costs from these counties to the city.

The results described above highlight the importance of looking at zoning reforms in a broader context outside the city in which it takes place. Because individuals don't need to live and work in the same location, making housing more affordable in one location can have impacts on cities in a commuting distance to it. It also shows how heterogeneous the impacts can be across the metropolitan area.

Many cities in the United States zone most of their residential areas as single-family detached houses. They account for seventy five percent of the residential land in Los Angeles, CA; and seventy nine percent in Chicago, IL, for example. This restriction on development can impact by how much a city can attract new workers, while at the same time driving up housing costs and increasing commuting times from home to work. Many local and state governments have been pushing for zoning reforms that allow more densely packed buildings to increase housing affordability and attract new workers. In recent years, besides Minneapolis, cities such as Seattle and Portland have introduced or passed bills in an effort to reduce or eliminate neighborhoods exclusively zoned as single-family housing. The effects of such policies on neighboring cities is often left out ot the debate. Although the potential gains from upzoning may seem obvious for the city that implements the policy, less clear are the second-order effects that come from population reallocation across an urban area. This paper contributes to the zoning reform literature by highlighting such general equilibrium effects.

This paper does not deal directly with the potential distributional conflicts that may arise between renters and homeowners. Zoning rules exist in the real world sometimes for reasons that are not internalized in the model. For instance, homeowners may use zoning to intentionally reduce density around where they live, or to force higher sorting through income in their neighborhoods. They may also want to use their properties as a source of financial investment. In such case, an increase in house prices and rents due to land-use regulations is beneficial to homeowners. My model is silent about these features of the real world, choosing instead to focus on the spatial and labor market implications of the policy.

Related Literature This paper dialogues with both the literature on quantitative spatial economics and the one on the impact of zoning regulations on spatial misallocation of workers.

The field of quantitative spatial economics has been growing in the past decades, beginning with papers such as Lucas and Rossi–Hansberg (2002) and more recently synthesized in Allen and Arkolakis (2014) and Redding and Rossi-Hansberg (2017). Ahlfeldt et al. (2015) develop a quantitative model of a city building upon international trade models such as Eaton and Kortum (2002). They use the exogenous variation at the city block level of the division and reunification of Berlin to estimate and quantify the agglomeration and dispersion forces present inside a city. Tsivanidis (2020) evaluates the impact of the introduction of a faster public transportation network in a city. Heblich et al. (2020) use data on bilateral commuting flows to inform a quantitative spatial model where commuting costs change due to the introduction of passenger steam railways in 19th century London. These papers highlight the importance of separation between workplace and residence locations for workers inside modern metropolitan areas and the general equilibrium effects of changes in commuting costs across locations. Contrary to these papers, mine focus on changes in housing development costs and their general equilibrium effects.

Owens III et al. (2020) studies the urban structure of Detroit using a model with residential externalities can generate multiple equilibria at the neighborhood level. They include neighborhood-specific fixed costs in housing development to allow for empty neighborhoods in equilibrium when few residents want to live there. Differently from this paper, their model features a housing cap per neighborhood. While the paper analyzes the interaction between developer incentives and residents location preferences on the distribution of Detroit economic activity, it doesn't focus on zoning reforms. Couture et al. (2019) find that the rise in income among the rich increased demand for luxury amenities in cities, driving housing prices up in downtown areas, pricing out many low-wage workers.

The literature of land-use regulations and economics activity was recently surveyed by Glaeser and Gyourko (2018). At the city level, Kulka (2020) studies the effect of minimum lot sizes on household sorting by income. The paper quantifies the welfare effects of reducing minimum lot sizes using data from Wake County in North Carolina. The paper finds that decreasing minimum lot sizes in rich neighborhoods brings in lower-income workers. Households with at least the area's median income benefit from the policy. This paper, in contrast, focuses on zoning reforms that change the number of units that can be developed by lot, and considers the effects of the reform on seven counties in the metropolitan area. Parkhomenko (2019) and Khan (2020) study the consequences of decentralized control over land use regulations. Both papers find welfare gains in centralizing land-use regulations in higher levels of government instead of allowing them to be chosen locally. My contribution to this literature is the study of general equilibrium effects of zoning reforms across a metropolitan area.

At the national level, several papers study the role of housing supply constraints in the allocation of economic activity across space. Ganong and Shoag (2017) looks at income convergence across regions in the United States. They introduce nonhomotheticity in housing demand to capture higher housing expenditures among lower income households. They show that increases in housing supply regulations were an important factor to explain why lower wage workers are not moving to high-income places as much as they did three decades ago. Herkenhoff et al. (2018) and Hsieh and Moretti (2019) study land-use regulations and spatial misallocation in the United Sates. Both find negative impacts of land-use regulations on the United States' level of GDP per capita. In particular, Herkenhoff et al. (2018) model land-use regulations in a similar way as this paper, by interpreting housing productivity heterogeneity as exogenous differences in land use-restriction. Fajgelbaum and Gaubert (2018) study optimal spatial policies in the presence of local agglomeration and congestion forces. They find that spatial sorting by skill and wage inequality in larger cities in the U.S. is too high relative to efficient allocations. Martellini (2020) studies city-size wage premium in the United States and how relaxing housing regulation in cities affect the sorting of workers with different skill levels.

This paper is organized as follows. Section 2 discusses the Twin Cities metro area and the zoning reform implemented in Minneapolis. Section 3 presents the spatial model of the urban area. Section 4 discusses the calibration and estimation strategies used in this paper. The quantitative counterfactual analysis is presented in Section 5. Finally, Section 6 concludes.

2 The Twin Cities Metropolitan Area

The Minneapolis, Saint Paul and Bloomington Metropolitan Statistical Area, also known as the Twin Cities metropolitan area, is the only MSA in the state of Minnesota. It contains a total of seven counties in the State: Anoka, Carver, Dakota, Hennepin, Ramsey, Scott

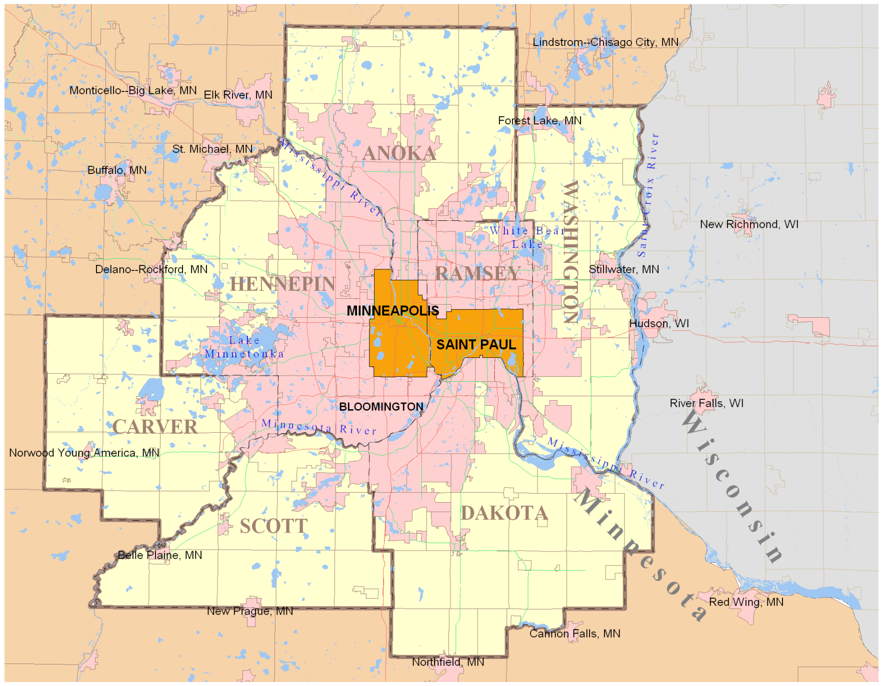


Figure 1: Map of Minneapolis, Saint Paul and Bloomington Metropropolitan Statistical Area

and Washington. The population of the metro area contains about 3.64 million people, being the third largest population-wise in the Midwest and the 16th largest metropolitan area in the United States.

The Twin Cities metro area gets its name from two neighboring cities that are considered to be the most important in the metropolitan area: Minneapolis and Saint Paul. The former is the largest and most populous city in the state, and the seat of Hennepin County, the state's most populous county. Outside Chicago, Minneapolis is the most densely populated city in the Midwest. The latter is the state's capital and located in Ramsey County, the state's most densely populated county. Figure 1 show the map of the Twin Cities metro area, with Minneapolis and St. Paul highlighted.

Even though Minneapolis is economically the most important city in the metropolitan area, it is far from concentrating the majority of its population and labor market. Table 1 shows the population and workplace shares in the Twin Cities. Minneapolis population is roughly ten percent of the metro area's population, and twenty one percent of the area's workforce works in the city. In fact, in other counties, at least twenty three percent of their own population work in the same county, highlighting that the economic activity in the metropolitan area is reasonably dispersed. Still, at least ten percent of the workforce living in each county works in Minneapolis, which suggests how important the city is for the overall metropolitan area.

	Population	Workforce	Work in same location	Work in Minneapolis
Anoka	12	7	31	18
Carver	3	2	27	10
Dakota	14	10	37	13
Hennepin*	28	35	57	21
Minneapolis	13	21	45	45
Ramsey	16	19	44	19
Scott	5	2	37	13
Washington	8	4	23	12

* Hennepin considers Hennepin County without Minneapolis

Table 1: Commuting Patterns in the Twin Cities (in %)

2.1 Zoning Reform in Minneapolis: the 2040 Plan

Until January 1st 2020, about seventy percent of Minneapolis' residential zoning was composed of neighborhoods zoned exclusively for single family detached homes. This meant that each parcel could only have a house where only one family could live in, and the house had to be surrounded by lawn, and not attached to a neighboring house. Figure 2 displays in green all the city regions zoned as single-family detached units and in blue all the other strictly residential parcels.

Starting in 2016, Minneapolis City Council proposed a twenty-year comprehensive plan to update the city's long-term plan for itself with respect to its urban landscape, economy and climate impact. The plan, named *Minneapolis 2040*, focuses on a wide variety of topics, such as land use, transportation, housing, public health, arts and culture. Of the interest to this paper is its plan to change residential zoning in the city, allowing for substantial upzoning.

The plan was approved by the city council and, effective in January 1st, 2020, the city's zoning code changed drastically. Population density in buildings in the downtown area was increased. Along important public transit routes, the city allowed for development of high density units. Nevertheless, the most substantial change regards single-family zoning. All neighborhoods until recently zoned as single family now allow for at most three dwelling units on an individual lot. This has the potential to triple the amount of housing units in most of the city.

