Foundations and Microfoundations: Building Houses on Regulated Land

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Abstract

The most common land use regulations in the United States govern lot size and structural intensity. I specify a residential builder's profit maximization problem that distinguishes between yard space and covered land and incorporates common regulations as constraints. The model yields a closed-form solution for the cost of minimum lot sizes and coverage ratios, which I estimate using tax appraisers' data from two large Texas counties. Minimum lot size regulations usually bind, even though the Houston and Dallas areas are known for their permissive regulation. The gains from deregulation are largest where housing prices are high, not where the largest share of parcels is constrained.

Generalizing, I show that a theoretical city regulated by binding minimum lot sizes grows less in response to a wage increase than a city with binding height and coverage limits. A city regulated only by impact fees is more responsive still.

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1. Introduction

A large literature considers the production of housing and growth of cities when regulatory constraints bind. However, most of this literature considers regulation in abstract forms. This paper contributes to the broadening understanding of housing production by characterizing the parcel-level implications of minimum lot sizes, height limits, and coverage ratios for the creation of subjective residential value, or "housing services."

Each type of regulation has distinct, sometimes testable, theoretical implications. This paper develops a model that distinguishes between land used as yard space and the house footprint subject to regulations that may distort the configuration of a parcel.

These microfoundations allow one to distinctly model common land use regulations and derive implications that are sometimes distinct. In particular, the stringency of minimum lot size and coverage requirements is proportional to the difference between the yard's share of home value and the elasticity of housing services with respect to yard size.

The model implies that the elasticity of housing services with respect to yard size will be equal to the yard's share of home value when lot size and coverage regulations are nonbinding. In addition, it implies that the elasticity will never be greater than the yard's share of value, regardless of regulation.

One is more likely to isolate the effects of a specific regulation where regulations are few and sometimes nonbinding. Thus, I test the model's implications using appraisal data on recently built single-family homes in Harris County and Dallas County, Texas. Harris County (which is regulated mostly by the City of Houston) is known for its lack of zoning and regulatory permissiveness. Both counties have plenty of new construction across a wide range of prices and heights.

Empirically, I find that land use regulations bind even in some very lightly regulated areas. In Houston neighborhoods around Rice University, relaxing the 3,500-square-foot minimum lot size by 500 square feet would increase the profitability of building a single-family home by $30,000. By contrast, there are areas with high land costs where constraints do not appear to bind. Those include Greater Heights in Houston, where old ranch homes have rapidly been replaced with townhouses, as well as the elite Park Cities in Dallas County, which appear unconstrained despite strict regulations and spacious yards.

Second, to test the model's fitness, I evaluate the implication that the elasticity of housing services with respect to yard size will never be greater than the yard's share of value. This implication is violated (at a 95 percent significance level) for less than 1 percent of parcels.

The paper proceeds with a brief review of the literature on regulation-constrained housing production. Section 3 presents a new theoretical model of parcel development into yard and house space and identifies several implications of the model. Section 4 uses a linear city model to explore the implications of three regulatory regimes. The second half of the paper is empirical. Section 5 reviews the regulatory institutions in Harris and Dallas Counties in order to put the model into context. Section 6 presents the data, drawn primarily from county assessors. Section 7 takes the parcel development model to the data, yielding point estimates for the cost of minimum lot size and coverage regulations. Section 8 presents those results and discusses the patterns that emerge in each county. Section 9 concludes.

2. Literature Review

Residential construction in the United States is regulated by local governments using a myriad of restrictions on the dimensions, location, and style of residential construction. As a shorthand, "zoning" is often used as an umbrella term for these regulations, although localities organize and label their land use regulations in a variety of ways.

Observational studies of land use regulation typically identify minimum lot sizes for single-family homes and unit-per-acre limits for multifamily housing as the most important aspects of zoning. Ellickson (2020) chooses to use minimum lot size and the presence (or absence) of by-right multifamily zoning as indicators of regulatory strictness. He notes that "lot-size regulations . . . largely determine the ambiance of an urban area" (16). Fischel (2015, 30) calls minimum lot size "the workhorse of suburban zoning." Minimum lot sizes frequently show up in the names of zones; in Dallas, for example, the R-16(A) zone requires at least 16,000 square feet for a single-family residence.

Minimum lot sizes are likely to bind in many contexts, and a handful of local tests exist. Furth and Gray (2019) observe bunching at zoned minima in Texas suburbs. White (1988) uses the prices of large, divisible lots, which differ in their modulo, to show that a 9,000-square-foot minimum lot size bound in Ramapo, New York. Isakson (2004), following White's approach, finds that the same lot size was nonbinding in small-town Iowa. Zabel and Dalton use a hedonic regression and event study framework to estimate, separately, the value of minimum lot sizes. They find, conditional on lot size and other characteristics, that an acre increase in minimum lot size is associated with a 9 percent increase in home price (2011, 580).

A handful of theory papers explicitly consider minimum lot size regulation. Bucovetsky (1984) and Henderson (1985) present similar models of minimum lot sizes with constant returns to scale production and sole occupancy. They show that when zoning is fully reflected in (lower) land prices, binding minimum lot sizes must raise total housing consumption. Henderson also considers the case where land prices do not fully adjust—for instance, because the regulations are universal. In this case, minimum lot sizes may decrease housing consumption (although they must still increase housing expenditure). Colwell and Scheu (1989) solve an optimal platting problem subject to two spatial constraints expressed as Lagrangians. They estimate a model in which “lot value is a Cobb-Douglas function of depth and frontage” (102) and find that the optimal lot size and depth in Champaign, Illinois, were slightly smaller than regulations allowed.

Brueckner (1983) finds that in the absence of regulation, an urban spatial model in which residents value yard space gives qualitatively similar predictions to the standard model in which land is only a factor of production. As in the standard model, structural density in Brueckner’s framework decreases with distance from the center. The production function in the present paper differs slightly from Brueckner’s. In his framework, covered land and structural capital are combined to create improved space in an unspecified production function. Improved space and yard are then arguments in a utility function. Here, I specify a production function: improved space is equal to the invested structural capital (K) and covers land $L^F = K/S$, where S is the number of stories. I use H to denote housing services, an unspecified combination of yard and improved space.

Broad studies of regulated urban growth typically assume that housing services are a divisible commodity. Under this assumption, minimum lot sizes do not matter, since any number of households can fractionally consume a very large house on a correspondingly large lot. Papers working within this framework have modeled regulation as floor area ratio regulations (Brueckner et al. 2017; Brueckner and Singh 2020), fees (Duranton and Puga 2019), and greenbelts (Turner, Haughwout, and van der Klaauw 2014). These choices are reasonable and allow the authors to gain insight into regulated urban growth.

There are, however, two potential problems with allowing tractable proxies to stand in for zoning rules in theoretical models. First, regulation-as-modeled may have implications that are invalid for other, more common forms of regulation. This is most obvious in the case of greenbelts, which are rare in the United States and tend to increase density in the buildable area—the opposite of the effect of more common regulations. Second, implications drawn from an abstracted form of regulation provide less guidance to policymakers who want to weigh the costs and benefits of specific reforms.

Under unit-specific regulations such as minimum lot size, the production function for housing takes on greater significance. Recent research on housing production functions, such as Epple, Gordon, and Sieg (2010), Combes, Duranton, and Gobillon (2021), and Albouy and Ehrlich (2018), estimates the relative contributions of capital and land in creating housing services while imposing few statistical restrictions. Epple, Gordon, and Sieg and Combes, Duranton, and Gobillon use nonparametric methods, allowing them to flexibly depart from scale assumptions. Parkhomenko (2020) imposes a Cobb-Douglas production function, but allows regulation to decrease builders' productivity and, distinctly, to increase land's share in construction.

In this paper, I retain the flexible production function but impose structure in two specific ways: by distinguishing land underneath the house as "footprint" and by allowing a cost premium for height.

Like the "zoning tax" literature following Glaeser and Gyourko (2003), the present paper is grounded in the theoretical insight that the value of land at the intensive margin is less than its average (or "extensive margin") value in the presence of density-restricting regulations. The same insight is central to Banzhaf and Mangum (2019). They model minimum lot sizes[1] and note that "a minimum purchase requirement is equivalent to a two-part tariff" (16). Using detailed national data, they find that the prices of housing services differ across neighborhoods, a finding I replicate here in two counties, partially as a consequence of differing regulation.

Since neither the marginal nor the average value of land is readily observable in most transactions, researchers in the zoning tax literature have used a variety of empirical strategies to uncover it. Glaeser and Gyourko (2003), Glaeser, Gyourko, and Saks (2005), and Glaeser and Ward (2009) start with home value as reported in the American Housing Survey and subtract R.S. Means estimates of construction costs at the metro area level. As Glaeser, Gyourko, and Saks note, metro-wide estimates of the hedonic value of land will be biased downward—and the zoning tax will be biased upward—if lots are larger in areas where land is cheaper (357–58).

Gyourko and Krimmel (2021) improve the measurement of average land price by using CoStar data on recent vacant land sales. They impute marginal land value from recent home sales in the vicinity of each transaction. The data are sparse; only 24 US metro areas had at least 20 qualifying vacant land sales from 2013 to 2018.

In the present paper, I advance the zoning tax literature by deriving the relationship among marginal land value, average land value, and specific zoning constraints and estimating it at the zip code level using tax assessor data on newly built homes. This empirical approach also has limits: it can be implemented only in areas with a sufficient rate of new construction and where the assessment authority provides timely and accurate data.

[1] An important caveat when comparing Banzhaf and Mangum's discussion of minimum lot sizes with others is that they explicitly consider a case where the minimum lot size applies to a neighborhood with vacant land remaining undeveloped, so the lot size does not limit the number of entrants. As they note, a minimum lot size acts as a constraint on the number of lots, with different implications, when subdivision possibilities are exhausted.

