How to Increase Housing Affordability? Understanding Local Deterrents to Building Multi-family Housing*

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Abstract

This paper studies how various zoning regulations interact to affect housing supply and affordability and which regulations policymakers should relax if they want to reduce housing prices. Using cross-sectional variation across space from novel parcel-level zoning data and a boundary discontinuity design at regulation boundaries in Greater Boston, we causally estimate the effect of various zoning regulations on housing supply and prices of single- and multi-family homes. We find that relaxing density restrictions (minimum lot size and maximum dwelling units), alone or jointly with relaxing other regulations, is most effective at increasing housing supply, particularly of multi-family properties, and reducing rents and house prices. Conversely, enabling multi-family zoning or relaxing height regulations alone has little impact. In addition, our results suggest that the recent Massachusetts policy to increase building density near transit stations can increase housing affordability by reducing rents and sale prices in suburban municipalities.

Keywords: multi-family zoning, height restrictions, minimum lot size, density, house prices, rents

JEL: H11, K25, R21, R31, R58

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1. Introduction

Housing is becoming increasingly unaffordable in many North American cities. In 98% of census tracts in the Greater Boston area, the median household spent more than 30% of their income on rent or mortgage costs—the threshold for being considered rent burdened. The scarcity of vacant parcels implies that solutions to the affordability problem must include plans for adding housing in already built-up areas. However, local deterrents to new construction in the form of zoning regulations can make housing more expensive and can adversely affect growth, wealth accumulation by younger households, and geographic mobility (Hsieh and Moretti, 2019; Herkenhoff et al., 2018; Dustmann et al., 2022; Ganong and Shoag, 2017; Deryugina and Molitor, 2021).

Over the past century, municipal governments across North America have adopted multiple forms of zoning regulations limiting new construction. However, it is unclear to economists and policymakers how regulations interact and which of these regulations matter, i.e., which regulations are a binding constraint on the housing supply.[1] Our first contribution is to examine how various zoning regulations interact to affect the supply and affordability of single-family and multi-family homes and which regulations policymakers must relax to reduce housing rents and prices. We focus on the three major zoning regulations affecting the residential landscape of most cities worldwide: multi-family zoning, i.e., whether or not the construction of multi-unit properties (e.g., apartments) is allowed on a parcel; maximum height restrictions; and density restrictions that determine the number of housing units allowed on one acre of land (e.g., minimum lot size). Note that relaxing regulations or upzoning means increasing height and allowing more density and multi-family homes.

Our first finding from studying interactions of zoning regulations is that relaxing density restrictions, either individually or with other regulations, results in the largest increase in the number of units and housing affordability in Greater Boston. The effect of other zoning regulations on housing outcomes can not be statistically distinguished

[1] California, Oregon, and Minneapolis recently allowed for multi-family zoning without relaxing density and height regulations (Miller, 2019; Wamsley, 2019; Economist, 2021), while Massachusetts recently relaxed restrictions on multi-family houses and density without relaxing height regulations.

from zero. This is because density restrictions like minimum lot size requirements are a binding constraint to increasing supply. While density restrictions play a crucial role in restricting supply in Greater Boston, other regulations may provide a binding constraint to supply in other regions. Nevertheless, our broader takeaway and methodology can be applied in any region in the world.

Our second contribution is to build a theoretical and empirical framework for economists and policymakers interested in understanding the effects of upzoning. Using novel parcel-level zoning data for 86 municipalities in Greater Boston, we exploit spatial variation in the three zoning regulations with a regression discontinuity (RD) approach. We study discontinuity in regulations at the zoning regulation boundaries instead of the more commonly used municipal boundaries (see Turner et al. (2014); Song (2021); Shanks (2021); Monarrez and Schönholzer (2022)).

This approach creates two benefits and a challenge. The first benefit is that by dividing zoning boundaries into regulation scenarios with either one or more regulations changing at the boundary, we can examine how regulations interact together to better simulate the policy effects of upzoning.[2] The second benefit of using zoning boundaries is that our results do not confound the effects of regulations with the unobserved differences in municipality characteristics, which, like zoning regulations, also change discretely at municipal boundaries.

The major challenge of our approach is that zoning regulation boundaries were not drawn randomly. In many cases, zoning boundaries overlap with roads, municipal and school boundaries, and natural features such that the underlying quality of the neighborhood is not continuous along these boundaries. Therefore, we restrict attention to zoning boundaries that do not overlap with the abovementioned features. It is also likely that zoning boundaries were delineated to either include or avoid certain areas due to sociopolitical reasons, creating curves in the boundaries. If the curves overlap with unobserved land quality, this violates the RD assumptions. To address this, we follow the approach from Turner et al. (2014) and restrict attention to straight-line segments of reg-

[2] We find minimal observed heterogeneity in the assignment of the different regulation scenarios to boundaries, allowing us to directly compare most of the results across scenarios (details in section 2.3.

ulation boundaries. We find no discontinuities in the vast majority of observed and unobserved location quality covariates at these boundaries. To estimate the causal effects of regulations on housing supply and prices, we compare buildings around straight-line regulation boundaries within municipalities and elementary school attendance areas. Most zoning regulations in Greater Boston were adopted in the first half of the twentieth century, with very few regulation changes since then. Because we examine the effects of cross-sectional variation in regulations on housing market outcomes in the 2010s, we interpret our estimates as the long-run causal effects of regulations.

We find that relaxing density restrictions alone or with other regulations increases the supply of housing units between 9% and 109% at the boundary. In addition, allowing for multi-family zoning doubles the chances that a given property is an apartment building rather than a single-family house. In comparison, relaxing height restrictions on its own or with allowing for multi-family zoning does not affect the supply of units. We conclude that height restrictions are not binding in Greater Boston. Additionally, we find that monthly multi-family rents fall by 4.2% and 6.9% ($54 to $101), on average, at boundaries where density regulations are relaxed alone or with allowing for more building height. For single-family houses, relaxing density regulations alone leads to a 4.4% ($28,488) decrease, on average, in sales price. Sales prices fall by an average of 2.2% ($13,394) at boundaries where density regulations are relaxed and multi-family homes are allowed. Again, we find no statistical price or rent differences across boundaries where multi-family and height restrictions are relaxed on their own or together.

We then use our theoretical framework to examine three mechanisms behind long-run differences in prices and rents across regulation boundaries–the composition effect, the sorting effect, and the option value. Zoning regulations affect prices and rents by changing housing characteristics (composition effect), leading households to sort based on heterogeneous preferences for house characteristics (sorting effect), or changing the option value of a parcel (this matters only for sales prices and not for rents). We find that price and rent differences at boundaries with more regulation restrictions, such as suburban municipalities near Boston, are likely driven by the composition effect. However, the sorting effect drives rent differences at boundaries near central Boston, where zoning regulations are lower than in suburban municipalities. Thus, in large parts of Greater Boston, zoning regulations operate primarily through changing house characteristics and forcing households to over-consume housing, reducing housing affordability.

Our third contribution is to use the causal estimates to assess the effects of the 2021 Massachusetts's Chapter 40A law (upzoning by allowing up to 15 housing units per acre and relaxing multi-family zoning) near transit stations on housing supply, prices, and rents. Our counterfactual framework and estimated local average treatment effects from interactions of regulations can be used to simulate the effects of upzoning if changes are local and small. In addition, unlike much of the literature that studies the effects of regulations on vacant land, we provide redevelopment policy estimates around the existing built-up housing environment. Thus, our setup is particularly well suited to study the effects of small-scale upzoning policies in already developed cities such as Massachusetts' Chapter 40A law mentioned above or the recent California Bill 2097 banning parking requirements near specific transit stations.

We find that Chapter 40A will have no long-run effects near many transit stations because the existing regulation is already lower than the new upzoning mandate. Our estimates suggest long-run multi-family rents fall by up to 6% in suburban municipalities. In addition, we find that the effects on single-family house prices are nonlinear. In the long run, sales prices fall by up to 11% near transit stations where the current regulation levels are well below the Chapter 40A mandate. However, the option value from the upzoning policy moderately increases the long-run single-family sale prices near transit stations closer to central Boston, with higher current regulation levels.

Our paper contributes to the literature studying land-use regulations[3] by providing a novel approach to studying how zoning regulations interact and which zoning regulations matter and by how much. So far, the literature has studied the effects of land-use regulations in one of two ways. First, many studies have analyzed the effects of zoning regulations separately, making it difficult to understand how different regulations interact.[4] Second, studies like Turner et al. (2014) and Herkenhoff et al. (2018) rely on

[3]Glaeser and Ward (2009); Glaeser and Gyourko (2018); Jackson (2016); Chiumenti (2019); Molloy (2020) study the effects of zoning regulations on supply and prices across North America.

[4]Anagol et al. (2021) study the effects of density regulations, Brueckner and Singh (2020) and Ding

either the survey-based Wharton index (Gyourko et al., 2021) or misallocation wedges, respectively, to document the effects of zoning regulations but do not provide a specific roadmap on how to lower the costs associated with said regulations. In addition, through the novel composition effect, the paper highlights how by increasing the size of the smallest housing unit available in the more regulated neighborhoods, stricter regulations increase the per-unit price of the smallest housing unit, reducing housing affordability (in effect, creating a two-part tariff (Banzhaf and Mangum, 2019)).

