The Unequal Effects of Upzoning: Evidence from Cook County

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Abstract

We quantify the real estate developer response to a variety of proposed zoning reforms by estimating a novel structural model of developer behavior using data from Cook County, Illinois. The structural model combines a flexible hedonic model of house prices with revealed preferences of developer behavior, enabling us to evaluate heterogeneous supply-side responses to zoning reforms. We find that a sweeping zoning reform allowing at minimum 3 units on every lot only increases the aggregate housing supply by 3.5 percent, with the average lot having 1.3 units built on it. Development is limited because the revenue from a 3-unit multifamily building typically does not justify the cost of purchasing and demolishing existing single-family homes. Furthermore, an alternative zoning reform to "streamline" the permitting process leads to essentially no new development. Simply lowering the fixed cost of new development without also allowing developers to build more units does little to ease supply constraints. In order to see a large supply-side response from developers, cities must either make more vacant land available for residential development or permit much higher density per lot.

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1 Introduction

Restricted zoning rules in high-productivity cities have limited developers' abilities to increase housing supply and ease affordability constraints. Despite the growing housing affordability crisis, few cities have voluntarily eased zoning restrictions in the past, likely due to opposition from incumbent residents. Nonetheless, high-housing-cost cities are increasingly considering or implementing large upzoning reforms. For example, Cambridge, MA, California, and Oregon have recently "banned single-family zoning" in an effort to increase the supply of housing and improve affordability. However, the amount of housing these types of reforms will bring depends on whether these changes lead to profitable opportunities for housing developers.

In this paper, we combine new data on parcel-level zoning and property characteristics with a model of real estate developers' profit maximization to quantify the extent to which a variety of proposed zoning restrictions would increase housing supply in the Chicagoland area. We also investigate the distributional consequences of these reforms across neighborhoods, income levels, and housing occupancy status, as well as the financial benefits to current property owners versus developers.

We begin by presenting a rich, structural model of housing developer decisions, subject to detailed and realistic zoning requirements. In particular, competitive developers have the ability to purchase existing single-family and multifamily properties, as well as vacant lots. When considering whether to purchase a property, developers have the option to renovate the existing structure by adding square footage, or to tear down the existing structure and build new single-family or multifamily housing, subject to zoning restrictions. Zoning restrictions include requirements for permitted use, minimum lot size requirements, minimum lot size per unit requirements, and maximum floor area ratio requirements. Developers face both fixed costs and variable costs when developing housing, which we allow to be distinct between renovation and new construction. Developers finally face idiosyncratic cost shocks at the parcel level, and developers will acquire and develop parcels only when profitable.

To estimate the model, we first need to take a stance on the price at which a developer can purchase a given property and the price that the developer could receive upon either renovation or replacement with new construction. In our baseline model, we assume that there is a representative monopolistic developer at the parcel level, which implies that the developer can purchase the property for the prevailing price on the owner-occupied market. We further assume that the developer will sell the property upon completion of the renovation / new construction and achieve the prevailing price on the owner-occupied market, taking into account the developer improvements. To determine these prices, we estimate a flexible hedonic price surface on individual, non-redevelopment, and residential property transactions between 2001 and 2018, including a variety

of housing characteristics such as number of units, square footage, lot size, building age, number of bedrooms, etc.

We structurally estimate our model using data from Cook County, Illinois, the second largest country in the United States with a population of 5.2 million as of 2020. To estimate the model, we bring to bear novel data on parcel-level zoning restrictions for the entire county from Zoneomics, as well as detailed annual assessor and transaction data from the Cook County Assessor Office and Cook County Recorder of Deeds. Having access to annual assessor data allows us to observe changes in parcel boundaries and characteristics over time. In particular, we observe whether a parcel is ever split or if the building age changes, indicating that the original structure was replaced with new construction.

We use a revealed preference approach to estimate the structural cost parameters of the developers' production function, exploiting both which parcels are chosen for development and the type of development that occurs. Intuitively, holding fixed and variable costs constant, the dispersion in parcel-level idiosyncratic costs is identified from the sensitivity of the development decision to variation in net revenues. Fixed costs are identified by the sensitivity of the development decision to (maximum) square footage, as high fixed costs will make smaller buildings unprofitable. Variable costs are then identified as the constant in the relevant logistic regression.

We find that the variable costs of new construction from 2008 to 2019 are $278 per square foot, close to survey data on construction costs from RS Means of $227 per square foot. The fixed cost to engage in new construction is $356,000, reflecting the regulatory costs of new construction. We find that the price per square foot of renovation is substantially higher at $360, reflecting the additional complexity of adding on to an already built property.

In terms of which properties are currently profitable for development in Cook County under current zoning restrictions, we find that such properties are more likely to be located in high-income and low-minority census tracts, reflecting the high price that new construction can command in those areas. However, within a census tract, the lowest value properties are those targeted for redevelopment.

Using our structural model of developer behavior, we analyze the effects of several zoning reforms in Chicago aimed at increasing housing supply. Our results show that allowing triplex construction on all residential lots (banning single-family zoning) leads to a modest increase in housing units–about 2.9 percent in the city and 6.2 percent in suburbs–with minimal changes in housing quality. When triplex zoning is combined with proportional density bonuses (increasing allowed floor area ratios), housing supply growth is more substantial, with unit numbers rising by approximately 6.3 percent in the city and 9.3 percent in suburbs, accompanied by significant improvements in housing quality. This modest housing supply response is driven by the fact that it is only profitable for developers to build new triplex housing when the purchase cost of the land,

currently occupied by single-family housing, is cheap. Since many owner-occupants are willing to pay more than a developer just to live in the home as is, many lots that legally allow triplexes will remain single-family housing.

In contrast, reducing permitting and administrative costs by 25 percent, a reform advocated as "cutting red tape," results in negligible effects on both the quantity and quality of housing. This is driven by the fact that simply lowering the construction costs (in this case the fixed cost of permitting) of new buildings leads to little increased housing supply. This is consistent with the city of Chicago being quite supply inelastic with respect to housing prices.

Ultimately, to generate large housing supply responses through zoning reform, cities will need to pursue one of two strategies: (1) allow for substantially larger increases in units, creating the profit incentives for developers to demolish existing single-family structures, or (2) convert vacant commercial land to residential use. Since vacant land is empty, such land would be more affordable for developers to purchase, providing them with a greater incentive to make a profit.

2 Data

We study housing development in Cook County, Illinois, the second largest county in the United States with a population of 5.2 million in 2020 (Census 2021). We bring together data from multiple sources to observe property characteristics, property transactions, development activity, and land use restrictions in Cook County.

We begin with property tax rolls from the Cook County Assessor Office, which provide us with a variety of property characteristics for the universe of parcels in Cook County from 1999 to 2023.[1] We observe property characteristics such as the size of the lot, the size of all buildings on the lot, the year each building was built, and the number of housing units in each building. For residential buildings with six or fewer housing units as well as condominiums, we additionally observe interior characteristics, such as number of bedrooms, number of bathrooms, and type of heating, ventilation, and air conditioning.[2]

Using annual parcel maps from the Cook County Assessor Office, we spatially link parcels over time from 1999 to 2023. This allows us to observe changes in parcel boundaries over time. In particular, this allows us to determine whether a parcel is ever split, a common occurrence when a tract of land (single parcel) is subdivided into separate parcels for multiple new developments. Appendix Section 7 describes our procedure for linking parcels over time.

[1] A parcel is a piece of real estate defined for the purposes of property taxation.

[2] We observe the following interior characteristics: number of bedrooms, number of full bathrooms, number of half bathrooms, number of stories, type of garage, type of attic, type of basement, type of porch, and type of heating, ventilation, and air conditioning. Interior characteristics are not comprehensively recorded for condominiums. When possible, we supplement with data from Midwest Real Estate Data, the primary Multiple Listing Service for the Chicagoland area.

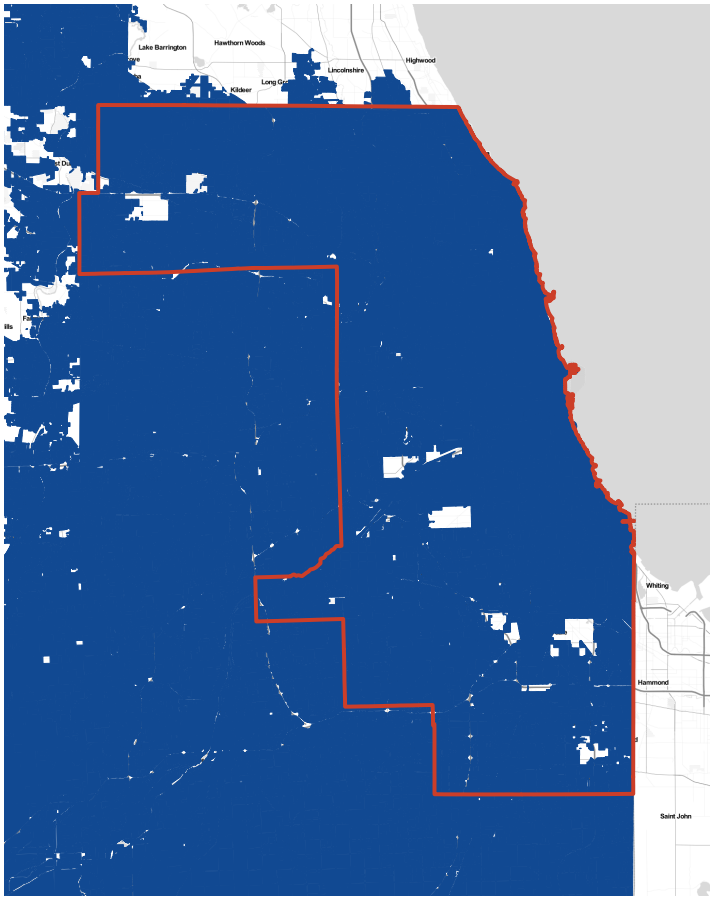
Data from the Cook County Recorder of Deeds details the transaction history for each parcel since 1999. We observe transaction dates and prices, buyer and seller names, as well as whether the parcel was sold individually or as part of a portfolio sale. To limit transactions to those that are likely arms-length (i.e., between unfamiliar buyers and sellers), we exclude transactions with prices below $10,000.[3]

Finally, we spatially merge our parcel maps to the 2023 municipal zoning maps provided by Zoneomics. Figure 1 presents municipalities in the Chicago Metropolitan Statistical Area for which we have municipal zoning maps, where the red border indicates the geographical boundary for Cook County. Our coverage is comprehensive–we are missing maps only for a select number of small municipalities. This allows us to observe the 2023 cross-section of land use restrictions for each parcel, such as the permitted use (e.g., single-family, multi-family, commercial), minimum lot size, minimum lot size per unit, and maximum floor area ratio. In particular, this allows us to determine the development capacity of each parcel.[4] Table 1 presents summary statistics on land use restrictions for all parcels in Cook County.

[3] As a robustness check, we exclude transactions where buyers and sellers share the same last name. Results are qualitatively similar.

[4] Land use restrictions in the U.S. have been relatively static in the past few decades. For example, Chicago's last comprehensive land use plan was adopted in 1966.

Figure 1: Coverage of municipal zoning maps in the Chicagoland area



Note: The shaded blue area reflects municipalities for which we have zoning maps. The red border indicates the geographical boundary for Cook County.

Table 1: Summary statistics of land use restrictions in Cook County

Variable	**Mean**	**Std. dev.**	**Min.**	**Max.**
Permitted use				
Missing	2.1%			
Single-family	37.2%			
Duplex	15.2%			
Multi-family	26.4%			
Minimum lot size (sq. ft.)	8,458	39,403	1,650	1,742,000
Minimum lot size per unit (sq. ft.)	4,870	9,076	100	217,800
Maximum floor area ratio	1.51	2.20	0.01	16.00

3 Quantifying residential development

To characterize residential development activity in Cook County, we begin by identifying historical development events, as well as measuring each existing parcel's potential for further development. We distinguish between infill redevelopments–i.e., developments on parcels with existing residential buildings–versus vacant land developments. We then use our measures of development potential to provide descriptive evidence about the type of parcels that get developed. This evidence serves as motivation for our structural model of developer behavior.

3.1 Observing historical infill redevelopments

We identify infill redevelopments by looking for changes in property characteristics. Specifically, we define a parcel as having undergone redevelopment if the parcel: (i) experiences a 10% increase in residential building square footage relative to the previous year or (ii) includes any residential building with a year built between 1999 and 2023. We further classify redevelopments as renovations or new construction. A renovation is defined as a redevelopment where existing housing is not demolished, and therefore year of building remains the same. A new development is defined as any redevelopment where a new building is constructed, and therefore year of building is updated. Our procedure notably excludes renovations with no change in square footage. Such renovations are often associated with no change in any observable property characteristics, and thus are difficult to comprehensively observe. The overwhelming majority of significant renovations (i.e., renovations with an increase in number of bedrooms or bathrooms) experience greater than a 10% increase in building square footage.

Table 4 provides summary statistics for the redevelopment events in our sample. Due to data quality issues in 1999 and 2000, we limit our sample to redevelopments from 2001 to 2023. Some parcels experience multiple redevelopment events (e.g., due to delayed construction). In such cases, we only consider the first year of redevelopment observed. Finally, we link arms-length transactions to redevelopment events, where we define a transacted parcel as experiencing redevelopment if the parcel is redeveloped within five years after the transaction year.

Table 2: Summary statistics of redevelopment events in Cook County

Transactions, 2001-2019	**Count**
Arms-length	1,802,578
Single-family or multiplex	1,003,906
Redevelopment	61,706
Redevelopment	**Share**
New construction	32.7%
Merge via APN	71.7%
Merge via parcel boundaries	28.3%
Renovation	67.3%
Merge via APN	95.9%
Merge via parcel boundaries	4.1%

3.2 Observing historical developments for vacant land

We identify vacant land developments by looking for changes in property characteristics. Specifically, we define a parcel as having undergone development if the parcel did not include any residential buildings in 1999 and eventually includes any residential building with a year built between 2000 and 2023. We exclude developments involving the construction of multiplex buildings with 20 or more units.[5]

Table 3 provides summary statistics for the development events in our sample. Due to data quality issues in 1999 and 2000, we limit our sample to developments from 2001 to 2023. Some parcels experience multiple redevelopment events (e.g., due to delayed construction). In such cases, we only consider the first year of redevelopment observed. Finally, we link arms-length transactions to redevelopment events, where we define a transacted parcel as experiencing development if the parcel is developed within five years after the transaction.

Table 3: Summary statistics of development events in Cook County

Transactions, 2001-2019	**Count**
Arms-length	1,802,578
Residential vacant land	51,242
Redevelopment	12,394

[5]Such developments typically do not conform to zoning restrictions, and are therefore subject to discretionary review. Therefore, these developments are not impacted by by-right zoning reforms.

3.3 Quantifying development potential

To ultimately measure the potential profit a developer could earn from (re)developing a given parcel, we need to calculate the potential revenue that the development could generate. As a first step, we measure each parcel's development potential under the current zoning rules. We use our municipal zoning maps to determine each parcel's land use restrictions. We combine a parcels' permitted use (e.g., single-family, multi-family, commercial), minimum lot size, maximum floor area ratio, and minimum lot size per unit to calculate the maximum number of units and maximum number of square footage that can be built on each parcel.