In a related research program, Brueckner et al. (2017) and Brueckner and Singh (2020) impose more theoretical structure and identify regulatory stringency as the elasticity of land value with respect to floor area ratio (FAR) maximums. They show that the elasticity is related to the (unobserved) unconstrained optimum. Their estimates depend on two key steps: assuming a specific, invertible functional form for the production function and accurately observing the published FAR regulations.

I follow Brueckner and coauthors by measuring regulatory strictness without imposing equilibrium assumptions beyond a zero-profit condition. I expand on their approach by adding three more constraints and allowing unbuilt land to produce housing services. Empirically, I show that measures of regulatory strictness—although not the same as Brueckner et al.'s definition of stringency—can be estimated without observing regulations or having a functional form for the production function.

The present paper is in tension with Tan, Wang, and Zhang (2020), who show that when the housing services production function is Cobb-Douglas, land's share of the housing value increases as FAR decreases. In contrast, I observe no such regularity. They thus proceed by using land's share as a proxy for regulatory stringency, and they document that it decreases with distance from the center. In the present paper, I also observe the highest land shares in zip codes near the centers. But these are not necessarily due to stringent regulation, because the same zip codes also have high hedonic land values. Such spatial variation in housing hedonics is worthy of continued research.

The current approach has clear limitations. The production function and multifaceted regulation explored here would be cumbersome additions to existing urban growth models. And although it offers an empirical procedure to identify how tightly regulatory constraints bind in specific geographies, it does not, in the absence of a specified production function, provide a counterfactual.

3. Model of Parcel Development

This section presents a new theoretical model of parcel development into yard and house space and identifies several implications of the model.

Households enjoy "housing services," which are a function of improved indoor space ("house") and unimproved outdoor space ("yard"). Houses and yards are bundled on indivisible parcels. A household can occupy only one parcel. Houses have a height in stories, which is continuous and no less than one.[2] The floor space of each home equals its footprint times its height. The footprint of a house occupies land that has no consumption value.

A competitive builder facing costless entry and exit maximizes the profit from a residence in location x subject to regulatory constraints. Although this framework allows for a stylized representation of many types of regulation, I explicitly model three that commonly govern single-family construction in Harris or Dallas Counties: minimum lot sizes, maximum lot coverage, and height limits.

Another variety of regulation (e.g., design requirements, energy efficiency standards) adds to the fixed or variable costs of the building. I do not model the latter but doing so would be straightforward in this framework. Covered parking requirements, which are common, would be more difficult to model, since they add a third, intermediate use of space.[3]

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[2] Appraisal data distinguish height down to the half story, but the vast majority of houses have a natural number of stories. In pitched-roof houses, builders offer varying amounts of finished space on the top story by adjusting the height.

[3] Garage space is cheaper than improved living space and is an imperfect substitute for both improved and yard space.

For ease of reference, table 1 provides a glossary of variables introduced throughout the paper.

Table 1: Glossary of notation

Parcel development model	
$h(k, L^Y)$	Housing services derived from enjoyment of house and yard
k	Improved house space and the variable costs of its creation
$c(s)$	Cost of house height s (think "stories")
I	Impact fees and other fixed per-unit costs of construction
L^Y	Yard space (i.e., unimproved land)
L^F	Land used as the footprint of the house
p^H	Price per unit of housing services
r	Price per square foot of land
$\prod$	Builder's profit from a single residence
MLS (λ^M)	Minimum lot size, in square feet (associated Lagrangian multiplier)
COVERAGE (λ^C)	Maximum lot coverage, as a percentage of lot area
HEIGHT (λ^S)	Height limit, in stories
Θ	Elasticity of housing services with respect to yard space
Θ^0	Θ when no regulation binds; this equals the yard's share of home value
Static city model	
$j \in \{M, SC, I\}$	City index
x	Distance from city centroid and index of location
$\bar{x}$	Urban fringe distance from centroid
r_A	Agricultural (outside option) land rent
τ	Travel cost per unit of distance from the centroid
w	Wage
N	City population
$\bar{u}$	Outside option utility level
$d(x)$	Population density, in households per square foot of land, at location x
$f(x)$	Floor area ratio at location x
$k(x)$	Home size at location x
Ω	Elasticity of city size with respect to wage
$\Psi(x,\bar{u})$	Bid-rent function
$a(x)$, $a(x,\bar{u})$	Consumption of / Hicksian demand for nonhousing good
Empirical model	
i	Individual house index
x	Neighborhood index (narrower geography)
z	Zip code or small city index (larger geography)
Θ_z^E	Estimated elasticity of housing services w.r.t. yard space for zip code z
Φ_z^E	Estimated elasticity of housing services w.r.t. improvements for zip code z
δ_i	Depreciation as a percentage of structure value
q_i ; $\tilde{q}_i$	House quality; associated categorical coefficient

Builders produce housing services on each parcel using a concave, differentiable function $h(k, L^Y)$ that is a function of finished and yard square footage. House production requires structural capital k in proportion to the square footage, but it also requires land and incurs a height cost $c(s)$ that rises in the number of stories s.[4] Finally, each housing unit incurs some fixed costs I that include impact fees, utility systems, appliances, and transaction costs.[5] The prices of land and housing services at location x are given by r_x and p_x^H, respectively. The cost of capital k is the numeraire.

Since improved space k and height s fully determine the house's footprint, L^F, equation (1) gives the builder's problem

$$\Pi = \max_{k, L^Y, s} \{p_x^H h(k, L^Y) - k - c(s) - r_x(L^Y + L^F) - I\} \tag{1}$$

$$MLS - (L^Y + L^F) \leq 0 \qquad (\lambda^M)$$

$$\frac{L^F}{L^Y + L^F} - COVERAGE \leq 0 \qquad (\lambda^C)$$

$$s - HEIGHT \leq 0 \qquad (\lambda^s).$$

The coverage maximum can be rewritten as

$$\frac{1 - COVERAGE}{COVERAGE} L^F - L^Y \leq 0.$$

The first-order condition of the Lagrangian with respect to yard space L^Y is given in equation (2):

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[4] Eriksen and Orlando (2021) argue that R.S. Means cost estimates indicate that height costs can be approximated by a step function with discrete increases at 3 and 7 stories. They find that both horizontal and vertical extension between steps is associated with modest economies of scale. However, they do not consider pedestal construction, which vertically mixes construction techniques.

[5] Epple, Gordon, and Sieg credit the conception of housing services as "homogeneous and divisible" (2010, 906) to Muth (1960) and Olsen (1969). Observation shows, however, that housing units are only occasionally divided (for instance, among housemates). One family occupying two adjacent houses is even rarer; those who want lots of space buy big homes, not multiple homes. Observation also shows a wide variety of new home sizes, clearly intended to meet diverse demand, but at different per-square-foot prices. I believe this is explained by substantial fixed costs for each housing unit: utility systems, appliances, and transaction costs that are not replicated as square footage are added at the margin. This feature of home construction is important in reconciling the fact that (a) builders supply homes of diverse sizes and (b) the marginal value of square footage is less than the average value. In support of fact (b), see Sirmans et al.'s (2006) meta-analysis of hedonic home price studies, which finds an average square footage coefficient of 0.34.

$$\frac{\partial h}{\partial L^Y} = \frac{(r_x - \lambda^M - \lambda^C)}{p_x^H}. \tag{2}$$

Combes, Duranton, and Gobillon (2021) show that the expression can be transformed into an elasticity of housing services with respect to the optimal level of the input. This operation crucially replaces the unobserved price of housing services p_x^H with the observed residence value $p_x^H h$.

The resulting elasticity of housing services with respect to optimal yard space, Θ, is given by equation (3):

$$\Theta \equiv \frac{\partial \ln h}{\partial \ln L^Y} = \frac{L^Y(r_x - \lambda^M - \lambda^C)}{p_x^H h}. \tag{3}$$

When neither constraint binds—and both λ's equal zero—the elasticity equals the yard's share of home value.

Define Θ^0 as the potentially counterfactual elasticity of housing services with respect to yard space that would arise if regulation were assumed to be nonbinding:

$$\Theta^0 \equiv \frac{L^Y r_x}{p_x^H h}. \tag{4}$$

Now one may subtract equation (3) from (4) and rearrange terms:

$$\begin{aligned} \Theta^0 - \Theta &= \frac{L^Y(\lambda^M + \lambda^C)}{p_x^H h} \\ \lambda^M + \lambda^C &= (\Theta^0 - \Theta)\frac{p_x^H h}{L^Y}. \end{aligned} \tag{5}$$

In words, the difference between the production elasticity with respect to yard space and that factor's cost share equals the shadow cost of the related regulations scaled by yard size and home value.

This insight is the model's workhorse. After estimating Θ across observations of recently built homes within each zip code or small city, one can compute estimated values of $\lambda^M + \lambda^C$ for each home.

Although a corresponding derivation can be done for improvements k, the outcome is not as clean. Houses include a fixed cost I, which is at least partially composed of physical improvements such as appliances and utility systems. Thus, the difference between the cost share of improvements (including physical fixed costs) and the elasticity of housing services with respect to improved space (excluding fixed costs) does not isolate the regulatory Lagrangian multipliers from the unobservable fixed cost.[6]

4. Modeling Regulations in a Static City Model

The model introduced in Section 3 implies that different regulations can have different implications for parcel development. In this section, I argue that different regulatory approaches also yield distinct implications for compactness, supply elasticity, and rent gradients across an entire city. To do so, I analyze housing supply in a standard city model under three different regulatory regimes.

A key result is that supply elasticity with respect to wages is lowest in a city constrained by minimum lot sizes (City M), higher in a city constrained by height limits and coverage ratios or, equivalently, a floor-area ratio[7] (City SC), and highest in one constrained by impact fees (City I).[8]

[6] Back-of-the-envelope calculations suggest that in areas that appear to be unconstrained, typical fixed costs are in the \$30,000–\$60,000 range. This seems reasonable. But without reliably pinning down fixed cost, I cannot go a step further to distinguish fixed costs from regulatory constraints.