An important outcome from this zoning reform will be how the economic activity, population distribution and local labor markets will be affected in the metropolitan area. The reform will not only affect Minneapolis, but all the surrounding cities. It is therefore important to analyze the policy change in the context of the entire metropolitan area, no

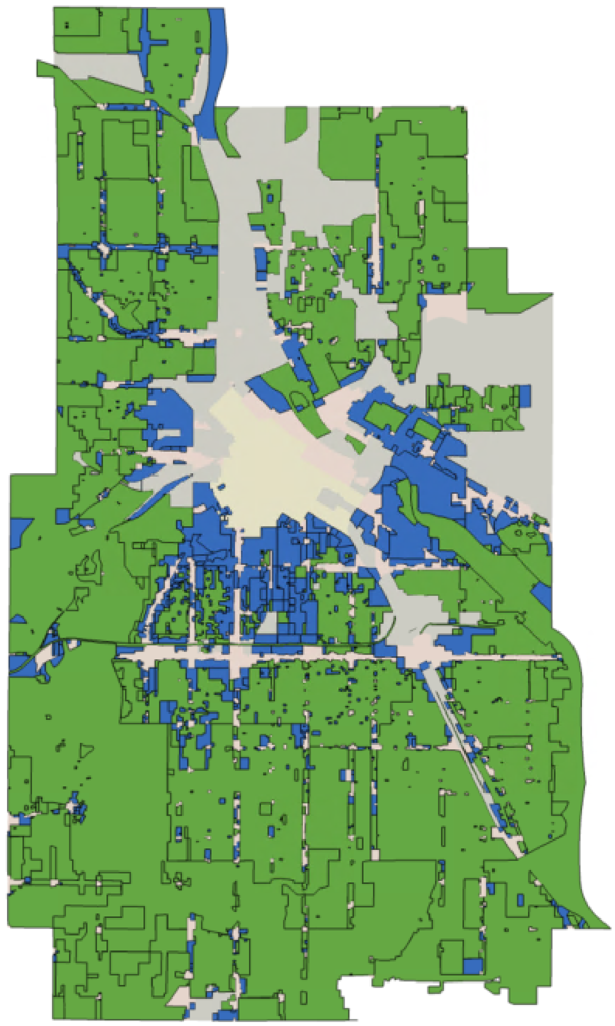


Figure 2: Residential Zoning in Minneapolis up to 2019

the city itself. We can expect workers to move in to Minneapolis as a result of an increase in housing affordability, and as a consequence more jobs in Minneapolis and locations nearby. The next section presents an urban model that allows us to make predictions of what to expect in the aftermath of such policy change.

3 Model

To quantify the general equilibrium impacts of neighborhood upzoning, I build a quantitative spatial equilibrium model of a metropolitan area. There is a finite and discrete set Ω of neighborhoods. There are four sets of agents: workers, consumption goods producers, housing producers, and absentee land and firm owners. There are $\overline{R}$ workers in the city who can live and work in distinct locations. They are indexed by a pair ij, where $i \in \Omega$ and $j \in \Omega$ correspond to their workplace and residence locations, respectively. Each location produces a homogeneous consumption good, produced by a representative firm. Housing is developed locally as well.

Worker's problem Worker values consumption of a single good, c, housing services, h, exogenous neighborhood amenities, s_j, and idiosyncratic preferences from living in location j and working in i, ϵ_{ij}. I represent commuting costs from j to i by adding a parameter $\kappa_{ij} \geq 1$. I use a Cobb-Douglas utility function to represent the worker's preferences over consumption and housing service. The worker's problem is:

$$\max_{\{c,h,i,j\}} \frac{s_j}{\kappa_{ij}} \left(\frac{c}{\alpha}\right)^{\alpha} \left(\frac{h}{1-\alpha}\right)^{1-\alpha} \epsilon_{ij} \quad \text{subject to} \quad c + r_j h = w_i$$

where w_i is the wage in workplace i and r_j is the pre-tax rental rate of a unit of housing. I assume the worker supplies inelastically one unit of labor. Denote $\hat{V}_{ij} \equiv V_{ij} \times \epsilon_{ij}$ as the counterfactual indirect utility. We can represent it as

$$\hat{V}_{ij} = \frac{w_i s_j}{\kappa_{ij} r_j^{1-\alpha}} \times \epsilon_{ij}.$$

I assume that the worker's preference over local amenities is represented by the vector ϵ_k, which is i.i.d and drawn from a Type II extreme value (Fréchet) distribution:

$$F_{ij}(\epsilon) = \exp\left(-a_{ij}\epsilon^{-\theta}\right),$$

where a_{ij} is the location-specific amenity term, $a_{ij} > 0$ and $\theta > 1$. Worker's location choices to work and live are the ones that maximize their counterfactual indirect utility.

Production in Neighborhood i Technology given by $Y_i = A_i n_i^{\beta},\ \beta \in (0,1]$. I introduce agglomeration effects: $A_i = \overline{A}_i n_i^{\eta}$. There is a homogeneous good in the city and the representative firm in each location behaves competitively. Because I allow for decreasing returns to scale in production, potential profits are claimed by absentee firm owners.

Housing Sector in j There's a representative developer that behaves competitively. Production of housing services per location is given by the Cobb-Douglas function $G_j L_j^{\phi} M_j^{1-\phi}$, where L_j is the quantity of land, M_j is materials and G_j is local productivity of the housing sector. The price of materials is given by ι and is homogeneous across locations. Land prices are region-specific, and given by p_j. The developer's problem is given by

$$\max_{L,M}\ r_j G_j L^{\phi} M^{1-\phi} - \iota M - p_j L$$

The price of land is derived from an ad-hoc supply function given by $p_j = \left(H_j/L_j\right)^{\overline{\psi}}$, $\overline{\psi} > 0$. Restrictions on development in each neighborhood are interpreted as changes in G_j. Land rents from the housing sector go to absentee land owners.

3.1 Equilibrium

3.1.1 Firm's Optimization

Local wages are given by input's marginal productivity: $w_i = \beta \overline{A}_i n_i^{\beta+\eta-1}$.

3.1.2 Worker's Location Choice

Appendix C presents the detailed derivations of the equilibrium conditions of the model. From the law of large numbers, the fraction of workers living in location j and working in neighborhood i, π_{ij}, can be represented by:

$$\pi_{ij} \propto a_{ij} \left(\kappa_{ij} r_j^{(1-\alpha)}\right)^{-\theta} \left(w_i s_j\right)^{\theta}.$$

The equation above is a gravity equation for commuting, describing overall patterns of workers' workplace and location choices. It shows that the fraction of the population living in j and working in i is increasing in the location taste shock a_{ij}, wages paid in i, and amenities in j. Similarly, the share of workers is decreasing in costly it is to commute between the pair ij, how high are residential taxes in j, and rent (r_j). Sensitivity to these variables depend on shape parameter θ of location taste

Summing across residential locations, we get the share of workers in location i:

$$\pi_i = \sum_{j' \in \Omega} \pi_{ij'} = \lambda \sum_{j' \in \Omega} a_{ij'} V_{ij'}^{\theta}.$$

The share of workers living in location j is given by:

$$\pi_j = \sum_{i' \in \Omega} \pi_{i'j} = \lambda \sum_{i' \in \Omega} a_{i'j} V_{i'j}^{\theta}.$$

Equivalently, the share of workers living in location j that commute to i to work is given by:

$$\pi_{i|j} = \frac{a_{ij} V_{ij}^{\theta}}{\sum_{i' \in \Omega} a_{i'j} V_{i'j}^{\theta}} = \frac{a_{ij} \left(\frac{w_i}{\kappa_{ij}}\right)^{\theta}}{\sum_{i' \in \Omega} a_{i'j} \left(\frac{w_{i'}}{\kappa_{i'j}}\right)^{\theta}}.$$

3.1.3 Rental Markets

Housing Demand Housing demand for residents in j commuting to i is given by

$$h_{ij} = (1-\alpha) \frac{w_i}{r_j}.$$

Let $\overline{w}_j = \sum_{i \in \Omega} \pi_{i|j} w_i$. Aggregating across working neighborhoods, we get the total housing demand, H_j^d:

$$H_j^d = R_j (1-\alpha) \frac{\overline{w}_j}{r_j}.$$

Housing Supply Using the first-order condition for materials in the housing developer problem, the zero profit condition, and the land supply equation, we get the relationship between housing rent, housing demand and land

$$r_j = \rho_j \left(\frac{H_j}{L_j}\right)^{\psi}, \ \psi \equiv \phi \times \overline{\psi}.$$

Housing Equilibrium From the housing demand equation, the relationship between the number of residents on that neighborhood and total housing demanded is given by

$$H_j = \left[\frac{(1-\alpha)\overline{w}_j}{\rho_j} R_j L_j^{\psi}\right]^{\frac{1}{\psi}}.$$

3.1.4 Labor Market Clearing

In each region, the amount of labor demanded for each skill has to be equal to the amount of labor supplied. The latter is determined by the amount of workers living in each region that commutes to a specific neighborhood to work:

$$n_i = \sum_{j\in\Omega} \pi_{i|j} R_j \quad \forall i \in \Omega.$$

Definition 1. *Given a geography $\{\overline{H}_i\}_{i\in\Omega}$, the equilibrium of the model is defined by a set of location observables such that:*

1. *Given the number of workers in each location, the quantity produced in each region is given by the location's production function.*

$$Y_i = A_i n_i^{\beta}.$$

2. *Given wages, rents and commuting costs, the share of workers commuting from neighborhood j to i follows, $\forall\, i, j \in \Omega$:*

$$\pi_{ij} = \lambda a_{ij} \kappa_{ij}^{-\theta} r_j^{-\theta(1-\alpha)} \left(w_i s_j - r_j \overline{h}\right)^{\theta}.$$

3. *Given wages, number of residents, zoning restrictions and rents, housing supply is given by*

$$H_j = \left[\frac{(1-\alpha)\overline{w}_j}{\rho_j} R_j L_j^{\psi}\right]^{\frac{1}{\psi}}.$$

4. *Given wages, commuting costs, outside-option utility, location preferences, and housing supply, the number of residents in each location follows:*

$$R_j = \sum_{i\in\Omega} \pi_{ij} \overline{R}, \quad \forall j \in \Omega.$$

5. *Given wages, zoning restrictions and fixed costs, rents are given by*

$$r_j = \rho_j \left(\frac{H_j}{L_j} \right)^{\psi}.$$

6. *Given the number of residents in each neighborhood and commuting probabilities, the labor supply in each neighborhood is given by*

$$n_i = \sum_{j \in \Omega} \pi_{ij} \overline{R}.$$

7. *Given the number of workers in each location, local output and prices, firms' first-order conditions determine the wages.*

$$w_i = \beta \overline{A}_i n_i^{\beta+\eta-1}.$$

3.2 The Effects of Changing Zoning Regulations

In this model, changes in local zoning regulations are interpreted as changes in local productivity of the housing sector, G_j. Therefore, if a neighborhood is allowed to build more housing units per parcel or decreases the minimum lot size of each parcel, the model captures these changes as increases in G_j.