A given parcel j consists of its lot of size L_j^0 with housing of quality z_j^0, size S_j^0, age A_j^0 and number of units U_j^0. The development capacity of each property is constrained by its minimum lot size L_j^{min}, maximum floor area ratio F_j, and minimum lot size per unit L_j^{unit}. Given redevelopment, a developer may choose to either (i) renovate the existing housing or (i) build new construction. Given renovation, a developer may increase building square footage up to the maximum allowed by the maximum floor area ratio. However, the developer may not subdivide the parcel or increase number of units, and building age remains the same. In particular, any renovation must satisfy the following constraints:

$$
\begin{aligned}
A_j^1 &= A_j^0 \\
L_j^1 &= L_j^0 \\
S_j^1 &\geq S_j^0 \\
\frac{S_j^1}{L_j^1} &\leq F_j \text{ (maximum floor area ratio)} \\
U_j^1 &= U_j^0
\end{aligned}
$$

Given new construction, the developer can choose to subdivide the parcel into N_j^1 lots of size L_j^1 and on each lot, build housing of quality z_j^1, size S_j^1, $A_j^1 = 0$, and number of units U_j^1. In particular, any new construction must satisfy the following constraints:

$$
\begin{aligned}
A_j^1 &= 0 \\
L_j^1 &\geq L_j^{min} \text{ (minimum lot size)} \\
N_j^1 \cdot L_j^1 &= L_j^0 \\
\frac{S_j^1}{L_j^1} &\leq F_j \text{ (maximum floor area ratio)} \\
U_j &\leq \frac{L_j^1}{L_j^{unit}} \text{ (maximum units per lot)}
\end{aligned}
$$

In the case of new construction, we make two assumptions about developer behavior: (1) developers split lots evenly; and (2) developers split lots until zoning restrictions bind. That is:

$$
N_j^1 = \text{floor}\left(\frac{L_j^0}{L_j^{min}}\right) \text{ (minimum lot size)}
$$

We allow for developers to choose whether they build to the maximum units and square footage allowed under the current zoning rules.[6] In the case where developers choose to build to the maximum:

$$
\begin{aligned}
N_j^1 &= \text{floor}\left(\frac{L_j^0}{L_j^{min}}\right) \text{ (minimum lot size)} \\
L_j^1 &= \frac{L_j^0}{N_j^1} \\
\frac{S_j^1}{L_j^1} &= F_j \text{ (maximum floor area ratio)} \\
U_j &= \text{floor}\left(\frac{L_j^1}{L_j^{unit}}\right) \text{ (maximum units per lot)}
\end{aligned}
$$

As an example of how we quantify development capacity for new construction, consider a 12,000 square feet parcel zoned single-family, with a minimum lot size of 5,000 square feet, and a maximum floor area ratio of 0.4. We assume the developer splits the lot into 2 lots of 6,000 square feet. On each lot, the developer may build up to a 2,400 square feet house. Similarly, consider a 12,000 square feet parcel zoned multi-family, with a minimum lot size of 5,000 square feet, a

[6]For new construction, developers typically build housing until zoning restriction binds. Appendix [TK] provides descriptive evidence.

minimum lot size per unit of 2,000 square feet, and a maximum floor area ratio of 0.4. We assume the developer splits the lot into 2 lots of 6,000 square feet. On each lot, the developer may build up to a 2,400 square feet building with 3 units.

Finally, we assume developers choose housing quality z_j^1 similar to housing quality of existing renovations and new construction. We calibrate interior characteristics, such as number of bedrooms per building square feet, to averages of renovated or newly constructed residential buildings in the data.[7] While these calculations provide us with the options a developer could build under the zoning restrictions of a given parcel, they do not directly speak of the revenue that would be generated by building the different options. To measure revenue potential, we build a hedonic model of property values below.

3.4 Hedonic model

We estimate a hedonic model on the sample of individual, non-redevelopment, and residential property transactions from 2001 to 2019.[8] We further limit the sample to single-family housing and multi-family housing with six or less units.[9] Valuing multi-family buildings with seven or more housing units is difficult as the Cook County Assessor Office does not record interior property characteristics.

We estimate the following regression equation:

$$\log(p_{it}) = \sum_{\tau} \left(1(t=\tau) \times \beta^{\tau} \mathbf{X}_{it}\right) + \sum_{j} \left(1(d(i)=j) \times \beta^{j} \mathbf{X}_{it}\right) + \lambda_{c(i)t}$$

In this equation, p_{it} is the price of transaction i in year t, district $d(i)$, and census tract $c(i)$, and $\mathbf{X}_{it}$ is a vector of property characteristics.[10] Specifically, we estimate year-varying and district-varying coefficients for the following property characteristics: recent redevelopment, number of housing units, building age, building size, lot size, number of bedrooms, number of bathrooms, number of stories, type of garage, type of attic, type of basement, type of porch, and type of heating, ventilation, and air conditioning. The variable $\lambda_{c(i)t}$ captures census tract-year fixed effects. Our estimated hedonic model has a goodness-of-fit of $R^2 = 0.79$.

[7] In particular, we calibrate the following interior characteristics: number of bedrooms per building square feet, number of bedrooms per building square feet, number of stories, type of garage, type of attic, type of basement, type of porch, and type of heating, ventilation, and air conditioning. For continuous variables, we match the mean; for categorical variables, we match the mode.

[8] We truncate the sample to 2019 to allow enough time to observe post-transaction redevelopments.

[9] For now, we assume developers do not convert redevelopments into condominiums.

[10] For the purposes of government administration, Cook County is split into 17 commissioner districts.

3.5 Descriptive evidence

To motivate our structural model of developer behavior, we provide descriptive evidence on our observed historical infill redevelopments. First, we conduct a variance decomposition exercise to understand what predicts whether a parcel is redeveloped. We begin by regressing an indicator for whether a parcel sold in 2017 is eventually redeveloped on census block group fixed effects. That is, we run the following regression:

$$y_i = \beta X_i + \lambda_{b(i)} + \varepsilon_i \tag{1}$$

where y_i is some outcome (e.g., whether a parcel is redeveloped) for parcel i in 2017. The characteristics of the parcel are denoted by X_i and $\lambda_{b(i)}$ captures fixed effects for census block group. We then project our estimates for the census block group fixed effects on characteristics about census block groups. That is, we run the following regression:

$$\hat{\lambda}_b = \beta X_b + \varepsilon_b \tag{2}$$

where $\hat{\lambda}_b$ is the estimated fixed effect for census block group b and X_b are characteristics about the census block group. Table 4 presents the results of such regressions.

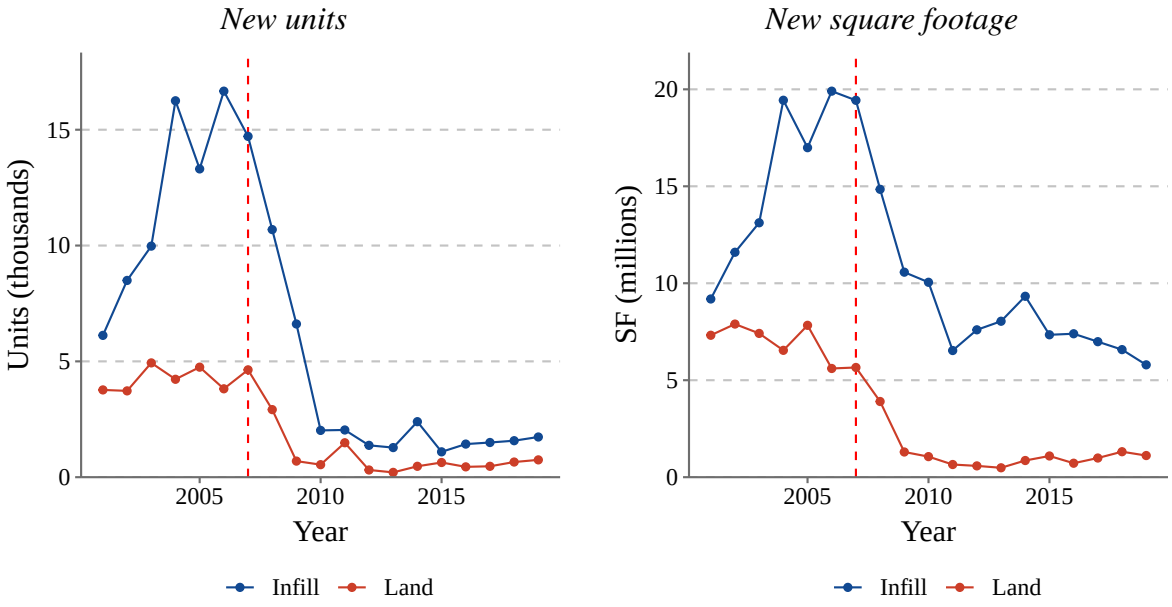
We find that 14.2% of the variation in whether a parcel is redeveloped is explained by the location of the parcel (Column 1 of Table 4). Including characteristics about the existing buildings on the parcel as well as the parcel's zoning increases the variation explained to 17.2% (Column 3 of Table 4). Developers typically redevelop low-quality housing in richer neighborhoods.

Table 4: Regression of redevelopment on parcel characteristics, 2017

Redeveloped	**(1)**	**Pairwise regression**		**(2)**		**(3)**	
(2017)		**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
Census block group							
Population		−0.221	(0.258)				
Median income		1.927	(0.187)				
% white		1.666	(0.164)				
% college		2.462	(0.168)				
Median home value		2.696	(0.177)				
Distance to CBD		−25.503	(2.587)				
Parcel							
Lot SF				0.695	(0.336)	0.932	(0.397)
House SF				−3.237	(0.378)	−3.276	(0.377)
House age				3.456	(0.212)	3.563	(0.217)
# bedrooms / 1,000 SF				1.095	(0.213)	1.113	(0.212)
# bathrooms / 1,000 SF				0.288	(0.169)	0.255	(0.169)
# units				0.974	(0.287)	0.875	(0.288)
Zoning covariates						X	
Block group FE	X			X		X	
R^2	0.142			0.175		0.176	

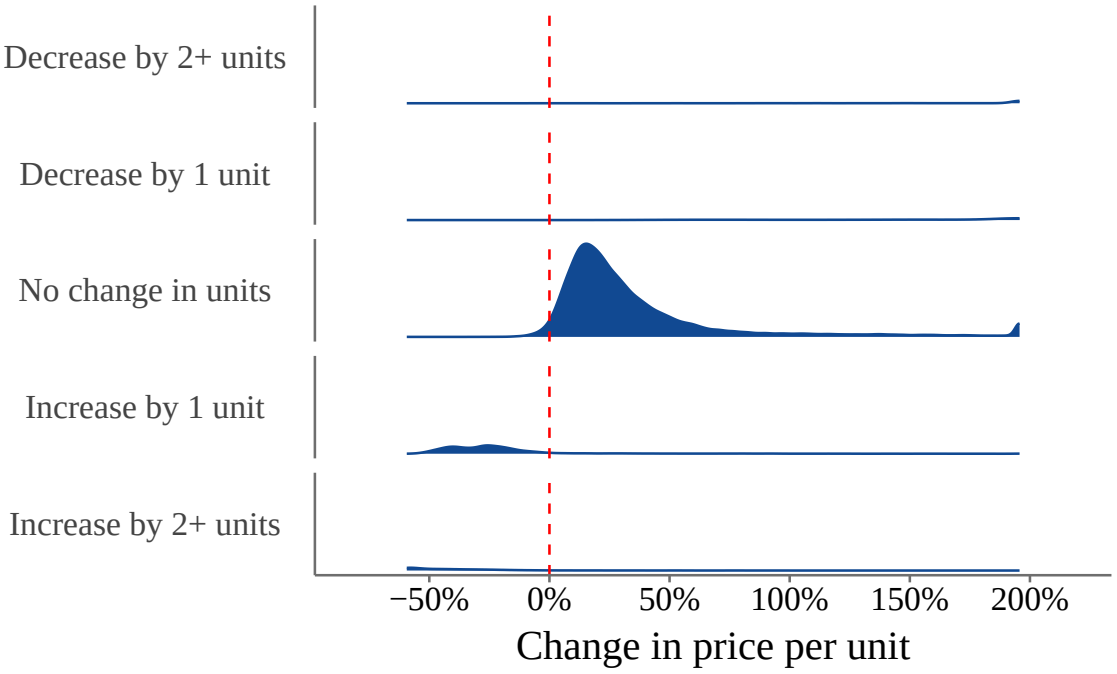
Furthermore, the majority of by-right development (i.e., development that conforms to zoning restrictions) is infill redevelopment. Figure 2 presents the amount of new units and new square footage by development type from 2001 to 2019 in Cook County. The majority of new units derive from infill redevelopment, whereas the vast majority of new square footage also derives from infill redevelopent.

Figure 2: New units and new square footage by development type



Despite the fact that the majority of new units derive from infill redevelopment, infill redevelopment typically does not change number of units. Figure 3 presents the distribution of infill redevelopments that increase or decrease unit size. We find the vast majority of infill redevelopments do not change unit size, and housing becomes higher quality as measured by price per unit predicted by our hedonic model.

Figure 3: Distribution of changes in units and price for infill redevelopments



Next, we present descriptive statistics on the development potential for each parcel in Cook County in 2017. We define a parcel's current development intensity as: (i) its existing building square footage divided by the maximum building square footage allowed according to the parcel's zoning; and (ii) its existing number of units divided by the maximum units allowed according to the parcel's zoning.[11]

Figure 4 presents the distribution of parcel-level square footage development intensity in 2017 by whether the parcel was sold in 2017, and if sold, whether the parcel was eventually redeveloped.[12] Figure 5 presents the distribution of parcel-level unit development intensity in 2017 by whether the parcel was sold in 2017, and if sold, whether the parcel was eventually redeveloped.[13] For the universe of parcels in 2017, parcels sold and undeveloped look similar in their development potential to parcels unsold. In contrast, parcels sold and developed are noticeably less developed, both in terms of square footage and units.

[11] We assume developer behavior as defined in Section 3.3.

[12] We winsorize values of development intensity greater than 100%. Such parcels are typically parcels with grandfathered zoning.

[13] We winsorize values of development intensity greater than 100%. Such parcels are typically parcels with grandfathered zoning.

Figure 4: Distribution of parcel-level square footage development intensity in 2017

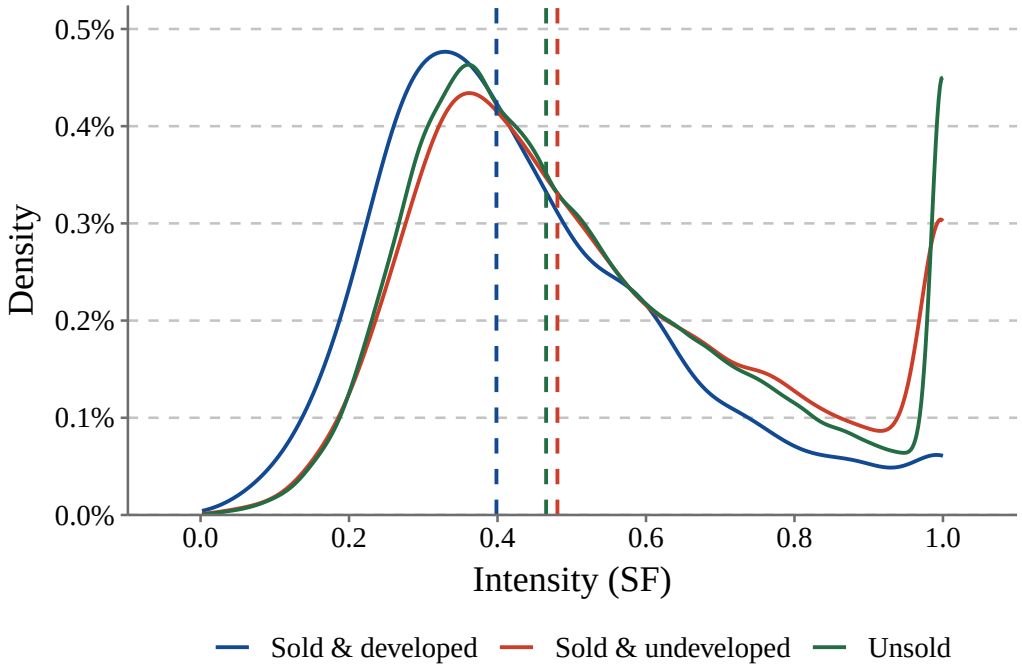
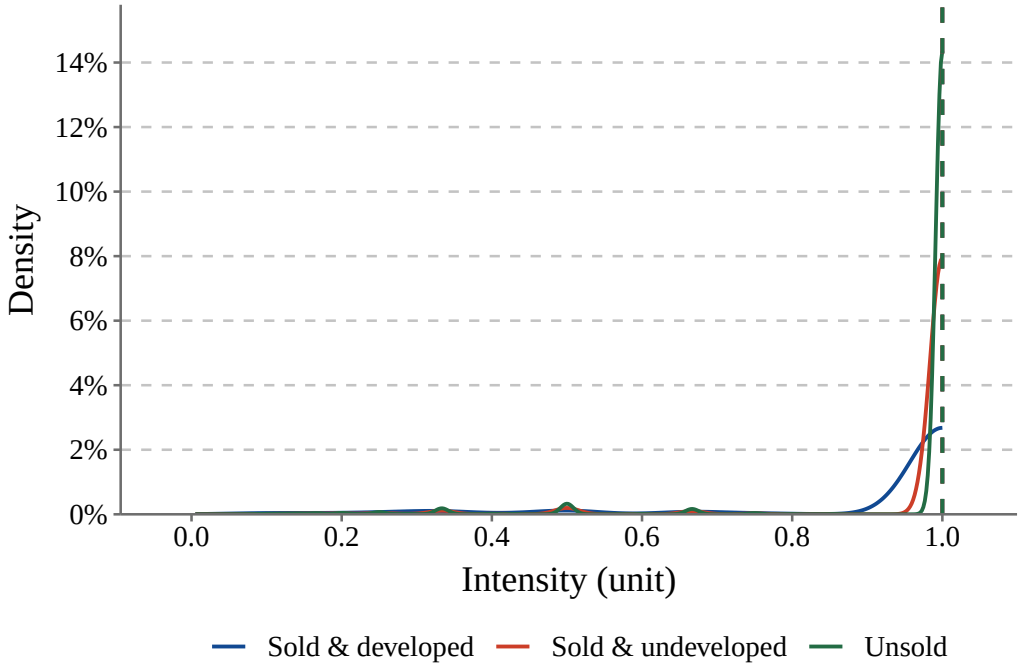


Figure 5: Distribution of parcel-level unit development intensity in 2017



We again conduct a variance decomposition exercise, where we regress a parcel's square footage development intensity on census block group fixed effects following equations (1) and

(2). We find that 29.4% of variation a parcel's square footage development intensity is explained by the location of the parcel (Column 1 of Table 5). Including characteristics about the existing buildings on the parcel as well as the parcel's zoning increases the variation explained to 53.9% (Column 3 of Table 5). When parcel characteristics are included, approximately 20% of the variation is explained location instead (Figure 6). We find that parcels closer to Chicago's central business district have higher development intensity (Figure 7). Parcels in richer neighborhoods as well as parcels with newer homes also have higher development intensity.