[7] The dual binding constraints in City SC are equivalent to a special case of a binding FAR since they fix k/L. Everything argued here would be valid for a binding FAR regulation; I chose to use height and coverage because they are common regulations in Harris and Dallas Counties.

[8] City I is distinct from the modeling of regulation in Duranton and Puga (2019), in which only migrant households must pay an impact fee, and all households are implicitly subject to a universal minimum lot size constraint.

The model cities considered here are linear, static, open, and indexed by j. Locations within each city are indexed by their distance x from the centroid. In each city, assume that the city-specific regulation is tight enough to bind everywhere and calibrated such that the cities have a common wage w and equal populations N; also assume that production costs and utility functions support such an equilibrium. The cities differ in their density and extent, which is measured by the distance from the centroid to the city edge, $\bar{x}_j$. Without loss of generality, assume $I = 0$ in Cities M and SC.

Free migration guarantees that residents of all three cities achieve a utility equal to $\bar{u}$, which is set by an unmodeled outside option. Undeveloped land has a rent r_A set by its agricultural value.[9]

Each resident requires exactly one housing unit and commutes to the centroid. Commuting costs are monetary and equal to τx. Residents derive utility from consuming improved space, yard space, and a nonhousing composite good. The utility function is twice differentiable and convex in each argument.

Housing units are produced as described in the previous section, with zero-profit builders buying land and capital[10] to produce housing units that may vary in size but nonetheless house a single resident. Since the technology allows three degrees of freedom (finished space, yard space, and height), solving for the optimal parcel configuration would be laborious. However, for a given technology and regulatory restrictions, the optimal configuration is fully determined by the land rent $r(x,w)$ and the achieved utility $\bar{u}$ of a resident in that location.

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[9] City I closely parallels the models expounded in Brueckner (1987, 822–30, 836–38) and Duranton and Puga (2014, 784–86, 795–97). The binding minimum lot size in City M is the same as simplifying assumptions made in Duranton and Puga (2019), Guthrie (2010), and Saiz (2010).

[10] Without loss of generality, let the price of a unit of capital be equal to the price of the numeraire nonhousing consumption good.

4.1. Compactness

Since the production technology is continuous and differentiable in these examples (in which constraints either always or never bind), the implicit function theorem allows us to characterize production and configuration as two differentiable functions of land rent:

- Structural density $f(r(x))$, expressed in units of finished space per unit of land
- Floor space consumption $k(r(x))$, expressed in homes (or people) per unit of finished space

Together, these define the population density, which can be expressed as a function of distance: $n(x) = f(r(x))/k(r(x))$. Density is the inverse of land per household, so $n(x) = 1/L(x)$. A familiar result shows that population density declines with distance—that is, $dn(x)/dx \leq 0$.[11]

City I must be the most compact, and City M the least. To see this, recall that the edge resident in all three cities faces land costs equal to r_A. After paying the impact fee I, the edge resident in City I has a disposable income equal to $w - I - \tau\bar{x}_I$. If $\bar{x}_I \geq \bar{x}_{SC}$, the edge resident at $\bar{x}_{SC}$ has a higher disposable income than the edge resident at $\bar{x}_I$. For the two to achieve the same utility, the City SC resident must be forced to purchase an excessively large lot. This implies that the edge resident of the more extensive city (I) is occupying less land than the edge resident of the more compact city (SC). For this to be true, and the populations to be equal, population density would have to be lower in the interior of City I than at its edge, violating $dn(x)/dx \leq 0$.

In both City M and City SC, structural density $f(r(x))$ is constant,[12] so housing consumption is proportional to population density. If $\bar{x}_{SC} > \bar{x}_M$, then the edge resident of City M has a higher

[11] See Brueckner (1987, 828) and Duranton and Puga (2014, 786).

[12] In City SC, this is due to constraint. In City M, the Alonso-Muth condition implies that disposable income must be equal for all households after paying for land and commuting; otherwise, one would achieve higher utility. With the same disposable income and same amount of land, residents will build identically sized houses.

disposable income (because her commute is shorter) but a smaller lot and thus has the option of renting more land and achieving the same configuration as the $\bar{x}_{SC}$ resident. That she chooses not to indicates that the utility from that outcome is lower, implying $\bar{x}_M \geq \bar{x}_{SC} > \bar{x}_I$.

Likewise population density at the urban edge must be lowest in City M:

$$n(\bar{x}_M) \leq n(\bar{x}_S SC) < n(\bar{x}_I). \tag{6}$$

4.2. Wage Elasticity of Supply

The wage elasticity of supply, like compactness, is highest in City I and lowest in City M. Formally the elasticity of population (or number of housing units) with respect to the city wage level, it is of course distinct from other supply flexibility metrics. One implication of the model is that this elasticity is higher in City SC than in City M, but the opposite is true of the elasticity of housing capital with respect to land price.

In City M, a minimum lot size *MLS* binds everywhere, so every parcel has a fixed amount of land *M*. A resident choosing to live at a distance $\bar{x} + \epsilon$ from the centroid would achieve utility below $\bar{u}$. The price of land at each location adjusts to precisely offset the commuting cost.[13] At all points in the city, residents will choose same-sized houses.[14]

Now suppose the city's wage increases by $\epsilon > 0$. In the new static equilibrium, the city will expand. In fact, a resident at a location ($\bar{x} + \tau\,\epsilon$) would have the same disposable income as the original edge resident, would face land cost r_A, and would thus optimize her dwelling in the same way as the previous edge resident. In the interior of the city, land prices would rise to fully offset

[13] By assumption, all residents have the same land consumption. If, after paying for commute and land, some have a higher remaining disposable income, then they are better off, violating the free mobility assumption.

[14] Since all residents have the same land and the same disposable income, they will optimize by choosing the same-sized residence.

the wage increase and residents would build houses identical to those in the original static equilibrium.[15]

With constant population density, the wage elasticity of supply in City M reduces to a simple expression:

$$\Omega_M = \frac{\Delta N_M/N}{\Delta w/w} = \frac{\frac{\tau\epsilon n(\bar{x}_M)}{N}}{\frac{\epsilon}{w}} = \frac{w\tau n(\bar{x}_M)}{N} = \frac{w\tau}{\bar{x}}.$$

In the other two cities, the elasticity cannot be so simply expressed, both because density $n(r(x))$ `varies across space and because density can vary in response to a wage increase. However, for a small enough ϵ, the extensive margin of city growth can be approximated by $\epsilon\, n(r(\bar{x}))$, as in equation (7). The inequalities between population densities in equation (6) imply the inequalities between extensive margin elasticities in equations (7) and (8):

$$\Omega_j^{extensive} \approx \frac{\frac{\tau\epsilon n(\bar{x}_j)}{N}}{\frac{\epsilon}{w}} = \frac{w\tau n(\bar{x}_j)}{N} \geq \frac{w\tau n(\bar{x}_M)}{N}. \tag{7}$$

$$\Omega_M \leq \Omega_{SC}^{extensive} < \Omega_I^{extensive}. \tag{8}$$

Thus, the extensive margin elasticity is smallest in City M and largest in City I.

To evaluate changes in the interior population density, I take the total derivative of population density with respect to wage, suppressing the argument of $r(x)$ for readability:

[15] Suppose instead that an interior resident increased his nonhousing consumption. Then his housing consumption must be lower, or his utility would exceed $\bar{u}$. But his land use is fixed by the minimum lot size, so he must have reoptimized by decreasing his housing capital expenditures. If this were possible, it would have been possible in the previous equilibrium since the relative price of housing capital has not changed. The same logic rules out reoptimizing by consuming more housing capital. Thus, the fixed minimum lot size implicitly fixes the optimal parcel configuration.

$$
\begin{aligned}
n(x) &= \frac{f(r)}{k(r)} \\
\frac{dn(x)}{dw} &= \frac{1}{k(r)}\left(\frac{\partial f(r)}{\partial r}\frac{\partial r}{\partial w}\right) - f(r)\left(\frac{\partial k(r)}{\partial r}\frac{\partial r}{\partial w}\right).
\end{aligned} \tag{9}
$$

$$
\Omega_j \approx \frac{w}{N}\left(\tau n(\bar{x}_j) + \int_0^{\bar{x}_j} \frac{dn(x)}{dw}dx\right).
$$

The first expression in equation (9) is the intensive margin: higher wages lead to bulkier construction via higher land rent. The second is the economy margin: at higher land rents, consumers shift away from yard consumption and toward consumption of the numeraire. Each ratio on the right-hand side of equation (9) is positive with the exception of $\partial k(r)/\partial r$, which is ambiguous. The effect of higher rents on demand for structural capital, which has an intermediate factor share, may be positive or negative. However, the budget constraint dictates that a resident at x cannot consume more land (yard plus footprint) as well as more housing and numeraire. Thus, $dn/dw \geq 0$, even if $\partial k(r)/\partial r$ is positive.

In City SC, the intensive margin—the first expression on the right-hand side of equation (9)—is zero because structural intensity is constrained and constant. Thus, the economy margin must be positive and $\partial k(r)/\partial r < 0$ to satisfy the budget constraint.[16]

Taking the extensive, economy, and intensive margins together yields the total wage elasticity of supply in Cities SC and I:

$$
\Omega_j \approx \frac{w}{N}\left(\tau n(\bar{x}_j) + \int_0^{\bar{x}_j} \frac{dn(x)}{dw}dx\right).
$$

Comparing across the three cities, $\Omega_I > \Omega_M$, and $\Omega_{SC} > \Omega_M$.

[16] This result is familiar from the two-good city model. The fixed land-capital ratio collapses structure and yard into a single good for substitution purposes.

While I make no attempt to quantify the relative differences in responsiveness, recent data make clear that interior margins are substantial, though secondary, sources of housing supply, despite the prevalence of constraints. From 2012 to 2018, 13 percent of net new housing units in the United States were added in the densest quartile of Census Tracts.[17]

4.3. Land Rent Gradients

A standard result of the monocentric city model is that land rent declines with distance from the centroid. Here, the gradient is steepest in City I and least steep in City M. Residents of the denser cities have more ways to economize on land in pursuit of shorter commutes, making central land relatively more valuable.