In the model, the mechanism works as follows. When housing productivity goes up in a location, housing can be produced at lower marginal cost. This has the effect of lowering rents for those already residing in location, which is equivalent to a movement along the housing demand curve. As a consequence, residents already living in the location demand more housing. Residential amenities may move upwards or downwards, depending on how much rent and housing demand respond to the change.

The second-order effects of the policy change come from the general equilibrium structure of the model. Due to lower rents in the location, residents from other locations move, which is equivalent to a shift in the housing demand curve. As an effect, rents goes up. The population and rent increases unequivocally increases taxes collected in the location, making room for a higher supply of neighborhood amenities, which again reinforces the incentives to move in. Because of commuting costs, some of the new residents change their workplace location to work nearby. The possibility of a downward-sloping labor demand curve if $\beta + \eta < 1$, wages tend to fall locally and rise in locations farther away that lost residents and workers.

Other general equilibrium effects are also present. For instance, locations that lose workers producing the consumption good due to the spatial reallocation of residents will observe an increase in local wages, an unintended effect of the policy. In addition, because of commuting costs, locations close to the one which implemented the policy may observe an increase in population as well. These results highlight the importance of analyzing changes in housing policies in a broader context other than the city or county that implemented them if there are nearby regions that will be directly impacted by it.

4 Data and Calibration

In this section, I apply the model presented above to analyze the impact of allowing for upzoning in the Minneapolis 2040 plan. I set up the model so that it replicates patterns of the data on the Twin Cities before January 1st 2020, when the new zoning rule took place. That is, the model is supposed to replicate the commuting patterns, local population and labor force, rents and wages across the Twin Cities metro area when most of the residential part of Minneapolis was zoned as single-family, detached, units. I then use the data on higher-density areas to inform the change in housing productivity we should expect to happen when the neighborhoods are allowed to upzone.

The seven counties comprising the Twin Cities metro area contain 702 census tracts in total. Of these tracts, 113 are in the city of Minneapolis. The objective is to use data at the tract level on housing, population, wages, commuting patterns, property taxes, rents and commuting costs to inform the model.

4.1 Mapping to Data

The main data sources used for the empirical exercise are the following. I use data on wages, residents and workers from the Longitudinal Origin-Destination Employment Statistics (LODES). They provide origin and destination data on the population of workers that at the Census block level, as well as data on wages by brackets. I use Minnesota Geospatial Commons' Metro Regional Parcel Dataset, which compiles parcel-level data for all the seven counties, as the source for zoning and rents in each Census tract. Monthly rent is calculated using the following formula:

$$\frac{r}{1+r}\frac{\text{Average Building Value/Units}}{1-(1+r)^{-T}}, \quad r = 0.06/12,\ T = 20 \times 12$$

Commuting costs are calculated using IRS estimate of \$0.58 cents per mile. I compute distance across locations in miles using Google Maps. I use local, county-level property tax rates to calibrate τ_j. Productivity can be obtained by inverting the model to match wages.

4.2 Gravity Equation

Following Monte, Redding and Rossi-Hansberg (2016), I regress commuting patterns on commuting costs, origin and destination fixed effects to identify the shape parameter of the Frechet distribution, θ:

$$\log\left(\frac{\pi_{ij}}{\pi_{jj}}\right) = -\theta \log\left(\frac{\kappa_{ij}}{\kappa_{jj}}\right) + \mu_i + \mu_j + u_{ij}$$

The estimated θ was 4.4, within the bounds of the literature. For location taste shock, I use $a_{ij} = \pi_{ij}\left(\frac{\kappa_{ij}}{w_i}\right)^{\theta}$.

4.2.1 Identification of Housing Productivity Parameters

From the equilibrium conditions of the model, I can write the housing productivity parameter for every tract as proportional to MSA-wide parameters from the model, rent, population density (residents per square mile) and the data equivalent of $\overline{w}_j$:

$$G_j = \text{constant} \times \text{Rent}_j^{-1}\left\{\left(\frac{\text{Residents}_j}{\text{Land}_j}\right)\left[(1-\alpha)\frac{\text{Average Wage}_j}{\text{Rent}_j}\right]\right\}^{\psi}.$$

Given parameters and data, I can recover G_j. Heuristically, given rents and square mileage, a higher number of residents imply that housing can be built at a lower marginal cost, suggesting higher productivity of the housing sector. Similarly, given wages and population density, a higher value for rent implies that housing is developed at a higher marginal cost, which suggests lower productivity of the housing sector in the particular tract. As Figure 3 shows, the model-inferred productivities are associated with higher density in each Census tract, in line with what is expected in this framework.

In addition, pinning down G_j is crucial for the model to reproduce rents as seen in data. As Figure 4 shows, if I assume that G_j is equal to one in every tract, the model does a much worse job at matching rent rates at the tract level compared to the specification in which I allow tract-level productivity differences for the housing sector.

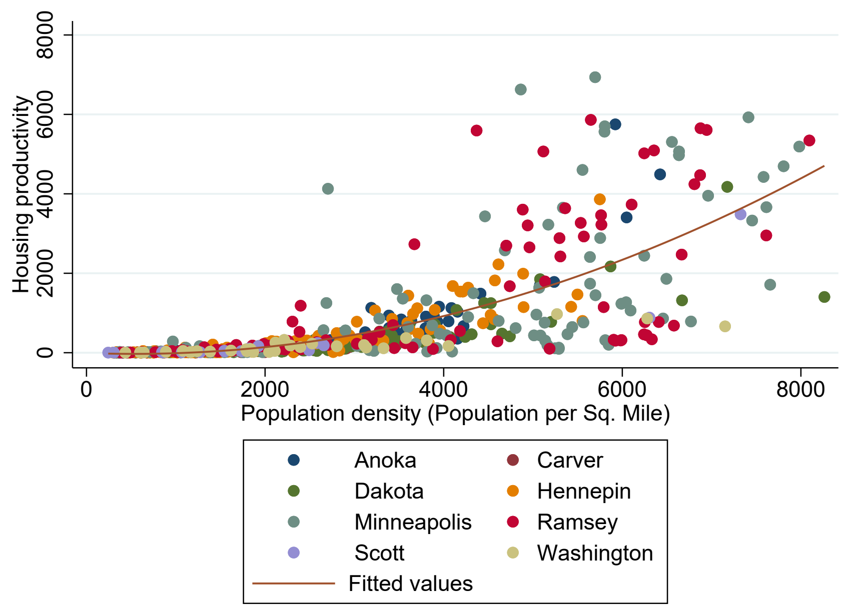


Figure 3: Relationship Between Model-Based Housing Productivity and Population Density

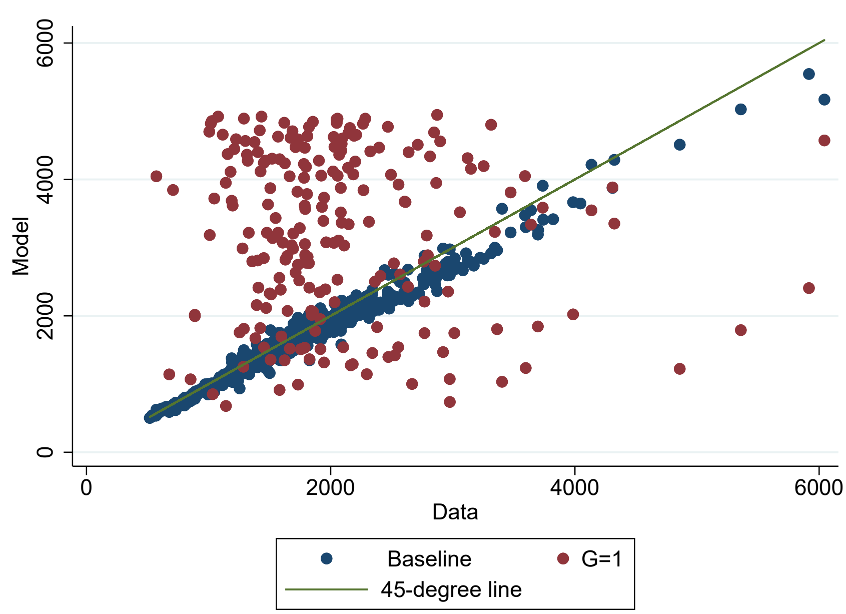


Figure 4: Model Fit–Baseline vs. Homogeneous Productivity in Housing Sector

4.2.2 Identification of Amenities

From the location choice problem faced by the workers, we have the following system of equations. For every $j \in \Omega$:

$$\pi_j = \lambda \sum_{i \in \Omega} a_{ij} \left(\kappa_{ij} r_j^{(1-\alpha)}\right)^{-\theta} \left(w_i s_j\right)^{\theta}.$$

From the data and estimation of θ, we know $\pi_j, a_{ij}, \kappa_{ij}, w_i, r_j \ \forall i, j \in \Omega$. The objective is to find the set of s_j that solves the system above. Note that the right-hand side of the equation is homogeneous of degree zero with respect to the vector of amenities, since $\lambda^{-1} = \sum_{i,j \in \Omega} a_{ij} \left(\kappa_{ij} r_j^{(1-\alpha)}\right)^{-\theta} \left(w_i s_j\right)^{\theta}$. Therefore, it is sufficient to normalize λ to one and solve for s_j such that it matches the distribution of residents in each Census tract:

$$s_j = \frac{\pi_j r_j^{\theta(1-\alpha)}}{\sum_{i \in j} a_{ij} \left(\kappa_{ij}\right)^{-\theta} \left(w_i\right)^{\theta}}.$$