This paper also ties into the literature studying broad effects of zoning regulations. If households cannot afford to live near productive cities, they may re-locate to regions with worse opportunities and health outcomes (Chetty and Hendren, 2018; Chyn and Katz, 2021). Furthermore, Bertaud and Brueckner (2005) and Brueckner and Singh (2020) show that height restrictions limit housing near commercial city centers and cause urban sprawl, creating damaging environmental effects (IPCC, 2022). Additionally, this paper relates to the literature studying the adoption of zoning regulations in the 20th century and its long-term consequences (Shertzer et al., 2016, 2018; Trounstine, 2018). Methodologically, the paper is related to the literature using RD methods to study various spatial outcomes (Dell, 2010; Coury et al., 2022; Severen and Plantinga, 2018; Bayer et al., 2007; Anagol et al., 2021; Harari and Wong, 2021). The paper also contributes to the literature on housing affordability focused on project-based low-income buildings (Diamond et al., 2019; Sinai and Waldfogel, 2005). Unlike these studies, we take a broad view of affordability, where a fall in sale prices and rents in all housing types, not just project-based buildings, increases affordability.

The rest of the paper proceeds as follows. Section 2 describes the background to the regulatory framework and data. Section 3 provides the theoretical and empirical framework and section 4 explains boundary selection and tests RD assumptions. Section 5 discusses the results and section 6 presents the policy effects of relaxing regulations.

(2013) study building heights, and Zabel and Dalton (2011) and Kulka (2020) study minimum lot size.

2. Regulatory framework for housing and data

2.1 Zoning regulation framework

We focus on the three major zoning regulations that affect the building of residential multi-family and single-family units: whether multi-family housing is allowed, maximum height restrictions, and maximum dwelling units per acre (DUPAC) or density restrictions.[5]

Multi-family zoning: Multi-family housing construction (i.e., apartment buildings) can be allowed by right, by special permit, or not allowed at all on a particular parcel.[6] This zoning regulates the type of housing and is the most common way multi-family housing is regulated in North America. The green, yellow, and purple lines in Figure 1 show the boundaries where multi-family regulation changes. The underlying data come from Appendix Figure C.1, which shows considerable variation in the use of multi-family zoning within and across towns, with some municipalities disallowing multi-family construction entirely and with others allowing it only in certain areas (often in city centers). Only 16% of the land area in Greater Boston allows multi-family housing by right, with another 26% allowing it by special permit.

Building height restrictions: Height restrictions indicate the maximum allowable building height. Even if multi-family zoning is allowed, municipalities often use height restrictions to limit the size and shape of buildings. The light blue, red, and purple lines in Figure 1 show the boundaries where maximum height regulation changes, either alone or with other regulations. Appendix Figure C.2 shows the variation in building height restrictions across Greater Boston. 70% of the land area limits building heights to 35 feet (or 3.5 floors) or less, the typical height of a single-family home.

DUPAC: DUPAC regulations limit residential density, the total number of units, and lot sizes that developers can build on. DUPAC is constructed by counting the number of lots allowed on one acre following minimum lot size requirements and multiplying this

[5]The terms DUPAC and density are interchangeably used throughout the paper. Another significant regulation that affects the supply of multi-family housing is minimum parking requirements. However, due to a lack of data, we cannot incorporate parking requirements in the analysis.

[6]Following a conservative approach, we compare areas where multi-family housing is either allowed by right or by special permit against areas where multi-family housing is not allowed.

number by the maximum allowable dwelling units for each parcel. Thus, this measure captures not only the zoning restrictions from minimum lot size requirements but also maximum dwelling units restrictions, allowing comparisons across municipalities that regulate residential density in different ways. The dark blue, yellow, and red lines in Figure 1 show the boundaries where DUPAC regulation changes. Appendix Figure C.3 shows underlying data and how the DUPAC restrictions vary spatially. In roughly one-quarter of the land area, developers can build only one residential unit per acre.

Using the three zoning regulations, we study six zoning regulation scenarios. The first three columns in Table 1 show scenarios 1–3, where only one of the three zoning regulations changes at the boundary segment and the other two regulations stay the same. The next three columns show scenarios 4–6, where two zoning regulations vary at a given boundary. In Panel A, we report the average DUPAC and height restriction and the share of multi-family zoning across both sides of a given regulation scenario boundary. The summary statistics show little variation in mean height across various regulation scenarios. However, the mean density varies from 7.9 units per acre for boundaries where only height regulations change to 35.6 units for boundaries where both the DUPAC and height change. For multi-family zoning, the greatest diversion is also for boundaries where both density and height change which has the highest share of allowing multi-family housing (82%). We discuss the implications of these differences further in Section 2.3. We also report the variation in the mean number of housing units, multi-family rents, and single-family house sale prices among buildings within 0.2 miles of a regulation boundary of the six regulation scenarios in Panel A.

2.2 Interaction of zoning regulations

While all three zoning regulations have relatively straightforward definitions, their implementation and interactions can be complex. Across locations, different zoning regulations can act as a binding constraint. Therefore, one should expect that relaxing binding regulations should increase housing units. Conversely, relaxing only regulations that do not bind does not necessarily result in more units being built. We use an example to illustrate when a regulation is binding, conditional on the presence of other regulations.

Suppose a municipality allows five dwelling units to be built on one acre of land, i.e., DUPAC = 5, and has maximum height restrictions of 20 feet. If multi-family buildings are not allowed, one possible distribution is five single-family units of two floors, each on 1/5th-acre parcels. Now, suppose this municipality relaxes multi-family zoning without relaxing DUPAC and height restrictions. In that case, one can rearrange some of the five housing units into apartment buildings, i.e, there can be some parcels with two-unit apartments with two floors total and some single-family houses, but the overall housing density on that acre of land will remain at five. In this case, DUPAC zoning is the binding constraint on increasing the overall supply of housing.

Now suppose this municipality allows DUPAC = 24, but keeps the current restrictions on height and does not allow multi-family buildings. Since multi-family buildings are not allowed, each parcel's density cannot be more than one housing unit. To ensure that houses are at least 1,200 square feet (0.028 acres) and there is some space around each house, we can reduce each parcel's size to 1/20th an acre such that 20 single-family houses of two floors can be built. In this case, even though 24 units per acre are allowed, only 20 are built, and multi-family zoning is the binding constraint on increasing the housing supply. Now, suppose the municipality allows DUPAC = 45 and multi-family buildings are allowed. However, the municipality keeps the current restrictions on the maximum height at 20 feet. On each of the previous 1/20th-acre parcels, one can build two-unit apartments with two floors total such that there are 40 housing units. Although 45 units per acre are allowed, only 40 are built, and maximum height restrictions are the binding constraint on increasing the housing supply.

2.3 Assignment of regulation scenarios to boundaries

It is possible that the assignment of regulation scenarios to boundaries is not random. If this is the case, we might not be able to compare results across the six regulation scenarios because the differences in local average treatment effects across scenarios could be driven by the underlying factors that drive assignment. In Panel B of Table 1, using a t-test, we compare the means of share under age 18, share over age 65, share Black residents, distance to local municipality center, and travel time to central Boston between the most common regulation scenario–scenario 3, i.e. only density changes–and all other regulation scenarios. We find little variation in the share of the population under age 18 and over 65 across scenarios 1 through 5. In addition, there is little variation in the distance of the boundaries of the six regulation scenarios from the center of their municipalities (1.29 to 1.95 miles).

While the share of Black residents varies from 4.9% to 12.4% across different regulations scenarios, this variation is only about half of the standard deviation of the share of Black residents at the Census block level. However, there is some variation in the assignment of scenarios to boundaries as one radially moves out from central Boston. Specifically, regulation scenario 6 (DUPAC and height change) is more prevalent near central Boston (mean 10.7 miles transit distance to Central Boston), while other regulation scenarios are found everywhere (mean 14.5 to 18.8 miles to Central Boston). In addition, regulation scenario 6 has a slightly larger share of working-age adults. To alleviate concerns regarding scenario 6, we estimate the policy effects separately for Boston and municipalities near Boston, where all regulation scenarios are equally likely to be found. In summary, given the relatively minimal treatment heterogeneity across the assignment of regulation scenarios to boundaries, we proceed with comparing results across the various regulation scenarios.

2.4 History of the adoption of various zoning regulations

It is worth considering why municipalities deploy multiple zoning instruments simultaneously. It could be because each regulation provides a particular benefit to residents. However, it is also possible that homeowners seeking to preserve their neighborhood structures prefer having multiple regulations, making upzoning reforms more challenging. In addition, historical events may also have led to this redundancy in regulations.

Boston and Cambridge first adopted broad zoning categories—dividing land into residential, industrial, or commercial areas—and maximum height restrictions in 1918 and 1920 (Knauss, 1933; MacArthur, 2019), respectively, following New York's introduction of zoning regulations in 1916. The neighboring municipalities of Brockton, Brookline, and Newton soon followed and adopted broad zoning categories and maximum height restrictions in the early 1920s (Hillard, 2020; Neilson, 1934). Appendix Table C.1 illustrates the year of the first zoning adoption across 42 municipalities in our sample. However, by the 1950s, these municipalities found that broad zoning categories and height regulations "did not sufficiently limit the housing potential of a given parcel, and recommended changes to the zoning to cap the total amount of habitable floor area in a structure relative to the area of the parcel on which it sat [density]" (MacArthur, 2019). Thus, in 1956, towns in Greater Boston adopted comprehensive zoning laws, including density or DUPAC regulations (Bobrowski, 2002).