To formalize this, I use the bid-rent approach (following Duranton and Puga 2015). Let $\Psi(x,u)$ be the rent for land at location x when residents can achieve utility u within their budget:

$$\Psi(x,\bar{u}) \equiv \max_{L,k,s,z} \left\{ r | u(L^Y, k, z) = \bar{u}, w = \tau x + rL + k + c(s(x)) + a(x) \right\}. \qquad (10)$$

Let the Hicksian demand for housing capital, including height costs, be $k(L, x, \bar{u})$. It is conditional on total land $L(x)$ and summarizes the optimal parcel configuration. Likewise, let $a(L, x, \bar{u})$ be the Hicksian demand for the nonhousing good. Substituting, one obtains

$$\Psi(x,\bar{u}) \equiv \max_{L} \left\{ \frac{w - \tau x - k(L,x,\bar{u}) - a(L,x,\bar{u})}{L} \right\}. \qquad (11)$$

Differentiating equation (11) around the optimum, the envelope theorem eliminates the k and a terms, leaving an Alonso-Muth condition:

[17] HUD Aggregated USPS Data on Address Vacancies, 2012q1–2018q1. Data are described in Furth (2019). Tracts in the top quartile are decidedly urban and have little vacant land; a typical tract in the 76th percentile is Census Tract 2345.01, Los Angeles, which surrounds Crenshaw Senior High School.

$$\frac{dr(x)}{dx} = \frac{-\tau}{L(x)} = -\tau n(x). \qquad (12)$$

The second equality in equation (12) follows because population density $n(x)$ is the inverse of land per household.

In City M, where population density is constant, the rent gradient is constant. In the other cities, the rent gradient becomes steeper close to the centroid, where density rises. And even at the urban fringe, as shown above, density is lowest in City M and highest in City I, so the rent gradient at the fringe is steepest in City I and flattest in City M.

When wages increase, land rent increases more in Cities I and SC than in City M. The increased population densities allowed by economy and intensity margins in Cities I and SC increase the steepness of the price gradient at every point, per equation (12). Steeper gradients from a common base (r_A) implies higher price levels at every point.

This result further implies a word of caution: not all supply elasticities are equally informative. Suppose one chose to measure the elasticity of housing capital with respect to land rent. In Cities M and SC, housing capital is in a fixed ratio to land area. But land rents vary more, both over space and across changing wage levels, in City SC than in City M. Thus, one would find a higher elasticity of housing capital with respect to land rent in City M than in City SC, even though this paper's preferred supply elasticity, Ω, is higher in City SC.

4.4. Partially Bound Cities

The three cities analyzed above have regulations that bind everywhere. To generalize, allowing regulations to bind in some but not all locations can be conceptually straightforward. Imagine a linear city where minimum lot sizes bind only within a distance x_m of the centroid. It can be modeled as the sum of a City M of initial length $2x_m$ and a City I with an impact fee of

τx_m. Although this does not approach the multifaceted patchwork of regulations encountered in the real world, it does allow researchers to tailor models to density, bulk, or fee-based regulations as the context dictates.

Likewise, given that different regulations affect different margins of responsiveness, researchers who model regulation should note the implications of the regulatory regime they have assumed.

5. Empirical Context: Harris and Dallas Counties

Returning to the micro scale, the remainder of the paper uses the implications of the builder's decision model presented in Section 3 to estimate the stringency and marginal cost of two common land use regulations.

I estimate equation (16), in Section 7, using data from the appraisal authorities of the two most populous counties in Texas: Harris and Dallas. Aside from providing large samples, these counties have diverse land prices and housing typologies. They also provide complete appraisal data online, a relatively rare service.

Harris County is the least-regulated urban county in the United States. Siegan (1972), Berry (2001), Mixon (2010), Qian (2010), and others have studied Houston's regime of land use regulation without zoning. Although the City of Houston has some land use regulations, it has a record of granting variances liberally and has recently decreased minimum lot sizes and setbacks, as Gray and Millsap (2020) document in detail. Some blocks, however, are governed by public "Special Local Minimum Lot Sizes" and private deed restrictions of varying stringency. Speyrer (1989) finds that private deeds and public zoning raise prices indistinguishably in a small sample of Houston-area sales. The theoretical and empirical approach in this paper makes no distinction between public and private regulation.

Since 1999 (within I-610) and 2013 (citywide), Houston has allowed residential lots as small as 1,400 square feet. However, lots smaller than 3,500 square feet must compensate by setting aside open space on a sliding scale; lots below 2,000 square feet require 600 feet of open space set aside for use by all subdivision residents.[18]

Houston's embrace of small lot subdivisions has resulted in an uncommon urban form: groups of 4–10 townhouses (often detached, but with only a few feet between the houses) with shared driveways, replacing a previous generation of typical suburban development. Figure 1 shows a common juxtaposition of old and new.

Figure 1. Townhouses and Ranch Houses in Shady Acres, Houston

Source: Imagery ©2021 Houston-Galveston Area Council, Maxar Technologies, Texas General Land Office, U.S. Geological Survey. Map data ©2021 from Google Maps.

For small infill subdivisions like these, the legislated minimum lot size can bind even if the observed lot size is above the minimum. A 10,000-square-foot lot can be divided into 7 lots of 1,428 feet—almost equal to the legislated minimum. But an 11,000-square-foot lot also provides 7 legal lots. In the latter case, the lot size is binding at 1,571 square feet.

[18] City of Houston, *Code of Ordinances* Sec. 42-181 through 42-184.

Outside of Houston, Harris County extends to the northwest a full 45 miles from downtown, and much of it remains unincorporated. Indeed, most of the observations in this paper come from unincorporated Harris County. Under Texas's extraterritorial jurisdiction (ETJ) law, large cities govern land use for up to 5 miles around their borders. Houston has extended its ETJ via "finger annexations" along major roads so that it reaches most of its unincorporated suburbs. Houston imposes a 5,000-square-foot minimum lot size in its ETJ.[19] The lot size can be shrunk—theoretically down to 1,400 square feet—by dedicating common open space within the subdivision.

Harris County includes many smaller cities, especially on the older east side of the county, adjacent to Galveston Bay. One of these, Pasadena, is unzoned; the rest have zoning. Eastern Harris County, however, has relatively low housing demand, so few homes have been built there recently.

Of more interest is a group of wealthy enclave cities advantageously located near Houston's main employment centers. Land values are extremely high, and the median house is appraised at $1.25 million.

Dallas County covers about half as much land as Harris County and lacks the vast unbuilt expanses. Most of the county's land is incorporated and zoned by the City of Dallas and many smaller cities.

Relatively little has been written about regulation in Dallas County. Fairbanks (1999) covers the early history of zoning in Dallas. Burr (2002) reviews *Dews v. Sunnyvale*, a 1988 legal attack on racially exclusionary zoning that dragged on until 2013, when the Town of Sunnyvale

[19] City of Houston, *Code of Ordinances* Sec. 42-181—Single-family residential lot size.

resolved the final case by allowing a small apartment complex in an industrial area.[20] The Sunnyvale cases seem to prove the rule by exception: Sunnyvale stood out as a contrast to its permissive suburban neighbors.

The current paper is not the first to compare Dallas with Houston: Peiser (1981), Siegan (1990), and Marcano, Festa, and Shelton (2017) do the same. Marcano, Festa, and Shelton characterize Dallas's regulatory stance as one of "uncoordinated lenience," relying on 899 developer-friendly Planned Development Districts, "each with its own litany of sub-ordinances and many containing sub-PDs within them" (2017, 11).

Estimates from any two counties' data have little external validity. Nonetheless, Houston and Dallas are among the major cities in which one would least expect to find binding regulatory constraints.

6. Data

To test the microeconomic model presented in Section 3, I use parcel data published by the tax authorities of Harris and Dallas Counties.

Appraisal or assessment data have been used in several recent studies, including Epple, Gordon, and Sieg (2010) and Resseger (2013), despite the reasonable concern that the data do not arise from market transactions. Clapp, Bardos, and Wong argue that "assessors use considerably more information than is observed by [researchers] to determine land and building value" (2012, 243). The Dallas Central Appraisal District reappraises properties if recent sale prices diverge by more than 5 percent from appraised values.[21] The Harris County appraisal and

[20] Kevin Cummins, "Low-Income Housing Begins Construction in Sunnyvale: Riverstone Trails to Be First Apartment Units in Town Limits," *Mesquite News*, September 18, 2013.

[21] I follow the appraisal authorities in using the word "appraise" rather than "assess" to describe the process of assigning an estimated market value. Various exemptions allow owners to pay taxes based on *assessed* values, which are lower than the *appraised* values.

assessment process is sufficiently adversarial that a full 27 percent of owners protested 2019 assessed values.[22]

The model is written in terms of values at the moment of construction. Of course, construction does not occur in a moment, nor do we observe values at the time of construction. As time goes on, the value of land and demand for improvements at any particular location can change, and existing structures depreciate.

A salient concern, especially where regulation allows land to be readily repurposed, is that the option value of land may change to reflect a different best use.

My identification strategy relies on recency. Homes built relatively recently are more likely to still have improvement and land value similar to the value at the time of construction. In addition, option value is partly a function of existing structural capital (Clapp, Bardos, and Wong 2012), and parcels with new, undepreciated structures have lower option values.

Thus, the empirics are based on single-family homes, including townhomes, built from 2011 to 2019. In addition, I exclude properties for which $L < k/s$ (likely miscoded), those in the highest- and lowest-quality categories,[23] and those reporting less than 600 or more than 6,000 square feet of improved space.

In addition to improved and yard square footage, I include quality and depreciation (reported by the appraisal authority as a percentage) as determinants of current appraised home price.