Table 5: Regression of square footage development intensity on parcel characteristics, 2017

Development intensity	**(1)**	**Pairwise regression**		**(2)**		**(3)**	
(2017)		**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
Census block group							
Population		1.757	(0.719)				
Median income		2.504	(0.534)				
% white		2.052	(0.471)				
% college		5.745	(0.473)				
Median home value		6.650	(0.478)				
Distance to CBD		−95.141	(7.012)				
Parcel							
Lot SF				−6.529	(2.062)	−6.118	(2.171)
House SF				15.152	(0.695)	15.601	(0.593)
House age				−3.794	(0.291)	−3.857	(0.236)
# bedrooms / 1,000 SF				−3.865	(0.231)	−3.696	(0.191)
# bathrooms / 1,000 SF				0.050	(0.127)	0.010	(0.116)
# units				5.220	(0.482)	4.932	(0.388)
Zoning covariates						X	
Block group FE	X			X		X	
R^2	0.294			0.516		0.539	

Figure 6: Variance decomposition of square footage development intensity in 2017

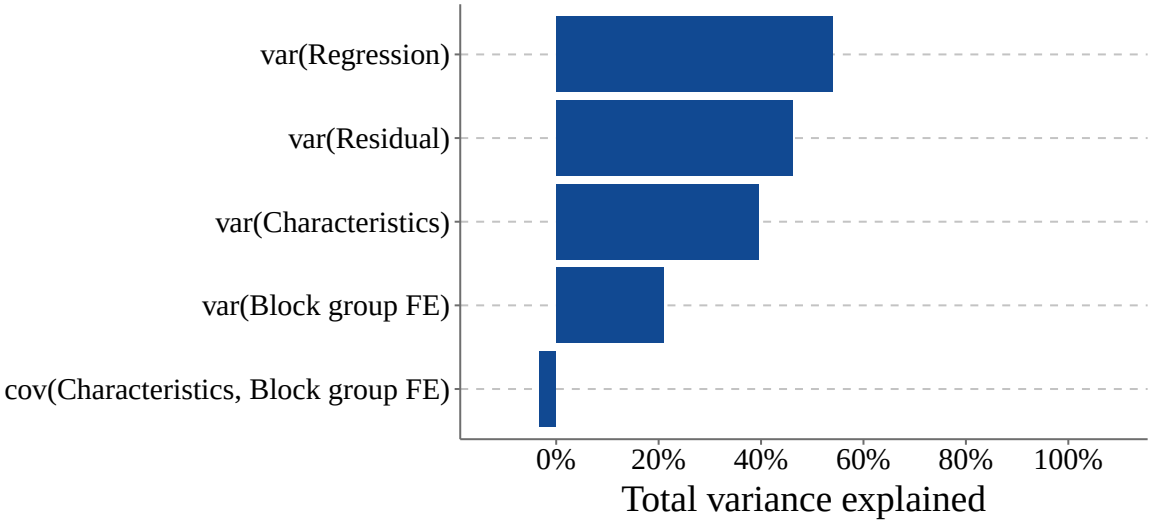
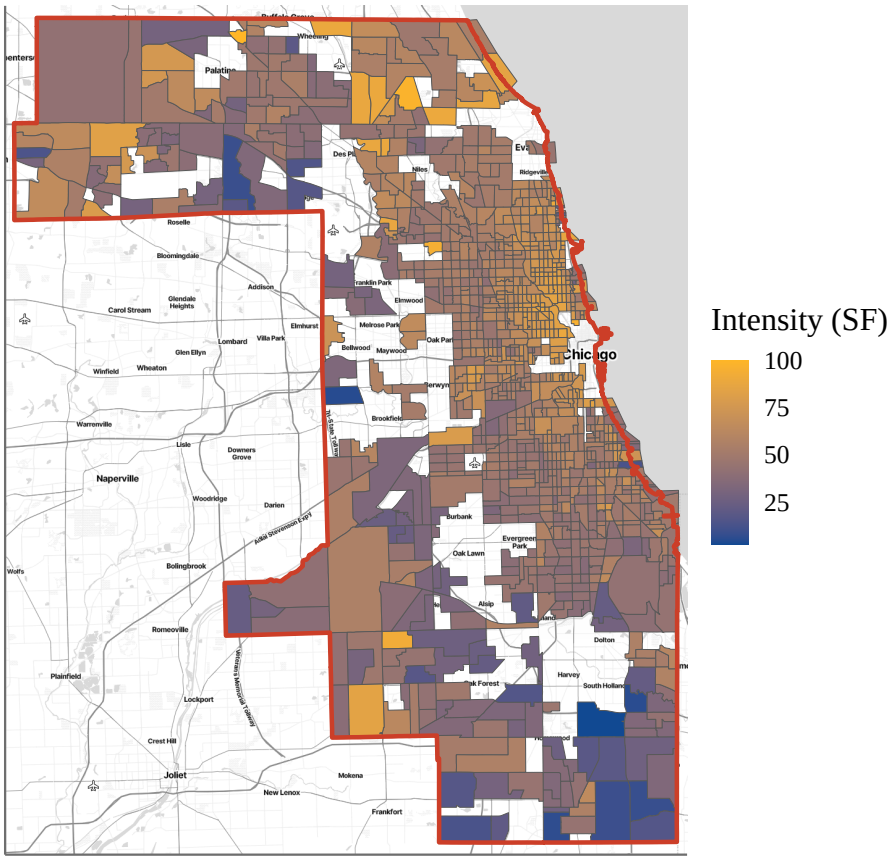


Figure 7: Tract-level square footage development intensity in 2017



Note: The red border indicates the geographical boundary for Cook County.

4 Housing supply

Having shown that parcels with ex-ante higher development potential are more likely to be redeveloped, we use revealed preferences by developers to specify and estimate a model of residential housing supply. We focus on estimating supply for residential housing with less than 20 units (e.g., single-family houses, multiplexes). Residential housing with less than 20 units are typically as-of-right developments and conform to zoning codes. In contrast, residential housing with more than 20 units (e.g., apartment buildings) typically apply for zoning exemptions and are built with discretionary approval by municipalities. We distinguish between infill redevelopment versus vacant land development.

4.1 Infill model set-up

Suppose residential properties are exogenously put up for sale by households. Each residential property j consists of a single lot of size L_j^0 with housing of quality z_j^0, size S_j^0, age A_j^0, and number of units U_j^0. Households can sell to another household at $p_t\left(z_j^0, A_j^0, S_j^0, U_j^0, L_j^0\right)$, where $p_t(\cdot)$ is the hedonic price surface in year t. Alternatively, households can sell to a developer at an endogenous price p_{jt}^*. Households will sell to the developer whenever $p_{jt}^* > p_t\left(z_j^0, A_j^0, S_j^0, U_j^0, L_j^0\right)$ and receive surplus $p_j^* - p_t\left(z_j^0, A_j^0, S_j^0, U_j^0, L_j^0\right)$.

Developers may choose whether to purchase the property. We assume there is always at least one developer who has capacity to take on the development job, if profitable. We assume there is some probability p that more than one developer has capacity to take on the development job and competes with the other developer for the purchase of the lot. We assume all developers are identical.[14] If a developer does not purchase the property, they receive their outside option given by:

$$\pi_{jt}^{OO} = 0 + \varepsilon_{jt}^{OO}$$

where ε_{jt}^{OO} is some idiosyncratic profit shock specific to the parcel, but common across developers. If a developer purchases the property, they may either renovate the existing housing or build new construction, and then resell the property. Following Section 3.3, a developer may increase building square footage for renovations, but cannot change the number of lots, number of units, or building age. A developer may increase building square footage up to the maximum allowed by the maximum floor area ratio. For implementation, we discretize the developer's renovation choice set. Define the maximal addition as the difference between the maximum building square footage that can be built on a parcel as implied by zoning restrictions and the existing building square footage. Developers can increase building square footage by 10% of the maximal addition, 20% of the maximal addition, and etcetera up to 100% of the maximal addition. That is, given maximum floor area ratio F_j, the developer may choose from renovation intensity $r \in \{0.1, \ldots, 1.0\}$ such that:

$$S_1^{1r} = S_j^0 + r \cdot \left(F_j \cdot L_j^0 - S_j^0\right)$$

If the developer decide to build new construction, the developer can choose to subdivide the property into N_j^1 lots of size L_j^1 and on each lot, build housing of quality z_j^1, size S_j^1, age $A_j^1 = 0$, and number of units U_j^1. As detailed in Section 3.3, we assume developers split lots evenly until zoning restrictions bind. We make this assumption to simplify model complexity during estimation. A

[14] While it would be nice to enrich the model with developer heterogeneity, we know almost nothing about the developers who pursue these developments.

developer may build square footage up to the maximum allowed by the maximum floor area ratio. For implementation, we discretize the developer's new construction choice set. Developers can build square footage by 45% of the maximum, 75% of the maximum, or 100% of the maximum. A developer may build units up to the maximum allowed by the permitted use and minimum lot size per unit. Developers can build 1 unit per lot, 2 units per lot, 3 units per lot, 4 units per lot, or the maximum units per lot.[15] That is, given minimum lot size L_j^{min}, maximum floor area ratio F_j, and minimum lot size per unit L_j^{unit}, the developer may choose from new construction intensity $n \in \{0.45, 0.75, 1.00\} \times \{1, \ldots, U_j^{max}\}$ such that:

$$
\begin{aligned}
N_j^1 &= \text{floor}\left(\frac{L_j^0}{L_j^{min}}\right) \\
L_j^1 &= \frac{L_j^0}{N_j^1} \\
U_j^{max} &= \text{floor}\left(\frac{L_j^1}{L_j^{unit}}\right) \\
S_j^{1n} &= n_1 \cdot L_j^1 F_j \\
U_j^{1n} &= n_2
\end{aligned}
$$

Developers have the following construction cost functions for new construction and renovations:

$$
\begin{aligned}
C^{NC}(z,N,S,U) &= \alpha^{NC}(z) \cdot N \cdot S + \beta^{NC} \cdot N \cdot U + FC^{NC} + SPLIT^{NC} 1(N > 1) \\
C^{R}(z,S) &= \alpha^{R}(z) \cdot S + FC^{R}
\end{aligned}
$$

where NC denotes new construction, R denotes renovation, α is the variable cost of construction per square foot, β is the variable cost of construction per unit, FC is the fixed cost of construction, and $SPLIT$ is the fixed cost of subdividing the parcel into multiple new parcels. The fixed cost of construction, for example, captures the cost of demolition. Finally, we will allow these cost parameters to differ in the years prior to versus after the Great Recession. This proxies for changes in borrowing constraints that substantially changed due to the 2007-08 financial crisis. We assume construction costs do not vary across neighborhoods, but do vary across the city versus suburbs.

Developer profit for a given property, if they choose to redevelop, is therefore given by:

[15] If the maximum unit per lot is, for instance, 2, developers can choose to build either 1 unit per lot or 2 units per lot.

$$\pi^n_{jt} = N^1_j \cdot p_t\left(z^1_j, 0, S^{1n}_j, U^{1n}_j, L^1_j\right) - p^*_j - C^{NC}\left(z^1_j, N^1_j, S^{1n}_j, U^{1n}_j\right) + \sigma\varepsilon^{NC}_{jnt}$$
$$\pi^r_{jt} = p_t\left(z^1_j, A^0_j, S^{1r}_j, U^0_j, L^0_j\right) - p^*_j - C^R\left(z^1_j, S^{1r}_j\right) + \sigma\varepsilon^R_{jrt}$$

where p_t is the hedonic price surface at time t, n is the new construction intensity, r is the renovation intensity, ε_{jt} is an idiosyncratic profit shock, and σ is the dispersion of the profit shock.

Developer surplus is accordingly given by $\pi^n_{jt} - \varepsilon^{OO}_{jt}$ and $\pi^r_{jt} - \varepsilon^{OO}_{jt}$. Therefore, the joint surplus to developers and current property owners from developing is given by:

$$JS^n_{jt} = \Delta p^n_{jt} - C^{NC}\left(z^1_j, N^1_j, S^{1n}_j, U^{1n}_j\right) + \sigma\varepsilon^{NC}_{jnt} - \varepsilon^{OO}_{jt}$$
$$JS^r_{jt} = \Delta p^r_{jt} - C^R\left(z^1_j, N^1_j, S^{1r}_j\right) + \sigma\varepsilon^R_{irt} - \varepsilon^{OO}_{jt}$$

where:

$$\Delta p^n_{jt} = N^1_j \cdot p_t\left(z^1_j, 0, S^{1n}_j, U^{1n}_j, L^1_j\right) - p_t\left(z^0_j, A^0_j, S^0_j, U^0_j, L^0_j\right)$$
$$\Delta p^r_{jt} = p_t\left(z^1_j, A^0_j, S^{1r}_j, U^0_j, L^0_j\right) - p_t\left(z^0_j, A^0_j, S^0_j, U^0_j, L^0_j\right)$$

The equilibrium price the developer has to pay to the property owner depends on whether multiple developers are interested in buying the property for redevelopment. The probability that more than one developer is interested in buying the parcel is p. Thus, with probability $1-p$, the developer can act as a monopolist and offer to buy the parcel for (epsilon more than) the price a household would pay, $p_t\left(z^0_j, A^0_j, S^0_j, U^0_j, L^0_j\right)$. With probability p, multiple developers are interested in buying the property. Since they face identical costs, developers Bertrand compete away all of the developer surplus and the profit potential from redevelopment would flow fully to the original property owner. Therefore, the intensity of developer competition determines whether the profits from redevelopment flow to developers or property owners. However, without any assumptions on how this equilibrium price is set, the model implies that the likelihood a given parcel gets redeveloped depends on the joint surplus between developers and property owners. The transfer of funds between these groups to purchase the parcel drops out of the calculation because any purchase price for the property between: (1) the price a household would pay and (2) the price above which would lead to negative profits would not change the developer's decision of whether they would want to buy the property to redevelop. The developer's decision is characterized by:

$$\pi_{jt}^{n} = \Delta p_{jt}^{n} - C^{NC}\left(z_j^1, N_j^1, S_j^{1n}, U_j^{1n}\right) + \sigma\varepsilon_{jnt}^{NC}$$
$$\pi_{jt}^{r} = \Delta p_{jt}^{r} - C^{R}\left(z_j^1, N_j^1, S_j^{1r}\right) + \sigma\varepsilon_{jrt}^{R}$$
$$\pi_{jt}^{OO} = 0 + \varepsilon_{jt}^{OO}$$

Here, Δp denotes the developer's gross revenue of redevelopment (i.e., difference in resell price relative to purchase price), providing us a microfounded measure of development potential.[16] Notably, we assume separate construction cost functions (and therefore profits) for renovation and new construction. The developer maximizes profit by choosing between building new construction with intensity $n \in \{0.45, 0.75, 1.00\} \times \{1, \ldots, U_j^{max}\}$, renovating the existing housing with intensity $r \in \{0.1, \ldots, 1.0\}$, and the outside option.