2.5 Data

We use data on parcel-level zoning regulations from digitized maps compiled by the Metropolitan Area Planning Council (MAPC) for their Zoning Atlas project. Our sample of municipalities in Greater Boston consists of 101 towns from the Zoning Atlas, which provides a snapshot of zoning regulations as observed in 2010. To the best of our knowledge, the MAPC Zoning Atlas and the Desegregate Connecticut Zoning Atlas (Bronin, 2021) are the only two comprehensive zoning datasets in North America that provide complete zoning codes and bylaws data for a state or region.[7]

The data on housing units and characteristics come from town tax assessment records compiled by the Warren Group for 2010–2018. These records reflect the near universe of all residential and mixed-use buildings in Greater Boston.[8] The number of single- and multi-family units from the Warren Group data is similar to the total units from the American Community Survey (ACS) (see Appendix Figure C.4). The Warren data contain information on the type of building (whether it is single- or multi-family), the number of units in a building, the parcel size and building area, the year of construction for a building, the tax-assessed value, the sale price and date, and building characteristics (e.g., number of rooms and bathrooms).

For single-family homes, we use the sale price from the last time the property was sold for those buildings sold during our study period (2010–2018). For multi-family

[7]We correlate town-level averages of our parcel-level zoning data with the Wharton Index (WRLURI) of a given town for the 26 out of 101 municipalities with a WRLURI. A one standard deviation increase in the average DUPAC in our town level corresponds to a decrease of 0.007 standard deviations in WRLURI, where lower values indicate lower levels of regulations. A one standard deviation increase in average town-level height and multi-family zoning by-right corresponds to a decrease of 0.06 and 0.07 in WRLURI.

[8]Condominiums, which represent 10% of residential buildings in the Warren data for Greater Boston, are excluded from analysis because of the inconsistent way they are reported in tax assessment data, making it difficult to determine the size, sale prices, or assessed value for the entire condominium building.

rents, the entirety of unit or building-level historical rental data is challenging to find.[9] McMillen and Singh (2020), for instance, use survey data on rent. We use data from CoStar, which provides historical rental information for buildings with five or more units, and detailed information on multi-family building characteristics such as the number of units, floors, year built, and parcel size. We use market rent for 18,536 multi-family buildings (2010–2018) from CoStar. For the remaining 112,992 buildings, we impute rent using the building's tax-assessed value. Appendix A provides details of the imputation process. While imputing rental data for most buildings with two to four units may seem out of the ordinary, it is similar to using assessed property values, where the imputation process is outsourced to towns or counties.

Appendix Figure A.1 plots the 2018 CoStar market rents and imputed rents used in the paper against the ACS 2018 Census Block Group rents. As seen in the figure, rents in our sample track the neighborhood ACS rents for the most part. One exception is the higher end of the distribution where the ACS data are top-coded, and our sample better captures the higher end of market rent distribution. Another exception is monthly rents ranging from \$500 to \$1,400. Our sample slightly overestimates the density of properties compared to the ACS distribution. For robustness, in Section 5.3 we show results excluding rents in the \$500–\$1,400 range in Figure 9 and find little statistical differences compared with the case where we do not exclude these rents.

Amenities like school quality and proximity to transit are essential factors for consumer location decisions. For unbiased estimates, we are careful to rule out these channels. We use the 2016 elementary school attendance area boundaries from the National Center for Education Statistics School Attendance Boundary Survey (SABS). In the final sample, we exclude 15 towns for which we cannot find elementary school attendance boundaries. Appendix Figure C.5 displays the final sample of 86 towns. Data on open spaces, roads, and transit come from MassGIS. Parcel-level data on slope, soil quality, and depth to bedrock comes from Massachusetts Natural Resources Conservation Ser-

[9] Note that single-family houses can be rented and multi-family apartments can be owned. However, since we do not observe data on ownership status or per-housing unit sale prices for multi-family apartments, we focus on the sale prices for single-family houses and rents for multi-family housing. In addition, there can be variation in rents within a multifamily building. We use the average rent per year across all housing units in a building.

vice. Lastly, we use Census 2010 block level data for demographic characteristics.

3. Theoretical framework and empirical strategy

3.1 Model

We build the following theoretical framework to understand how various zoning regulations interact and affect the housing supply and prices. In a two-location model of a city, consider two neighborhoods L and R on either side of a zoning regulation boundary located at $x = 0$. There is either a single- or multi-family building (if zoning permits) at each location (parcel) x within bandwidth $-\underline{x}$ and $\underline{x}$. If a multi-family building is located at x, then more than one housing unit will be at x.

Let $p(x, h(z^k), z^k)$ be the sale price for single-family homeowners or rent for renters of multi-family units for a housing unit located at x.[10] Price $p(.)$ is a function of zoning regulation vector z^k, $k = L, R$. Vector z^k denotes whether multi-family zoning is allowed, the maximum building height, and the maximum DUPAC in neighborhood k, where a higher z^k indicates less restrictive zoning regulations. Without loss of generality, the left neighborhood is always more regulated than the right, such that $z^L \leq z^R$. We assume that zoning regulation constraints are binding. Price $p(.)$ is a function of $h(z^k)$, which is the vector of housing unit characteristics. Importantly, housing unit characteristics $h(z^k)$ are a function of the zoning regulations.

Consumers belong to a type τ. They are heterogeneous in their preferences (γ^τ) and the location of their outside option. The outside option location has a reservation utility of ν^τ. Consumers earn wage w, choose location x, derive housing utility $V(x, h(z^k), z^k, \gamma^\tau)$, and pay $p(x, h(z^k), z^k)$ for their chosen location. The utility of a consumer is $U(x, h(z^k), z^k, \gamma^\tau) = u(w - p(x, h(z^k), z^k))V(x, h(z^k), z^k, \gamma^\tau)$.

Assumption 1: *Housing markets are not locally segmented at the regulation boundary* $x = 0$*; i.e., they face the same demand and supply shocks.*

Assumption 2: *The city population increases at an exogenous rate* $\kappa > 0$ *such that there is an increase in population and housing demand over time.*

[10] We consider the distinction between owners and renters when discussing the option value of zoning regulations. Renters rent from absentee landlords.

Then, in equilibrium, residents are indifferent between all locations x and the outside option, and the housing market clears. We divide a consumer's housing utility $V(.)$ into direct housing utility $V^{direct}(.)$ and neighborhood housing utility $V^{neighbor}(.)$ following Turner et al. (2014).[11] $V^{direct}(x, h(z^k), z^k, \gamma^\tau)$ is a function of the location x, housing unit characteristics $h(z^k)$, and the zoning vector z^k. $V^{neighbor}(z^k)$ is a function of the zoning vector and represents how zoning affects the neighborhood density and neighbor characteristics, i.e., characteristics of the parcels near x but not of $h(x)$ itself. Under the functional form of utility $u(.) = \exp^{(w - p(x, h(z^k), z^k))}$, the price per unit is given by

$$p(x, h(z^k), z^k, \gamma^\tau) = w - \nu^\tau + \ln(V^{direct}(x, h(z^k), z^k, \gamma^\tau)) + \ln(V^{neighbor}(z^k)). \tag{1}$$

From Equation 1, it follows that

$$\begin{aligned} p(x, h(z^L), z^L, \gamma^\tau) - p(x, h(z^R), z^R, \gamma^\tau) &= \ln(V(x, h(z^L), z^L, \gamma^{\tau_L})) - \ln(V(x, h(z^R), z^R, \gamma^{\tau_R})) \\ &\quad + \ln(V^{neighbor}(z^L)) - \ln(V^{neighbor}(z^R)). \end{aligned}$$

Assumption 3: *As* $|x_L - x_R| \rightarrow \epsilon$ *for a small* ϵ, $\ln(V^{neighbor}(z^L)) - \ln(V^{neighbor}(z^R)) \rightarrow 0$. *Thus, consumers in neighborhood* R *located very close to the boundary* $x = 0$ *have the same immediate neighbor exposure and neighborhood density as consumers in the* L *neighborhood very close to the boundary.*

Then, close to the boundary, the housing unit price and rent differences expressed below only arise from direct location utility $V^{direct}(x, h(z^k), z^k, \gamma^\tau)$.

$$p(x, h(z^L), z^L, \gamma^\tau) - p(x, h(z^R), z^R, \gamma^\tau) = \ln(V(x, h(z^L), z^L, \gamma^{\tau_L})) - \ln(V(x, h(z^R), z^R, \gamma^{\tau_R})). \tag{2}$$

3.2 Mechanisms behind price differences across boundaries

In our theoretical setup, the long-run equilibrium price differences from Equation 2 are not zero; i.e., $p(x, h(z^L), z^L, \gamma^\tau) - p(x, h(z^R), z^R, \gamma^\tau) \neq 0$. This is because of three fundamental mechanisms. First, due to regulation-induced differences in housing characteristics across boundaries, the sale price or rent of the smallest housing unit available on a given side jumps discretely at the boundary if the regulation binds. We call this the composition effect. Second, consumer heterogeneity in preferences (γ^τ) and different

[11] Turner et al. (2014) refer to direct utility as own lot effect and neighbor utility as external lot effect.

demand elasticities across the boundary result in a discrete jump in prices and rents at the boundary; we call this the sorting effect. Third, for owners, the option value of land jumps discretely at the boundary.