I estimate elasticities and constraints separately at the level of zip code or small city. In Harris County, I combine the Memorial Villages as a single geography and separate River Oaks

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[22] Avenancio-Leon and Howard (2020) find significant racial bias in assessments nationwide—with Black and Hispanic homeowners paying higher taxes—but not in Texas (figure 5, p. 49).

[23] Homes of "superior" quality derive substantial value from features—architecture, tennis courts, etc.—that are not well reflected in square footage. The few recently built houses given the lowest-quality rating are likewise suspect: they may be intended as temporary shelter or otherwise be departures from standard housing production.

(an iconic Houston neighborhood regulated by strict private covenants) from the zip codes that overlap it. Location value p_x^H is allowed to vary within zip codes but is assumed constant at the "neighborhood" level. I measure average elasticities and regulatory tightness at the zip code level as a matter of sample-size pragmatism; in theory, these could also vary by neighborhood.

Dallas County has relatively compact municipal boundaries that frequently align with zip code boundaries. Thus, I use the intersection of city and zip code as the unit of geographic analysis. In a few cases with small sample sizes (Balch Springs, Duncanville, Highland Park, and Mesquite), I merge all the zip codes within the same city.

Neighborhoods, as defined by each appraisal authority, are often very small and typically include a single subdivision. Neighborhood enters into equation (16) as the neighborhood-specific price of housing services $\ln p_x^H$. Functionally, $\ln p_x^H$ is the coefficient of a dummy variable.

The analysis includes only zip codes that have over 20 included observations. These zip codes include 97 percent of all single-family residences in Harris County and 89 percent in Dallas County.

The Harris and Dallas County authorities report quality differently. In Harris County, quality is rated on a 6-point scale, with cardinal values attached to each. In Dallas County, there are 28 residential "building classes," which are not monotonically ranked. In both counties, I treat quality as a categorical variable.

Table 2 gives descriptive statistics of the houses included in the sample.

Table 2: Descriptive statistics of included houses

	Harris County			Dallas County		
	10th	Median	90th	10th	Median	90th
Home value	$163,546	$253,641	$519,755	$169,940	$357,800	$917,980
Yard's share	7%	11%	18%	8%	13%	23%
Improvement's share	70%	83%	88%	69%	82%	89%
Effective year built	2012	2015	2018	2012	2015	2017
Lot size (sq. ft.)	2,483	6,121	10,369	2,838	7,300	11,577
Yard size (sq. ft.)	1,206	4,039	7,740	1,804	5,482	9,521
Indoor space (sq. ft.)	1,768	2,538	3,952	1,529	2,540	4,162
Stories	1	2	2	1	2	2
Included observations		105,579			20,212	
All houses built after 2010		111,189			22,780	
All single-family homes appraised		990,228			495,244	
Obs. per zip or city	45	246	2,108	58	198	582
Obs. per neighborhood	1	9	121	1	4	46

Notes: Included observations were built after 2010, have between 600 and 6,000 internal square feet, between 1 and 15,000 square feet of yard, are of neither the highest- nor the lowest-quality rating, and are in zip codes or small cities with over 20 such observations. "All single-family homes appraised" excludes agricultural parcels and parcels with multiple uses. In the last row, only neighborhoods with data are included, and neighborhoods that span multiple zip codes are split accordingly.

7. Estimation Strategy

Recall from Section 3 that Θ is the elasticity of housing services with respect to yard space. I proceed by estimating this elasticity, Θ_z^E, for each zip code or small city z and comparing Θ_z^E with the yard cost shares Θ_i^0 for each observation. Recall that Θ^0 is defined as Θ when all constraints equal zero, which equals the yard's share of cost.

I assume that the housing services function $h(k, L^Y)$ is log-linear within each zip code or small city, so that log housing services can be expressed as a linear function of its (log) arguments.

Allowing the housing services function to differ across localities accommodates both the potential non-log-linearities of the housing services function and the sorting of households with different preferences across space. The housing services function is a reflection of the marginal buyer's utility function. Since households sort themselves geographically, the housing services function is likely to differ.

In equation (13), Φ is the elasticity of housing services h with respect to improved space k:

$$\ln(h_i) = \Theta_z^E \ln L_i^Y + \Phi_z^E \ln k_i. \tag{13}$$

However, we do not observe h_i but p_x^H h_i. Adding $\ln(p_x^H)$ to both sides of equation (13) yields equation (14). Under the assumption that the price of housing services is constant within a neighborhood, $\ln(p_x^H)$ becomes a fixed neighborhood effect:

$$\ln(p_x^H h_i) = \Theta_z^E \ln L_i^Y + \Phi_z^E \ln k_i + \ln p_x^H. \tag{14}$$

Taking the model to the data requires two additional wrinkles: depreciation and quality. The model considers houses at their time of construction and assumes a single quality level for capital. But estimation requires pooling several years of data to achieve a large enough sample size. Thus, the structural capital of older houses should ideally be adjusted for depreciation and quality, as shown in equation (15):

$$\ln(p_x^H h_i) = \Theta_z^E \ln L_i^Y + \Phi_z^E \ln((1-\delta_i)q_i k_i) + \ln p_x^H. \tag{15}$$

Each assessment authority provides a subjective quality rating. In Harris County, the quality rating includes depreciation effects. In Dallas County, depreciation is separately estimated on a numerical scale. I proceed by replacing $\Phi_z^E \ln$ $((1 - \delta_i)q_i)$ with $\alpha \ln(1 - \delta_i) + \tilde{q}_i$ in Dallas County and with $\tilde{q}_i$ in Harris County, where $\tilde{q}_i$ is the coefficient of a categorical variable associated with the property's quality rating:

$$\ln(p_x^H h_i) = \Theta_z^E \ln L_i^Y + \Phi_z^E \ln k_i + \alpha \ln(1-\delta_i) + \tilde{q}_i + \ln p_x^H + \epsilon_i. \tag{16}$$

I estimate equation (16) separately for each geographic area z. Each zip code or small city z contains observations distributed across neighborhoods indexed by x. Under the given assumptions, the sum of the Lagrangians distorting yard space is the difference between Θ_i^0 and Θ_z^E adjusted for the ratio of home value to yard size.

As with Θ_z^E, all coefficients are assumed to be constant within a zip code or small city *z*. The price of housing services, however, is allowed to vary across neighborhoods *x* within *z*.

Contrary to theory, all houses within a neighborhood are not identically sized. Having used equation (5) to compute $\left(\lambda_i^M + \lambda_i^C\right)$ from the estimated $\left(\Theta_i^0 - \Theta_z^E\right)$ for each home, I then take the median of each, separately, for each zip code. I denote the zip-code-level medians with the subscript *z* and bear in mind that other moments (such as the mean) may be equally valid as descriptions of regulatory stringency.

Given the framing of the initial maximization problem, the Lagrangian multipliers can be interpreted as the marginal reduction of profits from the median residence built at location *x* due to a unit tightening in the relevant constraint.

The zero-profit condition and assumptions that building technology and cost are spatially invariant imply that regulation must increase the price of housing services p_x^H and/or lower land prices r_x of buildable lots where constraints bind. If that were not the case, either unregulated construction on that site would have yielded positive profits or the observed regulated construction yielded negative profits.

8. Results

Results are consistent with the model posited in Section 3. One key empirical implication is that the benefits to deregulation are largest in the most expensive areas, not the areas where the most parcels are constrained. However, the results do not show strong spatial patterns or correlations with other observables that would be plausibly valid out of sample.

8.1. Where Do Constraints Bind?

A central claim of this paper is, from equation (5), that the elasticity of housing services with respect to yard space, Θ, will be less than or equal to the yard's share of home value, Θ^0. If the estimated yard elasticity were often larger, the model would have proven to be a poor one.

As indicated in table 3, the vast majority of properties, especially in Harris County, show evidence of binding regulation. Neither Harris County nor Dallas County has a concerning number of properties in which the yard elasticity is significantly higher than the yard's share of value.

Table 3 also shows that regulatory stringency is not an obvious function of observable measures of regulation. Although minimum lot sizes are higher almost everywhere in Dallas County than in most of Harris County, and Dallas yards are indeed larger, minimum lot size and coverage regulations are more often nonbinding in Dallas.

Table 3: Is the yard elasticity less than or equal to the yard's share of value?

	Houston within I-610	Harris County, other incorporated	Harris County, unincorporated	Dallas County
Less $\left(\Theta_i^E < \Theta^0\right)$	54.3%	78.8%	98.2%	66.6%
Not significantly different	43.5%	21.0%	1.8%	31.0%
More $\left(\Theta_i^E > \Theta^0\right)$	2.1%	0.2%	0.0%	2.4%
Observations	12,792	21,543	71,253	20,212

Note: Difference is evaluated at a two-tailed 95 percent significance level.

Table 4 helps explain the patterns. Yard space has very little marginal value in unincorporated Harris County: even the 99th percentile Θ_i^E is only 0.05. Central Houston, by contrast, has much smaller yards and higher yard elasticities. Still, the majority of Central Houston properties show evidence of constraint.

Table 4: Values and sizes of yards

	Percentile	Central Houston (within I-610)	Harris County, other incorporated	Harris County, unincorporated	Dallas County
Marginal yard value, Θ_i^E	25th	0.05	0.02	0.01	0.01
	75th	0.12	0.07	0.03	0.10
Yard share of value	25th	10%	9%	9%	10%
	75th	19%	17%	13%	16%
Yard size	25th	748	2,542	3,405	3,838
	75th	1,893	5,743	5,974	7,260
Stringency $\left(\Theta^0 - \Theta_i^E\right)$	25th	0.02	0.05	0.06	0.04
	75th	0.11	0.13	0.10	0.12
Marginal regulatory cost $\left(\lambda_i^M + \lambda_i^C\right)$	25th	\$6	\$3	\$3	\$2
	75th	\$35	\$21	\$6	\$10
	95th	\$67	\$51	\$8	\$34

8.2. Zoning Tax

The marginal regulatory cost $\left(\lambda_i^M + \lambda_i^C\right)$ reported in the final row of table 4 is a version of the "zoning tax." Glaeser and Gyourko (2003) estimated a zoning tax per square foot of $3 in metropolitan Houston and $5 in metropolitan Dallas based on 1999 data. Glaeser, Gyourko, and Saks (2005) found that metropolitan Houston's 1998 zoning tax was insignificantly different from zero. More recently, Gyourko and Krimmel (2021, table 2, p. 44) estimated a median zoning tax of $4.27 from 8 vacant land sales in Dallas County from 2013 to 2018.[24] I estimate a median zoning tax of $4.24 for Dallas County (using 2019 data covering parcels built from 2011 to 2019).