Figures 8 presents the distribution of parcel-level net revenue in 2017 by whether the parcel was sold in 2017, and if sold, whether the parcel was eventually redeveloped. Figure 9 presents the distribution of parcel-level net revenue normalized by the maximum square footage allowed to be built on the parcel in 2017 by whether the parcel was sold in 2017, and if sold, whether the parcel was eventually redeveloped. For the universe of parcels in 2017, parcels sold and undeveloped look similar in their net revenue to parcels unsold. In contrast, parcels sold and developed have noticeably higher net revenue.

[16]Note that purchase prices reflect households' willingness to pay as predicted by our hedonic model, not actual prices paid by developers.

Figure 8: Distribution of parcel-level net revenue in 2017

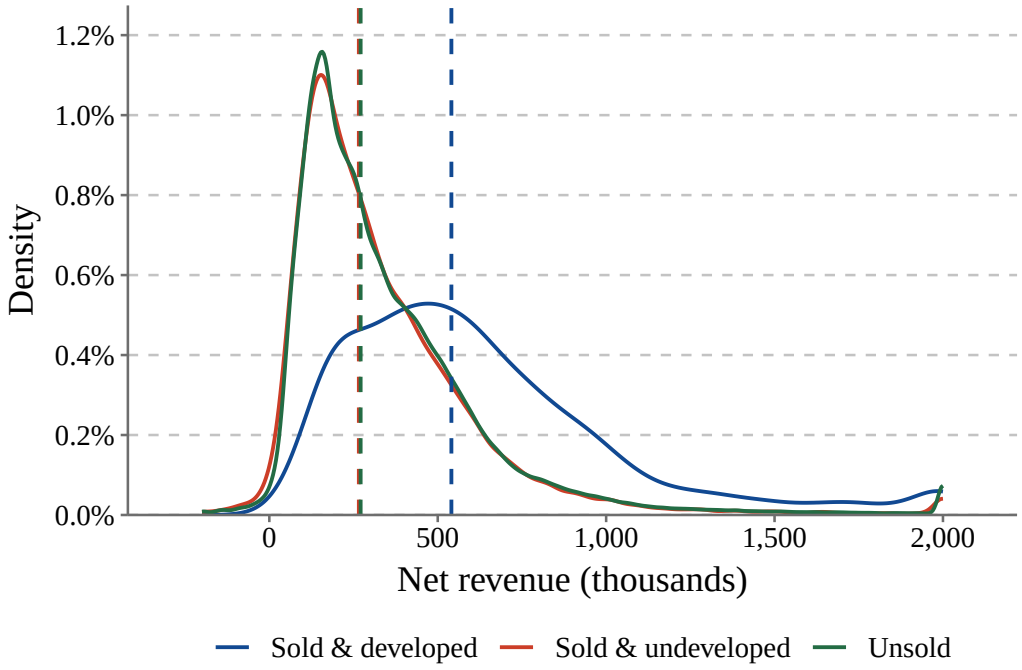
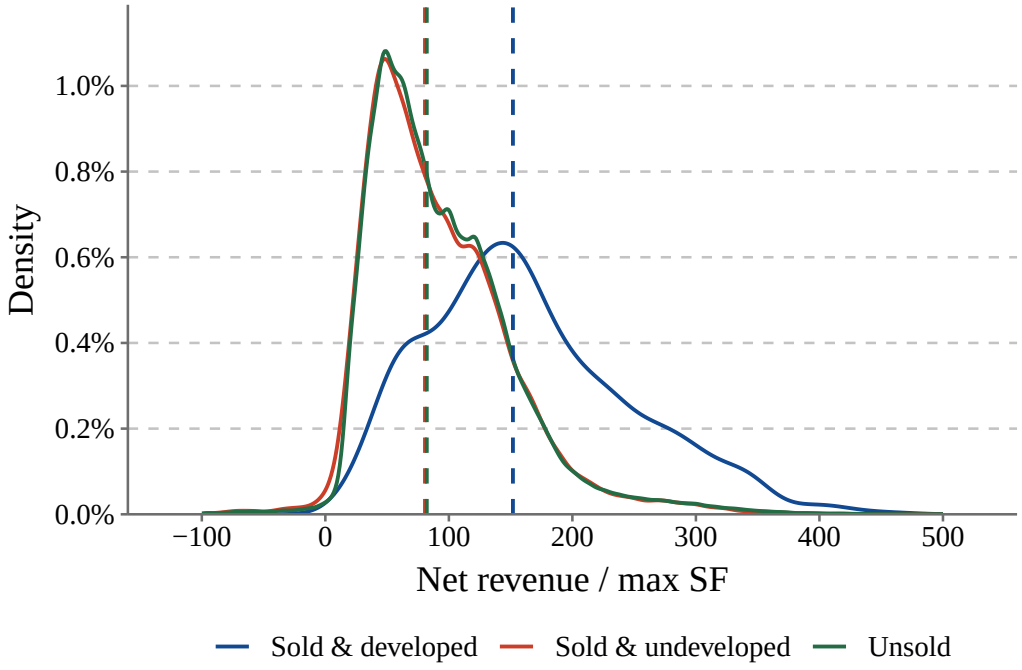


Figure 9: Distribution of parcel-level net revenue per maximum square feet in 2017



We again conduct a variance decomposition exercise, where we regress a parcel's net revenue on census block group fixed effects following equations (1) and (2). We find that 78.5% of variation

a parcel's square footage development intensity is explained by the location of the parcel (Column 1 of Table 6). Including characteristics about the existing buildings on the parcel as well as the parcel's zoning increases the variation explained to 87.1% (Column 3 of Table 6). When parcel characteristics are included, approximately 80% of the variation is explained by location instead (Figure 10). We find that parcels closer to Chicago's central business district have higher net revenue (Figure 11). Parcels in richer neighborhoods as well as parcels with older homes also have higher net revenue.

Table 6: Regression of net revenue on parcel characteristics, 2017

Net revenue / max SF	**(1)**	**Pairwise regression**		**(3)**		**(4)**	
(2017)		**Estimate**	**SE**	**Estimate**	**SE**	**Estimate**	**SE**
Census block group							
Population		6.020	(1.626)				
Median income		32.518	(1.008)				
% white		33.437	(0.860)				
% college		43.221	(0.738)				
Median home value		38.829	(0.860)				
Distance to CBD		−206.653	(15.874)				
Parcel							
Lot SF				1.735	(0.655)	2.233	(0.864)
House SF				−15.297	(0.465)	−15.182	(0.461)
House age				16.682	(0.426)	16.459	(0.415)
# bedrooms / 1,000 SF				3.490	(0.131)	3.469	(0.129)
# bathrooms / 1,000 SF				−3.253	(0.101)	−3.213	(0.100)
# units				11.541	(0.379)	11.702	(0.381)
Zoning covariates						X	
Block group FE	X			X		X	
R^2	0.785			0.869		0.871	

Figure 10: Variance decomposition of net revenue per maximum square feet in 2017

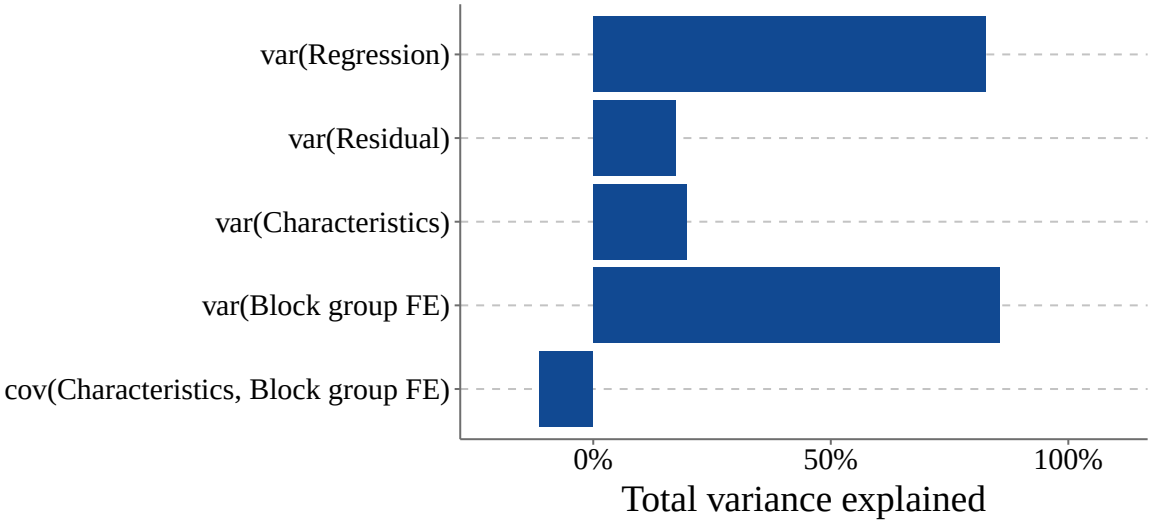
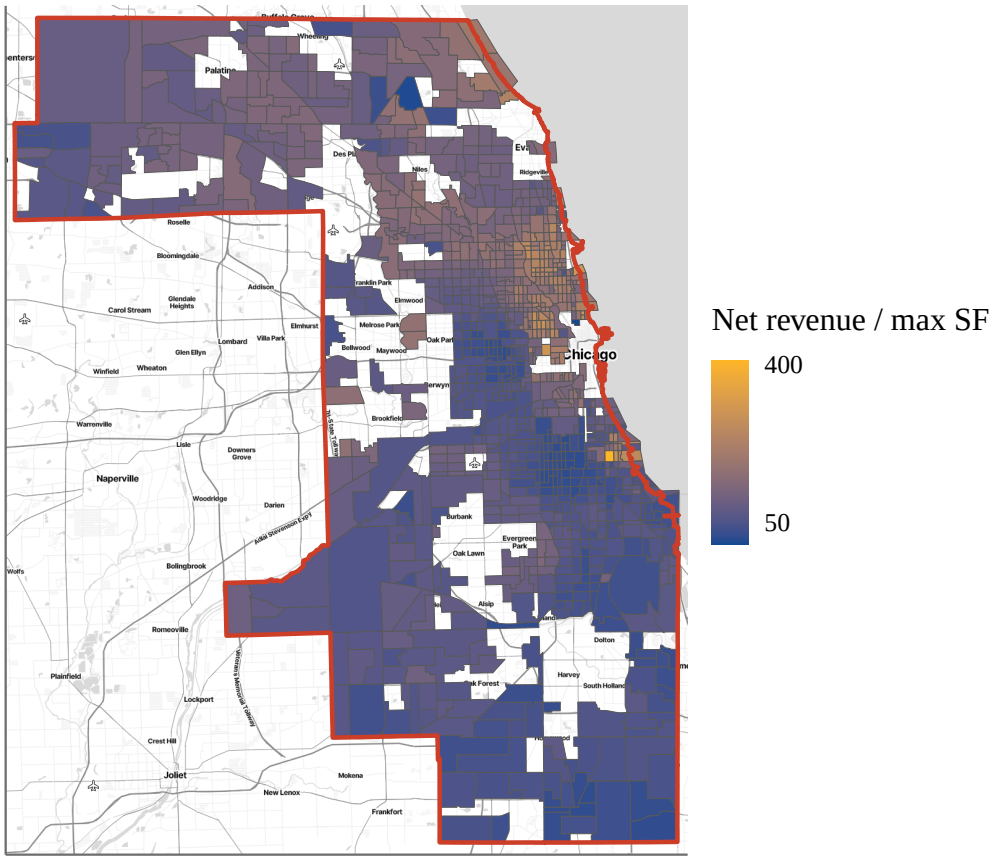


Figure 11: Tract-level net revenue per maximum square feet intensity in 2017



Note: The red border indicates the geographical boundary for Cook County.

4.2 Validation of development potential

We assess the accuracy of our hedonic regression model to predict prices that developers much pay to buy parcels to redevelop and ultimately sell off back to households. Since we fit our hedonic regression only to properties that sell to non-developers, it is possible that there is unobservable selection into which parcels are targeted by developers, making our hedonic predicted prices of lots going through redevelopment biased.

We take transactions within 5 years of a redevelopment event as defined in Section 3.5. For each transaction, we predict log price per square foot using the estimated hedonic model specified in Section 3.4. We predict log price per square foot for each parcel according to its existing characteristics as well as imputed characteristics assuming developer behavior as defined in Section 3.3.[17]

[17]For new construction, we assume developers build to the maximum in both building square footage and units. For renovations, we additionally incorporate developers' ex-post choice of building square footage.

For transactions before the redevelopment event, we compare actual price per square foot paid by the developer for the parcel compared to our predicted price per square foot according to existing characteristics. For transactions after the redevelopment event, we compare actual price per square foot compared to our predicted price per square foot according to imputed characteristics.

Figure 12 presents our validation exercise via binscatter on parcels prior to redevelopment. Actual prices for transactions prior to redevelopment reflect purchases by developers. We interpret predicted prices from our hedonic model using existing characteristics as the price a household would be willing to pay for the parcel absent redevelopment. Therefore, we find that developers typically pay similar prices to households' willingness to pay for parcels that eventually experience new construction. In contrast, developers pay on average 10% higher prices than households' willingness to pay for parcels that are eventually renovated. Developers bidding up prices for parcels with excess development capacity is consistent with developers sharing profits with households, which we explicitly model in our bargaining model.

Figure 13 presents our validation exercise via binscatter on parcels post-redevelopment. Actual prices for transactions after redevelopment reflect sales by developers. Predicted prices from our hedonic model using imputed characteristics reflect the shadow price of a parcel's development capacity. We find that developers typically sell redeveloped parcels at a similar price to our imputed redevelopments. Therefore, our assumptions on developer behavior as defined in Section 3.3 are a reasonable first order approximation to actual developer behavior.