Composition effect: The price differences in Equation 2 are a function of housing characteristics $h(z^k)$. Differences in zoning regulations (z^k) result in discrete differences in housing type and characteristics across the regulation boundary such that $h(z^L) \neq h(z^R)$. For instance, in the case of DUPAC, the housing characteristic change can come from the smaller minimum lot size for the R neighborhood. If maximum height changes across the boundary, the discrete jump would be in the number of floors. Thus, the price per housing unit jumps discretely at the boundary ($p(h(z^L)) \neq p(h(z^R))$) and falls as one moves from the restricted L neighborhood with larger housing units to the relaxed R neighborhood with smaller housing units.

The mechanism of the composition effect driving price differences is novel and crucial in our setting and in understanding affordability. We study the universe of building types—single- and multi-family—which have significant differences in housing characteristics. This is unlike the literature, which compares the same housing types on either side of a given boundary and cannot examine the role of the composition effect in affordability.[12] However, by altering the characteristics and type of housing (single- or multi-family), zoning regulations increase the price of the smallest housing unit available in the more regulated neighborhood L, lowering overall housing affordability.

Sorting effect: Household heterogeneity in outside options (ν^τ) implies that demand in L and R neighborhood is not perfectly elastic.[13] Since households have heterogeneous preferences for housing characteristics γ^τ, at the boundary $x = 0$, households will sort along the regulation boundary based on these preferences; i.e., the demand elasticities are different on either side of the boundary. This will lead households who prefer larger units to sort into the L neighborhood. Thus, shifts in the supply curve in L and

[12]For instance, Turner et al. (2014) compare only vacant parcels, Zabel and Dalton (2011) and Glaeser and Ward (2009) compare only single-family houses, and Severen and Plantinga (2018) compare only multi-family buildings on either side of the boundary.

[13]This is unlike the models that use boundary RD design to elicit willingness to pay for characteristics that differ discontinuously at boundaries, such as school quality (Black, 1999), which assume that demand for housing is perfectly elastic on both sides of the boundary. Under this assumption, housing supply shifts from regulation cannot affect prices across boundaries.

R neighborhoods would result in a discrete jump in the price per housing unit at the boundary.[14] The difference in equilibrium prices from the sorting effect is represented in Equation 2, where γ^τ differs across boundaries. If demand is more inelastic (elastic) on the regulated side L, then the price per housing unit will be discretely lower (higher) on the relaxed side R of the boundary. Without heterogeneity in preferences, demand elasticities across boundaries are equal, and there are no differences from the sorting effect in equilibrium prices.

Option value: Relaxed zoning regulations represent increased options as parcels can be used for single- and multi-family use (or different heights, lot sizes, etc.), thereby increasing the parcel's future sales value. The option value is only present for owners, which in the context of the paper, only affects single-family sale prices. The option value mechanism results in a positive discrete jump in the land value per square foot at the boundary as one moves from the restricted side (L) to the relaxed side (R). Significantly, option value affects land prices independently of the type of structure built on the land.

3.3 Nonparametric differences across RD boundaries

We begin by nonparametrically estimating the differences in housing supply, prices, and rents across regulation boundaries following Imbens and Lemieux (2008) because we have a large enough number of observations near boundaries for all six regulation scenarios. The nonparametric plots allow us to examine the differences across regulation boundaries without imposing a polynomial trend on the distance to the boundary variable. We first subdivide the 0.2-mile area around either side of the regulation boundary into 0.02-mile (105.6-feet) bins of distance to the boundary. Then, we regress these distance bins and boundary fixed effects on the key outcomes of interest—distance to amenities, parcel quality, predicted rents and prices, the number of housing units, and the log of sale price and monthly multi-family rents (similar to Bayer et al., 2007).

Figures 3 - 9 plot a given outcome's average (coefficient) at each of the 20 distance bins, conditional on boundary fixed effects and relative to the normalized bin. Negative distances indicate the more regulated side of a boundary.[15] We normalize the bin clos-

[14]Following the assumption that markets are not locally segmented around regulation boundaries, both neighborhoods along the boundary receive the same supply shock.

[15]At boundaries where two regulations change but are not relaxed on the same side of the boundary,

est to the boundary on the less regulated side (0- to 0.02-mile bin) to zero and weigh all observations equally no matter how far they are from the boundary. Following Abadie et al. (2022), we report 95% confidence intervals using standard errors clustered at the boundary level to account for spatial correlation. The optimal bandwidth calculated using the methodology of Calonico et al. (2020) lies between 0.01 and 0.03 miles for all regulation scenarios and dependent variables. Thus, the optimal bandwidth corresponds to the two distance bins closest to either side of a boundary.

When studying the effects of the six regulation scenarios on the number of units, we report the results for the 2018 snapshot of buildings. We restrict the buildings to those built after adopting the first zoning restrictions in 1918; i.e., we remove buildings that were grandfathered in. For robustness, we also show results for the more conservative cutoff point where we restrict attention to buildings constructed after 1956 when density zoning restrictions were adopted. When studying the effects of the six regulation scenarios on single-family sale prices and monthly multi-family rents, we focus on sale prices and rents for 2010–2018 for all buildings in our sample, no matter the build year. The baseline model compares per-housing unit sale price and rent differences across boundaries without controlling for housing unit characteristics, therefore, providing the total effect of regulations on housing affordability.

3.3.1 Exploring mechanisms with the nonparametric model

An additional nonparametric model helps us understand the role of the three mechanisms–composition effect, sorting effect, and option value–in driving the total price differences. We begin by comparing sale price and rent differences across boundaries after controlling for housing unit characteristics. In an additional model, we also control for demographic characteristics because there is heterogeneity in household preferences (γ^{τ}) for house characteristics resulting in sorting along the regulation boundary. In principle, if we can completely control for household preferences, controlling for house characteristics would provide the magnitude of the composition ef-

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we proceed as follows to denote the strictly-regulated side. For regulation scenarios 4 and 5, we consider the strictly-regulated side to be the side that does not allow multi-family housing independent of the direction of change of height and DUPAC, respectively. For scenario 6, we standardize height and DUPAC regulations. The side with a larger decrease in standardized regulation constitutes the strict side.

fect (Cinelli et al., 2020). Any residual single-family sale price differences in this model would come from the option value effect.

To isolate the composition effect, we control for housing unit characteristics, including lot size, number of units per building, number of bedrooms, and number of bathrooms. To isolate the sorting effect, we control for demographic characteristics like share under 18, share over 65, household size, and racial composition[16] at the Census block level and income at the block group level. However, since we control for observable demographic characteristics at the Census block level and not the housing unit level, it is possible that we do not fully account for the sorting effect. First, aggregate characteristics might not accurately represent individual-level sorting. Second, unobserved household characteristics may drive sorting, which we cannot measure. This can create bias because γ^{τ} can affect both house characteristics (people with particular preferences choose particular houses) and the price (people with a higher willingness to pay for bigger houses live in bigger homes, making them more expensive).

The bias is likely negative because the willingness to pay for a large house is higher for households on the relaxed side who do not need to comply with stricter regulations compared to the willingness to pay for households on the strict side. In this scenario, after controlling for the composition and observable sorting effect in single-family sale prices, the residual price differences can arise from either the unobserved sorting effect or the option value. Null residual results would indicate that either the positive option value and negative sorting effect cancel each other out or do not matter individually. For multi-family rents, after controlling for the composition effect and observable sorting effect, the residual rent differences arise from the unobservable sorting effect. This is because multi-family renters do not have an option value; their landlords do.

3.4 Semiparametric model

In addition to estimating nonparametric differences in housing supply and prices, we also use a standard semiparametric RD regression to identify the causal effect of the regulation treatment within 0.2 miles or smaller bandwidth of the regulation boundary.

[16] The complete set of controls is: share of block population a) under 18, b) over 65, c) Black resident, d) Asian resident, e) Hispanic resident, f) non-Hispanic White resident, and g) ≥ 4 household members.

The semiparametric approach augments the nonparametric analysis in two ways. First, it provides estimates of a one-unit change in DUPAC, height, and multi-family regulations on housing supply and prices instead of the total difference across the boundaries. We use these estimates for evaluating Massachusetts' Chapter 40A upzoning policy in Section 6. Second, the semiparametric approach helps us study the marginal effect of individual regulations for regulation scenarios 4, 5, and 6, where two zoning regulations change at the border. This then helps us study how various zoning regulations interact with each other and affect equilibrium housing supply and prices. The parsimonious semiparametric regression model is given by

$$Y_{xt} = \rho_0 + \rho_1 \textbf{reg}_x + f_x(\text{dist}) + \lambda_x^{seg} + \phi_t + \epsilon_{xt} \quad -s \leq x \leq s, \tag{3}$$

$$Y_{xt} = \rho_0 + \rho_1 \textbf{reg}_{1x} + \rho_2 \textbf{reg}_{2x} + \rho_3 \textbf{reg}_{1x} \textbf{reg}_{2x} + f_x(\text{dist}) + \lambda_x^{seg} + \phi_t + \epsilon_{xt} \quad -s \leq x \leq s, \tag{4}$$

where, in both equations, Y_{xt} is either the number of units, log sale price for single-family homes, or log monthly rent for multi-family houses at location x in year t. We also use the equations above for a linear probability model where Y_{xt} is an indicator for either two- or three-unit buildings (gentle density) or four- or more unit buildings (high density) relative to single-family buildings. $\textbf{reg}_x$ is either a continuous regulation of DUPAC and maximum height (in 10 feet) or an indicator of whether multi-family houses are allowed. We use Equation 3 for regulation scenarios 1, 2, and 3, where only one regulation changes at the boundary, and use Equation 4 for regulation scenarios 4, 5, and 6, where two regulations change at the boundary. ρ_1 and ρ_2 in Equation 4 estimate the marginal effects of the two regulations and ρ_3 estimates the interaction effect. $f_x(\text{dist})$ is an *n*th-degree polynomial in the distance to the boundary, varying from linear up to a 5th-degree polynomial. We allow for separate trends on either side of the boundary. λ_x^{seg} is the boundary fixed effect for segment seg, which captures differences in unobserved amenities at the boundary level. ϕ_t is the house sale or rent year fixed effects used only in price regression models and not supply regression models. The bandwidth is $s = 0.02, 0.05, 0.1, 0.15$, or 0.2 miles. Since house characteristics are endogenous to the regulation, we do not control for them in the baseline semiparametric model.[17]

[17] As with nonparametric estimation, we consider the universe of buildings to study the effects on prices

4. Boundary selection and testing RD assumptions

In this section, we provide details on regulation boundary selection, address the endogeneity of the zoning regulation boundaries, and test whether RD assumptions hold along the selected straight-line boundaries. Before we proceed, note the timing of the quasi-experimental design in this paper. As highlighted in Section 2.4, municipalities in Greater Boston adopted different zoning regulations between 1918 and 1956. Since the mid-20th century, there have been only a few regulation changes,[18] and therefore we study the long-term effects on the housing market outcomes in the 2010s from the boundaries drawn in the first half of the 20th century.