However, unlike the previous authors, I hesitate to apply the difference in marginal value to a quarter-acre lot. I doubt that the marginal hedonic value of yard space equals the total hedonic value of the lot divided by the lot size. Rather, for any given buyer, it is likely that marginal yard value declines with yard size in the relevant range, and so the unregulated price would fall between the observed average and marginal prices.

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[24] Gyourko and Krimmel's inner ring is a circle that covers most of Dallas County. They do not have data for Houston.

8.3. Neighborhood Externalities

The possible existence of subdivision-level externalities poses a threat to the interpretation of $\left(\lambda_i^M + \lambda_i^C\right)$ as a zoning tax. A builder creating a single-home lot can ignore externalities that it creates. But most houses in Texas are built in large subdivisions, most of which constitute entire neighborhoods in the tax records. A subdivision developer optimizes the site accounting for the predictable neighborhood externalities.

If homebuyers value the size of neighbors' yards, the externality will create a wedge between the private marginal and the average land value in the same way as a minimum lot size requirement. In estimating equation (16), the external effect of yard size would be subsumed into the neighborhood fixed effect.

To test for this possibility, I reestimated the model after replacing the neighborhood fixed effect with neighborhood median yard size, median home size, and median home age. I limit the sample to neighborhoods with at least 50 houses. The coefficients for neighborhood medians are imprecisely estimated and vary widely, with about half of the coefficients for each variable negative and half positive. The evidence is consistent with no yard size externality on homes within a neighborhood.

8.4. The Marginal Cost of Regulation Varies Widely

Because regulatory stringency $\left(\Theta^0 - \Theta_i^E\right)$ differs modestly across the four regions shown in table 4, regulatory cost $\left(\lambda_i^M + \lambda_i^C\right)$ is driven by the wide differences in local housing costs and (to a lesser extent) yard size. Thus, despite having the fewest properties bound by regulation, Central Houston exhibits the highest estimated costs at the 25th, 75th, and 95th percentiles, as table 4 shows.

Figure 2[25] maps the median estimated costs across geographies, showing that they are highest on the affluent west side of central Houston and its enclave cities.

For example, in neighborhoods around Rice University, relaxing the 3,500-square-foot minimum lot size by 1,000 square feet would increase the profitability of building a single-family home by about \$60,000. Similar effects can be found in some of the other incorporated cities. In Bellaire, a wealthy enclave city, a 1,000-square-foot relaxation would be worth \$50,000.

Conversely, although 98 percent of unincorporated Harris County parcels face binding constraints, the benefit of relaxing constraints by 1,000 square feet is only \$8,000 at the 95th percentile. The low values are consistent with the fact that the average land value on single-family parcels in unincorporated Harris County is \$4 per square foot, with relatively little variance.

Another way to evaluate the costs of regulation is as relative to land value. Figures 3 and 4 map the median value of $\left(\lambda_i^M + \lambda_i^C\right)/r_i$ in each zip code. In cases where Θ^0 is not significantly larger than Θ_i^E, the regulatory cost is set to 0, although I certainly cannot reject substantial regulatory costs in many of those cases.

In about 1 percent of properties, and in the medians of a few zip codes, $\left(\lambda_i^M + \lambda_i^C\right)/r_i$ exceeds 100 percent. This may occur in properties with exceptionally low land prices or it may occur because of statistical error. Theory cannot rule out a regulatory cost exceeding the observed land price; it is merely impossible for the regulatory cost to exceed 100 percent of the unregulated land price.

[25] Figures 2 through 6 can be found at the end of the paper.

Three regularities emerge from figures 2–5. First, the affluent central areas of both counties have the highest absolute regulatory costs but the lowest relative regulatory costs. Second, Harris County has a ring of especially high relative regulatory costs, which loosely follows the Sam Houston Tollway. Third, the distant (and cheaper) suburban areas still face high relative regulatory costs even though land is very cheap.

8.5. Dallas County Geography

The data reveal three distinct areas in Dallas that differ from the rest of the county. Together, they make up most of the city of Dallas from the Trinity River to I-635. The first (labeled "1" in figure 6) is downtown and the adjoining neighborhoods to the north. Single-family construction there is dominated by townhouses with little yard space. However, the area is expensive enough to generate 3 of the 5 largest estimates of marginal regulatory cost, $\lambda_z^M + \lambda_z^C$, of \$30–\$40 per square foot, as shown in figure 5. Estimates indicate that marginal yard space has almost no value to buyers.

South Dallas (2) is much cheaper. Land value there averages less than \$100,000 per acre, compared with \$2 million downtown. The median new home in this area costs \$136,000, is 1 story tall, and has 4,050 square feet of yard space appraised at \$1.60 per square foot, which accounts for 5 percent of home value. Habitat for Humanity Dallas built 137 new homes in these zip codes from 2010 to 2015,[26] more than half the total for those years. The estimated value of marginal yard space—0.04 and 0.06—is very nearly equal to the yard's share of value, indicating that minimum lot size regulations are nonbinding.

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[26] Eric King, "Habitat for Humanity Transforming Parts of Dallas One Neighborhood at a Time," *NBC DFW*, February 2, 2016.

Area 3 is the elite residential area between White Rock Lake and the Dallas North Tollway, including the enclave cities of Highland Park and University Park. Home prices have 7 digits and yards are ample, typically 20–30 percent of the home's value. Unlike any other area I studied, however, the yards here are concomitantly highly valued, with Θ_z^E estimated between 0.17 and 0.41. These places show no evidence of a binding lot size or coverage constraint.[27]

Other affluent areas of Dallas County form an arc around Area 3, but have lower hedonic marginal yard value despite similar lot sizes and yard shares of value.

8.6. Correlates of Regulatory Stringency

In order to investigate the correlates of regulatory stringency, I reestimated the results using zip codes as the geography of interest. This lumps together areas in different jurisdictions in some cases but allows a consistent comparison with American Community Survey data reported at the zip code level.

In a variety of spatial regressions, I investigated raw and controlled correlations between my estimates and demographic information including median income, and population shares under age 18, foreign born, Black, Hispanic, or Asian. In addition, I used geographic information including the distance to downtown and a cubic polynomial of the angle of heading (that is, the compass direction) from downtown. I make no attempt to distinguish causal relationships.

In Harris County, two variables have consistently strong associations with regulatory stringency $\left(\Theta^0 - \Theta_i^E\right)$: under-18 share (positively) and Hispanic share (negatively). Although I have no intuition for the latter relationship, the first is logical. Families with children are likely to

[27] Sunnyvale, the town that lost a long court battle over its exclusionary zoning, and Far North Dallas (75248) also fit this pattern, although both have too wide a confidence interval to draw strong conclusions.

value yards more than others do. They may thus seek out "yard bargains": areas with yards that are bigger than the marginal buyer demands.

This relationship does not show up in Dallas County, however.

In Dallas, the same battery of regressions yields two other consistently significant associations: household income (negatively) and distance from downtown (positively). That is, places with high household incomes close to downtown are likely to have smaller gaps between the yard's share of value and yard elasticity. This pattern is exhibited by the zip codes that compose Area 3 in figure 6.

9. Conclusion

This paper presents a partial-equilibrium model of single-family housing supply in which residents value both improved and unimproved space and regulatory authorities use some combination of ordinances to limit density. The model shows that different regulations have different implications for the elasticities of housing services with respect to inputs.

By estimating those elasticities in lightly regulated Harris and Dallas Counties, I can deduce the marginal cost of minimum lot size regulations by zip code and identify where constraints are binding and nonbinding. I find that in some contexts, even a very low minimum lot size can be binding. Likewise, low prices do not always imply that constraints are nonbinding (although they do suggest that the total per-unit cost of the regulation is low). Conversely, a few high-priced areas are unconstrained, because buyers there place a high value on yard space.

The empirical results imply that the "production function" for housing services is not constant across space. Housing services—that is, the degree to which the marginal buyer values the physical features of a residence—are in the eye of the beholder, and markets are sufficiently segmented to reveal systematic spatial differences in the valuation of land.

This approach to estimating the costs of regulation has serious limitations. It relies on observing recently built properties, under the presumption of profit maximization by the builder. However, the most stringent regulatory regimes prevent construction altogether, or limit it to rebuilding on existing lots, which would limit sample size drastically. The paper also relies on the assumption that marginal yard space is equally valued at all locations within a zip code; counterexamples can be readily furnished. It remains to be seen whether this approach can be applied usefully to regions with much more regulation and much less growth.

Embedding the builder's problem in an open city general equilibrium, differences in regulation lead to differences in city density, land rents, and the relationship between wages and growth. In a standard monocentric city model, cities grow by building up, building out, and squeezing in—the intensive, extensive, and economy margins of adjustment. Minimum lot sizes shut down two of those margins, allowing cities to grow only by building out. Binding bulk regulations—modeled here as a height limit and coverage ratio—are a little looser, allowing households to squeeze in when wages rise. An economy with only impact fees—or no regulation—can build both up and out and may thus require less squeezing in.