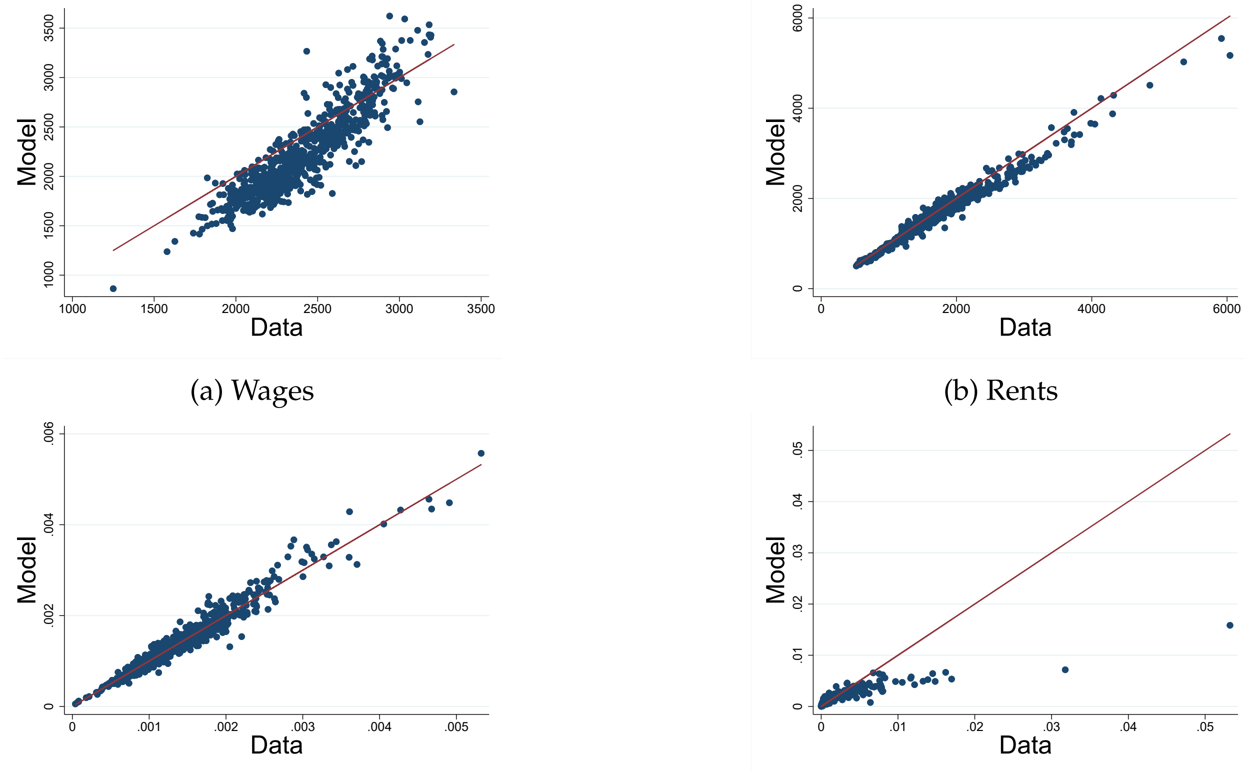
4.3 Calibration of MSA-Wide Parameters

The values I pick for the parameters on the worker and consumption goods production side come from standard sources in the literature. The value of the Cobb-Douglas parameter α is set to 0.76, as in Davis and Ortalo-Magne (2011). The value for β comes from Ahlfeldt et al. (2015) and is set to 0.8, while η is set to 0.06 as in Ciccone and Hall (1996). The parameters $\overline{\psi}$ and ϕ governing the local housing development come from Severen (2018). Table 2 in Appendix B summarizes the parameters used in the model.

5 Quantitative Exercise: The Impact of Zoning Reform

Using the estimated model, I evaluate the impact of Minneapolis zoning reform on the equilibrium prices and allocations across the metropolitan area. In my model, a zoning reform allowing for more density is interpreted as an increase in G_j. This modeling choice assumes that allowing for the development of more housing units in a single plot of land reduces the cost per unit. Appendix A provides a microfoundation as to why a zoning reform allowing for more units can be interpreted as an increase in tract-level productivity.

The model is able to replicate the data well, as Figure 5 shows. In particular, the model can match very well the distribution of rent values and population shares across the Twin Cities metropolitan area. The model can also successfully replicate the wage dispersion



(a) Wages (b) Rents

(c) Population Share (d) Worker Share

Figure 5: Model Fit
Scatter Plots and Trend Lines

as seen in the data. Where the model does not do as well is at matching the upper end of the distribution of the share of workers working at each location. Figure 5d shows that the model underpredicts the share of workers in tracts where they are more highly concentrated.

5.1 Zoning Reform in the Model

In this section, I discuss how I incorporate the zoning reform on G_j. The *Minneapolis 2040* plan rezoned the parcels previously marked as single family to allow for up to three dwelling units. As shown in Figure 2, single-family units constituted the vast majority of the residential parcels in the city. In my quantitative exercise, this reform is interpreted as an increase in G_j for the locations j that are affected by the reform.

To perform the exercise, I match the Census tracts with Minneapolis zoning map prior to the housing reform. The mapping between Census tracts and municipal zoning is not one-to-one, which means that zoning is not homogeneous for each tract. Restricting attention to residential zoning, about ten percent were fully zoned as single family. Figure

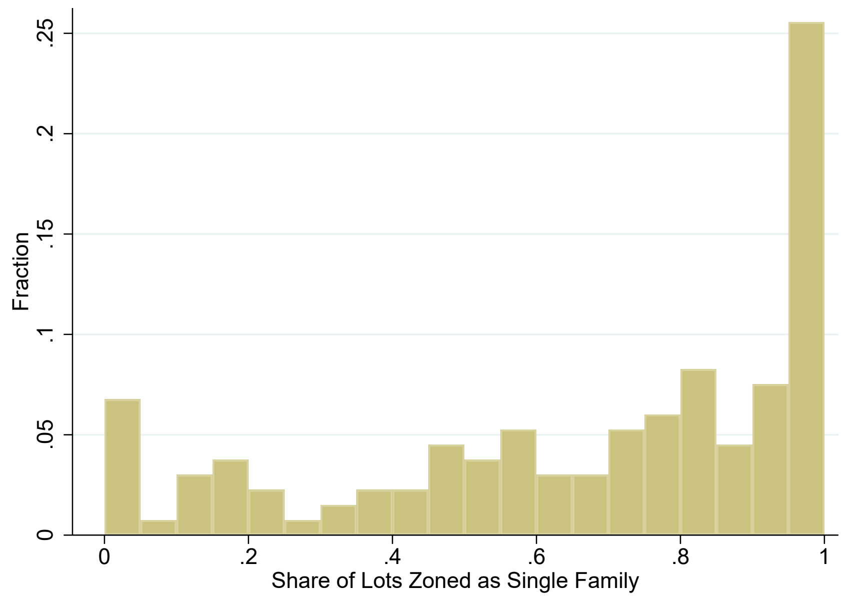


Figure 6: Distribution of Tracts by Share of Lots Zoned as Single Family

6 plots the histogram of the distribution of tracts by share of lots zoned as single family.

I then implement the following empirical strategy: with the estimated housing productivities G_j, I run the following regression:

$$G_j = \beta_0 + \beta_1 \times \text{share of single-family units}_j + \beta_2 \times dist_j + \beta_3 \times dist_j^2 + u_j,$$

where share of single-family units$_j$ represents the tract's share of residential parcels previously zoned as single family, and $dist_j$ is the tract j's distance, in miles, to the most central tract in Downtown Minneapolis. When I run this regression, the coefficient for share of single-family units and distance squared are negative. The fact that the former is negative serves as validation of the model.

I discipline the G_j's after policy in the following way: I use estimated equation above and set the share of single-family units to the minimum that I observe in the data, which is 0.03%. Because $\beta_1 < 0$ and different tracts have different shares of parcels zoned as single family, housing productivity will increase more in the tracts with higher initial shares of single-family units. Moreover, since the share comes from the zoning code, not de facto development, this method ensures that the productivity increase I introduce in the model primitives are exogenous. In addition, the inclusion of the quadratic polynomial form for distance allows my counterfactual housing productivities to increase more in tracts that are closer to Downtown Minneapolis. Adding this quadratic form in the construction of the counterfactual assumes that building at a lower marginal cost is likely increase

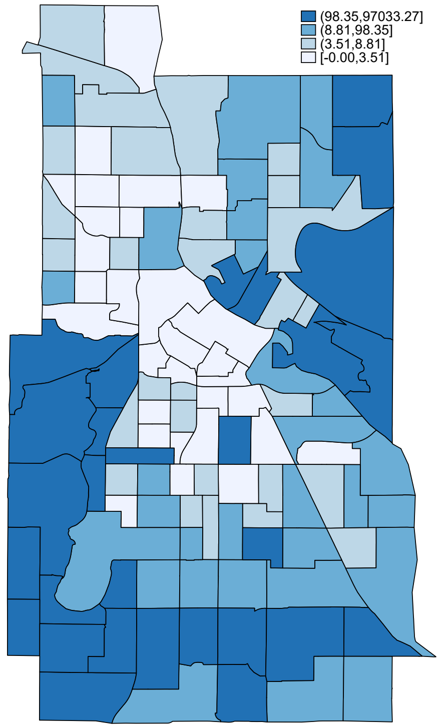


Figure 7: Distribution of Housing Productivity Growth in Minneapolis Before and After The Zoning Reform

in places that are already close to dense locations. Using the methodology, I find that median productivity in the housing development sector is expected to grow by 9 percent in the city. Still, productivity grows much more in some tracts, particularly the ones in the southwest region of the city, which is populated by big single-family homes. Figure 7 shows the change in the distribution of housing productivities inside Minneapolis.

5.2 Results

I now present the results of the quantitative exercise where I interpret the zoning reform in Minneapolis as a change in the productivity of the housing development sector. Figure 8 shows the impact of upzoning on rents. Overall, rent falls about 25 percent in Minneapolis. At the same time, population increases by about 4.6 percent in the city, as shown in Figure 9. Due to population reallocation, rents fall in other locations. The effects of the housing reform on rents is heterogeneous across tracts. As Figure 10 shows, this is true even for tracts outside Minneapolis. This highlights the importance of taking these general equilibrium effects across the metropolitan area: a decrease in marginal cost of producing housing in Minneapolis attracts workers to the city. This affects these workers' workplace decision, which consequently affects wages. In turn, wages and rents in other

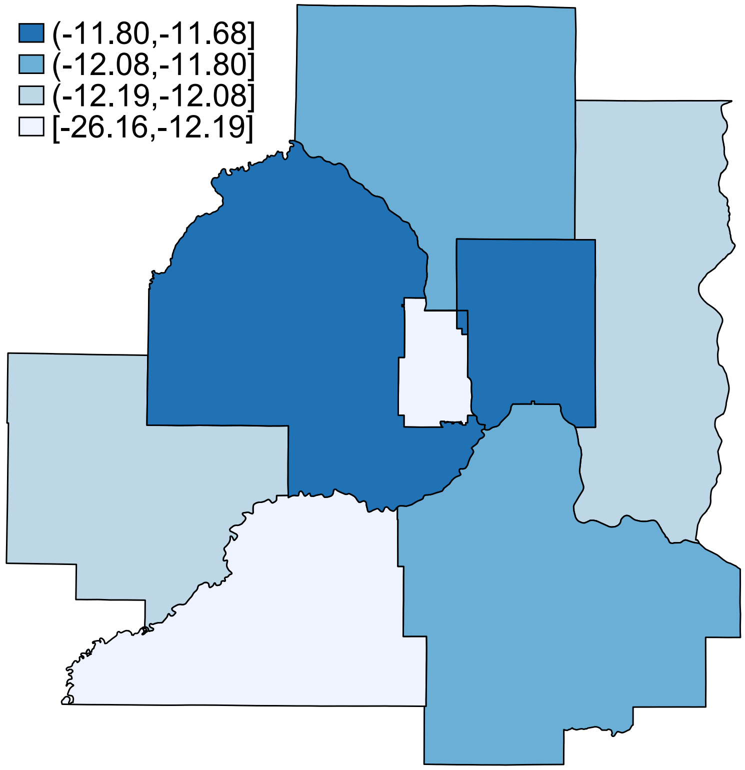


Figure 8: Impact on Rents

locations also respond to this migration decision, which further generates other migration decisions in other locations in the metropolitan area as well.