4.1 Exogeneity of regulation boundaries

4.1.1 RD boundary selection

The delineation of the regulation boundaries was likely not random (Davidoff, 2015). In many cases, zoning boundaries overlapped with roads, municipal and school boundaries, and natural features such that the underlying quality of the neighborhood is not continuous along these boundaries. Discontinuity in the underlying land and neighborhood quality violates the RD assumption that all relevant covariates besides zoning regulation treatment must vary smoothly at the regulation boundary.

There are 26,306 baseline zoning regulation boundaries along which one or two zoning regulations change. Figure 2 and Table 2 show the step-by-step removal of boundaries from the baseline to the final set shown in Figure 1. The average baseline boundary segment is 0.2 miles long and is distributed throughout Greater Boston (Figure 2a). We begin by removing zoning boundaries that overlap with municipal boundaries, leaving us with 24,475 boundaries. We do this to ensure that amenities like taxes, government spending, and town-specific zoning laws on wetlands do not change discretely at the zoning boundary. As a second step, we remove zoning boundaries that overlap with water bodies like lakes, rivers, and streams because the underlying land quality can dif-

and rents and restrict the analysis to buildings constructed after 1918 (1956) to study effects on supply.

[18] Zabel and Dalton (2011) find only 27 changes to minimum lot size regulations in Greater Boston 1988-1997. The municipalities adopting zoning changes had higher house prices and larger lot sizes (also see Glaeser and Ward, 2009). In an example from Wake County in North Carolina, Kulka (2020) finds that rezoning requests concern minimal amounts of land, and, annually, around five rezonings occur.

fer across the water bodies' east-west or north-south sides. As a third step, we remove zoning boundaries that overlap with major roads, such as smaller highways, multi-lane highways, numbered routes, arterial, or connector roads. This step is crucial because neighborhoods on either side of a highway or major road cannot be considered similar, and therefore the assumption of continuous unobserved neighborhood quality is violated for such boundaries. After the second and third steps, 21,328 boundaries remain. Figure 2b shows the boundaries removed in red when removing major roads and municipal and water body boundaries.

The preceding steps of boundary removal are standard in the literature that uses across-town land use variation or survey-based Wharton index (e.g., Glaeser and Ward, 2009 and Turner et al., 2014). However, we go further to ensure the validity of our identifying assumptions since parcel-level zoning data allow us to study within the town and across regulation scenario variation. Given the critical role school quality plays in house prices (Black, 1999), we remove zoning boundaries that overlap with elementary school attendance and school district boundaries (Kulka, 2020), leaving us with 20,863 boundaries. In addition, areas across broad-use zoning categories, such as residential and mixed-use areas, cannot be compared with each other because the amenities associated with strictly residential land are discretely different from land used for residential and commercial purposes. Thus, we further restrict regulation boundaries to those not overlapping with the broad-use zoning categories, leaving us with 9,674 or 36.8% of the baseline boundaries (Table 2). A significant reduction in boundaries when removing broad-use zoning categories implies that differences in broad zoning categories drive a substantial part of the variation in zoning regulations and that there is less variation in regulations within areas broadly zoned in the same category. Figure 2c shows boundaries removed in the last two steps in red. In addition to accounting for boundary overlaps, if a remaining zoning boundary segment intersects with one of the previously discussed boundaries (e.g., roads, school boundaries, etc.), we also split the given boundary. This step ensures that we only compare buildings across a regulation boundary that are located within the same municipality, school attendance area, and broad-use zoning district.

In addition, municipalities delineating zoning boundaries during 1918–1956 may have considered socio-political and racial motives and either included or avoided certain buildings and areas, thereby creating curves in the regulation boundaries. For instance, Shertzer et al. (2016) find that Chicago's 1923 zoning maps placed industrial use zoning in racial and ethnic minority areas. If the curves overlap with unobserved land quality differences that have persisted to date (Sood and Ehrman-Solberg, 2022), this will also violate the RD continuity assumption. Therefore, we restrict the sample to straight-line boundary segments following an algorithm similar to Turner et al. (2014) to ensure the exogeneity of regulation boundaries. We do this to eliminate curves in the boundary segments that may overlap with discrete jumps in unobserved land quality.

For each property, we find the perpendicular distance to its closest boundary, draw an orthogonal line 50 meters in both directions, and check if the endpoints of this line lie within a 15-meter buffer of the boundary. If that is the case, we consider the boundary line to be straight. After restricting the sample to straight-line boundary segments, the final boundary sample is 2,835 or 10.8% boundaries. The average boundary segment in the final sample is 0.35 miles long. Note that this is longer than our original average boundary length of 0.2 miles. We view this as evidence that our selection strategy removes shorter boundary segments that are more likely to have been endogenously determined. Figure 2d shows the removed boundaries with no straight-line segments in red and the final sample of straight-line boundaries in black.[19]

4.2 Testing spatial RD assumptions

The identifying assumption for RD requires that all relevant covariates, other than the regulation treatment and outcomes of the treatment, vary continuously at the zoning boundary (Assumption 3 above). In this section, we test this assumption by studying the continuity in observed and unobserved location quality at regulation boundaries.[20]

4.2.1 Continuity in parcel quality and neighborhood amenities

Figures 3a and 3b show that the Euclidean distance to water bodies and green space is statistically not distinguishable for buildings located within 0.2 miles on either side

[19] Appendix Figure C.6 illustrates the magnified sample of the final boundaries.

[20] Section 3.3 provides details on how we construct nonparametric plots.

of the DUPAC boundary.[21] Figures 3c and 3d show the Euclidean distance of a building to its assigned elementary school and the center of its municipality. The distance to the school and the municipality center is continuous at the boundary and not different for buildings within 0.2 miles on either side of the regulation boundary where both multi-family and density regulation change. Appendix Figure C.8 shows continuity across other regulation boundaries for these amenities. As seen from Figure 3e, the travel distance to Boston city center is continuous at the boundary and is statistically identical for buildings within 0.2 miles on either side of the regulation boundary where only multi-family regulation changes.[22] Again, Appendix Figure C.9a shows continuity across other regulation boundaries in travel distances to the Boston city center.

In contrast to the amenities mentioned above, buildings on the more restricted side of the boundary where DUPAC and height regulations change are measurably farther away from highways (Figure 3f). This is also true across regulation scenarios where either only density regulation changes or density and multi-family regulations change together (see Appendix Figures C.8e and C.8f). The jump at the boundary is not statistically significant in any of these boundaries. However, out of an abundance of caution, in Section 5.3, we test whether the key price results are driven by distance to the highway, and we find that they are not (Figures 9c–9f).

We also test whether parcel buildability changes discretely at the regulation boundaries to assuage the concern that housing supply and price differences across regulation boundaries are driven by differences in parcel quality or the cost of building across boundaries. Figure 3g plots the average parcel slope for parcels within 0.2 miles on either side of the boundary where DUPAC and height regulations change. While there is no discrete jump directly at the boundary, the slopes are smaller after 0.1 miles on the less restrictive side. We do not find such differences for other regulation types (see Appendix Figures C.9b and C.9c). Therefore, in Section 5.3, we test whether the key results across the boundary where DUPAC and height regulations change are driven by parcel

[21] One concern is that Euclidean distances do not reflect actual travel distances. Appendix Figure C.7 shows the correlation between Euclidean and walking distances across the boundaries in our sample. Since these two measures are highly correlated, we proceed with Euclidean distances.

