Regulatory Hurdles and Costly Delay in Housing Development*

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Abstract

This paper studies the effect of a discretionary permitting process on the supply of multifamily housing. Using the universe of permit applications in Seattle, Washington, beginning in 2008 when a unit count threshold for discretionary review was introduced, I show that proposed developments bunch at the threshold and that such a threshold induces a discontinuity in the unit count–development size relationship, introducing distortions to the housing stock. I then propose and estimate a novel model of the multifamily housing production function that explicitly accounts for a policy-induced discontinuity in the marginal cost of adding a unit. The estimated capital share of output is consistent with earlier findings from the literature if constant returns to scale (CRS) is assumed, but the estimates imply a relatively high degree of decreasing returns to scale, consistent with higher market valuations of developments with a larger number of smaller units. Estimates of the distribution of costs from discretionary review imply that the median cost of design review is small but highly variable and negatively correlated with the marginal unit cost, suggesting that developers who face a higher cost of design review and choose to build above the unit count threshold may compensate by providing lower quality amenities. Counterfactual simulations suggest that removing the design review threshold would have increased the number of units built by 12.5%, or 543 units, and that both average unit size and average revenue per unit would be lower.

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> "In the St. Aidan's case, as in many similar episodes across the country, a developer... tried to increase the density of housing in a desirable location. A group of motivated neighborhood defenders participated in the development process and raised a varierty of concerns about the project. They used every regulatory tool at their disposal to slow down, alter, and stop the development. While they ultimately were unable to stop the development, their participation had a dramatic impact on the housing produced. The project ultimately took eleven years to complete, and the final version included nearly 60 percent fewer housing units than the original proposal."
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> —Einsten, Glick, and Palmer (2019, p.25)

In most U.S. cities, multifamily housing developments (i.e., apartment buildings) undergo a discretionary public hearing process depending on their characteristics, usually correlating with density in the form of total unit counts or square footage. In this paper, data on the universe of residential construction permits in Seattle issued since 1990 and the universe of land use and construction permits applied for since at least 2006 are combined with data on parcel and building characteristics and annual financial information in order to estimate the effect of the discretionary permitting process on the supply of multifamily housing in Seattle, Washington, by comparing redevelopment choices above and below the threshold for discretionary review.

Since the housing crisis of 2007-2009, the supply of new housing has consistently lagged demand, resulting in rapidly rising rents and home prices in the United States, particularly in the urban cores of the nation's metropolitan areas. The economics literature has established both an empirical and theoretical link between density regulations and the multifamily housing supply. The effect of discretionary approval processes have been well-studied in the political science literature (e.g., by Einsten, Glick, and Palmer, 2019), but has garnered little attention within the economics literature. Glaeser, Gyourko, and Saks (2005) explicitly refer to case studies in which local opposition to multifamily developments lead to discretionary permit rejections as a possible explanation for the large and increasing residual that they find between home prices and marginal costs in Manhattan but do not attempt to directly support this explanation.

In short, the non-economics literature has established an empirical link between the discretionary approval of multifamily real estate developments and their supply, and the economics literature has speculated on its effect without directly assessing it. This paper seeks to bridge the gap between the level of interest in this topic and the level of economic analysis that has been applied to it.

The relationship between land use or other regulations and the housing supply is well-studied in the economics literature.[1] However, such research overwhelmingly focuses on the regulation and supply of single-family homes and does not address discretionary review as a barrier to supply.[2] One of the few papers that evaluates the effect of land use

1. For an extensive and recent review of the relationship between regulation and affordability as well as the economic costs of housing unaffordability, see Gyourko and Molloy (2015).

2. Explicitly studying multifamily housing development rather than relying on evidence from existing research on single-family development is critical due to the nature of supply in each market. Among the many critical differences are the regulatory regimes, which treat multifamily developments more like commercial real estate than residential real estate, and the development lags and demand for multifamily housing. Single-family homes are relatively inexpensive to build and take at most a year to construct. Multifamily developments require large commercial mortgages and upfront private investments and take several years to construct from initial planning to completion. Thus, multifamily development decisions are more sensitive to dynamic considerations. Finally, single-family homes are much more likely to be owner-occupied than multifamily units—according to the 2021 American Housing Survey, 64% of detached, single-family homes in the U.S. were owner-occupied, compared to

regulations on multifamily development is Glaeser, Gyourko, and Saks (2005), who show that, in Manhattan, the price of a new unit of housing greatly exceeds the marginal cost of constructing additional housing units, and that the ratio of prices to construction costs rose substantially, from 1.2 in 1996 to over 2.0 in 2002. They do not, however, attempt to explain the source of this gap. More recently, D'Amico et al. (2024) model the multifamily housing construction sector in order to evaluate the evolution of its productivity over time. They find that land use restrictions which limit the size of building projects also reduced the size of construction firms in equilibrium, which in turn reduced the productivity of the sector.

Many housing regulation papers rely on the Wharton Residential Land Use Regulation Index (WRLURI) developed by Gyourko, Hartley, and Krimmel (2019) to measure the restrictiveness of land use regulations in a given city. Among the measures of restrictiveness is the average approval time for new construction permits. Using an early version of these data, Mayer and Somerville (2000) estimate that each month of delay in subdivision approvals reduced single-family home permits by 9-13% across 44 MSAs and partial MSAs.[3] Caldera and Johansson (2013) found that this relationship holds for the overall housing supply across countries. They report that the U.S. has both the most elastic housing supply among OECD nations as well as the shortest building permit delays, which is consistent with an overall negative relationship they find between permit delays and housing supply elasticity.[4]

As the approach in this study requires the estimation of a production function for housing services, it also contributes to the literature on the supply of housing services. This literature is as old as the field of urban economics but its most recent era was spearheaded by Epple, Gordon, and Sieg (2010), who exploit the duality of the supply function and an assumption of constant returns to scale to flexibly and non-parametrically estimate the housing production function using land value assessments. They find that the production function is well-estimated by the traditional Cobb-Douglas functional form and that the capital share of output is nearly constant at 0.856. Ahlfeldt and McMillen (2014) compare this methodology to older alternatives to estimating the capital-land substitution, and their results also suggest that Cobb-Douglas is the best functional form for the housing production function. Combes, Duranton, and Gobillon (2021) exploit the zero-profit condition and profit maximization conditions to calculate the latent housing services variable for a sample of single family homes in France, which they use to non-parametrically estimate the housing production function. They confirm that Cobb-Douglas is a strong approximation of the housing production function and reject the assumption of constant returns to scale in favor of slightly decreasing returns to scale. Finally, Eriksen and Orlando (2022) model the production function for multifamily buildings specifically in order to estimate the impact of building height on marginal development cost. Eriksen and Orlando abstract from the unit count decision, however.

This study also contributes to the broad literature on the redevelopment of urban real property stocks, which

9.5% of units in buildings with 5 or more units.

3. Partial MSAs are used for MSAs that include multiple central cities, such as New York–Newark or San Francisco–Oakland.

4. They estimate a correlation coefficient of -0.56, significant at the 1% level.

generally focuses on residential development and was pioneered by Wheaton (1982), who was the first to develop a model of urban residential density patterns with renewable capital.[5] Siodla (2015) exploits the exogenous destruction of parts of San Francisco's real property stock in the early 20th century to determine that redevelopment frictions such as capital durability and legal restrictions pose strong and persistent barriers to the renewal of the city's housing stock. Schuetz (2020) uses permit data in Washington, D.C., to show that, in response to a demand shock, more strictly-regulated lots expanded supply through additions and renovations, while more loosely-regulated lots expanded supply through redevelopment and new construction. Bar-Ilan and Strange (1996) model the property owner's redevelopment decision under lags between the development decision and the income stream and uncertainty in the income stream. They find that sufficiently large development lags can induce "leapfrog" development, as opposed to more moderate increases in density over multiple redevelopments. Bulan, Mayer, and Somerville (2009) empirically support this result using condo development data in Vancouver, B.C., from the late 20th century to show that increases in both idiosyncratic and systematic risk delay redevelopment by as much as 13%. Finally, Dye and McMillen (2007) use redevelopment data from Chicago to show that density-increasing redevelopment occurs first in lots that are closer to public transit and commercial centers that have older and smaller existing land uses.

This study differs from the extant literature on regulatory barriers to the housing supply by estimating the effect of additional permitting frictions on multifamily redevelopment within a city rather than qualitatively evaluating them, quantifying the effect of single-family home regulations, quantifying the overall regulatory tax on multifamily development, or by comparing across cities with very different demand shocks and regulatory environments. Additionally, a novel estimation strategy is developed for the housing production function that enables the estimation of the housing production function for multifamily developments that considers both the developer's choice of unit count and the size of the development.

The paper proceeds as follows. Section 1 describes the regulatory environment for apartment buildings in Seattle. Section 2 presents a model of developers' production of housing services. Section 3 describes the data and presents descriptive statistics and analyses. Section 4 presents the estimation approach for recovering the model's parameters, with results presented in section 5. Section 6 uses the estimated model parameters to consider the consequences of Seattle's discretionary review policy, and section 7 concludes.

5. Only papers on residential redevelopment that intersect with regulatory frictions are referenced here, as this literature is too extensive to provide a comprehensive review.

1 Policy Background

1.1 Multifamily Zoning in Seattle

In Seattle, multifamily development is restricted to parcels based on their zoning designation, and these zoning designations influence how discretionary review is applied.[6] Figure 1 shows the zoning designations in the City of Seattle as of 2023.

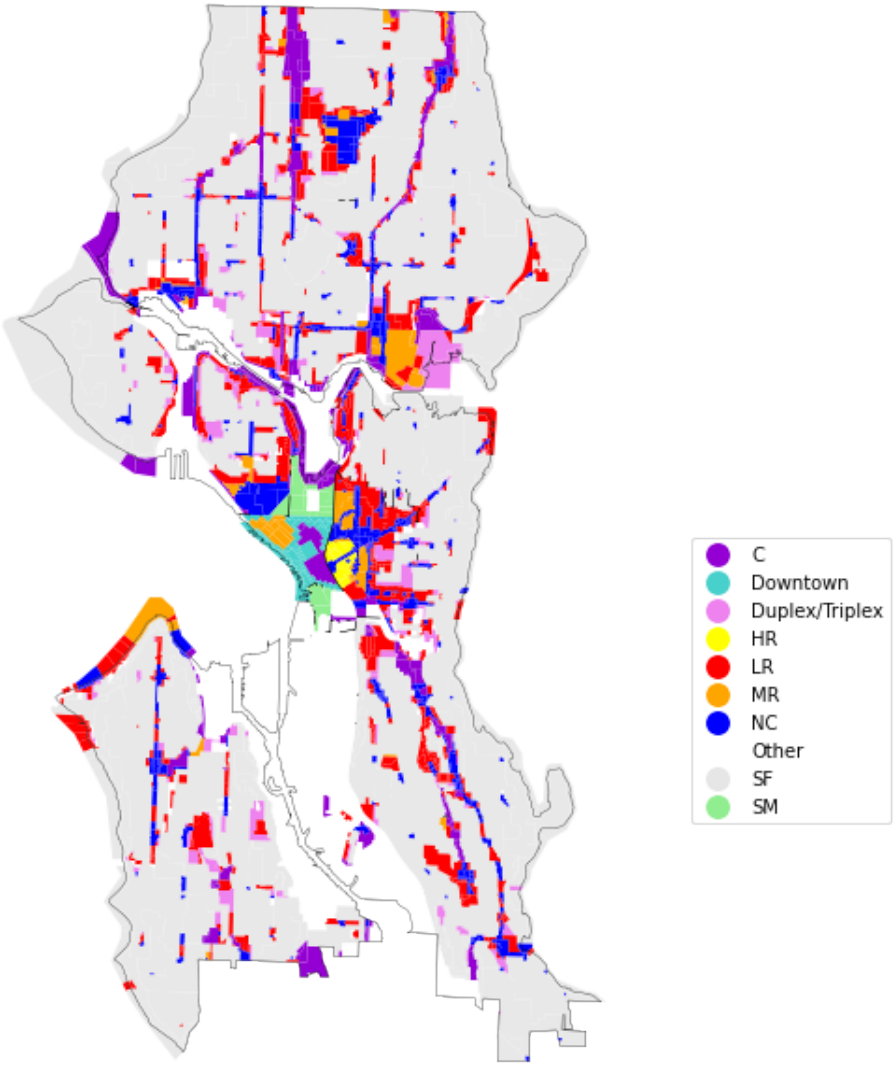


Figure 1: Map of Zoning Designations in the City of Seattle, as of 2023

6. See Title 23 of the Seattle Municipal Code for more information on zoning designations and related land use regulations.