Inside Minneapolis, the change in rents is negatively correlated with the population changes, as reflected in Figure 11. Many tracts experience a large inflow of residents, but still experience a drop in rents. As Figure 12 suggests, the mechanism explaining this large influx couples with rent drops in many tracts is largely explained by the negative association between the variation in rents and the tract's pre-policy share of lots zoned as single-family units. Intuitively, since these tracts are now allowed to develop more housing units per lot due to the zoning reform, they can supply more housing to residents at a substantially lower cost. Finally, the drop in rents is also negatively associated with the tract's distance to Downtown Minneapolis.

Upzoning in Minneapolis also has effects on wages across the metropolitan area. Figure 14 presents the predicted wage changes from the baseline resulting from the upzoning. At the aggregate level, wages rise in all counties, as well as in Minneapolis. Wages rise the most in Hennepin County, where they rise by about 0.42 percent. As Figure 15 shows, the wage increases outside Minneapolis are explained by a significant drop in the number of agents working in those locations.

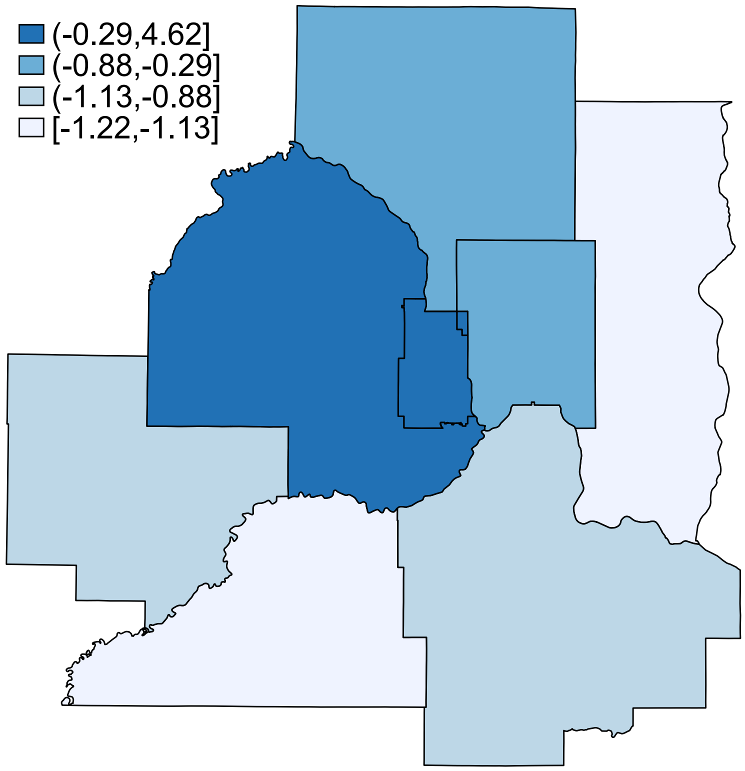


Figure 9: Impact on Distribution of Population

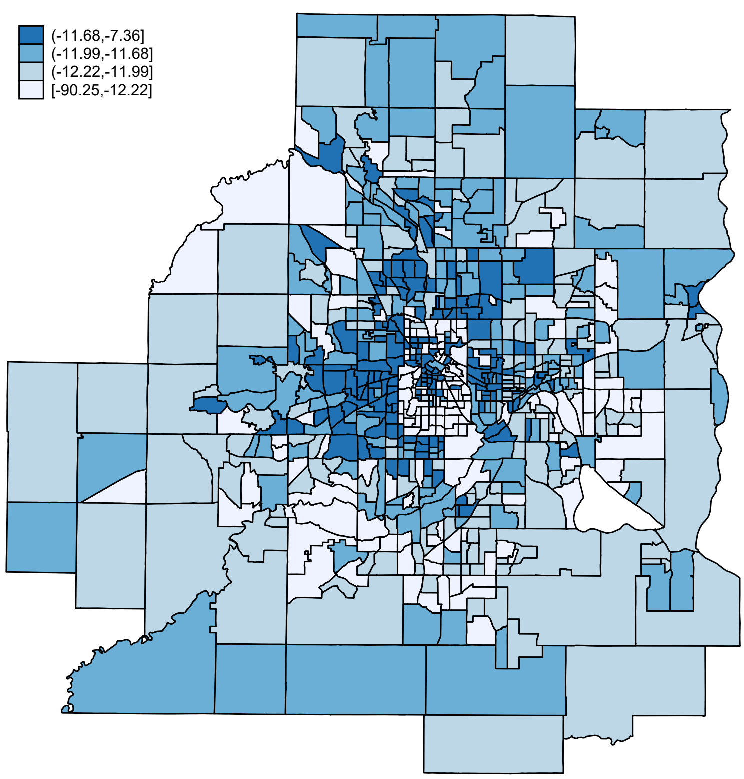


Figure 10: Impact on Rents–Tract Level

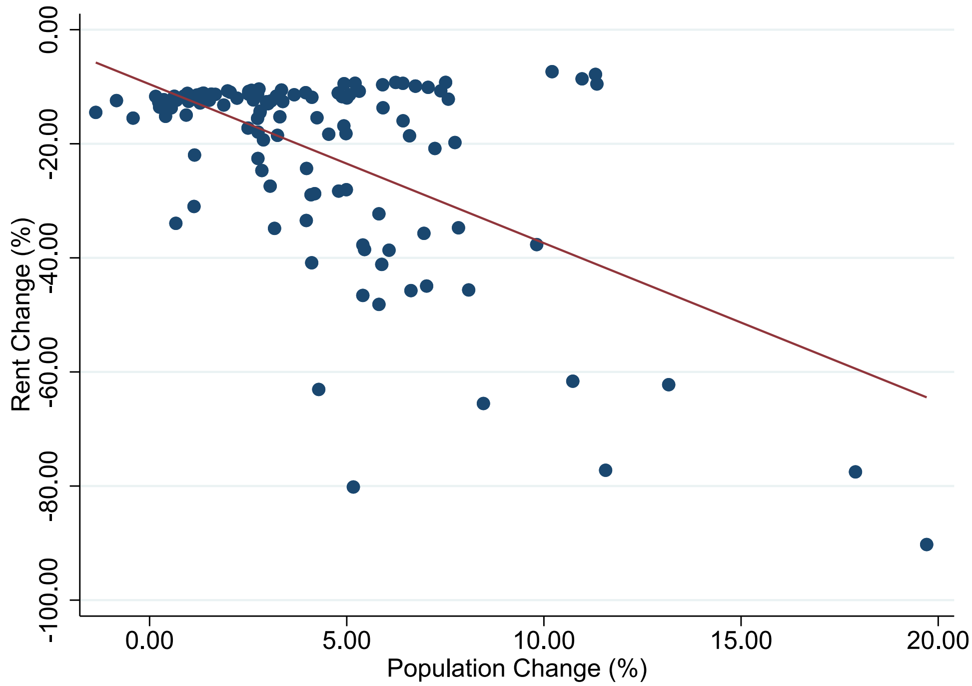


Figure 11: Relationship Between Population and Rent Changes
Scatter Plot and Trend Line

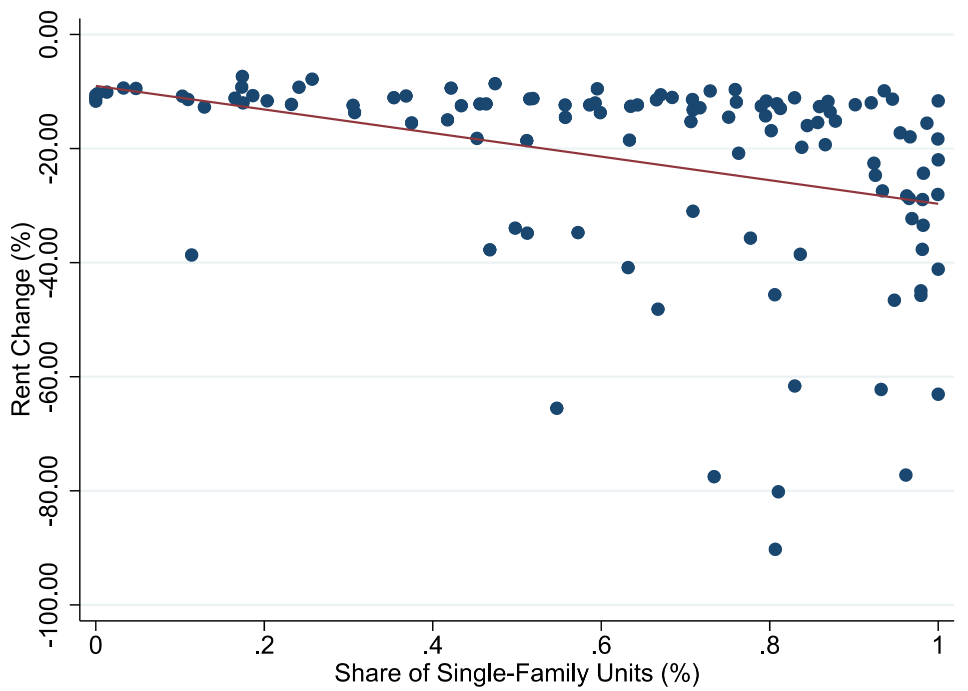


Figure 12: Relationship Between Rent Change and Share of Single-Family Units
Scatter Plot and Trend Line