Figure 12: Validation exercise on parcels prior to redevelopment

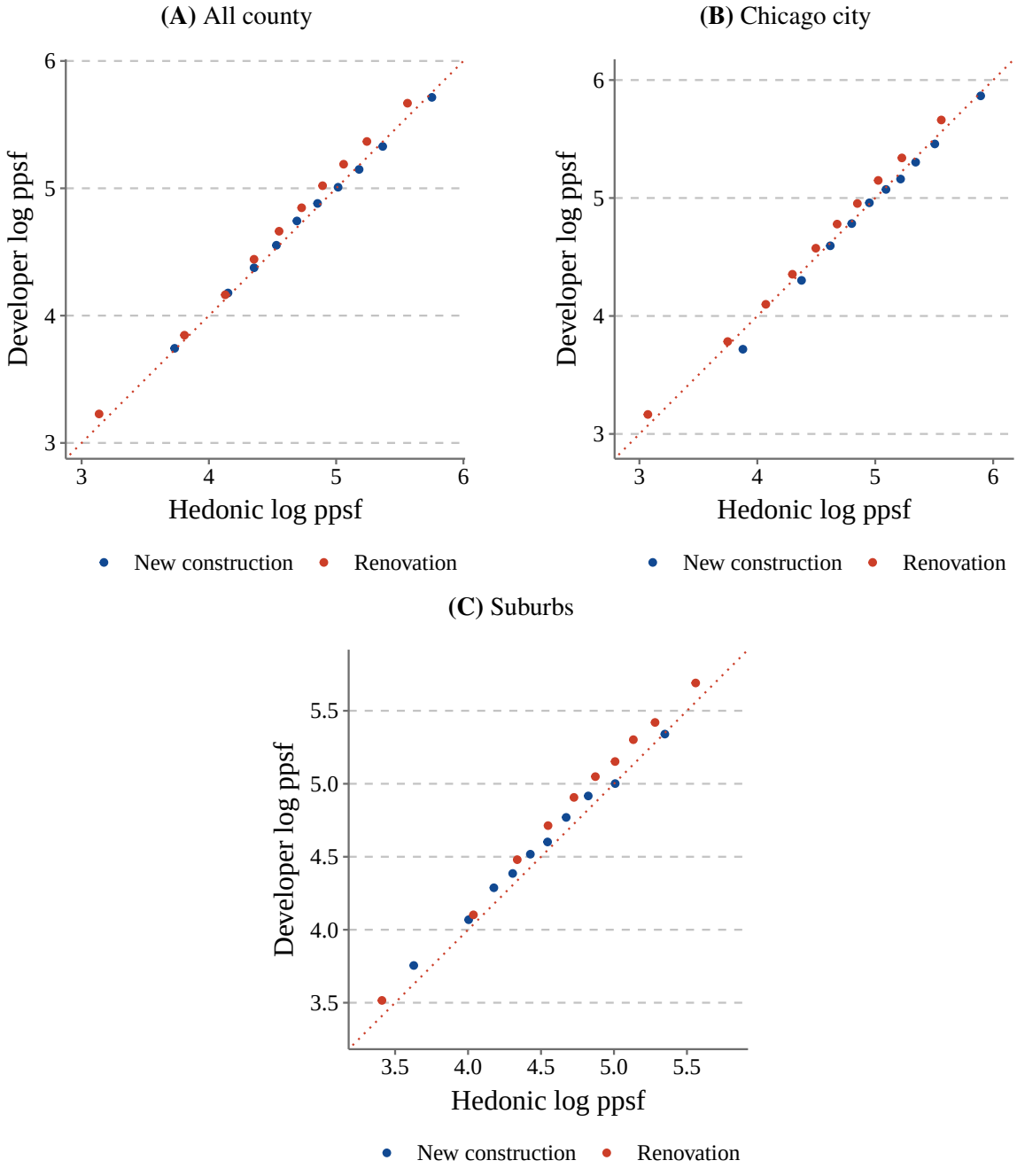
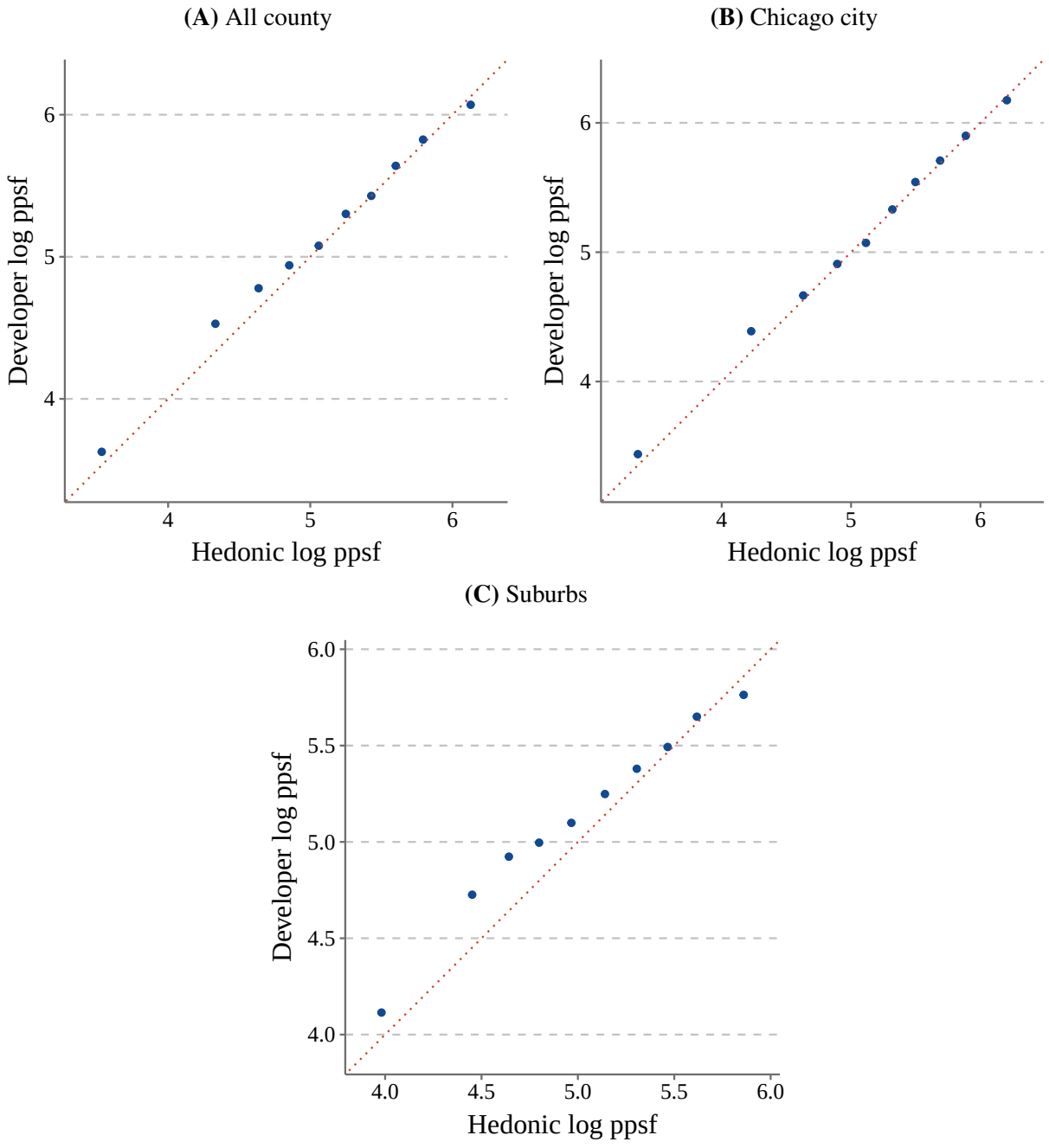


Figure 13: Validation exercise on parcels post-redevelopment



4.3 Infill model estimation

To estimate the model specified in Section 4.1, we normalize profit by each parcel's maximum building square footage as determined by its maximum floor area ratio:

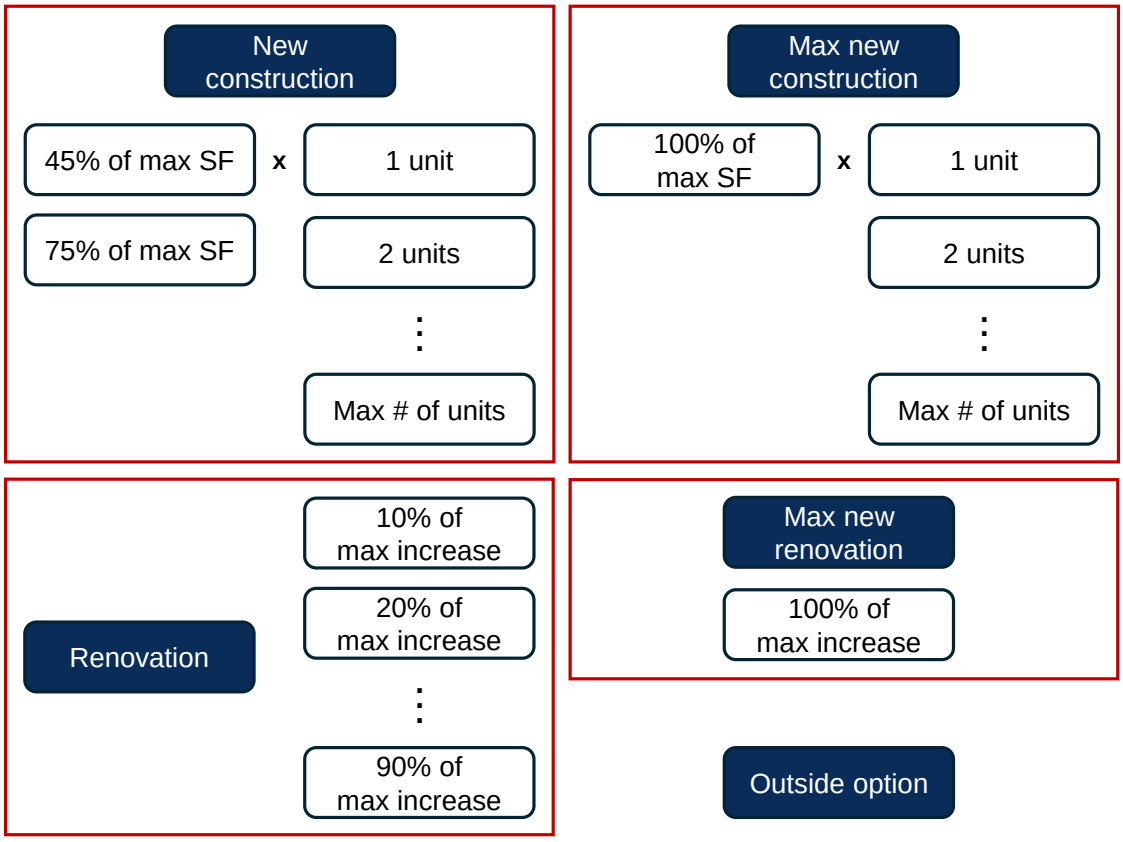
$$\pi_{jt}^{n} = \frac{\sigma^{-1}}{F_j \cdot L_j^0}\Delta p_{jt}^{n} - \frac{\sigma^{-1}}{F_j \cdot L_j^0}C^{NC}\left(z_j^1, N_j^1, S_j^{1n}, U_j^{1n}\right) + \varepsilon_{jnt}^{NC}$$
$$\pi_{jt}^{r} = \frac{\sigma^{-1}}{F_j \cdot L_j^0}\Delta p_{jt}^{r} - \frac{\sigma^{-1}}{F_j \cdot L_j^0}C^{R}\left(z_j^1, S_j^{1r}\right) + \varepsilon_{jrt}^{R}$$
$$\pi_{jt}^{OO} = 0 + \varepsilon_{jt}^{OO}$$

Normalizing profits by each parcel's maximum building square footage: (i) reduces the kurtosis of the distribution of profits, and (ii) allows for heteroskedastic profit shocks such that larger redevelopments experience larger profit shocks. Assume $\left(\varepsilon_{jnt}^{NC}, \varepsilon_{jrt}^{R}, \varepsilon_{jt}^{OO}\right)$ are distributed:

$$\varepsilon_{jnt}^{NC} = \xi_{B_{k(n)}} + \nu_{int}^{NC}$$
$$\varepsilon_{jrt}^{R} = \xi_{B_{k(r)}} + \nu_{irt}^{R}$$
$$\varepsilon_{jt}^{OO} = \xi_{B_{k(OO)}} + \nu_{it}^{OO}$$

where $\left(\nu_{int}^{NC}, \nu_{irt}^{R}, \nu_{it}^{OO}\right)$ are distributed extreme value type I, and (ξ_{B_k}) are nest-specific profit shocks. We assume five nests: no development (i.e., the outside option), maximum new construction (i.e., new construction where the developer chooses to build the maximum square footage), other new construction, maximum renovation (i.e., renovation where the developer chooses to build the maximum square footage), and other renovation. Figure 14 graphically portrays the nests for our model.

Figure 14: Nest structure for infill model



We further assume (ξ_{B_k}) are distributed multivariate normal, characterized by:

B_k	Nest
1	Outside option
2	Other new construction
3	Max new construction
4	Other renovation
5	Max renovation

$$\mu = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}; \sigma = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \sigma_2\text{`} & 0 & 0 \\ 0 & 0 & 0 & \sigma_3 & 0 \\ 0 & 0 & 0 & 0 & \sigma_4 \end{bmatrix}$$

That is, we assume that $\left(\varepsilon_{jnt}^{NC}, \varepsilon_{jrt}^{R}, \varepsilon_{jt}^{OO}\right)$ are distributed such that we estimate a mixed logit model via simulated maximum likelihood. Intuitively, σ^{-1} is identified by the coefficient on (nor-

malized) net revenue $\frac{\Delta p_{jt}}{F_j \cdot L_j^0}$. Holding construction costs fixed, the developer should be more likely to purchase and redevelop property when net revenue is high unless cost shocks are highly idiosyncratic. Variable costs α versus other costs (e.g., fixed costs FC) are identified by the types of redevelopments that occur with respect to building square footage. High fixed costs suggest that smaller redevelopments are relatively more likely to occur when net revenue is high, and larger redevelopments are relatively more likely to occur when net revenue is low. Variation in net revenue derives from cross-sectional differences in development capacity as well as longitudinal changes in housing prices. Our key identifying assumption is that construction costs are homogeneous across parcels and years.[18]

We present coefficients estimated on the sample of residential property transactions for Cook County from 2001 to 2018.[19] We separately estimate the model for single-family redevelopments versus multi-family redevelopments, and we allow construction costs to differ pre- and post-2007 financial crisis. Standard errors are calculated via bootstrapping. Table 7 presents construction cost estimates for single-family redevelopments, whereas Table 8 presents construction cost estimates for multi-family redevelopments. We benchmark our construction costs to construction costs from the R.S. Means company.[20] R.S. Means estimates single-family construction costs of $227.75 per square feet and multi-family construction costs of $345.16 for the city of Chicago in 2021.

[18] As a robustness check, we estimate our model with year-varying construction costs, therefore using only cross-sectional variation in net revenue. We find suggestive evidence that construction costs differ pre- and post- 2007 financial crisis, but are relatively constant otherwise.

[19] To match the hedonic model, we further limit the sample to single-family housing and multi-family housing with six or less units.

[20] Cost estimates from R.S. Means are best interpreted as the price of building residential housing efficiently, which means building several units at a time. One-off construction in particular would be much more costly (Glaeser and Gyourko 2018).

Table 7: Single-family supply model estimates

$ 2021	All county		City		Suburbs	
	2001-07	2008-19	2001-07	2008-19	2001-07	2008-19
New construction						
Variable cost	216.2	278.4	198.2	241.3	224.5	279.2
	(8.0)	(9.0)	(10.6)	(10.7)	(11.6)	(13.5)
Fixed cost (000s)	334.2	356.8	348.2	404.3	258.2	307.4
	(20.3)	(21.6)	(24.2)	(26.0)	(29.0)	(30.3)
Lot split (000s)	491.3	394.7	450.9	395.2	504.3	504.0
	(47.4)	(47.3)	(53.1)	(51.8)	(81.9)	(92.7)
Renovation						
Variable cost	331.1	360.9	250.68	281.9	369.1	387.8
	(10.9)	(12.0)	(11.2)	(11.5)	(17.0)	(18.8)
Fixed cost (000s)	−37.5	−36.1	31.7	40.3	−90.5	−89.8
	(7.9)	(8.3)	(8.6)	(9.6)	(17.2)	(19.3)

Table 8: Multi-family supply model estimates

$ 2021	All county			All county	
	2001-07	2008-19		2001-07	2008-19
New construction			Renovation		
Variable cost	346.6	440.0	Variable cost	284.5	383.6
	(19.1)	(19.6)		(18.5)	(33.0)
Unit cost (000s)	37.1	51.1	Fixed cost (000s)	12.6	−3.3
	(29.6)	(23.3)		(23.9)	(41.0)
Fixed cost (000s)	221.3	328.1			
	(40.9)	(34.3)			
Lot split (000s)	556.3	603.7			
	(66.8)	(67.0)			

Note: We do not separately estimate the multiplex low-rise supply model for the suburb sample due to a lack of multiplex redevelopments.

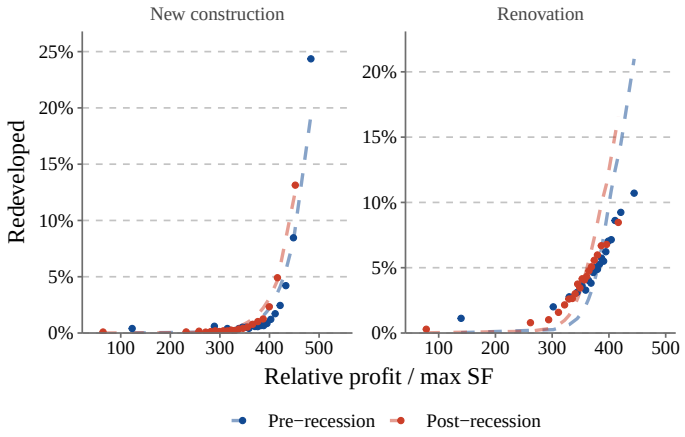
To evaluate model fit, we compare the redevelopment probabilities predicted by our model to actual redevelopments. We present binscatters of the relationship between model-implied profits and probability of redevelopment.[21] Figure 15 presents model fit for single-family redevelopments, whereas Figure 16 presents model fit for multi-family redevelopments. We find our model fits to

[21] Model-implied profits do not include idiosyncratic profit shocks, which are distributed generalized extreme value and therefore have a positive expected value.

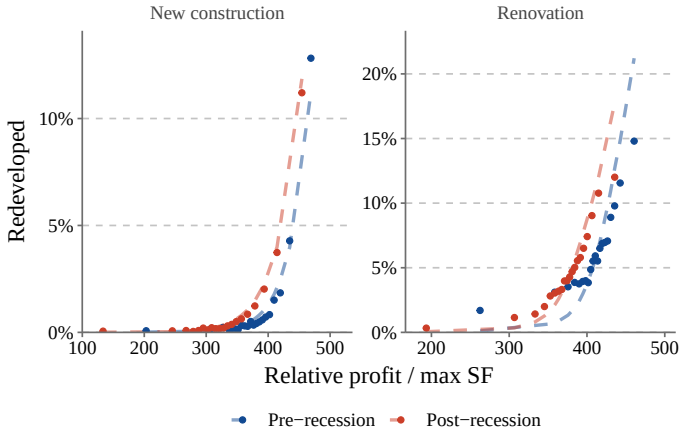
be reasonable, with the models for new construction fitting particularly well. Figure 17 presents census tract-level probabilities of redevelopment for transactions in 2019. To assess fit across time, Figure 18 presents model-predicted versus actual change in square footage per parcel by year.