The multifamily-specific zoning designations of low-rise (LR), mid-rise (MR), and high-rise (HR) heavily limit non-residential use. Commercial (C), neighborhood commercial (NC), and Seattle Mixed (SM) designations allow for apartments with a wider range of commercial uses. Downtown designations (DOC, DRC, DMC, DMR, PSM, IDM, IDR, DH, and PMM) allow for a wide range of uses but face unique land use restrictions and guidance, including as it relates to discretionary review. Although some of these zoning designations refer to types of buildings that are associated with density levels, it is not necessarily the case that all residential structures developed in lots under each designation could be referred to according to that designation. For example, a low-rise building (e.g., with eight units and two stories) could be built on a lot that is zoned HR for high-rise development, and a large apartment building would be permitted on a sufficiently large lot that is designated as LR for low-rise development.

1.2 Design Review

In Seattle, the discretionary permitting process for multifamily housing developments is referred to as design review. All developments are required to obtain a building permit, which is reviewed solely through a clerical process administered by the Seattle Department of Construction and Inspections (SDCI) and is approved if the proposed development meets the requirements of Seattle's building code. However, if a development meets certain criteria, the developer must also obtain a land use permit, also referred to as a master use permit, which can only be approved following a process referred to as design review.

If a development is required to undergo design review, then the developer must pay additional fees, hold additional meetings with SDCI staff, post public notices, hold public meetings, receive public comments about the development, and hold public meetings. The meetings are held by the local design review board, which is composed of local residents and design professionals, who are volunteers.[7] At the conclusion of the design review process, the design review board makes a recommendation to the director of the SDCI about whether the land use permit application for the development should be approved. Once the SDCI director approves or rejects the application, the decision may be appealed to an administrative judge, referred to as a hearing examiner, by "any person significantly affected by or interested in the permit".[8] The hearing examiner may accept, reject, or modify the SDCI director's decision, including by imposing additional conditions on the development's approval. This examiner's decision is final and may only be appealed through the state's court system.

Prior to May 2008, design review was required in most parcels that allowed multifamily zones if the proposed development exceeded subjective, ad-hoc thresholds laid out in the State Environmental Policy Act (SEPA). Beginning on May 30th, 2008, design review was required based on the unit count of the proposed development, which was determined by the zoning designation of the lot.[9] The thresholds were 8 units for low-rise designations, 20 units for

7. See A.1 for more information on the design review board.
8. Seattle Municipal Code §23.76.022(C)2.
9. Seattle Ordinance 122670.

mid-rise and high-rise designations, 4 units for commercial and neighborhood commercial designations, and 20 units (plus a square footage threshold that depends on specific designation) for downtown and Seattle mixed designations.

On July 1st, 2018, the thresholds were substantially overhauled.[10] Two new design review types, administrative and streamlined design review, were introduced, and the unit count thresholds were removed in favor of thresholds for the gross square footage of development (i.e., floor area of the building). In zones outside of downtown, streamlined design review applies only to certain lots and to developments between 8,000 and 15,000 square feet. Administrative design review applies to developments greater than 15,000 square feet (or 8,000 square feet in lots where streamlined design review does not apply) but below 35,000 square feet. Full design review applies to developments above 35,000 square feet. Streamlined design review is an administrative process similar to the process for construction permits, and the SDCI director's approval decision cannot be appealed. Administrative design review is more-or-less identical to full design review except that the approval recommendation is made by SDCI staff rather than by the design review board.

2 Model

Consistent with existing literature on the supply of housing services, housing services are assumed latent and produced by a Cobb-Douglas production function with capital (i.e., square footage of development) and land (measured in square footage of the lot) as inputs. While examples from the literature consider single-family homes, a multifamily structure on lot i delivers housing services to u_i households, where u_i is the number of units in the development. Thus, the housing services produced by the development on lot i are:

$$H_i = \sum_{k=1}^{u_i} k_{ik}^{\alpha_K} (L_i/u_i)^{\alpha_\ell} \tag{1}$$

Where k_{ik} is the square footage of the kth unit in the development on lot i and L_i is the square footage of lot i.

Assume, consistent with the findings from Combes, Duranton, and Gobillon (2021), that the production function exhibits decreasing returns to scale, i.e., $\alpha_K + \alpha_\ell < 1$. Then, by imposing a stronger assumption that results in some specification error, the production function can be simplified by letting $k_{ik} = K_i/u_i$ for all k, where K_i is the total square footage of the development on lot i:

$$H_i = u_i^{1-\alpha_K-\alpha_\ell} K_i^{\alpha_K} L_i^{\alpha_\ell} \tag{2}$$

Now, let p_{it} be the price of housing services in lot i in period t. Then the revenue from selling a development on lot i with (K_i, u_i, L_i) is $p_{it}H_i$. Assume that the costs of adding a unit to a development and increasing the square footage

10. Seattle Ordinance 125429.

of the development are linear and separable (i.e., have constant marginal costs). Finally, let ω_0 be the fixed cost of developing a lot and ω_1 be the cost of undergoing design review, which is only incurred when units proposed exceeds the statutory threshold for design review, $\overline{u}$. Then, the value function for a new development on lot i in year t is given by:

$$V_{it} = p_{it} u_i^{1-\alpha_K-\alpha_\ell} K_i^{\alpha_K} L_i^{\alpha_\ell} - aK_i - cu_i - \omega_0 - \omega_1 \mathbb{1}\{u_i > \overline{u}\} \tag{3}$$

An optimizing developer chooses (K_i, u_i) to maximize V_{it}. The first order condition for K_i is:

$$\frac{\partial V_{it}}{\partial K_i} = \alpha_K p_{it} u_i^{1-\alpha_K-\alpha_\ell} K_i^{\alpha_K-1} L_i^{\alpha_\ell} - a = 0 \tag{4}$$

Solving for K_i yields:

$$K_i = \left(\frac{\alpha_K}{a} p_{it} u^{1-\alpha_\ell-\alpha_K} L_i^{\alpha_\ell}\right)^{\frac{1}{1-\alpha_K}} \tag{5}$$

For unit count, the developer chooses u_i such that, for any positive integer Δu, the profit from increasing the number of units by Δu to u_i was positive and the profit from increasing the number of units by Δu to u_i would be negative:

$$\Delta V_{it} = p_{it} K_i^{\alpha_K} L_i^{\alpha_\ell} \left[u_i^{1-\alpha_K-\alpha_\ell} - (u_i - \Delta u)^{1-\alpha_K-\alpha_\ell}\right] - c\Delta u - \omega_1 \mathbb{1}\{u_i > \overline{u} \geq u_i - \Delta u\} \geq 0, \forall \Delta u > 0 \tag{6}$$

$$\Delta V_{it} = p_{it} K_i^{\alpha_K} L_i^{\alpha_\ell} \left[(u_i + \Delta u)^{1-\alpha_K-\alpha_\ell} - u_i^{1-\alpha_K-\alpha_\ell}\right] - c\Delta u - \omega_1 \mathbb{1}\{u_i + \Delta u > \overline{u} \geq u_i\} \leq 0, \forall \Delta u > 0 \tag{7}$$

In the absence of a discontinuity from design review, $\Delta u = 1$ would be the only relevant value to consider, since the marginal cost of adding a unit would be constant and the marginal revenue from doing so is continuous and non-negative. Plugging the first-order condition for K_i into the value function and simplifying yields:

$$V_{it} = \left(p_{it} u_i^{1-\alpha_\ell-\alpha_K} L_i^{\alpha_\ell}\right)^{\frac{1}{1-\alpha_K}} \left(\frac{\alpha_K}{a}\right)^{\frac{\alpha_K}{1-\alpha_K}} (1-\alpha_K) - cu_i - \omega_0 - \omega_1 \mathbb{1}\{u_i > \overline{u}\} \tag{8}$$

The first-order condition for u_i, accounting for the optimal value of K_i, is an interval with the following bounds:

$$u_i^{\frac{1-\alpha_\ell-\alpha_K}{1-\alpha_K}} - (u_i - \Delta u)^{\frac{1-\alpha_\ell-\alpha_K}{1-\alpha_K}} \geq \frac{c\Delta u + \omega_1 \mathbb{1}\{u_i > \overline{u} \geq u_i - \Delta u\}}{\left(p_{it} L_i^{\alpha_\ell}\right)^{\frac{1}{1-\alpha_K}} \left(\frac{\alpha_K}{a}\right)^{\frac{\alpha_K}{1-\alpha_K}} (1-\alpha_K)} \tag{9}$$

$$(u_i + \Delta u)^{\frac{1-\alpha_\ell-\alpha_K 1}{1-\alpha_K}} - u_i^{\frac{b(1-\alpha_\ell-\alpha_K)}{b-\alpha_K}} \leq \frac{c\Delta u + \omega_1 \mathbb{1}\{u_i + \Delta u > \overline{u} \geq u_i\}}{\left(p_{it} L_i^{\alpha_\ell}\right)^{\frac{1}{1-\alpha_K}} \left(\frac{\alpha_K}{a}\right)^{\frac{\alpha_K}{1-\alpha_K}} (1-\alpha_K)} \tag{10}$$

For all $\Delta u > 0$.

2.1 Asset Pricing Interpretation

The framing presented above assumes that the developer sells the development immediately following construction for a price of p_{it}. In reality, the developer may hold the investment and, in practice, most developers hold a share of the development with private investors holding the remaining shares. Assuming a perfectly competitive market for real assets, the relationship between the sales revenue displayed in equation 3 and the returns from holding a development on parcel i built in period t as a financial asset is given by:

$$p_{it} u_i^{1-\alpha_K-\alpha_\ell} K_i^{\alpha_K} L_i^{\alpha_\ell} = \mathbb{E}\left[\sum_{\tau=0}^{\infty} \beta^\tau \left[OpInc_{it+\tau}\left(u_i, K_i, L_i\right) - OpEx_{it+\tau}\left(u_i, K_i, L_i\right)\right]\right] \tag{11}$$

Where $OpInc_{it+\tau}$ and $OpEx_{it+\tau}$ are the rental income and operating expenses from the development in period $t+\tau$ and β is the discount factor. Under this assumption, the developer is indifferent between selling the development immediately following development and holding it as an asset.

3 Data and Descriptive Analyses

Most of the data were obtained through the Seattle Department of Construction and Inspections (SDCI), either through direct download from the Seattle Open Data Portal, or via public disclosure request. These data include all permit applications for new residential developments in Seattle beginning in 2005–2006, including the dates of application, issuance, and completion, the building type, square footage, design review status, geographic coordinates, and units proposed.[11] Contemporaneous zoning codes and lot sizes were obtained from the Seattle Office of Planning and Community Development through a public disclosure request and direct data download. Parcel characteristics relevant for assessed property value (e.g., traffic noise and quality of view) were obtained from the King County Assessor's Office.

As described in Section 1, from 2008 to 2018, the design review threshold was a unit count that depended on the zoning designation of the lot. Table 1 displays the number of applications by zoning designation and policy period. The plurality of applications are in low-rise (LR) zones, which have a threshold of 8 units and are distributed throughout the city, primarily along or just off of major arterials or outside of commercial clusters. To control for endogenous zoning designations and to avoid mis-specification by not accounting for non-residential considerations in mixed-use zones, the data are restricted solely to applications in low-rise-designated lots.