[22] Travel distance is calculated as the Manhattan distance from a building to the nearest transit station plus the distance from the station on the public transit route to central Boston.

slope. After controlling for parcel slope in the estimation, we find no statistical difference from the case where we do not control for this buildability factor (Figure 9f). Figure 3h shows no measurable difference in the depth to bedrock for parcels within 0.2 miles on either side of the boundary where only multi-family regulation changes. Appendix Figure C.9d shows continuity across other regulation boundaries in depth to bedrock.[23]

4.2.2 Continuity in neighborhood

Assumption 3 in the theoretical framework states that neighbors and neighborhood density are continuous close to the boundary, even though households sort across the boundary based on their preferences (γ^{τ}). We provide two supporting pieces of evidence for this assumption. First, the optimal bandwidth at which we are measuring causal effects of the regulation is relatively small. At 0.04 miles (211 feet) bandwidth, which corresponds to the first two bins around the boundary, 4-5 houses are compared, on average. Thus, it is not hard to imagine that the neighborhood exposure is similar on both sides close to the boundary. Second, there might be a concern that neighbors on either side of the boundary may not interact with each other – even if they are close to each other – if a road separates them, thereby generating different neighborhoods even though they are geographically extremely proximate. To alleviate this concern, in Section 5.3, we restrict the sample to boundaries that do not overlap with any small road (larger roads and highways were already excluded). Table 2 shows that about half of our final straight-line boundaries remain for this robustness test. Figures 9g-9i show that the effect on prices and rents is qualitatively similar in the sample with no roads compared to the baseline.

4.2.3 Continuity in predicted prices and rents

Next, we investigate the continuity of unobserved location quality at the boundary. To do so, we predict single-family sales prices and multi-family rents from all observed location amenities and the parcel buildability factors discussed above. Then, in Figure 4, we test whether there are discrete jumps in the unobserved location quality (predicted prices and rents) at the regulation boundaries. Jumps would indicate that zoning reg-

[23] In the Appendix (Figures C.9e and C.9f), we also find that parcel levels of clay (not ideal for building) and sand (ideal for building) are continuous at all boundaries.

ulations in the first half of the 20th century were delineated along dimensions of location quality unobservable to us and would violate the continuity assumption. Note that we observe a slight trend in predicted sale prices and rents across all these regulation boundaries. This is expected given that distances to location amenities are factored into equilibrium sales prices and rents. Importantly, we need to examine discontinuities at the RD boundary notwithstanding the trend.

We find no discontinuities in predicted sales prices for any boundary type and no discontinuities in predicted rents at boundaries where density and height change (Figure 4). However, there are some statistically significant but relatively small differences in multi-family rents across the regulation boundary where DUPAC changes alone (Figure 4b). Note that the jump's magnitude (0.004) is small relative to the rent differences we find across such boundaries in Section 5.2. Nevertheless, this finding suggests that the unobservable location quality might affect our rent difference estimands at boundaries where DUPAC changes.

In summary, Figures 3 and 4 reveal continuity across regulation boundaries in observed and unobserved location amenities—with the one potential exception of multi-family rents at density regulation boundaries. Thus, we believe that the final sample of straight-line boundaries is exogenous and that spatial RD assumptions hold.

5. Results

5.1 Zoning regulations and supply

We now discuss the long-run causal effects of regulations on the supply of housing units using nonparametric (Section 5.1.1) and semiparametric (Section 5.1.2) approach. As highlighted in Section 2.2, different zoning regulations should differ in their effect on the housing supply depending on which regulation is a binding constraint.

5.1.1 Zoning regulations and number of housing units

Figure 5 plots the nonparametric differences in the number of housing units per lot constructed after 1918.[24] The figure shows that relaxing density alone or with allowing multi-family housing or with relaxing height restrictions significantly increases supply,

[24] See Appendix Figure C.10, where we restrict the analysis to buildings constructed after 1956.

as measured by the number of units built. Figure 5a shows that increasing density restrictions results in an average 0.11-unit discrete jump in housing units on the restricted side relative to the first bin on the relaxed side, which we normalize to zero. For context, the jump corresponds to an 8.7% long-run difference at the boundary given that there is an average of 1.3 housing units per lot on the restricted side.

Figure 5b shows that increasing density and height restrictions result in an average 2.4-unit difference in housing units on the restricted side relative to the relaxed side. This jump corresponds to a 109% long-run difference at the boundary given that there is an average of 2.2 housing units on the restricted side. Figure 5c shows that reducing density restrictions and not allowing for multi-family housing results in an average 0.799-unit jump in housing units on the restricted side relative to the relaxed side. This jump corresponds to a 63.7% long-run difference at the boundary for an average of 1.25 housing units on the restricted side. Figure 5d shows that restricting multi-family housing without changing other zoning restrictions results in an average 0.598 or 51.2% long-run difference in housing units on the restricted side relative to the relaxed side.

Thus, we find a 9%–109% long-run difference in the supply of units per parcel at the boundaries where 1) only DUPAC is relaxed, 2) only multifamily zoning is relaxed, 3) DUPAC and multi-family zoning are both relaxed, or 4) DUPAC and height zoning are both relaxed. For these four regulation scenarios, for the most part, the effect is precisely estimated near and further away from the boundary at a 95% confidence interval with clustering at the boundary segment level. For comparison, we also report robust standard errors for the –0.02- to 0-mile bin in square brackets in Figure 5. The long-run differences in the number of housing units are noisy between –0.08 and –0.04 miles from the boundaries for regulation scenarios where either density restrictions or multi-family zoning is relaxed without changing any other restrictions (scenarios 1 and 3). If only the optimal RD bandwidth is considered (0 to 0.04 miles), no long-run differences can be distinguished from zero in the number of units when only density regulations are relaxed. However, long-run differences in housing units are precisely estimated when only multi-family zoning is relaxed right at the boundary (0- to 0.02-mile bandwidth).

We cannot statistically distinguish from zero the long-run differences in housing units per parcel across boundaries where either height regulations change alone or along with allowing for multi-family homes (Figures 5e and 5f). The null effects imply that height regulations are not a binding constraint at their current levels. Instead, the long-run supply of housing units hits the density and multi-family regulation constraints before height restrictions in Greater Boston. While height restrictions do not constrain supply in the Boston metro area, they can still be a binding constraint in other metros worldwide (Nakajima and Takano, 2021). For instance, some evidence using vacant parcels shows that height restrictions are very stringent; i.e., building heights significantly diverge from the regulation-free level in New York and Washington, DC (Brueckner and Singh, 2020).

The results in Figure 5 highlight the differences in supply in terms of units per parcel versus area-wide density. Changing DUPAC regulation primarily affects area-wide density instead of the number of units per parcel. For example, Figure 6f shows that lot size falls by 0.15 acres on the relaxed side of a boundary when only DUPAC changes. This implies that the observed changes in the number of units across the boundary in Figure 5a come from more homes built on smaller parcels. In contrast, Figures 6d and 6e show that the parcel size does not detectably differ at boundaries where multi-family zoning changes alone or along with changes in density restrictions. Thus, allowing multi-family units affects the number of housing units per parcel, i.e., leads to housing units being arranged vertically as apartments rather than as single-family houses.

5.1.2 Zoning regulations and type of housing units

To study the effects of regulations on type of housing supply, we run the semiparametric linear probability model from Equations 3 and 4, where the outcomes are indicators for the type of housing. The indicators equal one for gentle- (two and three units) or high-density (four or more units) buildings and equals zero for single-family housing. We interpret the effects of a given regulation as increasing the probability of gentle- or high-density multi-family building types compared to single-family housing. Table 3 shows the results for buildings constructed after 1918 with linear polynomial for the distance to the boundary. The linear distance trend does not drive the results (see Appendix Table C.2 where we use a cubic polynomial in the distance to the boundary). In addition, the results are robust to the choice of date to remove grandfathered-in buildings (see Appendix Table C.3 where we restrict to buildings constructed after 1956).

We find that allowing multi-family houses alone or with relaxing density restrictions increases the probability of a given property being gentle density compared to a single-family house. In particular, column 1 shows that the long-run probability of a gentle density building more than doubles relative to single-family houses when multi-family housing is allowed (relative to a 0.23 base share of two- to three-unit buildings). On the other hand, the effect on the probability of a high density building is 123% (column 7) but less precisely estimated, perhaps due to the smaller number of such buildings. Alternatively, this points to the complication created by other factors, such as higher construction costs and community opposition, to building larger apartment buildings.

When considering the boundaries where density and multi-family zoning regulations change (scenario 5), the marginal effect from multi-family regulation results in a higher long-run probability of gentle-density building by 108% compared to single-family houses, at the average DUPAC of 11.2 (Table 3, column 5). We also find a small effect of relaxing density and height restrictions (scenario 6) for the supply of high-density buildings (column 12) but not for gentle-density buildings (column 6). The marginal effect of relaxing DUPAC by one unit at such boundaries increases the long-run likelihood of high-density buildings by 0.12%, given the average height of 4.3 floors. Thus, the 109% difference in housing units we find in Figure 5d is driven by high-density properties. This is not surprising because boundaries where density and height restrictions change together (scenario 6) are primarily located near central Boston (Figure 1) where a majority of high-density buildings are (Appendix Figure C.11).

The semiparametric estimation, like the nonparametric estimation, finds null effects on the multi-family building type for boundaries where either height regulations change alone or along with allowing for multi-family homes (Table 3, columns 2, 4, 8, and 10). Again, the null effects imply that height regulations are not a binding constraint at their current levels in Greater Boston. In addition, even though we find long-run differences in the number of housing units across boundaries where only density is relaxed, we find a null effect of only changing DUPAC regulation on the type of multi-family housing (columns 3 and 9). From the discussion in Section 2.2, this is to be expected if only DUPAC regulation is relaxed without allowing for multi-family housing. In that case (37% of the boundaries), changing DUPAC regulation alone can only result in smaller single-family houses on smaller parcels but not multi-family buildings. We believe that these boundaries are driving the null effects.