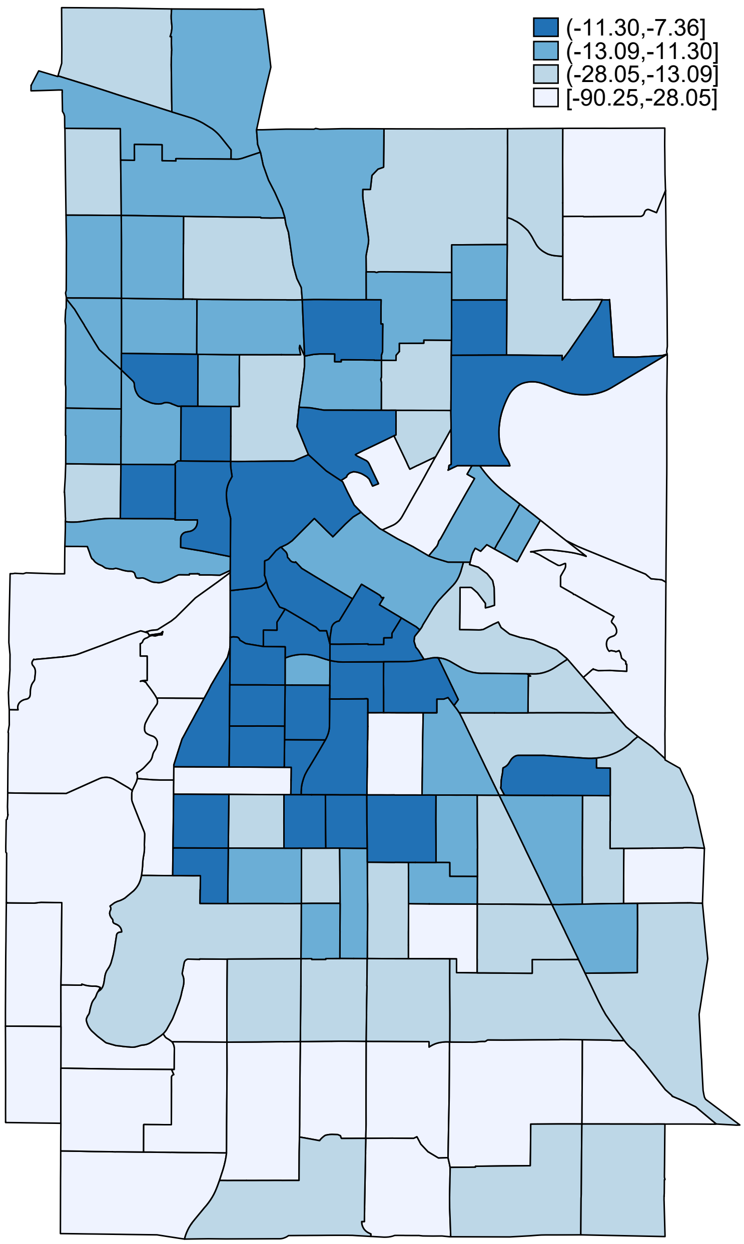


Figure 13: Effect of Housing Reform on Rents: Minneapolis

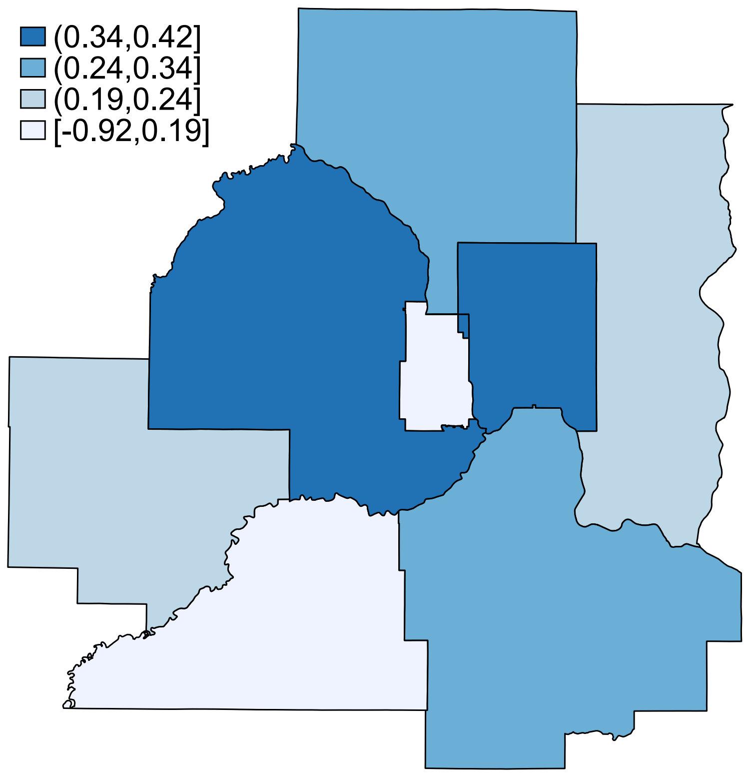


Figure 14: Impact on Wages

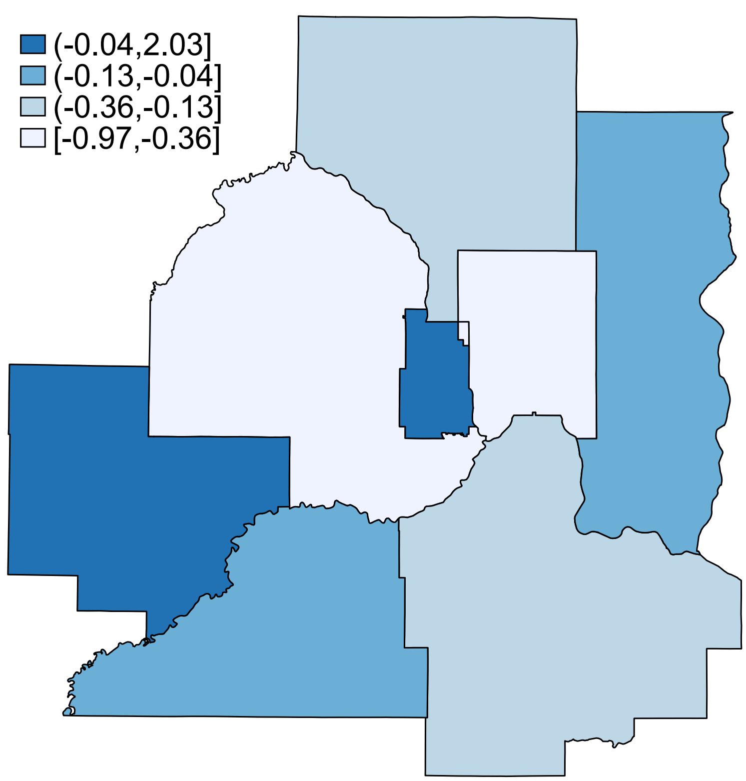


Figure 15: Impact on Distribution of Workers

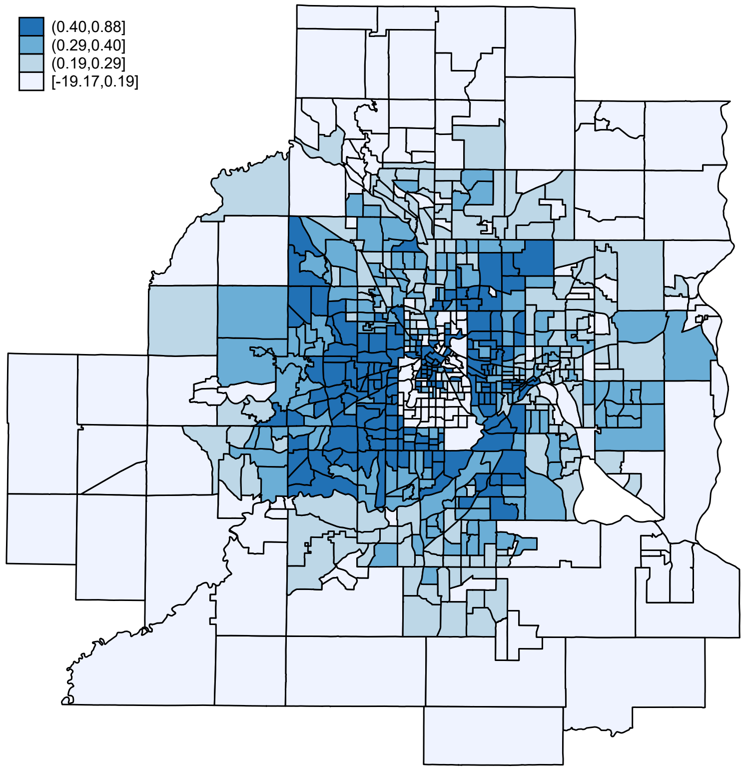


Figure 16: Impact on Wages: Tract Level

Looking at the results at the tract level allows us to inspect the mechanism more carefully. As Figure 16 shows, while wages increase in most tracts, many of them experience a wage drop. Figure 17 shows the reallocation of workers across the metro area. In addition, Figure 18 shows that the model implies that workers reallocate outside of Downtown Minneapolis, located in the center of the city, to tracts in the southwest and northeast parts of the city. Two forces are at play here. First, the parameters for the production function show that labor demand is downward sloping. Therefore, less workers in Downtown Minneapolis implies higher wages for the workers that keep working in the city center, even in the presence of agglomeration effects. Finally, because many agents decide to move to Minneapolis to reside in the areas mostly affected by to the zoning reform, as shown in Figure 19, many decide to work close by since commuting costs are lower. Further, the estimated set of location pair preferences from the Frechet distribution, a_{ij}, capture a strong preference for workers who live in Minneapolis to work around where they live.

Finally, we can look at the effects of the housing reform on productivity across the Twin Cities. Figure 20 plots the changes in productivity as a result of worker reallocation. The majority of the productivity gains occur in the tracts outside of downtown Minneapo-

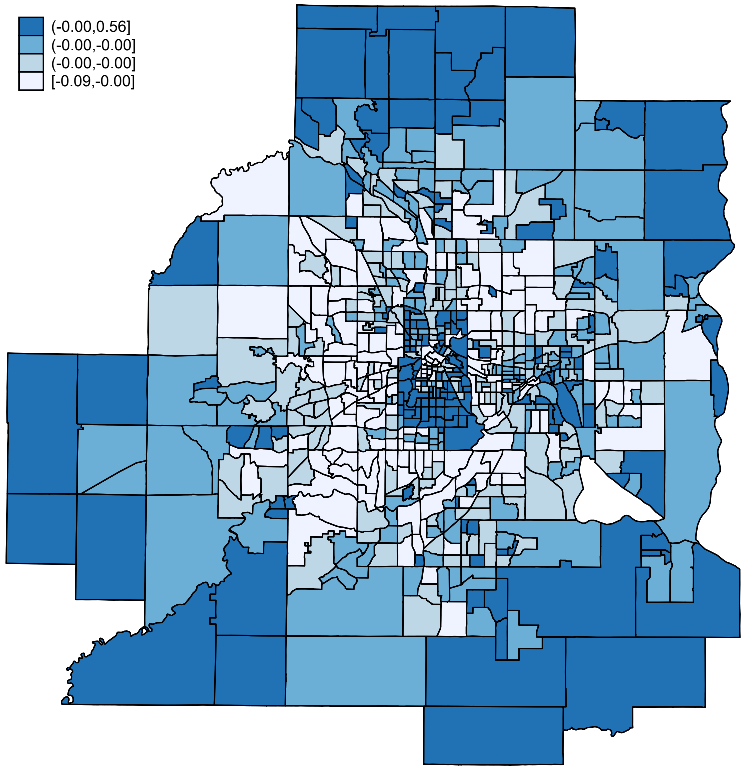


Figure 17: Impact on Distribution of Workers: Tract Level

lis, which is highlighted in Figure 21. Driving this result is the increase in workers in those locations, which induces agglomeration effects that increase productivity in those tracts.