Table 2 provides summary statistics for the permit application data in low-rise lots beginning in May of 2008, when

11. The exact start date is not clear, as the city began moving to a new system for documenting permits in 2005 and concluded the transition sometime in 2006. Some permits from before the transition have been digitized and are thus included in the sample, but not all. As the sample period begins in 2008, this uncertainty is not a concern for the analysis presented here.

Zoning Designation	2008-2018	Post-2018
Low-rise	247	185
Mid-rise	48	27
High-rise	5	0
Seattle Mixed	24	14
Neighborhood Commercial	223	135
Commercial	72	59
Downtown	18	3

Table 1: Applications by zoning designation and policy period

the unit count thresholds were first implemented. There were 435 applications for apartments in low-rise-designated lots during the sample period, with an average of 19 units proposed, which is skewed by a few large developments.[12] The median development was 8 units with 8,500 square feet of gross floor area on a 5,200 square foot lot. On average, these lots were 2.7 miles from downtown (i.e., the central business district, or CBD), 3.3 miles from the University of Washington campus, 1.2 miles from a light rail station, and half a mile from the nearest commercial district. Permit approvals took 16 months on average, with wide variation: the interquartile range is 1 year, with the shortest quarter of application delays lasting up to eight and a half months.

Only 315 of the 435 applications were approved, and only 250 issued permits were fulfilled to construction. Some of this difference is due to end-of-sample permit applications—the data include permits applied for mere weeks before the data were downloaded. Additionally, permits applied for in early 2008 were abandoned before or following issuance due to the financial crisis.

	avg	s.d.	min	p5	p25	Med.	p75	p95	max
No. Units	19	26.88	2	2	3	8	27	67	234
ft^2 dev. ('000)	15.5	29.76	1.5	2.5	4.5	8.5	14.7	41.4	354.6
Lot ft^2 ('000)	170.2	1775.50	0.6	1.7	4.2	5.2	8.5	31.0	28088.1
Year Applied	2017	3.85	2009	2011	2014	2017	2021	2023	2023
CBD Dist.	2.7	1.79	0.0	0.4	0.8	2.8	4.0	5.4	7.3
UW Dist.	3.3	2.31	0.0	0.3	1.8	2.7	4.0	8.3	9.5
LRT Dist.	1.2	1.08	0.0	0.2	0.4	0.7	1.9	3.5	3.9
Comm. Dist.	0.5	0.38	0.0	0.0	0.2	0.4	0.7	1.3	1.8
Delay to issuance (months)	16.2	12.25	0.6	3.9	8.3	12.9	20.2	44.5	79.6

Applied: 435
Issued: 315
Completed: 250

Table 2: Summary statistics for permit application data

Financial data, including operating income from residential rents, operating expenses, and capital expenses for a

12. The data exclude townhome and rowhome developments, which face a different regulatory regime, are more likely to be owner-occupied, and have different unit-square footage relationship constraints.

subset of apartments in Seattle are available from DealX, a commercial real estate data provider that sources data from commercial mortgage-backed securities pools. Table 3 displays summary statistics for the DealX data. Apartments in the DealX sample tend to be bigger than the universe of low-rise permit applications, in part because the DealX data include apartment buildings in all zoning designations. The data exhibit a range of normalized operating incomes and expenses, suggesting variation in the quality of buildings due in part to spatial and temporal factors. All variables denominated in dollars are adjusted to 2023 dollars using the Consumer Price Index (CPI) for all urban consumers, sourced from the U.S. Bureau of Labor Statistics and downloaded from the Federal Reserve Bank of St. Louis.

Variable	avg	sd	min	p5	p25	Med.	p75	p95	max
Revenue ('000)	1,006	1,808	53	122	247	429	780	4,051	21,320
Op. Ex. ('000)	411	719	20	44	93	172	322	1,801	7,620
NOI ('000)	594	1,155	-1,585	67	141	242	449	2,334	14,246
Cap. Ex. ('000)	347	607	13	47	88	164	304	1,247	6,438
Units	52	72	6	7	15	26	56	190	722
Yrs Since Build/Reno	19	10	0	3	11	21	28	34	48
Lot ft^2 ('000)	19.7	35.7	1.8	4.3	6.6	10.0	16.8	66.5	539.9
Gross ft^2 ('000)	45.9	72.7	3.4	5.5	10.3	20.2	41.9	166.6	590.9
Net ft^2 ('000)	32.9	47.8	2.9	4.6	8.8	14.6	29.9	146.2	331.7
Rev/Gross ft^2	24.9	16.5	1.6	9.8	16.7	21.8	28.4	45.4	173.3
OpEx/Gross ft^2	10.0	6.9	0.8	3.9	6.4	8.5	11.2	19.6	75.6
NOI/Gross ft^2	14.9	11.4	-25.6	5.2	9.3	13.1	17.5	29.7	121.9
CapEx/Gross ft^2	9.7	7.4	0.4	3.1	5.5	8.2	11.6	20.0	71.2
Gross ft^2/Lot ft^2	2.8	3.2	0.3	0.7	1.1	1.8	3.3	7.1	43.8
Gross ft^2/Lot ft^2	2.75	3.18	0.34	0.69	1.14	1.81	3.26	7.07	43.79
Net ft^2/Lot ft^2	2.01	2.01	0.33	0.60	0.94	1.54	2.19	5.85	27.34

Properties: 380
Observations: 1,622

Table 3: Summary statistics for DealX financial data

One way in which design review imposes costs on developers is through delays in the permitting process. To test the extent to which design review delays the permitting process, log delay in months is regressed on (log) unit count with year and neighborhood fixed effects according to the following specification:

$$\log\left(\text{Delay}_i\right) = \alpha_{t(i)} + \alpha_{n(i)} + \beta_1 \mathbb{1}\left\{\text{DesignReview}_i\right\} + \beta_2 \log\left(\text{Units}_i\right) + \epsilon_i \tag{12}$$

The results from equation 12 are displayed in table 4. The first three columns show the results including parcels of all zoning designations, while the last three columns show the results for low-rise-designated lots only.[13] On average, controlling for year and neighborhood fixed effects, design review increases permitting delay by five to seven and

13. The sample period begins in 2010 in order to exclude applications submitted just before the financial crisis, many of which were abandoned or intentionally delayed by the developer. Additionally, post-2018 applications that were subject to streamlined or administrative design review are excluded. The low number of observations in the specifications for the last three columns relative to the overall sample reflects these restrictions.

	All Permits			LR Zones Only		
	(1)	(2)	(3)	(4)	(5)	(6)
1(Design Review)	6.631***	5.116***	5.095***	2.252***	1.841***	1.811**
	(0.715)	(0.851)	(0.817)	(0.555)	(0.536)	(0.563)
log(Units Added)		1.751***	1.907***		2.151***	2.065**
		(0.317)	(0.343)		(0.645)	(0.669)
Constant	11.773***	7.201***	6.744***	10.847***	6.401***	6.601***
	(0.471)	(0.761)	(0.898)	(0.546)	(1.531)	(1.603)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Neighborhood FE	No	No	Yes	No	No	Yes
R^2	0.181	0.200	0.205	0.167	0.184	0.211
Clusters	13	13	13	13	13	12
Obs.	2,940	2,940	2,940	1,307	1,307	1,306

Jackknife standard errors, clustered by neighborhood, in parentheses.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Regression results for permit delay in months by design review status

half months for all zoning designations and around two months for low-rise-designated lots. All of these effects are significant at the 1% level except for the most controlled specification for low-rise-designated lots, for which the effect is significant at the 5% level.

Another economic cost of design review is distortions due to discrete thresholds. If increasing either unit count, u, or square footage, K, increases revenue, then a discontinuity in the cost of increasing one of these variables will lead to a discontinuity in the rate of substitution between the two variables. This is particularly relevant to the 2008–2018 policy period in which the threshold for design review was a unit count that is binding in more than half of the applications in the sample. While this can be shown in the model presented in Section 2, it can also be demonstrated using far fewer functional form assumptions:

Proposition: *For a sufficiently high cost of design review, ω_1, there are marginal lots that will redevelop below the threshold at a lower level of capital than they otherwise would have.*

Corollary: *Marginal lots will develop at higher levels of capital than inframarginal lots due to the higher price of housing services on marginal lots.*

A formal proof of this proposition is provided in Appendix A.2. The implication of this proposition is that, in the presence of design review with a non-zero cost, there will be a mass of developments at the design review threshold that would otherwise have developed at a higher number of units, and these developments will be larger (in terms of square footage) than those that would have developed at the threshold regardless of design review.

To test this proposition empirically, the unit counts and square footages of developments proposed during the

2008–2018 policy period, where a binding unit count threshold was in place, are compared to those proposed during the post-2018 policy period, when a rarely-binding square footage threshold was in place. Table 5 displays the number of applications by unit count and policy period. In both periods, even unit counts are more common than odd unit counts and the number of applications generally trends downward as unit counts increase. However, in the 2008–2018 period, the number of applications at the 8-unit threshold is higher than the number of applications at any other unit count except for 2 units (i.e., duplexes). In the post-2018 period, no such bunching is observed, and the share of developments that are proposed at the 8-unit threshold in the 2008–2018 period is three times larger than the share in the post-2018 period.

	2008-2018		Post-2018	
Housing Units	Applications	Share	Applications	Share
2	39	15.2%	59	24.4%
3	16	6.2%	24	9.9%
4	15	5.9%	20	8.3%
5	10	3.9%	12	5.0%
6	16	6.2%	23	9.5%
7	5	2.0%	9	3.7%
8	31	12.1%	10	4.1%
9	2	0.8%	7	2.9%
10	3	1.2%	5	2.1%
11	1	0.4%	2	0.8%
12	4	1.6%	10	4.1%
13	3	1.2%	2	0.8%
14	1	0.4%	4	1.7%
15+	110	43.0%	55	22.7%
Total	**256**	**100%**	**242**	**100%**

Table 5: Applications by units proposed and policy period in low-rise-designated lots

Figure 2 displays the relationship between square footage and units proposed by policy period, in logs. As predicted by the model and proposition above, there exists a discontinuity in the relationship between square footage and units proposed in the 2008–2018 period at the 8-unit threshold, but no such discontinuity exists in the post-2018 period. Table 6 displays the results of regressions testing the same relationship:

$$\log\left(DevSqft_i\right) = \beta_0 + \beta_1 \log\left(Units_i\right) + \beta_2 \mathbb{1}\left\{\text{Units}_i > 8\right\} + \beta_3 \mathbb{1}\left\{\text{Units}_i > 8\right\} \times \log\left(Units_i\right) + \epsilon_i \tag{13}$$

Using only observations from the 2008–2018 period, the coefficients on the dummy variable and its interaction with log units are large (in absolute terms) and statistically significant at the 1% level. In the same specification using only observations from the post-2018 period, the coefficients are small and statistically insignificant at conventional levels. These descriptive analyses, consistent with theory-based predictions, suggest that design review imposes non-negligible costs that induce developers to adjust the characteristics of some apartment buildings.