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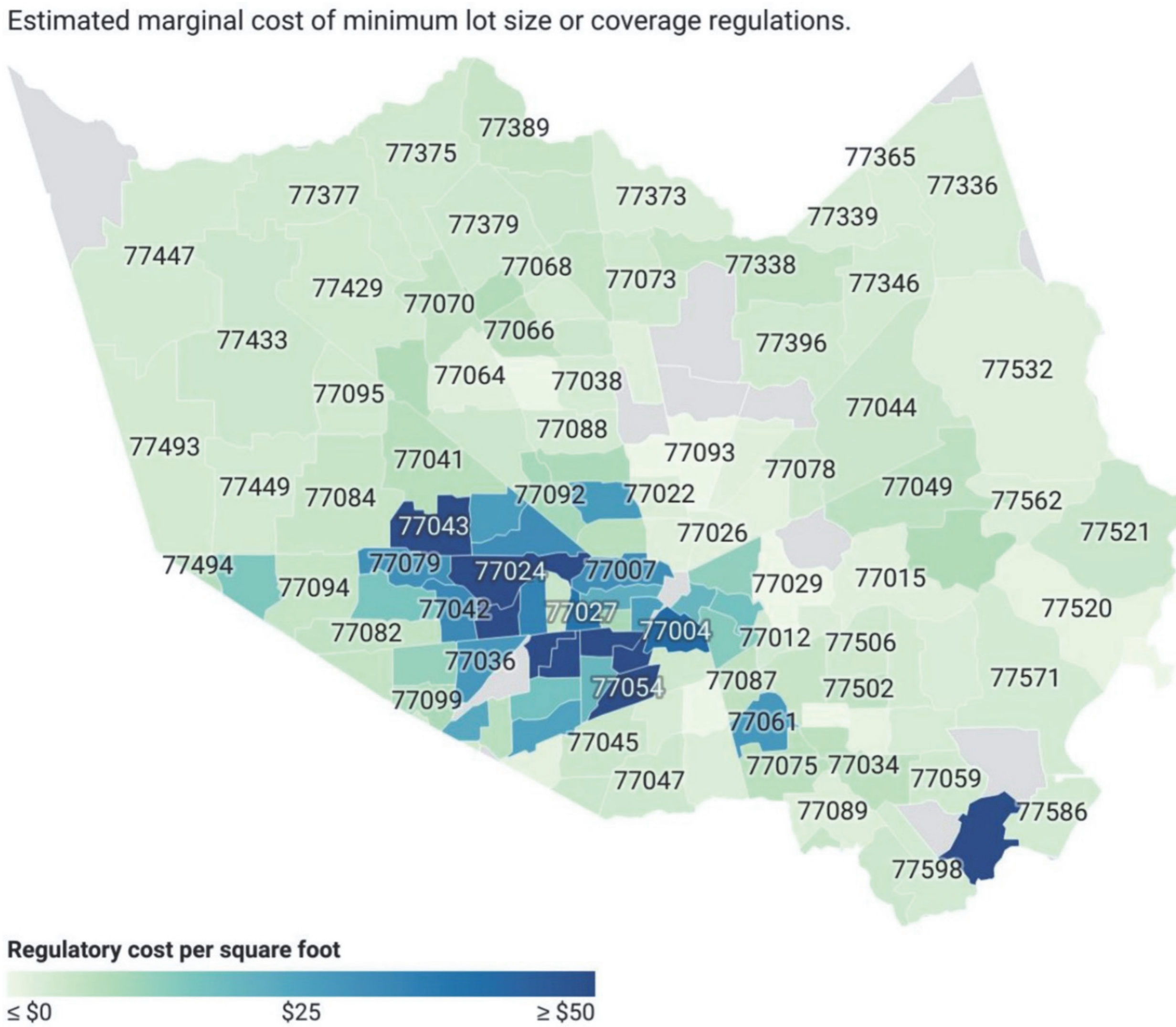
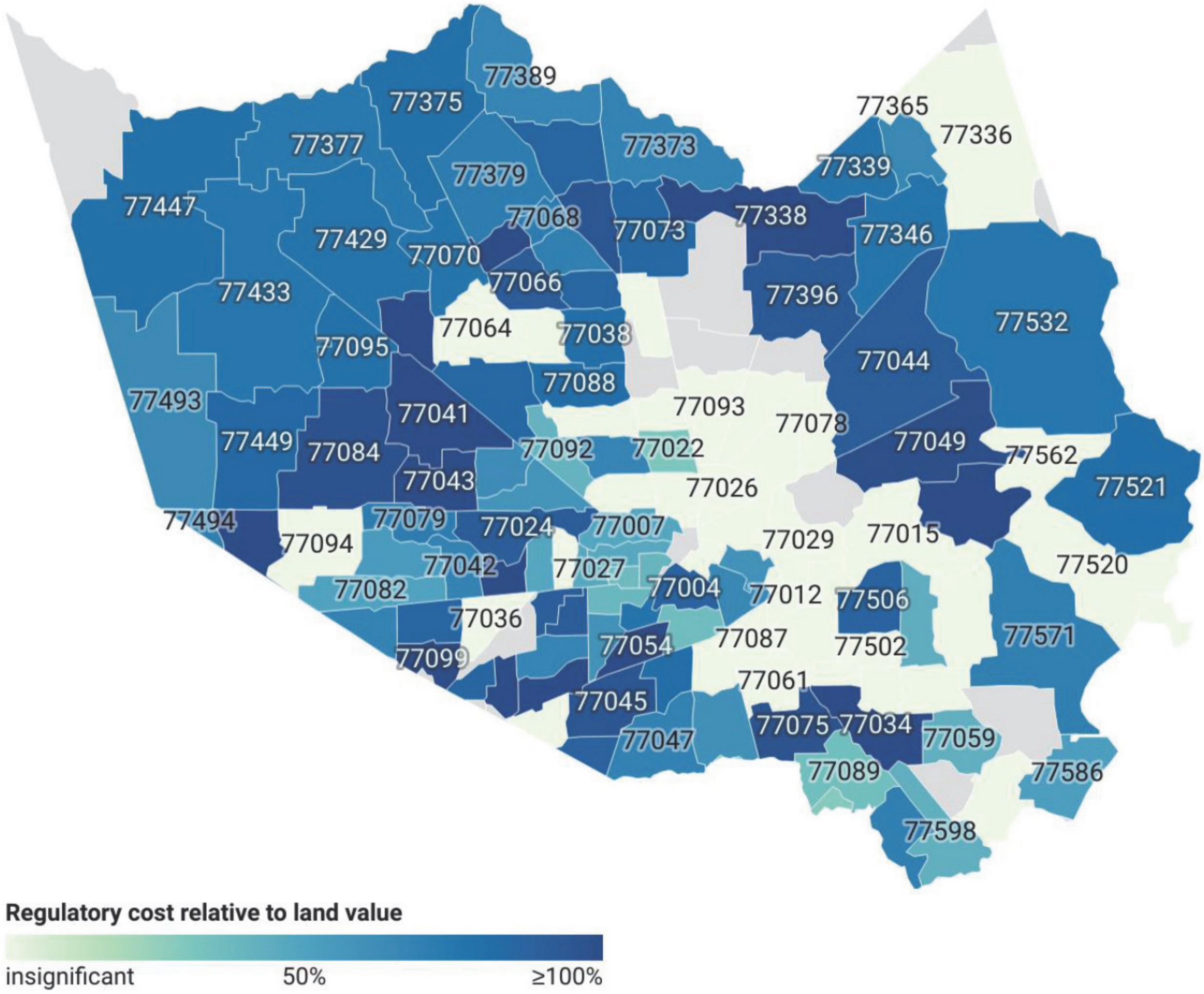
Figure 2. Regulatory costs, Harris County



Source: Harris County Appraisal District and author’s calculations. Created by author with Datawrapper.

Figure 3. **Relative regulatory costs, Harris County**

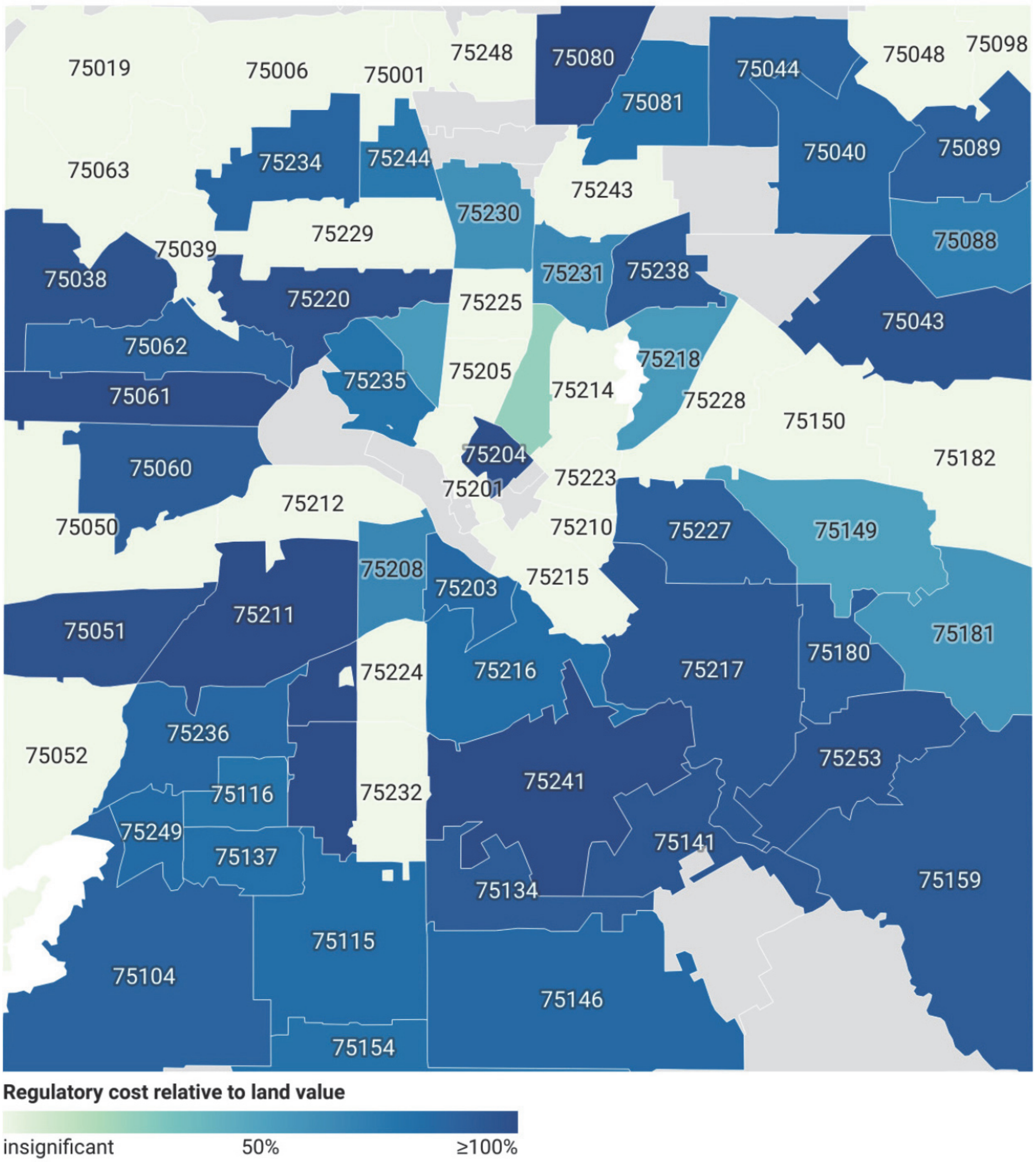
Estimated marginal cost of minimum lot size or coverage regulations as a percent of observed land value.