5.2 Zoning regulations and price effects

We now discuss the causal estimates of long-run differences in single-family sale prices and multi-family rents across the six regulation scenarios. Since we're interested in understanding the role of zoning regulations for housing affordability, as a starting point, the baseline nonparametric model estimates long-run causal differences in rents and prices without controlling for housing unit characteristics that are endogenous to zoning regulations. After discussing the baseline model results, we discuss the relative role of the three mechanisms—composition effect, sorting mechanism, and option value—and disentangle them to the extent possible within our research design.

5.2.1 Density regulation and interactions (scenarios 3 and 6)

When only DUPAC regulation is relaxed, the long-run equilibrium difference in the sale price for single-family houses falls by an average of 4.4% at the boundary (Figure 7a). Relative to the average sales prices on the strict side of the boundary, this amounts to a decrease of $28,488. To understand the role of the composition effect behind the baseline differences, we control for housing characteristics. As seen from Figure 8a, the sale price differences can no longer be statistically distinguished from zero, with clustered standard errors at the boundary segment level (robust standard errors are also reported for the –0.02- to 0-mile bin in square brackets in Figure 7). Thus, the composition effect likely drives the entire sale price difference across boundaries, implying that the sorting effect and option value are either null or relatively equal and opposite. Controlling additionally for demographic characteristics at the Census block level has no further impact on prices, implying that there is no substantial sorting effect (Appendix Figure C.13a).

The role of the composition effect is not surprising given that housing unit characteristics like the number of bedrooms (Figure 6a) and parcel size (Figure 6f) jump discontinuously at the boundary when only DUPAC regulation changes. Thus, the discrete jump in long-run sales prices per housing unit is driven by regulations targeting housing characteristics; i.e., there is no price difference in quality-adjusted housing. However, we focus on the baseline price per-housing unit differences for affordability and policy purposes. Note that the long-run sale price difference steadily increases as one moves away from the boundary in the baseline model but not after controlling for the composition effect. This is due to differences in housing characteristics on the same side of the boundary where the interior parcels (–0.2 to –0.1 miles) have larger parcels and more bedrooms and bathrooms than the border parcels (–0.8 to 0 miles in Figure 6). We interpret this as further evidence that neighborhood characteristics are not changing significantly within 0.2 miles of the boundary, and therefore, differences in neighborhood quality are unlikely to be driving the effects that we find.

When only density regulations are relaxed, the long-run equilibrium difference in the monthly rents for multi-family buildings falls by an average of 6.9% at the boundary on the relaxed side (Figure 7b). Relative to the average rent on the strict side of the boundary, this represents a fall in monthly rents of $101. The rent differences are statistically different from zero for the most part on the more regulated side. Note that the predicted rent (unobserved location quality) for the regulation scenario where only DUPAC changes was the only scenario that exhibited a slight jump at the boundary (Figure 4b). Thus, one must be cautious in interpreting rent differences at this boundary, which could be partially due to unobserved discrete changes in land quality. We control for housing characteristics to understand the mechanisms behind the multi-family rent differences. As seen from Figure 8b, the rent differences can no longer be statistically distinguished from zero with clustered standard errors. Thus, again, the composition effect is driving the long-run rent differences. Note that there is no option value for renters. Therefore, if the composition effect explains the rent differences, then the effect from the sorting mechanism must be zero.[25]

When density and height regulations both change at the boundary, there is no statistically significant difference in single-family sale prices across the boundary (Figure

[25]This is further confirmed in Appendix Figure C.13b, which shows that controlling for demographic characteristics makes little difference.

7c). In addition, after controlling for housing unit characteristics (Figure 8c) and the observed sorting effect (Appendix Figure C.13c), we find that neither is a salient mechanism at this boundary type. Figures 6b and 6h show that housing unit characteristics, like the number of bedrooms and bathrooms, are not statistically different across the boundary. Given the limitation of the methodology, we cannot confidently distinguish the role of the unobserved sorting mechanism from the option value for single-family sale prices. However, one reason behind null long-run sale price differences could be due to the negative sorting mechanism counteracting the positive option value jump at the boundary.

When density and height regulations change together, long-run monthly multi-family rents fall by an average of 4.2% at the boundary (Figure 7d), $54 relative to the mean rent on the restricted side of the boundary. The rent differences are not statistically significant with clustered standard errors at all distances from the boundary. This changes when we control for the endogenous housing unit characteristics (Figure 8d) but not when we also control for observable demographic characteristics (Appendix Figure C.13d): units on the strict side are significantly more expensive than units on the relaxed side. This residual difference in long-run rents indicates a robust unobservable sorting effect arising, and likely not the composition effect mechanism as observable characteristics are not statistically different across the boundary (Figures 6b and 6h).

5.2.2 Multifamily regulation and interactions (scenarios 1 and 5)

When considering boundaries where multi-family regulation changes, either by itself or along with density regulations, we can only examine the long-run price differences on single-family sale prices and not multi-family rents. This is because multi-family buildings are not allowed on one side of the boundary; hence, we observe no multi-family buildings or their rents on the more regulated side.

When multi-family regulation is the only regulation that changes across regulation boundaries, the difference in single-family house sale prices across boundaries cannot be statistically distinguished from zero (Figure 7e). Moreover, even after controlling for differences in housing characteristics (Figure 8e), we find the same null effect. Thus, the composition effect is not playing a role in the long-run equilibrium price differences.

Again, the null results can result from the positive option value mechanism canceling the negative jump from the sorting effect. However, controlling for demographic characteristics (Appendix Figure C.13e) makes no difference, therefore making it more likely that both option value and sorting effects are relatively small.

Among boundaries where both multi-family and density regulations change, the long-run single-family sale price difference is 2.2% at the boundary or $13,394 relative to the mean single-family sale price on the restricted side (Figure 7f). The sale price differences increase as one moves further away from the boundary. Like the regulation scenario where only DUPAC regulation changes, the composition effect is a key mechanism behind the long-run sale price differences. After controlling for single-family housing unit characteristics, the sale price difference can no longer be statistically distinguished from zero (Figure 8f). The effects from the sorting mechanism and option value are either null (Appendix Figure C.13f) or equal and opposite. The role of the composition effect is not surprising given that housing unit characteristics like the built area (Figure 6c), number of bedrooms, and number of bathrooms (Figure 6g) jump discontinuously at the boundary when DUPAC and multi-family regulation change. Thus, the discrete jump in long-run sales prices per housing unit is driven by regulations targeting housing characteristics.

5.2.3 Height regulation and interactions (scenarios 2 and 4)

When height regulation is relaxed either by itself or with multi-family regulation, we cannot statistically distinguish the long-run single-family sale price and multi-family rent differences from zero for the most part (Appendix Figure C.12). The price difference mechanisms of the composition effect or the sorting effect require a difference in the number, characteristics, or type of housing units. However, we find no such evidence (Figure 5 and Table 3) for regulation scenarios where height regulation is relaxed either by itself or with multi-family regulation because height regulation is not a binding constraint for housing in Greater Boston. In the absence of changes in housing unit supply across the boundary, the only source for long-run sale price differences comes from the jump in the option value, and we find little evidence of this effect.

5.3 Robustness of analysis

This section discusses the robustness of the price results to several potential confounding factors. First, we discuss how rent imputation may bias rent results. Second, we control for neighborhood amenities and parcel buildability factors that are measurably different on the more regulated side of the boundary. Third, we study long-run equilibrium differences only across boundaries that do not overlap with any roads, even small neighborhood roads.

While the imputed multi-family rents and CoStar market rents mostly track the asking rent distribution from the ACS, we slightly overestimate the proportion of rents between \$500 and \$1,400 (Appendix Figure A.1). This could result in an upward bias in our estimates if we systematically estimate low rents on the less regulated relaxed side of the boundaries compared to the more regulated side. For robustness, we drop rents in the \$500–\$1,400 range and re-estimate nonparametric differences in rents across regulation boundaries. In Figure 9a, we find similar and precise multi-family rent differences across the boundaries where DUPAC regulation changes. The long-run monthly rent difference in the restricted sample is 9.8% (in red and blue) compared to the 6.9% in the baseline (in gray). However, the long-run rent differences for boundaries at which density and height change are noisier than before (Figure 9a), which could be due to dropped rental data for many buildings around this boundary scenario. Nevertheless, we do not find a reversal of the previously estimated patterns in the restricted rental data, suggesting that inaccuracies in imputing rents are not driving our rent results.

In Section 4.2, we did not find any discontinuities at the boundary in any relevant covariates, i.e., neighborhood amenities and parcel buildability factors (Figure 3). However, we found buildings on the more restricted side to be measurably farther away from highways for boundaries of almost all regulation scenarios. The confounding effects of highway proximity are worrying because more affluent areas were likely able to prevent nearby highway construction.[26] Thus, we are concerned that distance to highways captures systematic differences in unobserved neighborhood quality. To assuage our

[26]Most interstate highways were planned in the 1940s and early 1950s, but construction did not start until after 1956, i.e., after most zoning regulations were set (Baum-Snow, 2007).

concerns, we control for distance to the highways in our nonparametric model. Figures 9c–9e show that the baseline single-family sale price and multi-family rents differences (in red and blue) are statistically identical to the model where we control for distance to highways (in gray).

In Section 4.2, for boundaries where density and height change together, not only are buildings on the restricted side measurably farther from highways but those on the relaxed side also have lower mean parcel slope and depth to bedrock. To ensure that these factors are not driving the main results, we control for distance to the highway, mean parcel slope, and depth to bedrock in the nonparametric model for boundaries where density and height change. Figure 9f shows that the baseline rent differences (in red and blue) are similar to the model with additional controls (in gray), although the long-run rent difference at the boundary changes from 4.2% to 1.6%.