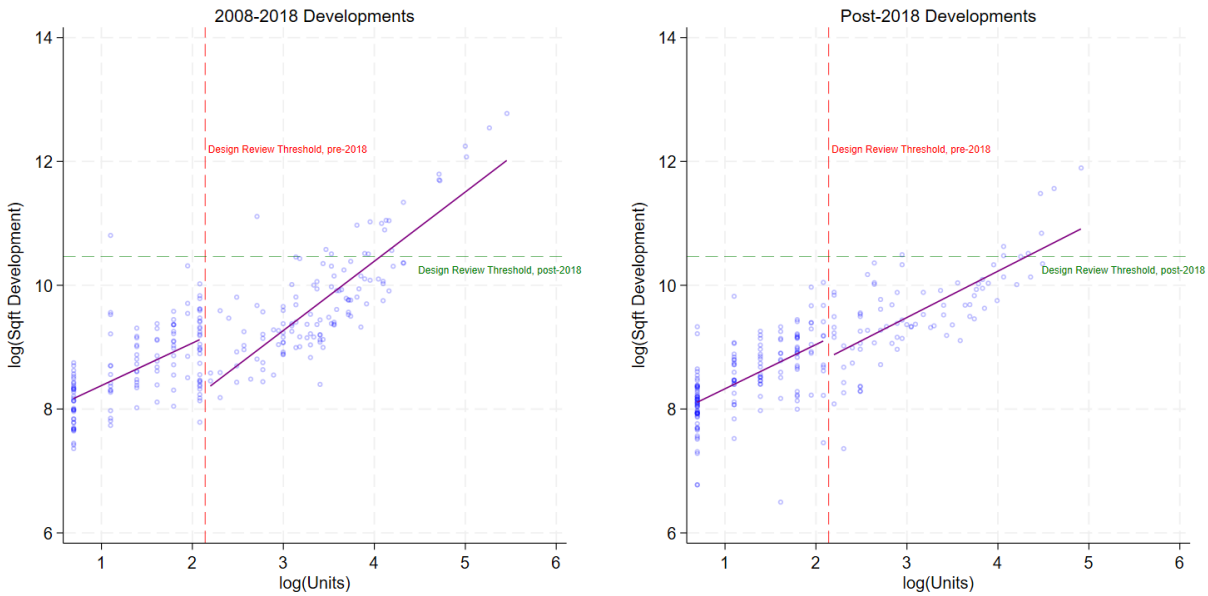


Figure 2: Relationship between square footage and units proposed by policy period, in logs

	2008-2018		Post-2018	
	(1)	(2)	(3)	(4)
log(Units)	0.638***	0.686***	0.618***	0.715***
	(0.036)	(0.081)	(0.029)	(0.085)
1(Units>8)		-1.780***		-0.380
		(0.314)		(0.323)
1(Units>8)*log(Units)		0.432***		0.034
		(0.116)		(0.125)
Intercept	7.662***	7.694***	7.701***	7.614***
	(0.084)	(0.113)	(0.062)	(0.104)
R^2	0.632	0.696	0.633	0.642
N	256	256	242	242
No. Above 8	124	124	85	85

*** : $p < 0.01$,** : $p < 0.05$,* : $p < 0.1$. Heteroskedasticity-robust standard errors in parentheses.

Table 6: Regression results for discontinuity in capital-units relationship by policy period

4 Estimation & Identification

4.1 Expected Profit Estimation

The data include annual financial flows for a subsample of existing buildings that were either newly constructed or underwent a major renovation during a sample period beginning in 2002 (with most observations beginning in 2005). Thus, operating profits are observed for buildings with a range of ages, though not for most proposed developments

in the sample period. To derive estimates of expected profit for all proposed developments in the sample, observed operating profits in the sample of existing buildings are used to estimate present-discounted expected profits in two stages: First, initial period net operating profit is estimated as:

$$\log\left(NetOpInc_{it}\right) = \alpha_t + \alpha_n + \alpha_z + \phi\log\left(K_i\right) + \psi\log\left(u_i\right) + \delta\log\left(L_i\right) + X'_{it}\beta + \sigma_\varepsilon\varepsilon_{it} \tag{14}$$

Where $NetOpInc_{it}$ is the first observation of net operating income of building i that was built in year t (within three years of construction), α_t, α_n, and α_z are year built, neighborhood, and zoning designation fixed effects; X_{it} is a vector of observable parcel characteristics and the city-wide median rent from the American Community Survey (ACS) in year t; and ε_{it} is assumed to be normally distributed.

Next, the evolution of net operating income (NOI) is estimated as an AR(1) process where innovations in NOI may vary deterministically with building age and observable characteristics:

$$\log\left(NetOpInc_{it+\tau}\right) = \alpha_z + \alpha_t + \delta_\tau\tau + \rho\log\left(NetOpInc_{it+\tau-1}\right) + \phi\log\left(K_i\right) + \psi\log\left(u_i\right) + \delta\log\left(L_i\right) + \varepsilon_{it+\tau} \tag{15}$$

Where $NetOpInc_{it+\tau}$ represents the net operating income of building i that was built in year t, τ years after construction.

To estimate the expected profit of each proposed development in the sample, the coefficient estimates from equation 14 (including the estimated variance of the error distribution) are used to estimate 1,000 simulations of the initial net operating income of each proposed development in the sample, $\widehat{NetOpInc}_{its}$, where s is one simulation. The evolution of net operating profits for each simulation is then estimated for 100 years using the coefficient estimates from equation 15. The expected profit of each proposed development is then calculated as the present discounted value of the simulated net operating income, $\widehat{NetOpInc}_{its}$, using a discount factor of 0.97. The expected profit of each proposed development is calculated as the expected value of the present discounted value of net operating income across all simulations:

$$\Pi_{it} = \frac{1}{\sum_{s=1}^{S}\phi_s}\sum_{s=1}^{S}\phi_s\sum_{\tau=0}^{100}\beta^\tau\widehat{NetOpInc}_{i,t+\tau,s} \tag{16}$$

Where ϕ_s is the probability of each simulation s.

As this is not a dynamic model and the time period of redevelopment is taken as given, in the following section, i will be used to denote an observation, which is a proposed development on a fixed lot in year t. Thus, time-dependent variables will be subscripted with $i(t)$.

4.2 Model Shocks

The model includes two optimization conditions for two variables, with shared parameters across the two equations. In order for the model to be able to rationalize the data, at least two structural errors are needed. The first is the price of housing services on lot i in period t, which has the following log form:

$$\log(p_i) = \overline{p} + d_{t(i)} + X_i'\gamma + \nu_i \tag{17}$$

Where X_i is a vector of observable, non-time-varying characteristics of lot i, such as its distance to points of interest, and ν_i has a gaussian distribution with variance σ_p^2. The second stochastic structural parameter is marginal cost of adding a housing unit, c, which is assumed to vary by lot i and period t:

$$\log(c_i) = \tilde{c}_{t(i)} + \eta_i \tag{18}$$

Where η_i has Gaussian distribution with mean μ_c and variance σ_c^2. Additionally, the efficient capital markets assumption provided in equation 11 is exploited to identify the scale parameters of the model, $\overline{p}$ and μ_c, in dollars and is estimated by introducing a measurement error term, ϵ_i, into the equation 11. Let Π_i represent the expected profit from developing lot i in period t. Then, the expected profit is given by:

$$\Pi_i = p_i u_i^{1-\alpha_\ell-\alpha_K} K_i^{\alpha_K} L_i^{\alpha_\ell} e^{\epsilon_i} \tag{19}$$

As specified, any estimate of the parameter ω_1 would be constrained by the development with the lowest unit count above u_i due to the domain of the log function as the model cannot rationalize a high cost of design review in the presence of even a single development with a unit count just above $\overline{u}$. Thus, ω_1 is also assumed to be stochastic and distributted log-normally with mean μ_ω and variance σ_ω^2. In what follows, the idiosyncratic cost of design review faced by observation i is denoted by ω_i.

Estimation proceeds via maximum likelihood. The following section describes the likelihood assigned to each observation.

4.3 Likelihood Function

The model includes three outcome variables, (Π_i, K_i, u_i), two structural errors, ν_i and η_i, and one measurement error, ϵ_i. In what follows, the structural errors are denoted by their model parameters, p_i and c_i respectively.

To derive the likelihood function for the model, $\ell(K_i, u_i, \Pi_i|\theta)$, the reduced form of each error term must be derived,

namely by removing p_i from the equations for u_i and Π_i. To do so, first invert the FOC for K_i with respect to p_i:

$$p_i = \left(\frac{a}{\alpha_K}\right) K_i^{1-\alpha_K} u_i^{\alpha_K+\alpha_\ell-1} L_i^{-\alpha_\ell} \tag{20}$$

Plugging this into equation 19 and inverting with respect to the measurement error term ϵ_{it} yields:

$$\epsilon_i = \log\left(\Pi_i / K_i\right) - \log\left(a/\alpha_K\right) \tag{21}$$

The first-order condition for the unit count choice, characterized by the inequalities in 9 and 10, can likewise be inverted with respect to c_i. After replacing p_i with the the inverse of the FOC for K_i provided in equation 20, the first-order condition for u_i can be expressed as:

$$c_i \geq \frac{a(1-\alpha_K)}{\alpha_K \Delta u} K_i \left[\left(\frac{u_i+\Delta u}{u_i}\right)^{\frac{1-\alpha_K-\alpha_\ell}{1-\alpha_K}} - 1\right] - \frac{\omega_i}{\Delta u} \mathbb{1}\left\{u_i > \overline{u} > u_i - \Delta u\right\} \tag{22}$$

$$c_i \leq \frac{a(1-\alpha_K)}{\alpha_K \Delta u} K_i \left[1 - \left(\frac{u_i-\Delta u}{u_i}\right)^{\frac{1-\alpha_K-\alpha_\ell}{1-\alpha_K}}\right] - \frac{\omega_i}{\Delta u} \mathbb{1}\left\{u_i + \Delta u > \overline{u} > u_i\right\} \tag{23}$$

Due to the discontinuity in marginal unit cost induced by design review and its non-zero ω_i, the likelihood function for observation i, $\ell_i(K_i, u_i, \Pi_i|\theta)$, is a piecewise function with three cases: $u_i < \overline{u}$, $u_i = \overline{u}$, and $u_i > \overline{u}$. Each case is delineated below. First, denote with $\phi(\cdot|\theta)$ the joint distribution of the model's shocks:

$$\begin{pmatrix} \epsilon_i \\ \log(p_i) \\ \log(c_i) \\ \log(\omega_i) \end{pmatrix} \sim \mathcal{N}\left(\begin{pmatrix} 0 \\ \overline{p} + d_{t(i)} + X_i'\gamma \\ \mu_c + \tilde{c}_{t(i)} \\ \mu_\omega \end{pmatrix}, \begin{pmatrix} \sigma_\epsilon^2 & 0 & 0 & 0 \\ 0 & \sigma_p^2 & \sigma_{p,c} & 0 \\ 0 & \sigma_{p,c} & \sigma_c^2 & \sigma_{c,\omega} \\ 0 & 0 & \sigma_{c,\omega} & \sigma_\omega^2 \end{pmatrix}\right) \tag{24}$$

Case 1: $u_i < \overline{u}$. The marginal cost of adding a unit is constant at c_i and the marginal benefit is decreasing in u_i, so we need only consider $\Delta u = 1$ for both the upper and lower bounds of the interval:

$$\ell_i^1(K_i, u_i, \Pi_i|\theta) = \int_0^\infty \int_{\underline{c}_i}^{\overline{c}_i} \phi(\epsilon_i, p_{it}, c, \omega \mid K_i, \Pi_i, u_i, \theta)(1-\alpha_K) f(c, \omega \mid K_i, u_i, \theta) dc d\omega \tag{25}$$

$$\underline{c}_{it} = \frac{a(1-\alpha_K)}{\alpha_K} K_i \left[\left(\frac{u_i+1}{u_i}\right)^{\frac{1-\alpha_K-\alpha_\ell}{1-\alpha_K}} - 1\right] \qquad \overline{c}_{it} = \frac{a(1-\alpha_K)}{\alpha_K} K_i \left[1 - \left(\frac{u_i-1}{u_i}\right)^{\frac{1-\alpha_K-\alpha_\ell}{1-\alpha_K}}\right] \tag{26}$$

Where $1-\alpha_K$ is the Jacobian term of the joint distribution, calculated as $\partial \log(p_{it}) / \partial K_i$, which is the absolute value

of the determinant of the jacobian matrix of $\phi(\epsilon_i, p_i, c_i)$.