Figure 15: Single-family profitability versus probability of redevelopment

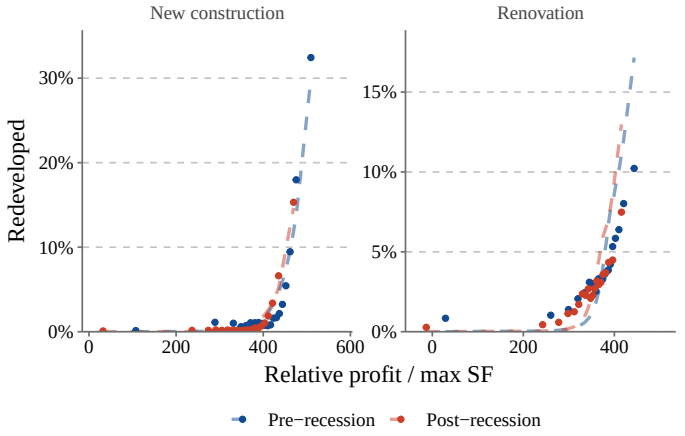
(A) All county



(B) Chicago city



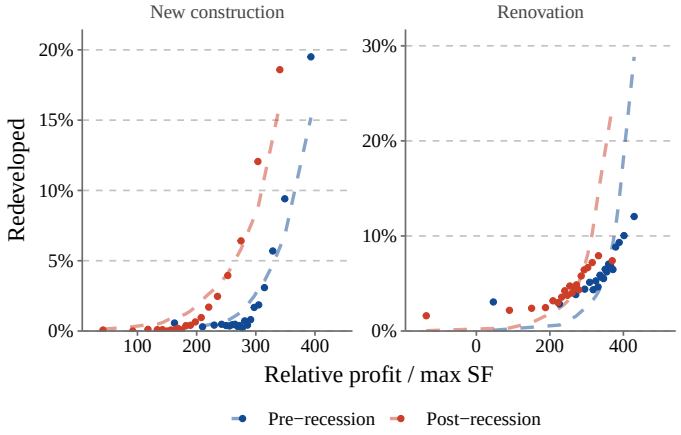
(C) Suburbs



Note: Dotted lines indicate model-predicted probabilities of redevelopment, whereas points indicate actual probabilities. Model-implied profits do not include idiosyncratic profit shocks, which are distributed generalized extreme value and therefore have a positive expected value.

Figure 16: Multi-family profitability versus probability of redevelopment

(A) All county



Note: Dotted lines indicate model-predicted probabilities of redevelopment, whereas points indicate actual probabilities. Model-implied profits do not include idiosyncratic profit shocks, which are distributed generalized extreme value and therefore have a positive expected value.

Figure 17: Tract-level probability of redevelopment in 2019

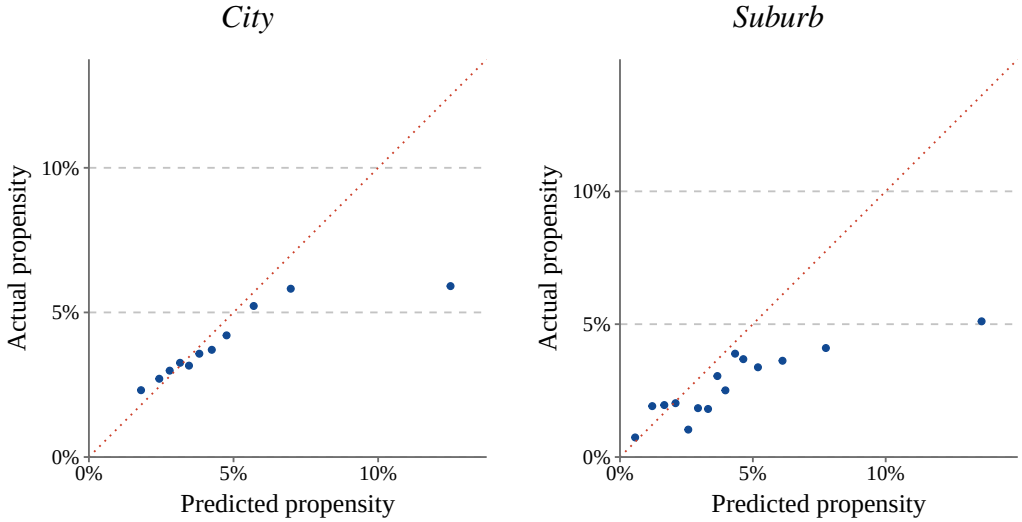
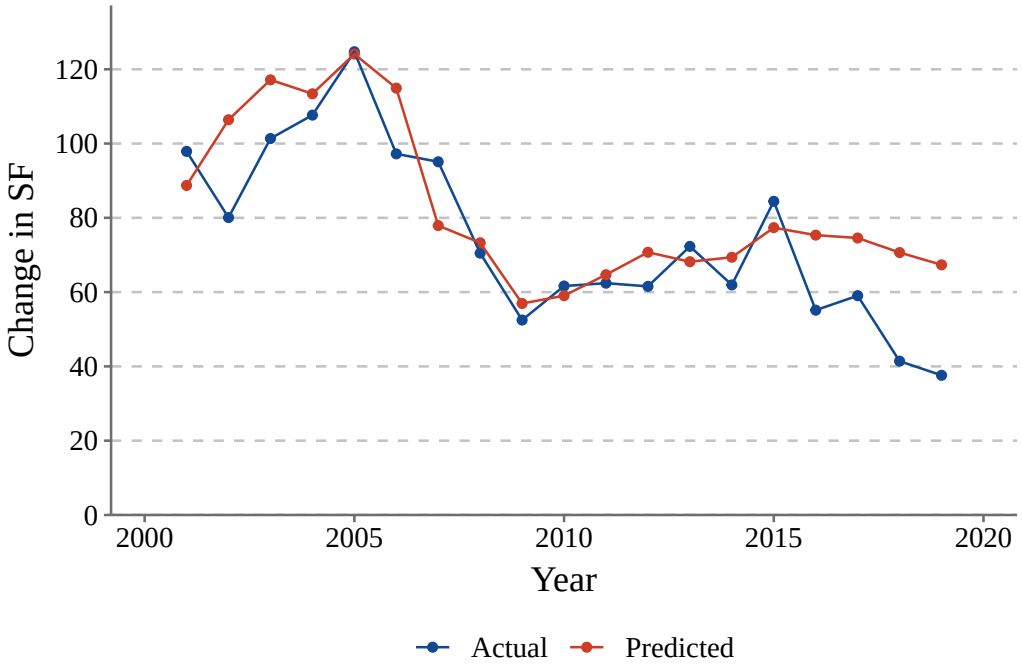
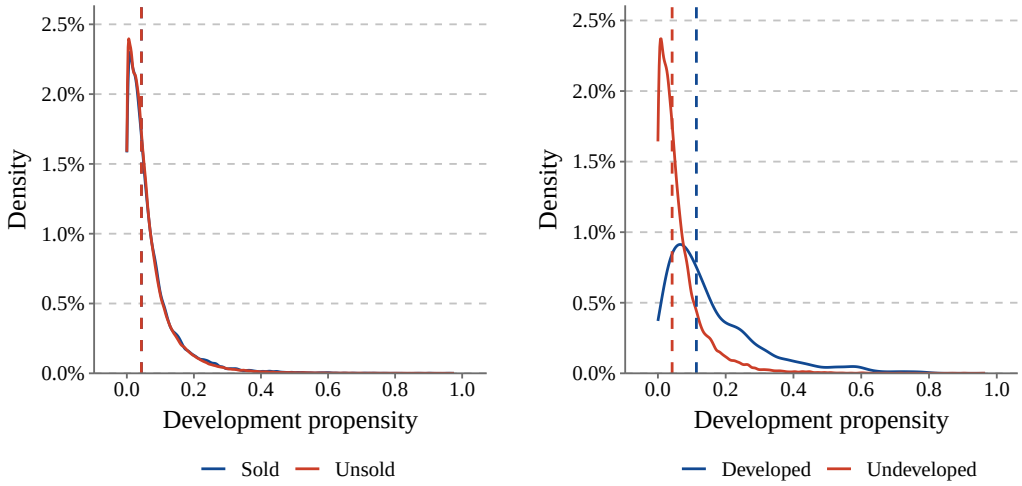


Figure 18: Annual change in square footage per parcel, 2001-2019



Figures 19 presents the distribution of parcel-level probability of redevelopment in 2017 by whether the parcel was sold in 2017, and if sold, whether the parcel was eventually redeveloped. For the universe of parcels in 2017, parcels sold and undeveloped look similar in their probability of redevevelopment to parcels unsold. In contrast, parcels sold and developed have noticeably higher probability of redevelopment.

Figure 19: Distribution of parcel-level probability of redevelopment in 2017



We again conduct a variance decomposition exercise, where we regress a parcel's probability of redevelopment on census block group fixed effects following equations (1) and (2). We find that 37.8% of variation a parcel's square footage development intensity is explained by the location of the parcel (Column 1 of Table 9). Including characteristics about the existing buildings on the parcel as well as the parcel's zoning increases the variation explained to 57.4% (Column 3 of Table 9). When parcel characteristics are included, approximately 50% of the variation is explained by location instead (Figure 20). We find that parcels closer to Chicago's central business district have higher probability of redevelopment (Figure 21). Parcels in richer neighborhoods as well as parcels with older homes also have higher probability of redevelopment.

Table 9: Regression of probability of redevelopment on parcel characteristics, 2017

Development propensity (2017)	(1)	Pairwise regression Estimate	SE	(3) Estimate	SE	(4) Estimate	SE
Census block group							
Population		0.585	(0.166)				
Median income		1.839	(0.116)				
% white		2.072	(0.101)				
% college		3.262	(0.094)				
Median home value		2.584	(0.105)				
Distance to CBD		−12.430	(1.649)				
Parcel							
Lot SF				1.850	(0.555)	1.892	(0.639)
House SF				−3.512	(0.112)	−3.504	(0.107)
House age				1.704	(0.063)	1.869	(0.062)
# bedrooms / 1,000 SF				0.652	(0.029)	0.687	(0.028)
# bathrooms / 1,000 SF				−0.148	(0.021)	−0.178	(0.020)
# units				1.394	(0.079)	1.217	(0.073)
Zoning covariates						X	
Block group FE	X			X		X	
R^2	0.378			0.557		0.574	

Figure 20: Variance decomposition of probability of redevelopment in 2017

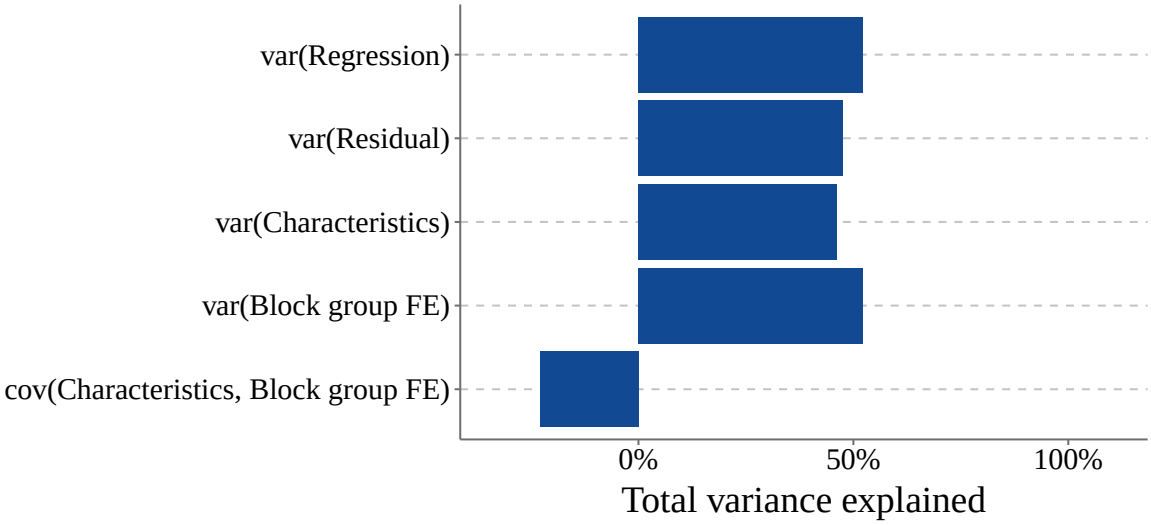
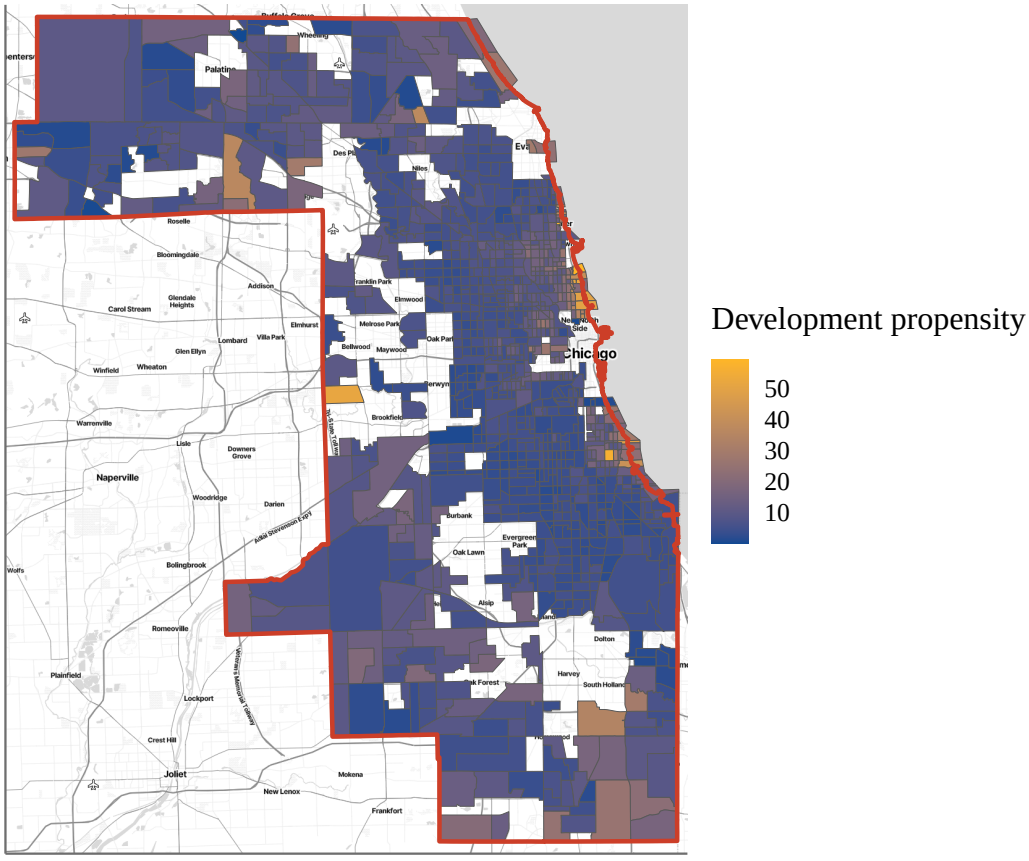


Figure 21: Tract-level probability of redevelopment in 2017



Note: The red border indicates the geographical boundary for Cook County.

Finally, recovering cost parameters for our model allows us to calculate expected joint surplus for all parcels, and estimate the bargaining parameters of our model. In particular, denote $D(j) = 1$ as indicating that a parcel is redeveloped. Taking the conditional expectation of the equilibrium solution for household surplus gives us that:

$$\beta = \frac{E_j\left[p^*_{jt} - p_t\left(z^0_j, A^0_j, S^0_j, U^0_j, L^0_j\right) \mid D(j) = 1\right]}{E_j\left[E_\varepsilon\left[\max\left\{JS^n_{jt}, JS^r_{jt}\right\}\right] \mid D(j) = 1\right]}$$

where $E_\varepsilon\left[\max\left\{JS^n_{jt}, JS^r_{jt}\right\}\right]$ is the expected joint surplus given redevelopment, and calculated via numerical integration. Importantly, given that a parcel is redeveloped, we observe realized household surplus $p^*_{jt} - p_t$ in the data (see Figure 13). Therefore, β can be estimated via method of moments.