Source: HCAD and author's calculations. Created by author with Datawrapper.

Figure 4. Relative regulatory costs, Dallas County

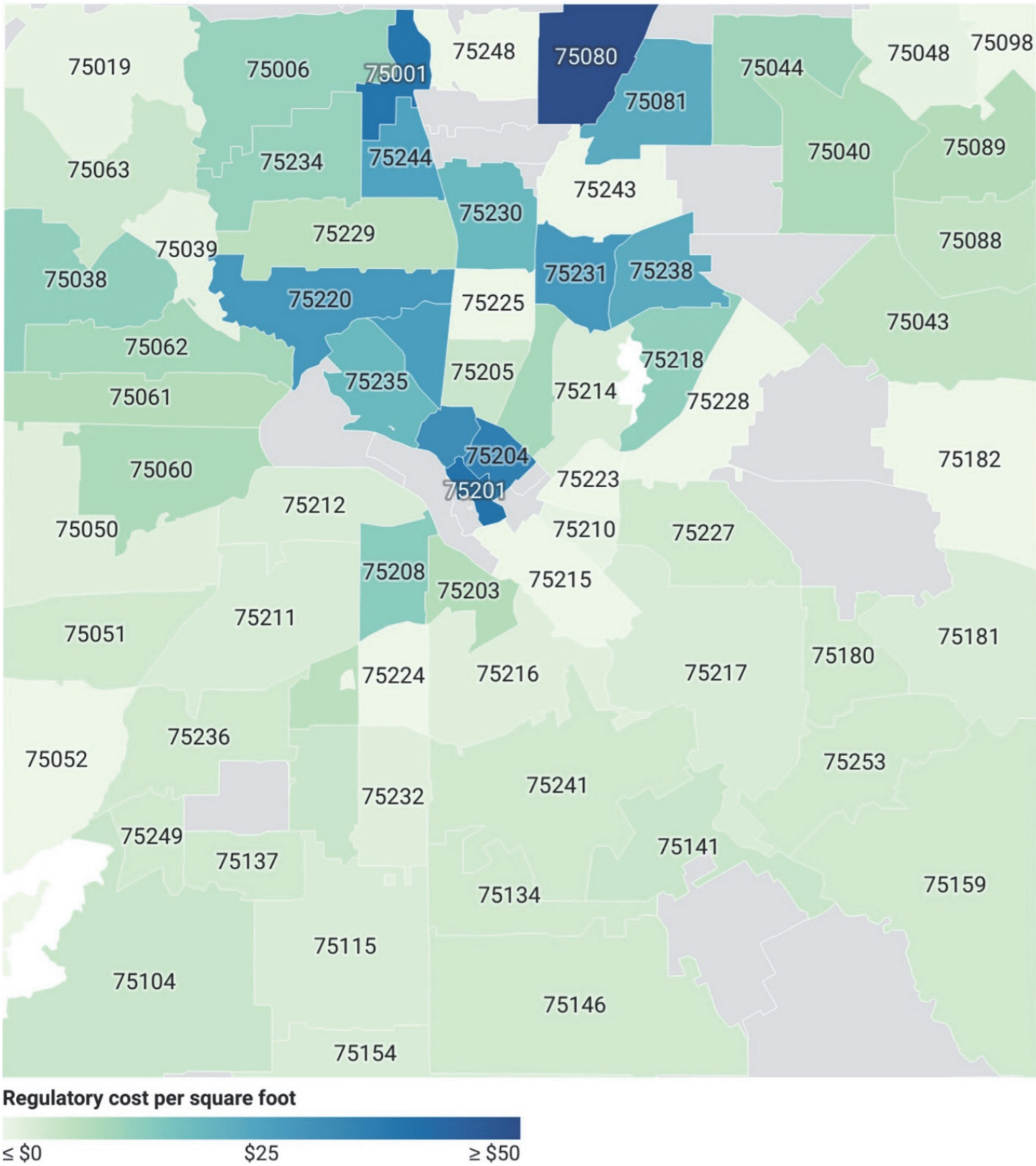
Estimated marginal cost of minimum lot size or coverage regulations as a percent of observed land value.



Source: DCAD and author's calculations. Created by author with Datawrapper.

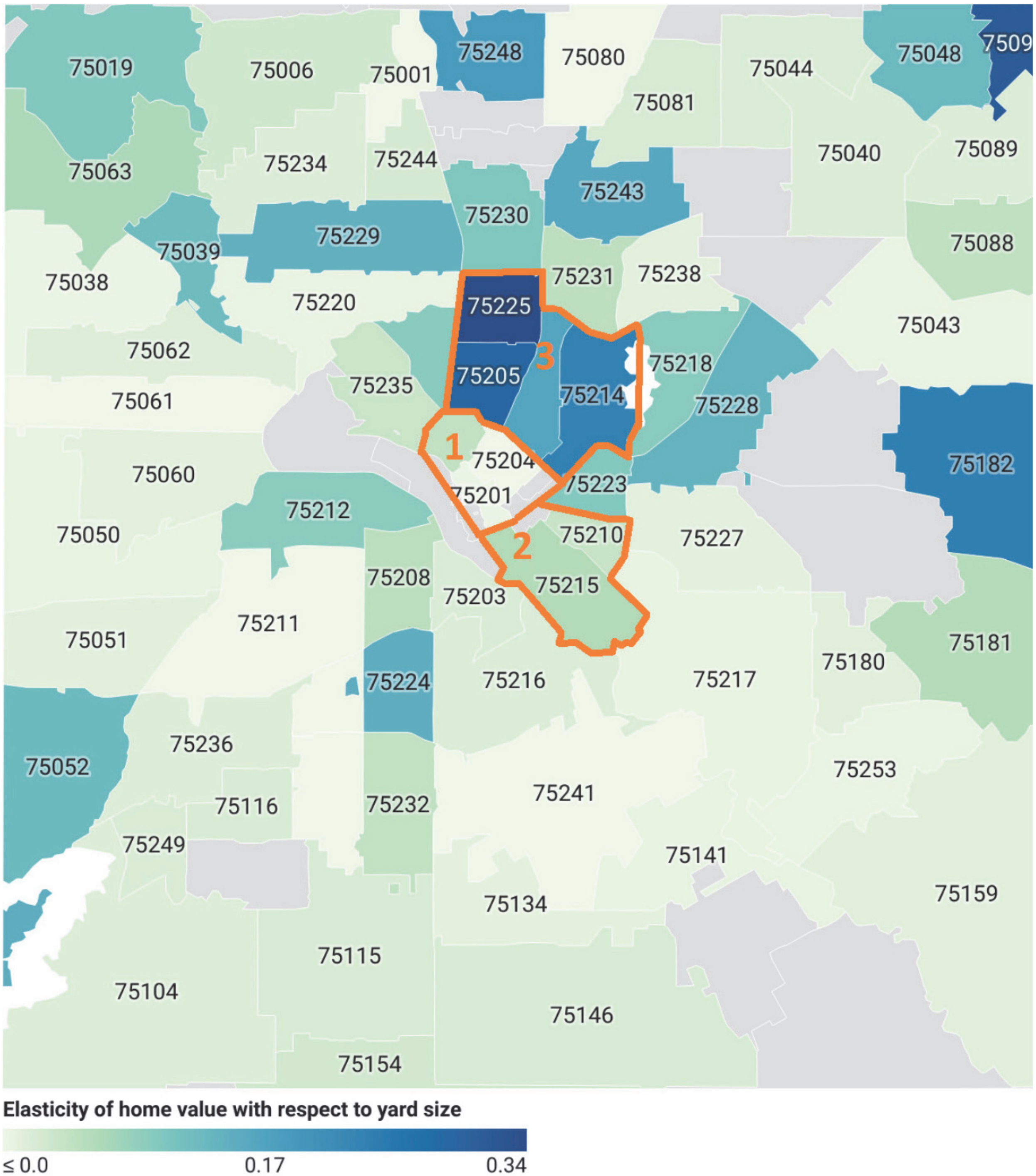
Figure 5. Regulatory costs, Dallas County

Estimated marginal cost of minimum lot size or coverage regulations.



Source: DCAD and author’s calculations. Created by author with Datawrapper.

Figure 6. Estimated elasticities in Dallas County



Source: Dallas Central Appraisal District and author's calculations. Created by author with Datawrapper.