Case 2: $u_i > \overline{u}$. The marginal cost of adding the next unit is constant at c_i, but for every marginal unit cost c, there exists a cost of design review, $\underline{\omega}_i(c)$, such that the developer is indifferent between u_i and $\overline{u}$. All other rationalizable values of ω_i are below this threshold, as any value above this threshold would induce the developer to choose $u_i = \overline{u}$.

$$\ell_i^2(K_i, u_i, \Pi_i|\theta) = \int_{\underline{c}_i}^{\overline{c}_i} \int_0^{\underline{\omega}_i(c)} \phi(\epsilon_i, p_{it}, c, \omega \mid K_i, \Pi_i, u_i, \theta)(1-\alpha_K) f(c, \omega) \mid K_i, u_i, \theta) d\omega dc \tag{27}$$

$$\underline{\omega}_i(c) = \left(\frac{\alpha_K}{a}\right)(1-\alpha_K) K_i \left[1 - \left(\frac{\overline{u}}{u_i}\right)^{\frac{1-\alpha_\ell-\alpha_K}{1-\alpha_K}}\right] - c(u_i - \overline{u}) \tag{28}$$

Case 3: $u_i = \overline{u}$. The marginal cost of adding the last unit was constant at c_i, but adding the next unit would incur a cost of ω_i. Since the marginal cost of adding a unit is bounded below by zero and the cost of design review is unbounded above, for every marginal unit cost below $\underline{c}_i$, there exists an optimal unit count, $u^*(c)$, that the developer would have chosen if the cost of design review were zero. Furthermore, for each optimal unit count $u^*(c)$, there exists a cost of design review, $\underline{\omega}_i(c)$, such that the developer is indifferent between $\overline{u}$ and that unit count. Thus, for any marginal unit cost below $\underline{c}_i$, there exists a cost of design review above which the developer to choose $u_i = \overline{u}$.

$$\begin{aligned}\ell_i^3(K_i, u_i, \Pi_i|\theta) = &\int_0^{\infty} \int_{\underline{c}_i}^{\overline{c}_i} \phi(\epsilon_i, p_{it}, c, \omega \mid K_i, \Pi_i, u_i, \theta)(1-\alpha_K) f(c, \omega \mid K_i, u_i, \theta) dc d\omega \\ &+ \int_0^{\overline{c}_i} \int_{\underline{\omega}_i(c)}^{\infty} \phi(\epsilon_i, p_{it}, c, \omega \mid K_i, \Pi_i, u_i, \theta)(1-\alpha_K) f(c, \omega) \mid K_i, u_i, \theta) d\omega dc \end{aligned} \tag{29}$$

$$\underline{\omega}_i(c) = \left(\frac{\alpha_K}{a}\right)(1-\alpha_K) K_i \left[\left(\frac{u^*(c)}{\overline{u}}\right)^{\frac{1-\alpha_\ell-\alpha_K}{1-\alpha_K}} - 1\right] - c\left(u^*(c) - \overline{u}\right) \tag{30}$$

$$u^*(c) = \left\lfloor \left(\frac{a(1-\alpha_K-\alpha_\ell)}{\alpha_K c} u_i^{\alpha_K+\alpha_\ell-1} K_i\right)^{\frac{1}{\alpha_K+\alpha_\ell}} \right\rfloor \tag{31}$$

Let $j(i) = \{1, 2, 3\}$ be determined by the unit count of observation i and represent which of the three cases above. Then the log-likelihood function is given by:

$$L_n(\theta) = \sum_{i=1}^{N} \log\left(\ell_i^{j(i)}(K_i, u_i, \Pi_i|\theta)\right) \tag{32}$$

Optimization proceeds by maximizing $L_n(\theta)$, with respect to the parameter vector,

$$\theta = (\alpha_K, \alpha_\ell, a, \overline{p}, \gamma, \{\tilde{d}_t\}, \mu_c, \{\tilde{c}_t\}, \mu_\omega, \sigma_\epsilon^2, \sigma_p^2, \sigma_c^2, \sigma_\omega^2, \sigma_{p,c}, \sigma_{c,\omega})$$

One key parameter constraint, $\alpha_K + \alpha_\ell \in (0, 1)$, is required to derive a likelihood value, since the domain of the

log function is violated if this constraint is not met. As a result, the composite parameter $1 - \alpha_K - \alpha_\ell$ is estimated, rather than α_ℓ and α_K separately, and it is estimated with a change of variables that maps its domain to the real line. Similarly, to avoid imposing additional non-negativity or equation constraints, the spread parameters are estimated as two times the log of the standard deviation and the covariance parameter is estimated as a correlation coefficient, bounded between -1 and 1, and transformed to map to the real line. Standard errors for parameters estimated with transformations are calculated using the delta method.

4.4 Identification

All parameters of the model with the exception of a and α_K are point identified linearly either directly or in a composite parameter. The composite parameter $\log(a/\alpha_K)$ is identified by the scale of the ratio of expected profits to gross square footage, K_i. However, in the capital first order condition, α_K and α_ℓ are not separately identified. The linear form of equation 17 is:

$$\log(p_{it}) = \log(a/\alpha_K) + (1 - \alpha_K)\log(K_i/u_i) - \alpha_\ell \log(L_i/u_i) \tag{33}$$

Where only the composite parameter $\alpha_\ell/(1 - \alpha_K)$ is identified, which is also identified in the unit count first order condition. Thus, identification is achieved by assuming a value for the marginal cost of capital, a, using industry reports and existing literature, which vary from \$120 per square foot to \$200 per square foot. A marginal capital cost of \$175 per square foot is assumed, which is near the upper range of the results found by Eriksen and Orlando (2022), who use a sample of a range of cities in 2018. A cost at the upper end of the range is used to account for increasing costs from 2018 to 2023 and the fact that Seattle is relatively high-cost.

The land share parameter α_ℓ is identified by the covariance of lot size and development square footage (i.e., capital). The intercept (i.e., scale) of the price of housing services is identified jointly by the scale of expected profits and the scale of the square footage of development. The degree of decreasing returns to scale is identified in both of the first-order conditions for the capital and unit count. In the former, it is identified by the covariance between capital and unit count, and in the latter by width of the support of the marginal cost distribution that rationalizes each development's unit count. From the unit count first order condition, the likelihood function is strictly increasing (but concave) in the composite parameter $1 - \alpha_K + \alpha_\ell$ due to its widening of the support of the marginal cost distribution. However, this composite parameter's appearance in the first-order condition for capital ensures the identification of a finite maximum of the likelihood function with respect to $1 - \alpha_K + \alpha_\ell$.

The distribution of the cost of design review, ω_i, is identified by the unit count choice in cases 2 and 3, outlined above. Lower values of the cost of design review are rationalized in case 2 by low–unit count (but still above $\overline{u}$) developments, as such developments are less likely at higher values of μ_ω. Higher values of the cost of design review

are rationalized in case 3 by developments with $u_i = \overline{u}$, particularly those with characteristics that, conditional on model parameters, are more consistent with unit counts well above $\overline{u}$. Such developments are less likely at lower values of μ_ω. Furthermore, if there are many developments in both cases such that a high and low value of μ_ω are rationalized, then the model will be able to identify a distribution with a high variance. Thus, developments with $u_i = \overline{u}$ and $u_i > \overline{u}$ work together to identify the distribution of ω_i.

5 Results

5.1 Profit Estimation Results

The coefficient estimates from equations 14 and 15 are displayed in Table 7. Column (1) displays the results as displayed in the equation 14, which estimates initial-period profit after construction as a function of development and lot characteristics. Column (2) displays the results of equation 15, which estimates the evolution of profits over time.

In each specification, the coefficients on square footage (K) and unit count (u) are positive and statistically significant, suggesting that larger developments not only garner higher profit in the first period, as expected, but also higher profits in each subsequent period, conditional on the lagged dependent variable. The coefficient on lot size (L) is less than one standard deviation from zero in both specifications, suggesting that occupants of multifamily developments do not derive significant utility from the land associated with their building, contrary to evidence from occupants of single-family homes. The evolution of profits over time is highly persistent, with a coefficient on the lagged dependent variable of 0.8, precisely estimated with a standard error below 0.04.

In the AR(1) specification, the effect of building age is estimated separately for buckets of age, relative to the date of either construction or the last major renovation. Consistent with the literature and developer interviews, the rate of building depreciation is monotonically decreasing in age. In the first four years after construction, the rate of depreciation is over 2% per year, which decreases to 1% for years 5 to 25 and to 40 to 60 basis points for buildings older than 25 years. Each of these effects are statistically significant at the 1% level.

5.2 Model Estimation Results

5.2.1 Parameter Estimates

Parameter estimates from the full model are displayed in Table 8. Column (1) displays parameter estimates from a specification that includes parcel covariates in the form of the lot's distance to various points of interest, but does not include any time fixed effects. Column (2) displays results from the same specification as in column (1), but including time fixed effects for the price of housing services. Column (3) displays results from the same specification as in

	(1) Initial NOI	(2) AR Process
log(K)	0.5503***	0.0234
	(0.0897)	(0.0286)
log(u)	0.6955***	0.1283***
	(0.0760)	(0.0277)
log(L)	-0.0275	
	(0.0877)	
log(Med. Rent)	2.8010**	
	(1.4410)	
log(CBD Dist.)	-1.2868***	
	(0.3592)	
log(UW Dist.)	0.9183***	
	(0.3944)	
log(LRT Dist.)	0.4189*	
	(0.2651)	
log(Comm. Dist.)	0.6684***	
	(0.2263)	
σ_ε	0.1858***	
	(0.01393)	
log(NOI_{t-1})		0.8400***
		(0.0340)
Age × Years since build/reno:		
1-4		-0.0194**
		(0.00919)
5-25		-0.0080***
		(0.00309)
26-35		-0.0041**
		(0.00223)
36-60		-0.0046***
		(0.00129)
61-100		-0.0041***
		(0.00101)
>100		-0.0035***
		(0.00082)
Zoning Code FE	Y	Y
Neighborhood FE	Y	N
Year Built FE	Y	Y
R^2		0.945
Log-likelihood	23.51	
Obs.	89	1,158

Table 7: Profit estimation results

column (1), but including time fixed effects for the marginal unit cost. In Appendix A.3, results from specifications with cost time fixed effects (including and not including price time fixed effects) are provided, assuming that the cost of design review is zero (which greatly simplifies the estimation process).

Parameter	(1)	(2)	(3)
α_k	0.566	0.568	0.571
	(0.0013)	(0.0110)	(0.0042)
α_ℓ	0.363	0.377	0.355
	(0.0039)	(0.0336)	(0.0109)
$\overline{p}$	6.381	6.443	6.387
	(0.0160)	(0.2471)	(0.0968)
μ_c	9.788	9.509	10.193
	(0.0204)	(0.2834)	(0.1507)
μ_ω	6.209	6.074	6.223
	(0.0340)	(0.2730)	(0.1074)
log(CBD dist.)	-0.045	-0.063	-0.048
	(0.0185)	(0.1440)	(0.0562)
log(UW dist.)	-0.114	-0.107	-0.108
	(0.0101)	(0.0883)	(0.0310)
log(LRT dist.)	0.131	0.128	0.135
	(0.0051)	(0.0447)	(0.0172)
log(Comm. dist.)	0.179	0.158	0.168
	(0.0051)	(0.0446)	(0.0167)
σ_ϵ	0.416	0.398	0.377
	(0.0184)	(0.0166)	(0.0071)
σ_p	0.248	0.237	0.229
	(0.0018)	(0.0153)	(0.0058)
σ_c	0.694	0.681	0.630
	(0.0019)	(0.0153)	(0.0054)
σ_ω	5.187	5.024	5.100
	(0.0479)	(0.3617)	(0.1433)
$\rho_{p,c}$	0.178	0.184	0.208
	(0.0020)	(0.0171)	(0.0067)
$\rho_{c,\omega}$	-0.701	-0.703	-0.668
	(0.0155)	(0.1341)	(0.0374)
a	175	175	175
Log-likelihood	-3516	-3481	-3478
Price Year FE	N	Y	N
Cost Year FE	N	N	Y
Observations	251	251	251

Table 8: Parameter estimates for the full model

The mean of the unit cost distribution (μ_c) implies a median marginal unit cost between \$13,500 and \$26,700, depending on the specification. This cost includes the physical costs of dividing existing units into smaller units and adding the relevant amenities, such as appliances, as well as the foregone rent from reducing average unit size. Publicly-available estimates of this cost typically provide the *average* unit cost, which includes fixed costs and assumes a corresponding increase in square footage. Regardless, these costs typically range well above \$100,000 per unit. To compare the results of the estimation to these outside estimates, the implied variable cost per unit of an 8-unit development with an average unit size of 700 square feet at the median unit cost is about \$123k with a variable cost

per square foot of $176. This is around the lower range of industry estimates of total cost per square foot for a small (below 4 stories) apartment building.