6 Conclusion

In this paper, I analyzed the general equilibrium effects of upzoning in a city from the perspective of the metropolitan area. I built a spatial model with heterogeneous locations, amenities, productivities, agglomeration and congestion forces, and commuting to quantify the impact of the policy. Local housing policies affect the equilibrium outcomes not only of the city that implements the aforementioned policy, but also of the ones directly connected to it in the greater urban area.

I find quantitatively important effects throughout the metropolitan area. Housing becomes more affordable in the desired location, but this effect also spills over most of other counties as well. At the same time, I find that upzoning is likely to attract more workers, but at the cost of lowering wages due the increase in labor supply locally. In general, the whole metropolitan area benefits from the policy, not just the city which implemented the policy.

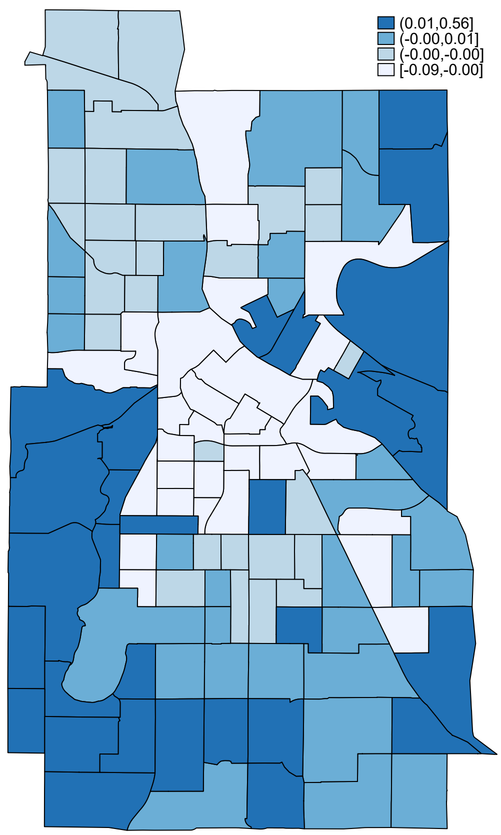


Figure 18: Distribution of Workers: Tract Level (Minneapolis)

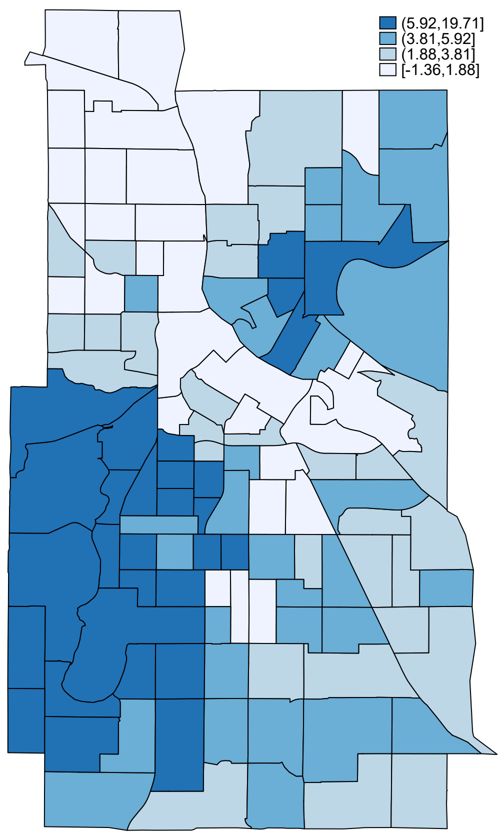


Figure 19: Impact on Distribution of Population: Tract Level (Minneapolis)

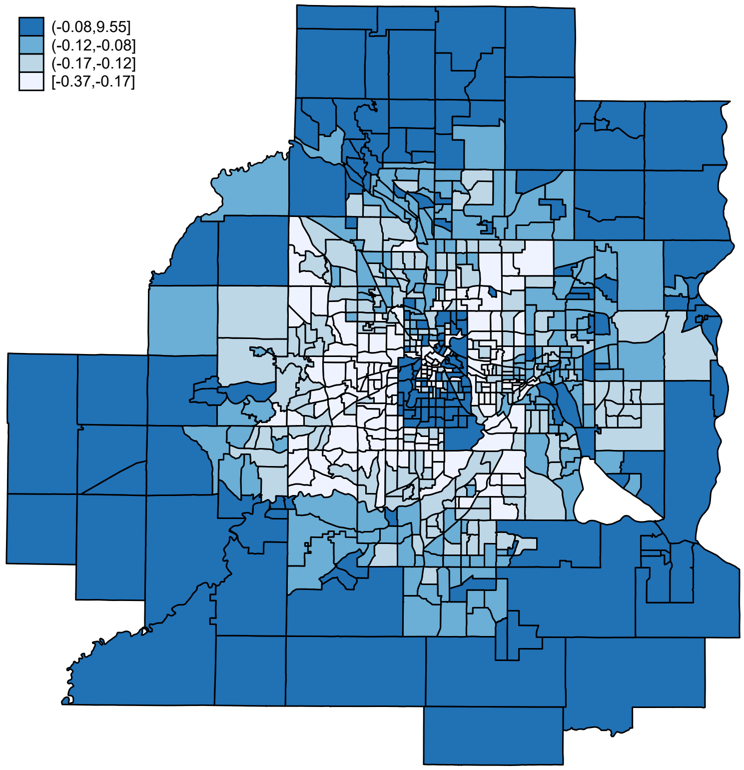


Figure 20: Impact on Productivity: Tract Level

The results from this paper highlight the importance of analyzing housing reforms in the perspective of a larger metropolitan area. They may have unexpected benefits and losses to nearby cities that could potentially be taken into account when discussing housing policies.

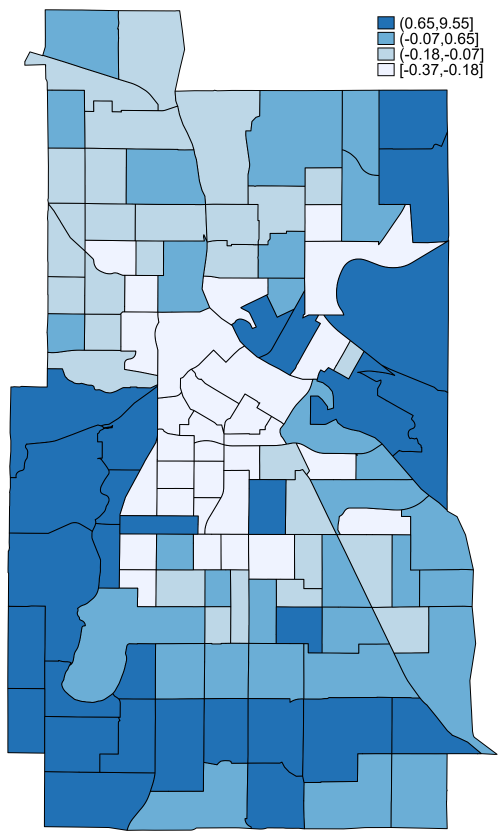


Figure 21: Impact on Productivity: Tract Level (Minneapolis)

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Appendix

A Tract-Level Housing Productivity and Zoning Reform

Suppose there's a developer that wants to build in a parcel with land size L_i in location j. They combine L_i with materials M_i to create total square footage in the parcel, with encompasses both floorspace by unit and number of units in the parcel. Developer chooses both u_i, the number of units in the parcel, and a_i, floorspace by unit. The parcel-level productivity is given by g_i. Their maximization problem is:

$$\max_{u,M} \; r_j u g_i L_i^{(1-\phi)} M^{\phi} - \iota M - p_j \left(\frac{u}{L_i} \right).$$

Given u, the supply of floorspace per unit is given by $g_i^{\frac{1}{1-\phi}} u^{\frac{\phi}{1-\phi}} \left(\frac{\phi r_j}{\iota} \right)^{\frac{\phi}{1-\phi}} L_i$. After maximizing with the respect to M, the developer then picks $u \in 0, 1, \ldots, \overline{u}$ that maximizes profits. Denote this u as $u^*(\overline{u})$. The upper bound, $\overline{u}$, is dictated by local zoning laws.

Similarly, suppose there is a representative developer at the tract level, with productivity G_j and land L_j. The supply function of this developer is given by $G^{\frac{1}{1-\phi}} \left(\frac{\phi r_j}{\iota} \right)^{\frac{\phi}{1-\phi}} L_j$.

The sum of total housing supplied by land, in both cases, is given by

$$\sum_{i \in j} h_i = \left(\frac{\phi r_j}{\iota} \right)^{\frac{\phi}{1-\phi}} \sum_{i \in j} g_i^{\frac{1}{1-\phi}} u_i^*(\overline{u})^{\frac{\phi}{1-\phi}} L_i$$

$$H_j = \left(\frac{\phi r_j}{\iota} \right)^{\frac{\phi}{1-\phi}} G_j^{\frac{1}{1-\phi}} L_j.$$

If we want to use the aggregate housing production function to represent the sum of housing supply by lot, internal consistency requires that

$$G_j = \left[\sum_{i \in j} \frac{L_i}{L_j} g_i^{\frac{1}{1-\phi}} u_i^*(\overline{u})^{\frac{\phi}{1-\phi}} \right]^{1-\phi}.$$

That is, tract-level productivity is the land-weighed sum of lot-level productivity and optimal unit choice. For the counterfactual exercise presented in the main body of the text to make sense conceptually, it is sufficient that the choice of $u^*(\overline{u}_{pre}) < u^*(\overline{u}_{post})$, where $\overline{u}_{pre}$ is the upper bound on development before the zoning reform and $\overline{u}_{post}$ is the upper bound after the zoning reform. In such case, an increase in number of units per lot is equivalent to a productivity increase in the tract level.