We estimate a household bargaining parameter of $\beta = 0.26$, implying that the majority of joint

surplus goes to the developer.

4.4 Vacant land model set-up

Suppose vacant land properties are owned by the representative developer. Each property j consists of a single lot of size L_j^0 with characteristics z_j^0. The developer may choose whether to develop property into residential buildings. If the developer does not develop the property, they receive their outside option given by:

$$\pi_{jt}^{OO} = g\left(z_j^0\right) + \varepsilon_{jt}^{OO}$$

where ε_{jt}^{OO} is some idiosyncratic profit shock.

If the developer develops the property, they can choose to subdivide the property into N_j^1 lots of size L_j^1 and on each lot, build housing of quality z_j^1, size S_j^1, age $A_j^1 = 0$, and number of units U_j^1. As detailed in Section 3.3, we assume developers split lots evenly until zoning restrictions bind. We make this assumption to simplify model complexity during estimation. A developer may build square footage up to the maximum allowed by the maximum floor area ratio. For implementation, we discretize the developer's new construction choice set. Developers can build square footage by 45% of the maximum, 75% of the maximum, or 100% of the maximum. A developer may build units up to the maximum allowed by the permitted use and minimum lot size per unit. Developers can build 1 unit per lot, 2 units per lot, 3 units per lot, 4 units per lot, or the maximum units per lot.[22] That is, given minimum lot size L_j^{min}, maximum floor area ratio F_j, and minimum lot size per unit L_j^{unit}, the developer may choose from new construction intensity $n \in \{0.45, 0.75, 1.00\} \times \{1, \ldots, U_j^{max}\}$ such that:

$$\begin{aligned}
N_j^1 &= \text{floor}\left(\frac{L_j^0}{L_j^{min}}\right) \\
L_j^1 &= \frac{L_j^0}{N_j^1} \\
U_j^{max} &= \text{floor}\left(\frac{L_j^1}{L_j^{unit}}\right) \\
S_j^{1n} &= n_1 \cdot L_j^1 F_j \\
U_j^{1n} &= n_2
\end{aligned}$$

Developer profit for a given property, if they choose to develop, is therefore given by:

[22] If the maximum unit per lot is, for instance, 2, developers can choose to build either 1 unit per lot or 2 units per lot.

$$\pi_{jt}^{n} = N_j^1 \cdot p_t\left(z_j^1, 0, S_j^{1n}, U_j^{1n}, L_j^1\right) - C^{NC}\left(z_j^1, N_j^1, S_j^{1n}, U_j^{1n}\right)^{NC} - f\left(z_j^0\right) + \sigma\varepsilon_{jnt}^{NC}$$

where p_t is the hedonic price surface at time t, n is the new construction intensity, C are the construction cost functions estimated in Section 4.3, ε_{jt} is an idiosyncratic profit shock, and σ is the dispersion of the profit shock. We denote as gross profit as the following:

$$\Delta\, p_{jt}^{n} = N_j^1 \cdot p_t\left(z_j^1, 0, S_j^{1n}, U_j^{1n}, L_j^1\right) - C^{NC}\left(z_j^1, N_j^1, S_j^{1n}, U_j^{1n}\right)$$

and parameterize the value of the outside option (which can alternatively be interpreted as the ncremental cost of vacant land development):

$$f\left(z_j^0\right) + g\left(z_j^0\right) = \alpha \cdot L_j^0 + FC$$

where α is the incremental variable cost of vacant land development per lot square foot and FC is the incremental fixed cost of vacant land development. Here, Δp denotes the developer's gross profit of redevelopment (i.e., difference in sale price relative to construction costs), providing us a microfounded measure of development potential. As we directly observe developer's gross profits, we can directly estimate the outside option. The developer maximizes profit by choosing between building new construction with intensity $n \in \{0.45, 0.75, 1.00\} \times \{1, \ldots, U_j^{max}\}$ and the outside option.

4.5 Vacant law model estimation

To estimate the model specified in Section 4.4, we normalize profit by each parcel's maximum building square footage as determined by its maximum floor area ratio:

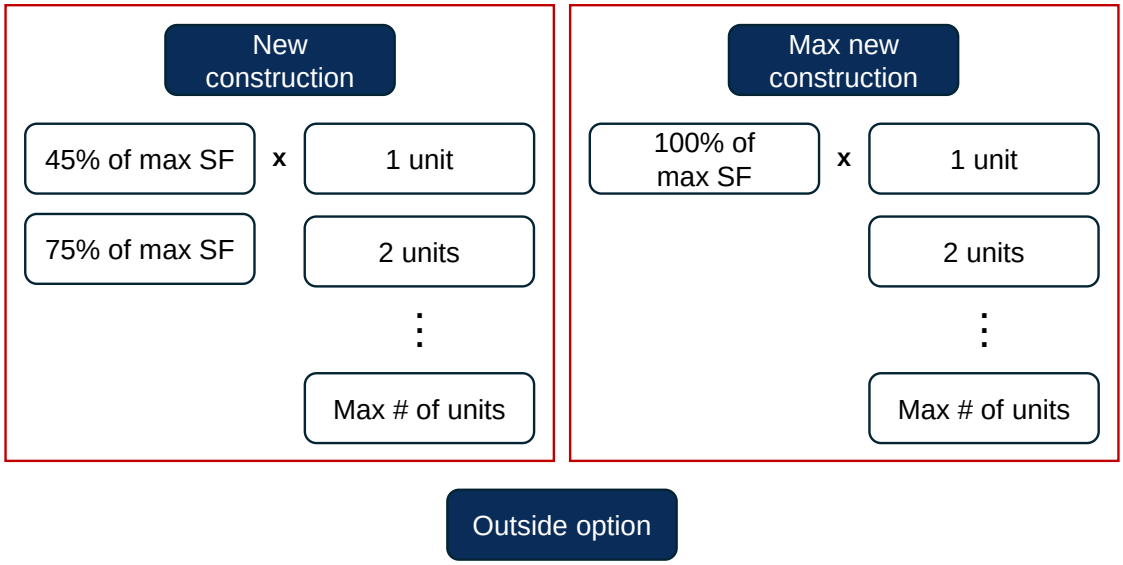
$$\begin{aligned}
\pi_{jt}^{n} &= \frac{\sigma^{-1}}{F_j \cdot L_j^0}\Delta p_{jt}^{n} - \frac{\sigma^{-1}}{F_j \cdot L_j^0}\left(f\left(z_j^0\right) + g\left(z_j^0\right)\right) + \varepsilon_{jnt}^{NC} \\
\pi_{jt}^{OO} &= 0 + \varepsilon_{jt}^{OO}
\end{aligned}$$

Normalizing profits by each parcel's maximum building square footage: (i) reduces the kurtosis of the distribution of profits, and (ii) allows for heteroskedastic profit shocks such that larger redevelopments experience larger profit shocks. Assume $\left(\varepsilon_{jnt}^{NC}, \varepsilon_{jt}^{OO}\right)$ are distributed:

$$\varepsilon_{jnt}^{NC} = \xi_{B_{k(n)}} + \nu_{int}^{NC}$$
$$\varepsilon_{jt}^{OO} = \xi_{B_{k(OO)}} + \nu_{it}^{OO}$$

where $\left(\nu_{int}^{NC}, \nu_{it}^{OO}\right)$ are distributed extreme value type I, and (ξ_{B_k}) are nest-specific cost shocks. We assume three nests: no development (i.e., the outside option), maximum new construction (i.e., new construction where the developer chooses to build the maximum square footage), and other new construction. Figure 22 graphically portrays the nests for our model.

Figure 22: Nest structure for vacant land model



We further assume (ξ_{B_k}) are distributed multivariate normal, characterized by:

$B(j)$	Nest
1	Outside option
2	Other new construction
3	Max new construction

$$\mu = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}; \sigma = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \sigma_3 \text{`} \end{bmatrix}$$

That is, we assume that $\left(\varepsilon_{jnt}^{NC}, \varepsilon_{jt}^{OO}\right)$ are distributed such that we estimate a mixed logit model via simulated maximum likelihood. Intuitively, σ^{-1} is identified by the coefficient on (normalized) gross profit $\frac{\Delta p_{jt}}{F_j \cdot L_j^0}$. Holding the value of the outside option fixed, the developer should be more likely to develop property when gross profit is high unless cost shocks are highly idiosyncratic. The value of the outside option is identified by the types of developments that occur with respect to lot characteristics.

We present coefficients estimated on the sample of vacant land transactions for Cook County from 2001 to 2019. We separately estimate the model for truly vacant land versus other land types (e.g., garages), and we allow the value of the outside option to differ pre- and post-2007 financial crisis. Standard errors are calculated via bootstrapping. Table 10 presents outside option estimates for vacant land developments.

To evaluate model fit, we compare the development probabilities predicted by our model to actual developments. We present binscatters of the relationship between gross profits and probability of development.[23] Figure 23 presents model fit for vacant land developments, whereas Figure 24 presents model fit for other land developments. We find our model fits to be reasonable, though noisier than the infill redevelopment model.

Table 10: Vacant land supply model estimates

$ 2021	**Vacant**		**Other**	
	Pre	**Post**	**Pre**	**Post**
VC	4.1	21.4	65.7	117.1
	(4.4)	(7.7)	(34.4)	(33.8)
FC (thousands)	479.3	351.4	576.1	615.7
	(127.9)	(78.3)	(219.8)	(172.5)

[23] Gross profits do not include idiosyncratic profit shocks, which are distributed generalized extreme value and therefore have a positive expected value.

Figure 23: Model fit for vacant land

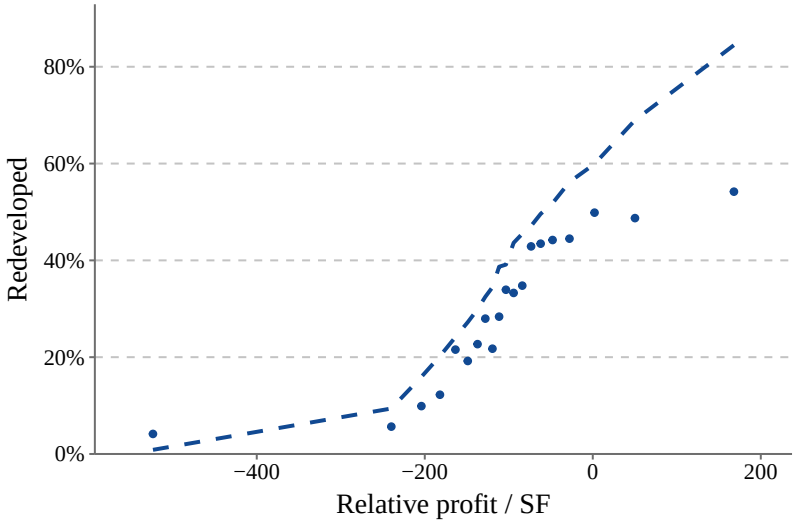
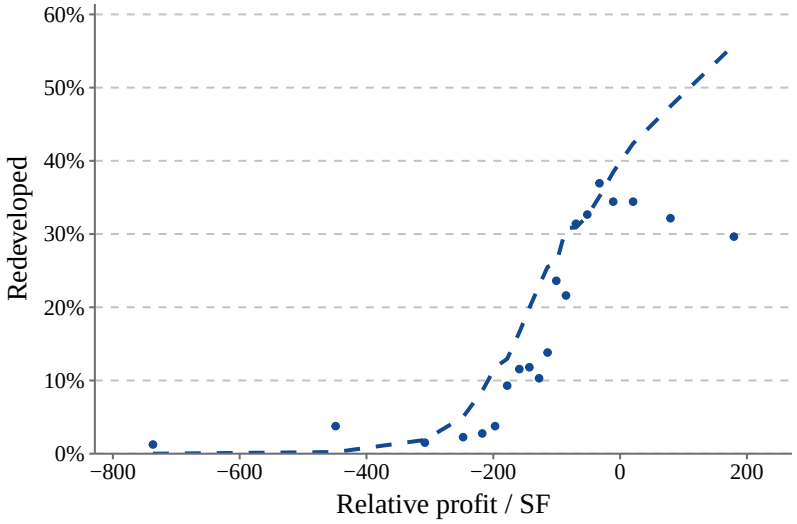


Figure 24: Model fit for other land



5 Counterfactuals

5.1 Supply-side response to zoning reforms

Using our model of developer behavior, we evaluate the supply-side response to a number of different types of potential zoning reforms. A currently proposed zoning reform in Chicago is to "ban single family zoning" and allow at least 3 units on every lot. We compare a few different ways to implement this type of reform. First, we set the minimum lot size per unit to one third

of minimum lot size, therefore allowing any standard lot to build 3-unit multifamily housing.[24] A second alternative way to allow three units on all lots is to also allow these 3-unit buildings to have a density bonus. This allow for more total square feet to be built on the lot, in addition to relaxing the number of units from 1 to 3 per lot. Without this additional density bonus, we would only be allowing developers to build 3 units in the fixed amount of total square footage already allowed for under the single family zoning. We implement this by increasing maximum floor area ratios proportionally to the increase in units from the triplex reform.[25]

In addition to the Chicago proposal to ban single family zonoing, many policy makers, including Kamala Harris, are pushing for permitting reform to "cut red tape" and ease the administrative burden of the permiting process for new developments. To simulate how cutting red tape would impact development, we reduce the fixed cost of construction by 25%. The fixed costs of construction, as estimated by developer revealed preference, should encompass all the soft costs rolled into the redevelopment process, including permitting.

To simulate the supply-side response for each of these counterfactuals, we hold fixed the observed hedonic pricing function that we already estimated in the data. Thus, we are not allowing prices to drop from the increased supply of new housing. Since this house price decline driven by the new construction would surely dampen the profits developers would be able to make, these counterfactuals should be taken as an upper bound on the amount of new development that would be created.

Table 11 presents how the housing stock changes under the triplex zoning reform. The total number of units built increase by 2.9% in the city and 6.2% in the suburbs, with negligible change in the quality of the housing stock. We then calculate the effect of the triplex zoning reform on housing values. To do so, we use our estimates in Section 4.3 to recalculate joint surplus from the development oppurtunity, which can be split between property sellers and developers. Consistent with our bargaining model, we assume that 26% of the change in joint surplus goes to households, thus driving up their property values. Figures 25 and 26 present a binscatter of the change in housing values by census block group median income. Parcels in census block groups with higher median income see larger changes in housing values in level terms, but parcels in census block groups with lower median income see larger changes in housing values in percent terms.

[24] As an example, supposed we have 10,000 sq. ft. lot with a minimum lot size of 5,000 sq. ft. We would set the minimum lot size per unit to 1,666 sq. ft. per unit. Developers could then split the lot into two 5,000 sq.ft., and build 3 units on each lot.

[25] As an example, suppose we are considering a density bonus where we additionally triple maximum FAR. Suppose we have a 10,000 sq. ft. lot with a minimum lot size of 5,000 sq. ft. and minimum lot size per unit of 5,000 sq. ft. prior to the reform. We would multiply the existing maximum FAR by 5,000 / (5,000 / 3) = 3. Suppose instead we have a 10,000 sq. ft. lot with a minimum lot size of 5,000 sq. ft. and minimum lot size per unit of 2,500 sq. ft. prior to the reform (i.e., the lot already allows for duplexes). We would multiply the existing maximum FAR by 2,500 / (5,000 / 3) = 1.5.