Consistent with decreasing returns to scale, $\alpha_K + \alpha_\ell$ lies around 0.925 or 0.945, depending on the specification. Existing estimates of the parameters of the production function for housing, with the exception of Combes, Duranton, and Gobillon (2021), assume constant returns to scale (CRS). Thus, in comparing to those estimates, the capital factor share $(\alpha_K/(\alpha_K + \alpha_\ell))$ is the appropriate metric, which is estimated at around .60 to 0.62 across the three specifications. This is narrowly within the 0.601 and 0.767 estimated by Combes, Duranton, and Gobillon (2021) after imposing CRS and below the 0.856 estimated by Epple, Gordon, and Sieg (2010).

When accounting for decreasing returns to scale, the capital production share is about 0.57 and between 0.35 and 0.37 for land. This land share is within the range of estimates from the literature but the capital share is much lower, with the exception of some estimates by Combes, Duranton, and Gobillon (2021), depending on methodology. Part of this discrepancy is simply due to differing assumptions: assuming CRS necessarily inflates both capital and land production shares. Combes, Duranton, and Gobillon do not estimate a constant value for $\alpha_K + \alpha_\ell$, but rather an implies value for each decile of parcel size by alternatively imposing and relaxing a CRS assumption. 0.92 is consistent with their estimate for the 5th to 6th deciles of parcel size, and they find that returns to scale decrease with parcel size. In the production function, greater decreasing returns to scale imply that a development with smaller units and less land per unit delivers more housing services than a development with larger units and more land per unit, *ceteris paribus*, which is consistent with statements from developers.

The estimated correlation between the price of housing services and marginal unit costs is between 0.178 and 0.21, and the correlation between the cost of design review and marginal unit costs is strong and negative, at around -0.7. Both of these results are consistent with marginal unit cost being a choice variable for the developer: on parcels where housing services are more valuable, they invest in higher quality units, and they can only justify paying the cost of design review when their marginal unit costs are sufficiently low. This result is also consistent with the discontinuity displayed in figure 2, which shows that slope in the relationship between square footage and unit count is much steeper for developments that undergo design review. If a continuous unit count choice is assumed, then combining the two first-order conditions implies a square footage per unit that is increasing in marginal unit cost. Thus, if lower design review costs are required to build closer to the unit count threshold and are associated with higher marginal unit costs, then average unit sizes will be increasing as unit count increases following the unit count threshold, which manifests as a steeper slope in the log relationship between total development square footage and unit count to the right of the discontinuity.

Consistent with the number of developments proposed at both the unit count threshold and just above it, the estimated spread parameter for the cost of design review, σ_ω, is large, between 5.0 and 5.2. Though the mean of the distribution is estimated at a relatively small 6.2, implying a median cost well below $1,000, the costs at the upper end

of the distribution are very large. Figure 3 displays the dollar cost of design review by quantile, starting at the median design review cost.[14] Also displayed are the median marginal unit cost and the median and average expected profit. Although three-quarters of developments face a design review cost below the median marginal unit cost, the upper tail of developments face a prohibitive cost. These costs above $1 million should not necessarily be interpreted literally, but rather as an anticipated rejection, as rejection itself is not included in the model and can only take the form of a functionally infinite design review cost (since rejections of legally-allowable developments are only possible when undergoing design review).

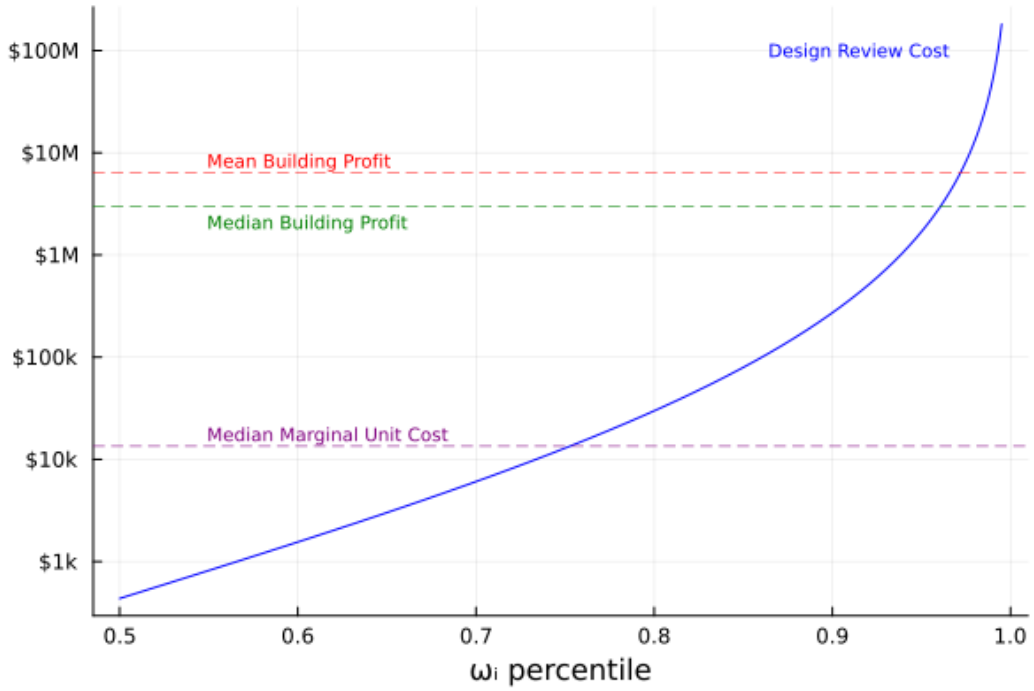


Figure 3: Design review cost by percentile

A design review cost distribution with a low median but extremely high variance is consistent with design review costs being determined by (mostly) unobservable lot characteristics. An empty lot in an already relatively dense neighborhood is unlikely to receive any opposition that would be taken seriously by the design review board, the SDCI director, or an administrative judge (in the event of an appeal of permit approval). However, a large development in a low-density residential neighborhood that requires the demolition of a beloved property that is considered historic by locals though lacks historic designation is likely to face significant opposition. Between these two extremes are a range of cases that result in a range of opposition and corresponding design review costs.

14. Figure 3 uses the estimated parameters from column (2) of table 8. All model fit and counterfactual results are also based on this specification.

5.3 Model Fit

5.3.1 Simulated Developments

Given the estimated model parameters, it is possible to simulate the unit count, square footage, and expected profit for each lot that was proposed for development during the sample period. For each observation i (which includes a parcel and development year) and simulation s, four shocks are drawn from the joint distribution whose mean and covariance matrix were estimated in the previous section: $\epsilon_{i,s}$, $p_{i,s}$, $c_{i,s}$, and $\omega_{i,s}$. The price, marginal unit cost, and design review cost shocks are then used to calculate the optimal unit count, which accounts also for the optimal square footage per unit conditional on unit count. Without considering the cost of design review, the optimal unit count is given by the first-order condition of the value function after replacing the capital choice with its optimal value:

$$u^*_{i,s} = \left\lfloor \left(\frac{1-\alpha_K-\alpha_\ell}{c_{i,s}} \right)^{\frac{1-\alpha_K}{\alpha_\ell}} \left(\frac{\alpha_K}{a} \right)^{\frac{\alpha_K}{\alpha_\ell}} p_{i,s}^{\frac{1}{\alpha_\ell}} L_i \right\rfloor \tag{34}$$

Where $\lfloor \cdot \rfloor$ is the floor function, which rounds down to the nearest integer. Given the cost of design review, the simulated unit count is given by:

$$u_{i,s} = \begin{cases} \overline{u} & \text{if } V_{i,s}(\overline{u}) > V_{i,s}(u^*_{i,s}) \\ u^*_{i,s} & \text{Otherwise} \end{cases} \tag{35}$$

Where $V_{i,s}(\cdot)$ is the after replacing the capital choice with its optimal value. It is possible for the optimal unit count to be less than the value calculated in equation 34 because this value is calculated without accounting for the cost of design review, which is incurred only if $u > \overline{u}$. After calculating the optimal unit count, the optimal square footage is calculated using the capital first-order condition of the value function given in equation 5, and estimated profit is calculated as the revenue from selling the development, given $(p_{i,s}, K_{i,s}, u_{i,s}, L_i)$, minus the costs of construction and design review.

5.3.2 Comparison to Observed Developments

To compare model predictions to observed developments, each development in the city is simulated 1,000 times via the process described in the previous section. Table 9 presents summary statistics for each of the three response variables: unit count, square footage, and expected profit. The summary statistics of the simulated data are calculated by first calculating the metric across each of the observations within a simulation and then averaging across the 1,000 simulations.

The first two columns compare the number of units between the observed and simulated data. The simulated data fit the observed data well in the bottom half of the distribution, but the maximum unit count is much larger in the

	No. Units		Sqft ('000)		Expected NOI (Mil. $)	
	Data	Simulation	Data	Simulation	Data	Simulation
mean	18.3	16.0	13.65	13.72	5.32	4.58
sd	20.5	27.4	17.94	16.58	6.40	6.30
min	2.0	2.0	1.58	0.56	0.55	0.14
p5	2.0	2.0	2.40	1.78	0.66	0.49
p25	4.0	4.0	4.74	4.84	1.47	1.40
p50	8.0	8.0	8.99	8.94	2.86	2.76
p75	28.0	16.0	14.59	16.44	7.14	5.38
p95	60.0	54.0	36.93	40.51	15.49	14.28
max	150.0	246.0	175.84	141.16	56.01	55.34

Table 9: Model fit summary statistics

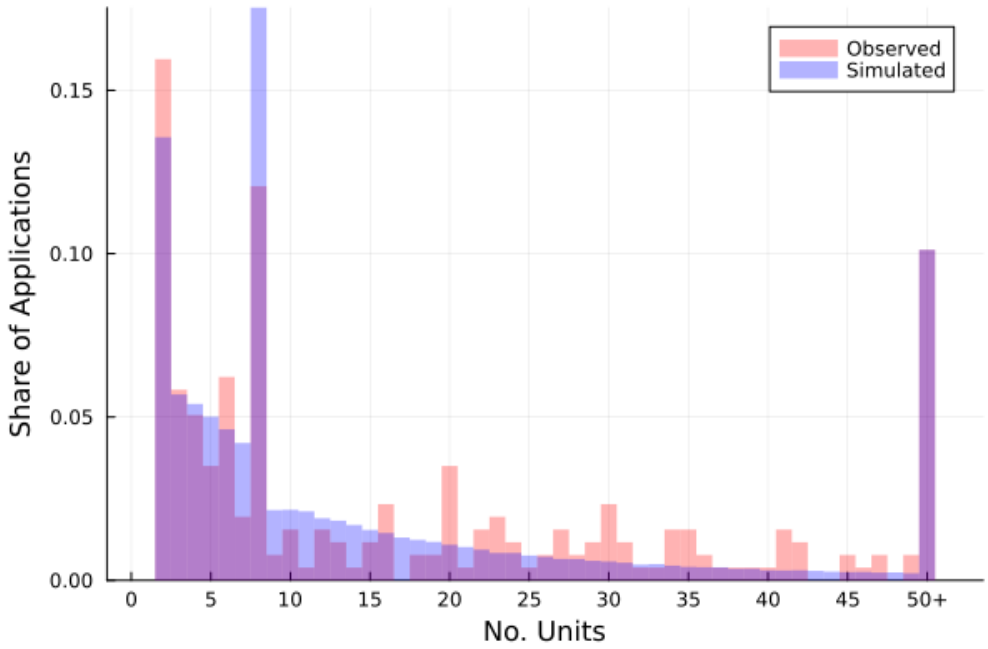
simulated data, and the 75th percentile development has many more units in the observed data. Panel (a) of Figure 4 displays the distribution of unit counts for both the observed and simulated data. The share of developments that develop at the design review threshold is higher in the simulated data than in the observed data. The simulated data underestimate the share of developments with an intermediate number of units, primarily between 20 and 50. This could be due to increasing marginal unit cost after the design review threshold, which is not accounted for in the model.