B Parameters

Parameter	Value	Source
α	0.76	Davis and Ortalo-Magne (2011)
β	0.8	Ahlfeldt et al. (2015)
η	0.06	Ciccone and Hall (1996)
ϕ	0.3	Severen (2018)
ψ	6.7	Severen (2018)
θ	6.99	Regression
ι	0.06	Owens III et al. (2020)

Table 2: Parameter Values

C Further Model Derivations

C.1 Worker's Location Choice

Before exploring the problem, it is convenient to define the following probability:

$$G_{ij}(v) = \Pr(\hat{V}_{ij} \leq v).$$

Let $\psi_{ij} \equiv a_{ij} V_{ij}^{\theta}$. Using the definition of counterfactual indirect utility above and the functional form of the Fréchet distribution, we have:

$$G_{ij}(v) = \Pr\left(\epsilon_{ij} \leq \frac{v}{V_{ij}}\right) = F_{ij}\left(\frac{v}{V_{ij}}\right) = \exp\left(-\psi_{ij} v^{-\theta}\right).$$

Similarly, by independence of the draws,

$$\begin{aligned}
\Pr\left(\max_{i,j\in\Omega}\{\hat{V}_{ij}\} \le v\right) &= \Pr\left(\cap_{i,j\in\Omega}\left(\hat{V}_{ij} \le v\right)\right) \\
&= \prod_{i,j\in\Omega} \Pr\left(\hat{V}_{ij} \le v\right) \\
&= \prod_{i,j\in\Omega} G_{ij}(v) \\
&= \prod_{i,j\in\Omega} \exp\left(-\psi_{ij} v^{-\theta}\right) \\
&= \exp\left(-v^{-\theta} \sum_{i,j\in\Omega} \psi_{ij}\right).
\end{aligned}$$

From the law of large numbers, the fraction of workers living in location j and working in neighborhood i, π_{ij}, can be represented by:

$$\begin{aligned}
\pi_{ij} = \Pr\left(\hat{V}_{ij} \ge \max_{i',j'}\{\hat{V}_{i'j'}\}\right) &= \int_0^\infty \prod_{i',j'\in\Omega} G_{i'j'}(v) dG_{ij}(v) \\
&= \int_0^\infty \exp\left(-v^{-\theta} \sum_{i',j'\in\Omega} \psi_{i'j'}\right)\left(\psi_{ij}\theta v^{-\theta-1}\right) dv \\
&= \psi_{ij} \int_0^\infty \theta v^{-\theta-1} \exp\left(-v^{-\theta} \sum_{i',j'\in\Omega} \psi_{i'j'}\right) dv \\
&= \psi_{ij}\left[\frac{\exp\left(-v^{-\theta}\sum_{i',j'\in\Omega}\psi_{i'j'}\right)}{\sum_{i',j'\in\Omega}\psi_{i'j'}}\right]_0^\infty = \frac{\psi_{ij}}{\sum_{i',j'\in\Omega}\psi_{i'j'}} \\
&= \lambda a_{ij}\left(\kappa_{ij} r_j^{(1-\alpha)}\right)^{-\theta}\left(w_i s_j\right)^{\theta}.
\end{aligned}$$

where $\lambda \equiv \left[\sum_{i',j'\in\Omega}\psi_{i'j'}\right]^{-1}$.

The equation above is a gravity equation for commuting, describing overall patterns of workers' workplace and location choices. It shows that the fraction of the population living in j and working in i is increasing in the location taste shock a_{ij}, wages paid in i, and amenities in j. Similarly, the share of workers is decreasing in costly it is to commute between the pair ij, how high are residential taxes in j, and rent (r_j). Sensitivity to these variables depend on shape parameter θ of location taste

Summing across residential locations, we get the share of workers in location i:

$$\pi_i = \sum_{j' \in \Omega} \pi_{ij'} = \lambda \sum_{j' \in \Omega} a_{ij'} V_{ij'}^{\theta}.$$

The share of workers living in location j is given by:

$$\pi_j = \sum_{i' \in \Omega} \pi_{i'j} = \lambda \sum_{i' \in \Omega} a_{i'j} V_{i'j}^{\theta}.$$

Equivalently, the share of workers living in location j that commute to i to work is given by:

$$\pi_{i|j} = \frac{a_{ij} V_{ij}^{\theta}}{\sum_{i' \in \Omega} a_{i'j} V_{i'j}^{\theta}} = \frac{a_{ij} \left(\frac{w_i}{\kappa_{ij}}\right)^{\theta}}{\sum_{i' \in \Omega} a_{i'j} \left(\frac{w_{i'}}{\kappa_{i'j}}\right)^{\theta}}.$$

C.2 Rental Markets

Housing Demand Housing demand for residents in j commuting to i is given by

$$h_{ij} = (1 - \alpha) \frac{w_i}{r_j}.$$

Let $\overline{w}_j = \sum_{i \in \Omega} \pi_{i|j} w_i$. Aggregating across working neighborhoods, we get the total housing demand, H_j^d:

$$H_j^d = R_j (1 - \alpha) \frac{\overline{w}_j}{r_j}.$$

Housing Supply First-order condition for materials in the housing developer problem yields $r_j = \frac{\iota}{(1-\phi)G_j} \left(\frac{M_j}{L_j}\right)^{\phi}$. Using the zero profit condition and substituting for r_j gives us

$$\frac{\iota}{(1-\phi)G_j} \left(\frac{M_j}{L_j}\right)^{\phi} G_j L_j^{\phi} M_j^{1-\phi} = \iota M_j + p_j L_j$$

$$\frac{\iota}{(1-\phi)} M_j = \iota M_j + p_j L_j \Rightarrow M_j = \frac{1-\phi}{\phi} \frac{p_j L_j}{\iota}$$

Again, from the zero profit condition,

$$
\begin{aligned}
r_j &= \frac{\iota M_j + p_j L_j}{G_j L_j^{\phi} M_j^{1-\phi}} \\
&= \frac{\iota \frac{1-\phi}{\phi} \frac{p_j L_j}{\iota} + p_j L_j}{G_j L_j^{\phi} \left(\frac{1-\phi}{\phi} \frac{p_j L_j}{\iota} \right)^{1-\phi}} = \frac{\frac{1-\phi}{\phi} p_j + p_j}{G_j \left(\frac{1-\phi}{\phi} \frac{p_j}{\iota} \right)^{1-\phi}} \\
&= \underbrace{\frac{\iota^{1-\phi}}{G_j (1-\phi)^{1-\phi} \phi^{\phi}}}_{\equiv \rho_j} p_j^{\phi} = \rho_j p_j^{\phi}.
\end{aligned}
$$

Using the land supply equation, we get the relationship between housing rent, housing demand and land

$$
r_j = \rho_j \left(\frac{H_j}{L_j} \right)^{\psi}, \ \psi \equiv \phi \times \overline{\psi}.
$$

C.3 Welfare

Using similar arguments from the section on worker's location choice, the probability of a worker to work in neighborhood i and live in neighborhood j is $\exp\left(-v^{-\theta} \sum_{i,j \in \Omega} \psi_{ij}\right)$. Consequently, the expected utility of living in the MSA for such worker is:

$$
E(V) = \int_0^{\infty} v \left(\sum_{i,j \in \Omega} \psi_{ij} \right) v^{-\theta-1} \exp\left(-v^{-\theta} \sum_{i,j \in \Omega} \psi_{ij} \right) dv.
$$

Let $x = \left(\sum_{i,j \in \Omega} \psi_{ij}\right) v^{-\theta}$ so $x \in (\infty, 0)$ for $v \in (0, \infty)$, $dx = -\left(\sum_{i,j \in \Omega} \psi_{ij}\right) \theta v^{-\theta-1} dv$ and $v = \left(\frac{x}{\sum_{i,j \in \Omega} \psi_{ij}} \right)^{-\frac{1}{\theta}}$. Then

$$
\begin{aligned}
E(V) &= -\int_0^\infty v \exp\left(-v^{-\theta}\sum_{i,j\in\Omega}\psi_{ij}\right)\left[-\left(\sum_{i,j\in\Omega}\psi_{ij}\right)v^{-\theta-1}dv\right] \\
&= -\int_\infty^0 \left(\frac{x}{\sum_{i,j\in\Omega}\psi_{ij}}\right)^{-\frac{1}{\theta}} \exp\left(-x\right)dx = \int_0^\infty \left(\frac{x}{\sum_{i,j\in\Omega}\psi_{ij}}\right)^{-\frac{1}{\theta}} \exp\left(-x\right)dx \\
&= \int_0^\infty x^{\left(1-\frac{1}{\theta}\right)-1}\exp\left(-x\right)dx\left(\sum_{i,j\in\Omega}\psi_{ij}\right)^{\frac{1}{\theta}} \\
&= \Gamma\left(1-\frac{1}{\theta}\right)\left(\sum_{i,j\in\Omega}a_{ij}V_{ij}^{\theta}\right)^{\frac{1}{\theta}} = \Gamma\left(1-\frac{1}{\theta}\right)\left(\sum_{i\in\Omega}a_{ij}\left(\frac{w_i s_j}{\kappa_{ij}r_j^{1-\alpha}}\right)^{\theta}\right)^{\frac{1}{\theta}}.
\end{aligned}
$$

D Computational strategy

1. Guess array $\mathbb{V}^0$;

2. Compute $\lambda = \left[\sum_{i,j\in\Omega}a_{ij}V_{ij}^0\right]^{-1}$;

3. Calculate residents and workers by neighborhood using

$$
\begin{aligned}
R_j &= \lambda\sum_{i\in\Omega}a_{ij}(V_{ij}^0)^{\theta}\overline{R} \\
n_i &= \lambda\sum_{j\in\Omega}a_{ij}(V_{ij}^0)^{\theta}\overline{R}.
\end{aligned}
$$

4. Derive neighborhood wages using

$$
w_i = \beta\overline{A}_i n_i^{\beta+\eta-1}.
$$

5. Compute $\overline{w}$ and find housing by neighborhood using

$$
H_j = \left[\frac{(1-\alpha)\overline{w}_j}{\rho_j}R_j L_j^{\psi}\right]^{\frac{1}{\psi}}.
$$

6. Calculate rent using

$$
r_j = \rho_j\left(\frac{H_j}{L_j}\right)^{\psi}.
$$

7. Update indirect utility $\mathbb{V}^1$, where:

$$V_{ij}^1 = \frac{w_i s_j - r_j \overline{h}}{\kappa_{ij} r_j^{1-\alpha}}$$

8. Check if $||\mathbb{V}^1 - \mathbb{V}^0|| < 10^{-6}$. Stop if true. If not, set $\mathbb{V}^0_{new} = .25\mathbb{V}^1 + .75\mathbb{V}^0_{old}$.