Table 11: Counterfactual housing stock under triplex reform

	City			
	Status quo	**Expected**	**Triplex**	**Δ**
Price per unit	$197,216	$239,585	$236,494	−1.29%
Price per sq. ft.	$172.6	$167.5	$171.2	2.20%
Sq. ft. per unit	1,218	1,374	1,378	0.36%
Units	1.351	1.394	1.434	2.86%

	Suburb			
	Status quo	**Expected**	**Triplex**	**Δ**
Price per unit	$310,647	$345,042	$348,232	0.92%
Price per sq. ft.	$183.6	$175.8	$178.0	1.22%
Sq. ft. per unit	1,686	1,890	1,963	3.83%
Units	1.011	1.062	1.129	6.24%

Figure 25: Change in housing value under triplex reform

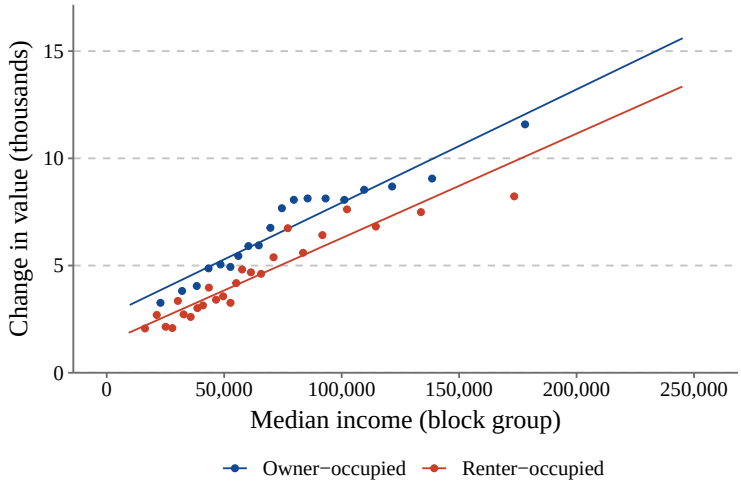


Figure 26: Percent change in housing value under triplex reform

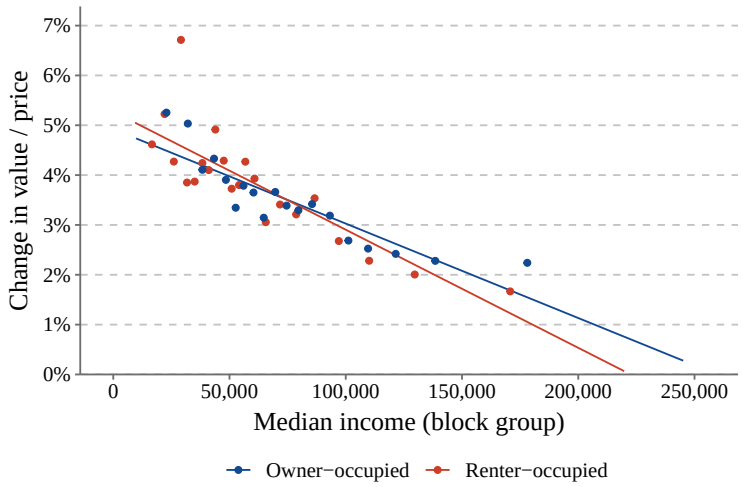


Table 12 presents how the housing stock changes under the triplex zoning reform where we also proportionately triple floor area ratios. Number of units increase by 6.3% in the city and 9.3% in the suburbs, with large increases in the quality of the housing stock. Figures 27 and 28 present a binscatter of the change in housing values by census block group median income. Parcels in census block groups with higher median income see larger changes in housing values in level terms, but parcels in block groups with lower median income see larger changes in housing values in percent terms.

Table 12: Counterfactual housing stock under triplex reform with density bonus

	City			
	Status quo	**Expected**	**Triplex + FAR**	**Δ**
Price per unit	$197,216	$239,585	$291,945	21.85%
Price per sq. ft.	$172.6	$167.5	$156.3	−6.68%
Sq. ft. per unit	1,218	1,374	1,937	41.00%
Units	1.351	1.394	1.482	6.33%

	Suburb			
	Status quo	**Expected**	**Triplex + FAR**	**Δ**
Price per unit	$310,647	$345,042	$428,878	24.30%
Price per sq. ft.	$183.6	$175.8	$161.2	−8.31%
Sq. ft. per unit	1,686	1,890	2,908	53.86%
Units	1.011	1.062	1.161	9.28%

Figure 27: Change in housing value under triplex reform with density bonus

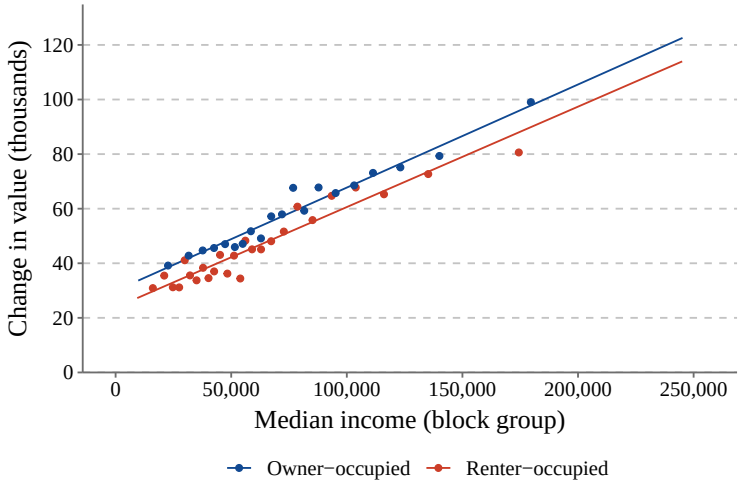


Figure 28: Percent change in housing value under triplex reform with density bonus

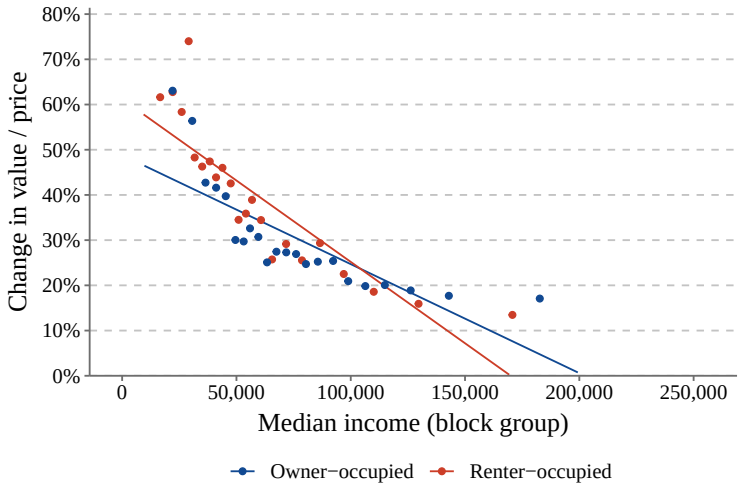


Table 13 presents how the housing stock changes under the red tape reform where we decrease fixed costs by 25%. We find negligible changes in both the number of units as well as the quality of the housing stock. Figures 29 and 30 present a binscatter of the change in housing values by census block group median income. Parcels in census block groups with higher median income see larger changes in housing values in both level and percent terms.

Table 13: Counterfactual housing stock under red tape reform

	City			
	Status quo	**Expected**	**Fixed cost**	**Δ**
Price per unit	$197,216	$239,585	$246,340	2.82%
Price per sq. ft.	$172.6	$167.5	$170.0	1.50%
Sq. ft. per unit	1,218	1,374	1,381	0.51%
Units	1.351	1.394	1.394	0.01%

	Suburb			
	Status quo	**Expected**	**Fixed cost**	**Δ**
Price per unit	$309,882	$346,510	$350,995	1.29%
Price per sq. ft.	$183.5	$174.5	$175.7	0.68%
Sq. ft. per unit	1,681	1,899	1,910	0.57%
Units	1.011	1.075	1.077	0.12%

Figure 29: Change in housing value under red tape reform

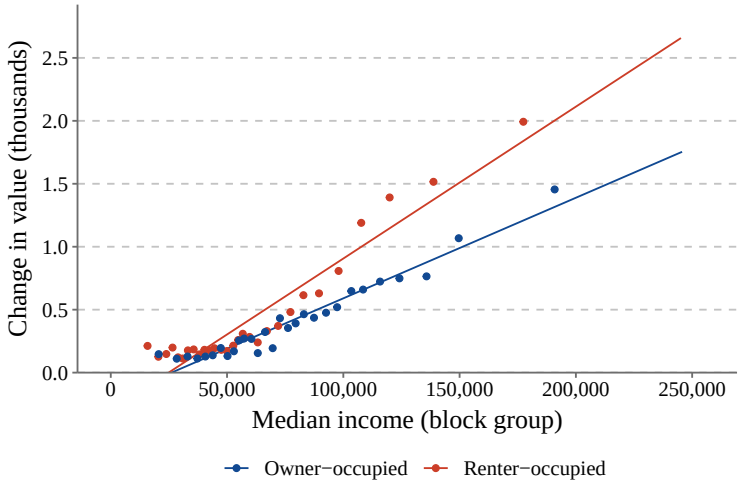


Figure 30: Percent change in housing value under red tape reform

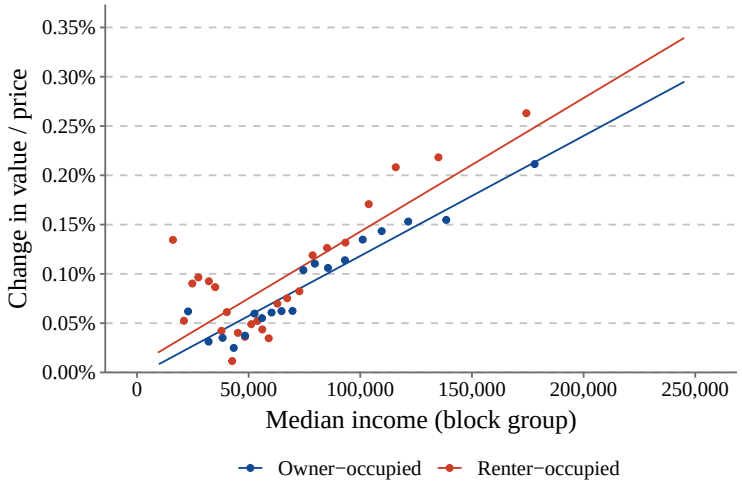


Table 14 presents the aggregate changes in the housing stock by type of development under our counterfactual reforms. We additionally simulate a counterfactual where the triplex zoning reform is paired with a density bonus where we proportionally triple maximum floor area ratios, but only if developers build new construction with the maximum number of units. We find that applying density bonuses only when developers build the maximum number of units actually increases the amount of units built for infill redevelopments, as developers are dissuaded from renovation. This highlights the importance of designing zoning reforms that properly account for developer incentives.

Table 14: Aggregate change in housing stock by type of development

	Infill			**Land**		
	Expected	**Policy**	**Δ**	**Expected**	**Policy**	**Δ**
Triplex	812,092	826,301	14,209	32,507	47,573	15,067
Triplex + FAR ×3	812,092	845,173	33,081	32,507	65,757	33,251
Triplex + FAR ×3 (max units only)	812,092	867,413	55,322	32,507	51,134	18,628
FC	812,900	812,112	−788	34,862	33,644	1,138

5.2 Housing supply elasticities

Finally, we simulate the effects of uniformly increasing the hedonic price surface by 10% in order to calculate parcel-level price elasticities. For all of our analyses, we compare counterfactual construction relative to expected construction rather than the status quo housing stock. That is, we assume all parcels first come to market and developers build under current zoning rules.

Finally, we simulate the effects of uniformly increasing the hedonic price surface by 10%

in order to calculate parcel-level square footage supply elasticities with respect to price. Figure 31 presents the distribution of the parcel-level change in square footage after a uniform increase in the hedonic price surface by 10%. We find that parcel-level housing supply elasticities are highly heterogeneous, though the median parcel is supply inelastic. Parcels located near downtown Chicago as well as the northern suburbs of Cook County are the most supply elastic (Figure 32).

Figure 31: Distribution of parcel-level changes in square footage from a 10% price increase

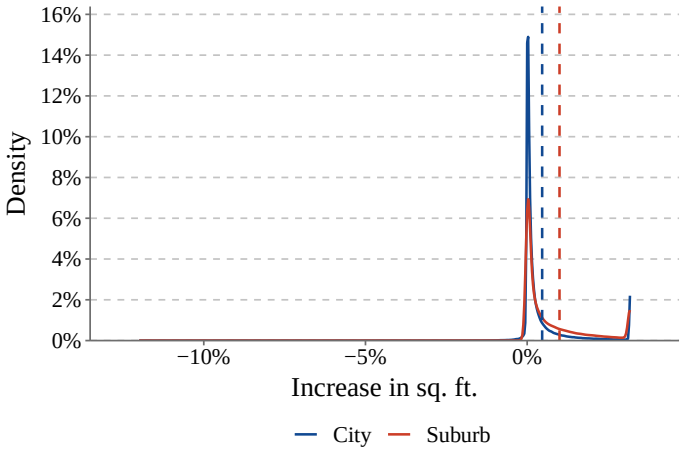
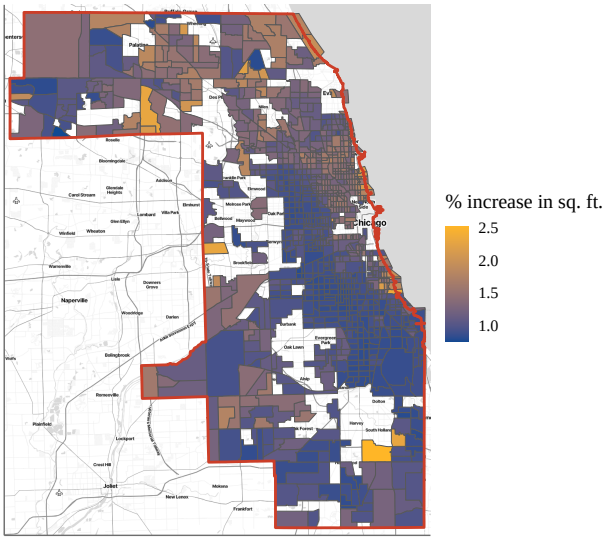


Figure 32: Map of tract-level changes in square footage from a 10% price increase



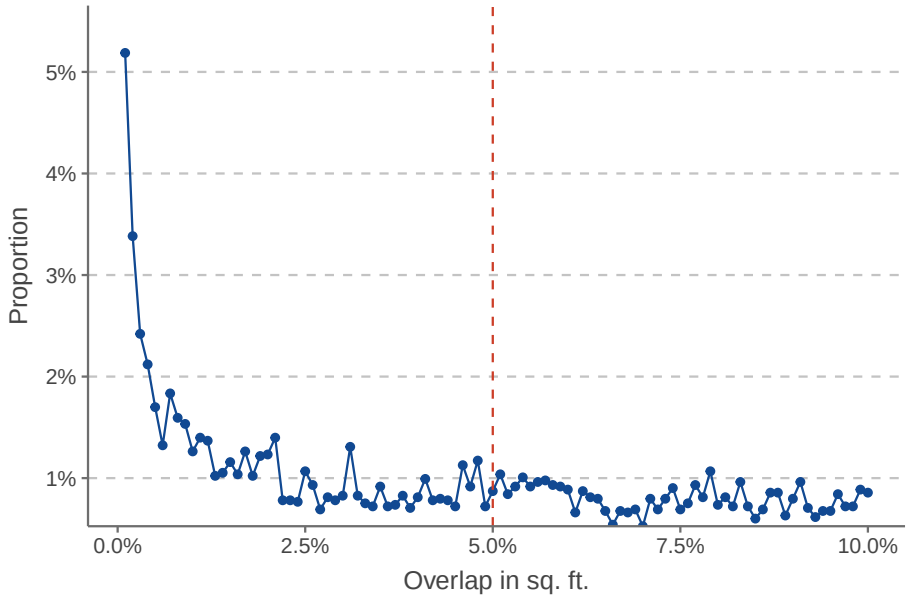
6 Conclusion

7 Appendix

We use annual parcel maps from the Cook County Assessor Office to link parcels over time. Observing changes in parcel boundaries allows us to determine whether a parcel is ever split, a common occurrence when a single parcel is subdivided into separate parcels for multiple new developments. Using parcel maps from 2000 to 2023, we first identify parcels that stayed unchanged over time. Of the 1,480,090 parcels that ever existed in Cook County between 2000 to 2023 (as identified by parcel number), 1,322,455 (89.3%) parcels were present in all years and stayed constant in geographic size. We then use the following procedure to link the remaining 157,635 (11.7%) parcels.

We begin with the 2000 parcel map for Cook County as a base and spatially merge in parcel maps from 2001 to 2023. We link a given parcel in year t to a base parcel in year 2000 if the overlap in geographic area between the two parcels is greater than 5% of the geographic size of either parcel. Figure 33 presents the distribution of overlap in geographic area between parcels in 2000 and parcels from 2001 to 2023.

Figure 33: Distribution of overlap between parcels



Note that two distinct parcels in 2000 may merge to the same parcel in a future year. For instance, this may occur when parcels are combined for redevelopment. Figure [TK] presents an

actual example of this in Cook County. In such cases, we group all parcels in 2000 that merge to the same parcel in a future year together to form a "parcel group." When evaluating changes in property characteristics to identify parcel redevelopment in Section [TK], we aggregate over all parcels in a parcel group.