The next two columns in Table 9 compare the square footage of developments between the observed and simulated data, and panel (b) of Figure 4 displays the two distributions. The simulated moments generally adhere to the observed ones, though the simulated data have larger mass on the higher end of the distribution and, understandably, predict the existence of developments that are far too small to exist in the real world. The observed data are nearly bimodal with peaks at around 5,000 and 10,000 square feet, while the simulated data are unimodal with a peak at around 5,000 square feet.

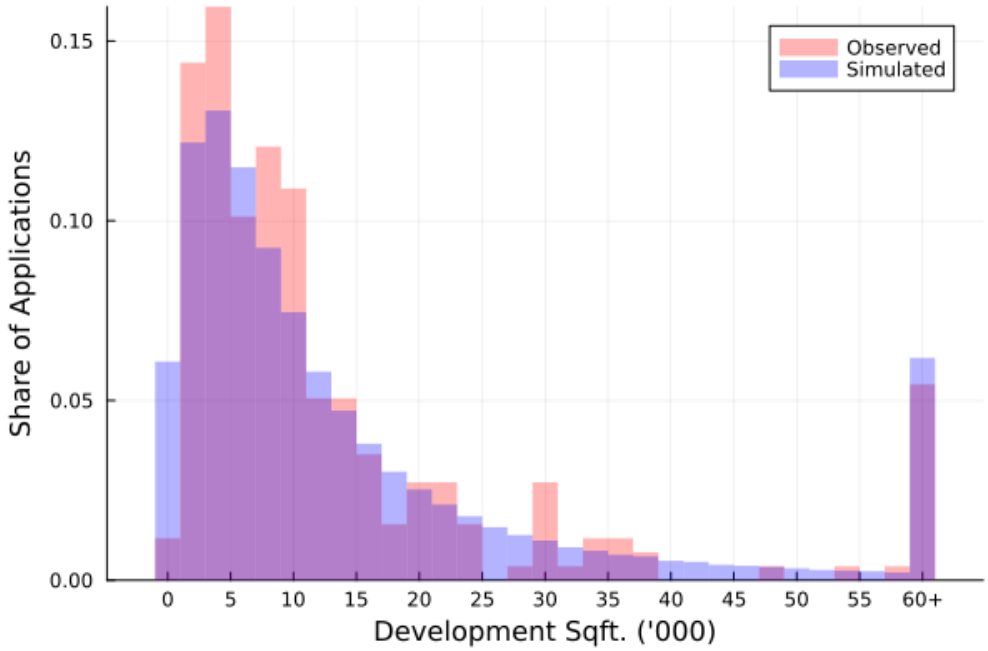
The final two columns of Table 9 compare the expected discounted net operating income (NOI) between the observed and simulated data. While the medians of the simulated and observed data are very close at around $2.8 million and the simulated data generally fit better in the second quartile and upper tail of the distribution but underestimate the data at the lower tail and third quartile. Across the three outcome variables, these results suggest that the model is a reasonable estimate of the true data generating process. However, it may be able to be improved by accounting for the increasing marginal unit cost after the design review threshold, a minimum allowable square footage, and increased costs for developments with odd unit counts.

6 Counterfactual Analysis

In the counterfactual analysis, the cost of design review is set to zero, and all simulated developments with shocks $(c_{i,s}, \omega_{i,s})$ that are inconsistent with the integration bounds of the observation i's likelihood calculation provided in



(a) Number of units per development



(b) Square feet of development

Figure 4: Distribution of observed and simulated development characteristics

section 4.3 are dropped. In other words, the counterfactual analysis assumes that the developer drew the same marginal cost shock as they did in the observed data. However, since the marginal unit cost is only set identified, each simulation draws from the set of rationalizable marginal unit costs. To obtain unit counts without design review, the same shocks are maintained, but unit count is calculated as simply the optimal unit count provided in equation 34.

	mean	sum	sd	min	p5	p25	p50	p75	p95	max
Number of units										
Data	18.3	4447.0	20.5	2.0	2.0	4.0	8.0	28.0	60.0	150.0
Sim. w/ Design Review	17.9	4355.1	24.8	2.0	2.0	4.0	8.0	22.0	61.0	194.0
Sim. w/o Design Review	20.2	4898.3	27.3	2.0	2.0	4.0	11.0	25.0	66.0	217.0
% Difference	**12.85**	**12.47**								
Sqft of Development ('000)										
Data	13.65	3317.16	17.94	1.58	2.40	4.74	8.99	14.59	36.93	175.84
Sim. w/ Design Review	13.73	3336.86	16.64	0.62	1.75	4.60	8.71	16.43	41.76	136.08
Sim. w/o Design Review	13.94	3388.09	16.74	0.62	1.76	4.67	8.90	16.78	42.20	136.33
% Difference	**1.53**	**1.54**								
Expected Discounted NOI (Mil. $)										
Data	5.32	1291.70	6.40	0.55	0.66	1.47	2.86	7.14	15.49	56.01
Sim. w/ Design Review	4.63	1125.34	6.45	0.15	0.48	1.34	2.69	5.40	14.87	55.34
Sim. w/o Design Review	4.70	1142.63	6.50	0.15	0.48	1.36	2.75	5.51	15.06	55.51
% Difference	**1.51**	**1.54**								

Table 10: Summary Statistics from Counterfactual Simulations

Table 10 displays the summary statistics of each of the three outcome variables (unit count, development size, and expected profit) from the counterfactual simulations. In each panel, the first row displays statistics from the data, the second row displays the statistics from the counterfactual simulations at the estimated cost of design review, and the third row displays the statistics from the counterfactual simulations at zero cost of design review. The first panel displays statistics for the unit count. Similar to the results in section 5.3.2, simulated unit counts match the data well, though slightly underestimate unit counts around the 75th percentile. However, the total number of units across LR lots in the 2008-2018 period is well-matched, with the simulated data only underestimating the observed unit count by 92 units, or 2%. When unit counts are simulated without design review, the total number of units increases by 543, or 12.5% The average number of units per development increases by 2, which, unsurprisingly, comes from the top half of the unit count distribution: while the minimum, 5th percentile, and 25th percentile unit counts are unchanged, the 50th, 75th, and 95th percentiles increase by 3-5 units. Figure 5 displays the histogram of simulated unit counts with and without design review. As expected, the discontinuous mass of developments at the design review threshold is reduced and spread out over the unit counts just above the threshold, with the reallocation decreasing as unit count increases. This is also observable in the recreation of the bunching table, table 11.

The second panel of table 10 displays the development size in thousands of square feet. Like with unit count, design review has a monotonic and negative effect on development size. However, the effect on square footage is smaller, as developments that are induced by design review to reduce unit count compensate in part by building larger units than they otherwise would if building at the 8-unit design review threshold were optimal. This model-based

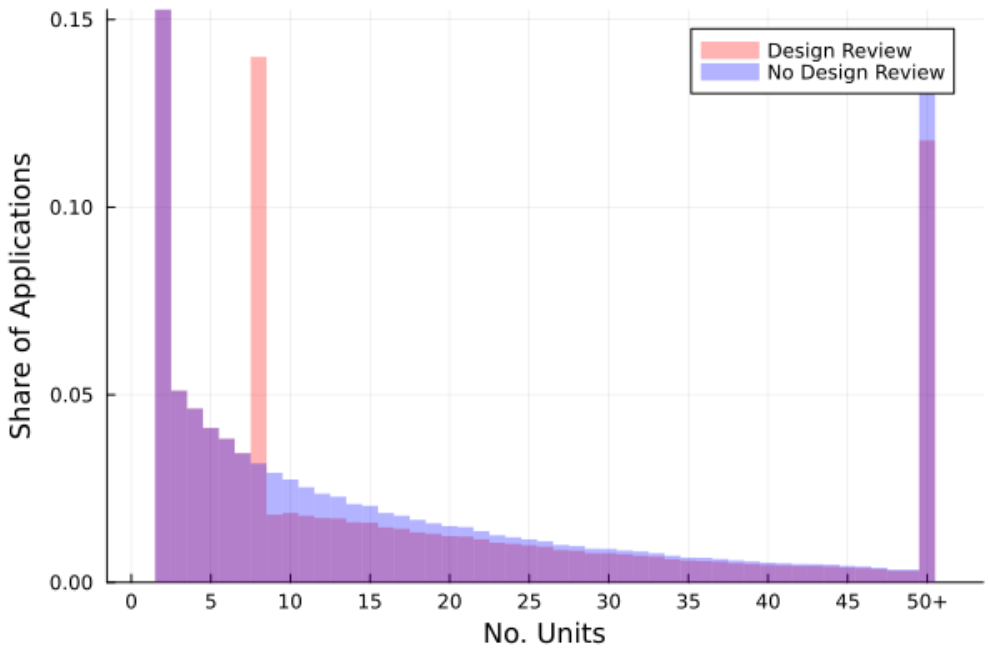


Figure 5: Simulated number of units per development with and without design review

reality is borne out in the summary statistics: average development size increases by a mere 210 square feet, or 1.54%, resulting in a total square footage increase of 51,230 square feet.[15] Again, only developments toward the middle and upper-middle of the distribution are affected, as the model predicts that developments with unit counts at the design review threshold become smaller and those just above the threshold become larger.

The third and final panel of table 10 displays the expected net operating income (NOI) from each development. Average expected NOI and the expected NOI at the bottom quarter of the distribution are largely unchanged, while total expected NOI increases by $17.29 million, or 1.54%. Unsurprisingly, the largest percentage increases in NOI occur in the third quartile of the distribution, where the largest density of buildings on the policy's margin are located. The relatively small change in NOI compared to the change in unit count is consistent with developers compensating for policy-induced unit count reductions by increasing the size or quality of the units.

7 Conclusion

As the national housing shortage continues to increase real home prices and rental rates in cities across the United States and many other developed countries, policy-makers increasingly seek to reform land use regulations to increase the supply of housing. One area that has received attention both among policy-makers and among researchers, particularly in the political science literature, is the costly and uncertain permitting process for multifamily developments.

15. Both of these estimates compare the simulated square footage with no design review to the simulated square footage with design review.

	Share of Applications		
Units	Observed	Simulated	Counterfactual
2	15.95	15.26	15.26
3	5.84	5.11	5.11
4	5.06	4.63	4.63
5	3.50	4.11	4.11
6	6.23	3.83	3.83
7	1.95	3.44	3.44
8	12.06	14.00	3.17
9	0.78	1.80	2.92
10	1.56	1.85	2.74
11	0.39	1.78	2.53
12	1.56	1.72	2.36
13	1.17	1.71	2.28
14	0.39	1.60	2.09
15+	42.41	37.56	43.46

Table 11: Share of applications at each unit count in the data and simulations

Notes: The first column displays the observed data. The second and third columns display the share of applications at each unit count across 1,000 simulations of each development in the data. The second column displays the simulated unit count at the estimated cost of design review. The third column displays the simulated unit count at zero cost of design review for all developments.

In the city of Seattle, Washington, from 2008 to 2018, an often-binding unit count threshold for discretionary review was in place for multifamily developments. In this paper, it is also shown that developments bunched at the unit count threshold and that there exists a discontinuity in the unit count–development size relationship at the threshold only for the period when the threshold was in place, consistent with developers satisfying higher demand for housing services on lots on the policy's margin by building larger units. A model of the production of housing services for multifamily developments is proposed and estimated using a sample of new developments in Seattle, Washington during the 2008–2018 period when a unit count threshold for discretionary review was in place.

The results, displayed in section 5 imply that, contrary to the assumptions of most existing literature on the production of housing services, the production function for multifamily housing is characterized by decreasing returns to scale. The cost of design review is estimated to have a large variance and to vary negatively with the marginal unit cost, implying that developers compensate for high permitting costs by investing in lower-quality units. In simulations of every in-sample lot that was redeveloped with new apartment buildings during the period when the unit count threshold was in place, removing design review would have increased the number of units by over 12%, or 543 units. Because developers trade off unit count and unit size, both the average unit size and the average profit per unit would be lower. Although further study is warranted in the margins on which developers accommodate the cost of design review, these results also suggest that developers reduce unit sizes when they are subject to design review but build larger units when they are dissuaded by design review from building larger developments.

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A Appendix

A.1 Seattle's Design Review Board

There are as many design review boards in the City of Seattle as there are districts, with each district's board composed of 5 local (to the the city, though not necessarily to the district) members who serve 2-year terms that may be repeated.[16] The five members consist of one representing "development-related interests", on representing the "deisgn professions" (usually professional architects), two representing the interests of local residents, and one representing "general business interests or landscape professions". Members are appointed by either the mayor or by the City Council, with half of the members in each interest group (e.g., development interests) appointed by the mayor and the other half appointed by the City Council, with the exception of local residents, for whom half are appointed jointly by the mayor and council, with the other half split between solely the mayor and solely the council.

Prior to May 2018, there were 7 design review districts in Seattle, displayed in Figure A1. The map amended by ordinance 125562, which added an additional district in East Seattle, mostly composed of areas that were previously part of the seventh district. This map, displayed in Figure A2, became effective in May of 2018.

16. This information, as well as all information in this section, is taken from the Seattle municipal code section 23.41.

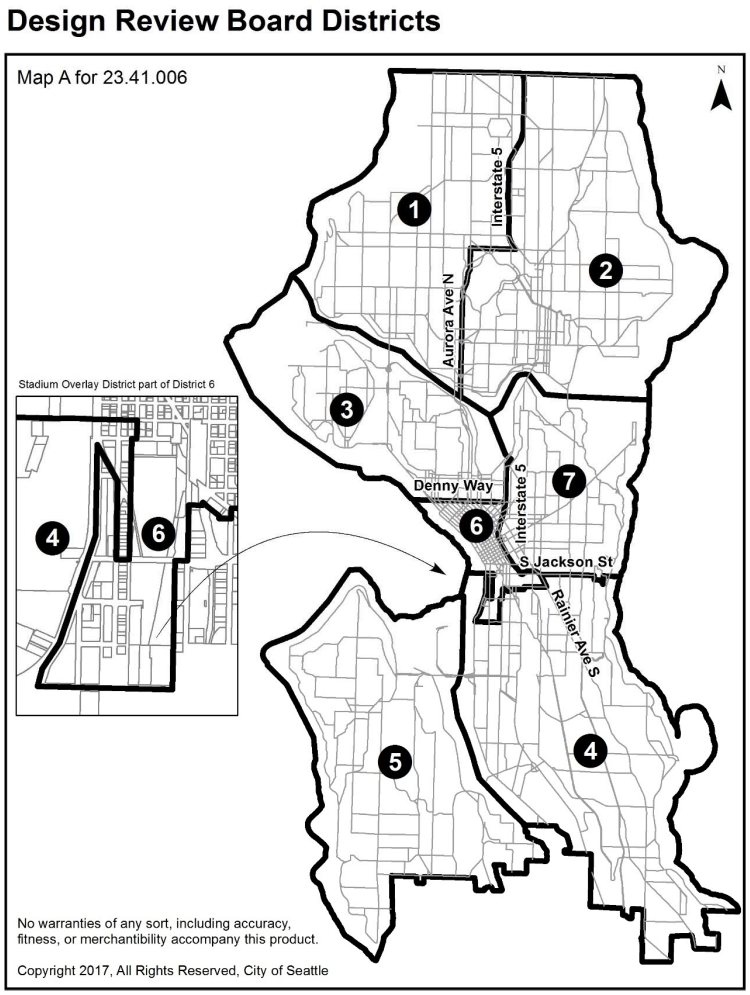


Figure A1: Design review district boundaries, pre-2018

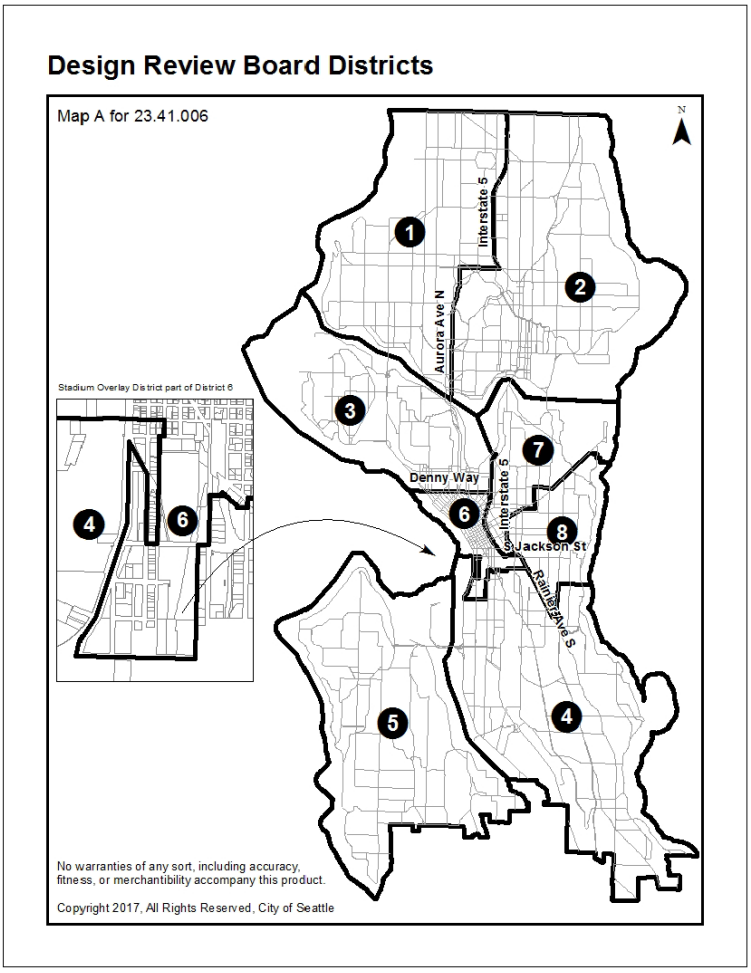


Figure A2: Design review district boundaries since 2018, as of 2024

A.2 Proof of Proposition

Let $V_p(K, u)$ be the value of a building with K square feet of capital and u units on a lot with price p, not including the cost of design review, ω, and let (K_p^*, u_p^*) be the optimal input choice in a world with no design review such that:

$$V_p(K_p^*, u_p^*) \geq V_p(K, u) \quad \forall (K, u) \tag{A1}$$

Assume that the optimal input choice for square footage is strictly increasing in price:

$$p' > p \Rightarrow K_{p'}^* > K_p^* \tag{A2}$$

Finally, let $\overline{u}$ be the design review threshold such that ω is incurred iff $u > \overline{u}$.

Proposition: $\forall p$ such that $u_p^* > \overline{u}$, $\exists \epsilon, \omega > 0$ such that $V_p(K_p^* - \epsilon, \overline{u}) \geq V_p(K_p^*, u_p^*) - \omega$

Proof. Choose p such that $u_p^* > \overline{u}$. Then, $\exists p' \neq p$ such that $u_{p'}^* = \overline{u}$ and $K_p^* > K_{p'}^*$. Thus, choose $\epsilon > 0$ such that $V_p(K_p^* - \epsilon, \overline{u}) \geq V_p(K, \overline{u})\ \forall K$. Then,

$$V_p(K_p^* - \epsilon, \overline{u}) - V_p(K_p^*, \overline{u}) \geq 0$$

$$V_p(K_p^*, u_p^*) - V_p(K_p^*, \overline{u}) \geq 0 \quad \text{(by eq. A1)}$$

Now, choose $\omega \geq V_p(K_p^*, u_p^*) - V_p(K_p^*, \overline{u})$. Then,

$$V_p(K_p^* - \epsilon, \overline{u}) - V_p(K_p^*, \overline{u}) \geq V_p(K_p^*, u_p^*) - V_p(K_p^*, \overline{u}) - \omega$$

$$\therefore V_p(K_p^* - \epsilon, \overline{u}) \geq V_p(K_p^*, u_p^*) - \omega \ \blacksquare$$

Corollary: $\forall p, \omega$ such that $V_p(K_p^* - \epsilon, \overline{u}) \geq V_p(K_p^*, u_p^*) - \omega$ for some $\epsilon > 0$, $K_p^* - \epsilon \geq K_{p'}$ for all $p' \leq p$ such that $u_{p'}^* = \overline{u}$.

A.3 Parameter Estimates without Design Review

The model results *not* accounting for the cost discontinuity at $\overline{u}$ (which equals 8 units) are displayed in Table A1.

Parameter	(1)	(2)	(3)	(4)
α_k	0.594	0.594	0.591	0.591
	(0.0143)	(0.0142)	(0.0141)	(0.0141)
α_ℓ	0.326	0.327	0.346	0.346
	(0.0877)	(0.0478)	(0.0675)	(0.0372)
$\overline{p}$	6.524	6.522	6.380	6.378
	(0.5329)	(0.2834)	(0.4220)	(0.2532)
μ_c	10.047	10.342	9.813	10.108
	(1.0986)	(0.6084)	(1.0680)	(0.5870)
log(CBD dist.)	-0.068	-0.068	-0.073	-0.073
	(0.0313)	(0.0291)	(0.0300)	(0.0268)
log(UW dist.)	-0.115	-0.115	-0.119	-0.119
	(0.0363)	(0.0277)	(0.0316)	(0.0261)
log(LRT dist.)	0.059	0.059	0.059	0.059
	(0.0384)	(0.0345)	(0.0363)	(0.0331)
log(Comm. dist.)	0.023	0.023	0.037	0.037
	(0.0518)	(0.0512)	(0.0526)	(0.0523)
σ_ϵ	0.508	0.508	0.507	0.507
	(0.0170)	(0.0170)	(0.0169)	(0.0169)
σ_p	0.257	0.257	0.255	0.255
	(0.0564)	(0.0319)	(0.0416)	(0.0244)
σ_c	0.694	0.656	0.694	0.656
	(0.0162)	(0.0154)	(0.0163)	(0.0154)
$\rho_{p,c}$	0.172	0.214	0.163	0.172
	(0.2935)	(0.1606)	(0.2222)	(0.1162)
Log-likelihood	-2903	-2848	-2873	-2821
a	175	175	175	175
Price Year FE	N	N	Y	Y
Cost Year FE	N	Y	N	Y
Observations	504	504	504	504

Table A1: Parameter estimates, assuming no discontinuity in the cost of adding a unit