Lastly, after restricting the sample to boundaries that do not overlap with any roads, the long-run single-family sale price difference at the boundary where DUPAC changes is 8.7% (Figures 9g) compared to the baseline 4.4% (Figure 7a). The long-run multi-family rent difference at the boundary where DUPAC changes is 8.2% in the no-road sample for boundaries (Figure 9h) compared to the baseline 6.9% (Figure 7b). Finally, the long-run single-family sale price difference at the boundary where the DUPAC and multi-family change is 4.1% in the no-road sample for boundaries (Figures 9i) compared to the baseline 2.2% (Figure 7f). Thus, the effect on prices and rents is more significant in the sample with no roads compared to the baseline. We interpret these results as further evidence that differences in unobserved neighborhood quality do not drive the baseline results. Overall, we can conclude that the main results are robust to sensible checks that seek to ensure that observed and unobserved neighborhood quality does not change across the boundary.

6. Policy effects of relaxing zoning regulations

In this section, we explain how we use the estimated causal effects of various zoning regulations to study the effect of the small-scale Massachusetts Chapter 40A upzoning law. Small-scale upzoning policies are an increasingly popular response to housing affordability issues worldwide.[27] The Massachusetts upzoning policy requires municipalities to allow for multi-family housing and a density of at least 15 units per acre within 0.5 miles of transit stops. We use our causal estimates to evaluate the upzoning policy's long-run effects on single-family sales prices, multi-family rents, and the number of units within a 0.2-mile radius of train stations in Greater Boston. Since we estimate equilibrium differences in already built-up areas and not vacant land[28], our policy counterfactual is particularly well suited to study the upzoning effects in developed cities and suburban towns (less than 1.9% of parcels in Greater Boston are undeveloped).

Before we proceed, we discuss a few caveats. First, note the timeframe of the counterfactual policy effects. In the short run, absent any supply changes after upzoning, the only change in sale prices can occur through increased option value of land for owners. The long-run causal effects estimated in this paper span over 60 years, during which Greater Boston's population increased by 59%. Thus, our counterfactual upzoning supply and price effects should be interpreted as long-run effects under a similar population growth rate. The second caveat is that the upzoning effects are calculated for a small area around the train stations (0.2-mile radius) and are not region-wide. Our RD framework is well suited to study small changes in limited areas like the Massachusetts Chapter 40A law or California's Bill 2097. However, the current analysis is not well suited to study the general equilibrium effects of large-scale zoning changes like those in Oregon or California, allowing multi-family buildings across most areas in their state. Another caveat is that we assume that the upzoning does not create political backlash affecting zoning decisions in other parts of Greater Boston. Finally, the counterfactual does not account for rising construction costs in the housing market (Schmitz, 2020).

We calculate the long-run price and supply effects around all Greater Boston commuter rail and metro stations. We study the effect of upzoning around the existing regulation boundary scenario near the stations, considering the current zoning regulation levels. Denote the new upzoning regulation vector at location x as $z_{40A}(x)$ and the existing zoning regulations around a train station as $z_0(x)$. Δp gives the average change in

[27] For example, 2022 California Bill 2097 banned parking requirements around transit stations. Ontario, Canada, included similar stipulations in the 2022 housing plan, as did Auckland, New Zealand in 2021.

[28] In contrast, Turner et al. (2014) and Brueckner and Singh (2020) study the effects on vacant land.

rents and sale prices ($p(x)$), and the number of housing units.

$$\Delta p = \frac{1}{\overline{x} - \underline{x}} \int_{\underline{x}}^{\overline{x}} \big(\max\{0, (z_{40A}(x) - z_0(x))\} \times \theta_i \times p(x) \big) d(x). \tag{5}$$

$$\theta_i = \begin{cases} \hat{\rho}_1 & i = \text{regulation scenario 1, 2, 3} \\ \hat{\rho}_1 + \hat{\rho}_3 \text{reg}_2 + \hat{\rho}_2 + \hat{\rho}_3 \text{reg}_1 & i = \text{regulation scenario 4, 5, 6} \end{cases}$$

θ_i is the average treatment effect of a one-unit change in DUPAC, height, or multi-family regulation across the six scenarios. Estimates $\hat{\rho}_1, \hat{\rho}_2, \hat{\rho}_3$ are from Equations 3 and 4 as described in Section 3.4. For regulation scenarios where two regulations change simultaneously, i.e., scenarios 4, 5, and 6, the marginal effects of the two regulations are calculated using the interaction term estimate $\hat{\rho}_3$ and the level of regulations at that boundary—reg_1 and reg_2. In Appendix B, we explain in detail how we arrive at θ_i and Δp for each regulation scenario i.[29]

Figure 10 plots the average long-run estimated change in housing units per parcel, monthly rents, and single-family sales prices from Chapter 40A upzoning near all transit stations across Greater Boston using Equation 5. Like the results discussed before, we find no statistical effects from Chapter 40A upzoning on supply, prices, or rents across boundaries where multi-family and height restrictions are relaxed together (scenario 4).[30] Stations marked with a gray X are not considered in our analysis because there are no regulation boundaries within 0.5 miles of the station. For stations marked with gray triangles, Chapter 40A policy will have no effect because density is already at or above the suggested maximum value of DUPAC = 15. As seen from the prevalence of gray triangles, this rules out effects at many stations, particularly closer to central Boston.

Figure 10a shows that the median long-run increase in housing units per parcel from

[29]We estimate semiparametric Equations 3 and 4 for three different municipality types as defined by MAPC: inner core municipalities, which represent Boston and municipalities near Boston; mature suburbs, which represent municipalities near the inner core; and developing suburbs, which represent municipalities further from the inner core (Figure C.14 provides a map of municipality types). Appendix Tables C.4 and C.5 show the semiparametric results across the three municipality types. In addition, within a municipality type, there is little heterogeneity in scenario type assignment to boundaries. Therefore, we can compare the Chapter 40A effects across regulation scenarios within a municipality type.

[30]Since Chapter 40A upzoning policy does not target height regulations, we would see no effects for scenario 2 (where only height regulation changes).

Chapter 40A upzoning is 0.18 units, i.e., a 23% increase. The increase in the number of housing units is particularly prominent in central Boston, with null effects in suburban municipalities (white circles). In this area, the effects are driven by relaxing regulations at boundaries where density and height change together, a prominent scenario in downtowns. In contrast, Figure 10b shows that multi-family rents decrease around train stations in suburban municipalities and not stations near central Boston. In particular, monthly multi-family rents in suburban municipalities decrease by the median of 4.9% or $88 per month. This implies that zoning regulations are especially binding for renters in suburban municipalities.

Figure 10c shows the estimated long-run effects from 40A upzoning on the sales price for single-family houses.[31] Note that single-family sale prices increase around many train stations while they decrease around others. This is mainly driven by a positive interaction effect ρ_3 when both multi-family and density regulation changes (column 5 in Appendix Table C.4). Specifically, at low current levels of DUPAC (stricter regulation), allowing multi-family houses lowers the long-run single-family sales price, i.e., negative composition or sorting effects around these stations outweigh the positive option value effect. As a result, the median long-run decrease in single-family sale prices is substantial at 8.5% or $131,617. In contrast, at higher current levels of DUPAC (less regulation), the marginal effect of allowing multi-family housing is positive, indicating that the positive option value effect post upzoning will outweigh the negative composition or sorting effects around such stations. However, the median long-run increase in single-family sales price is more modest in comparison at 1.2% or $5,735.[32]

In summary, policymakers wishing to use upzoning policies to increase housing affordability should consider the following four points. First, they should relax the regulations that are a binding constraint in their constituencies. For example, only relaxing maximum height regulations will likely not affect the housing market in Greater Boston. Second, they should consider whether the proposed new levels of regulation can have

[31] These estimates capture the upzoning effects for sale price per single-family unit and not the total sale value for parcel owners, which is the sum for all housing units on a parcel.

[32] The presence of local option value effects from upzoning around many train stations is similar to Pennington, 2021 and Asquith et al., 2021 who also find hyper-local effects of increased housing supply.

any bite. For example, 34% of Greater Boston's transit stations have lower current regulations than the upzoning policy recommendations. Third, it is essential to consider spatial heterogeneity in supply and price effects. For example, in Greater Boston, prices and rents are more likely to fall in suburban municipalities with current strict levels of zoning regulations. Thus, near suburban transit stations, upzoning affects prices and rents through the composition effect–by decreasing prices and rents of the smallest housing unit available. Fourth, upzoning policies may not equally affect the supply and prices of all housing types. For example, in Greater Boston, the affordability effects from upzoning are larger for single-family prices rather than multi-family rents, both in magnitude and the number of stations affected.[33]

7. Concluding remarks

Using novel data and methods, this paper studies which zoning regulations might be most effective at increasing the supply of multi-family housing and reducing prices and rents, thereby contributing to broad housing affordability. We find that relaxing density regulations, alone or with relaxing height and multi-family restrictions, significantly reduces single-family sale prices and multi-family rents in Greater Boston. However, only relaxing height and multi-family regulations does not have price effects that can be distinguished from zero. This is because density restrictions like minimum lot size requirements are a binding constraint in Greater Boston. In other cities, the binding regulations could be maximum height restrictions or minimum parking requirements. Thus, recent policy efforts abolishing single-family zoning in Minneapolis, California, and Oregon are likely to only affect affordability if multi-family zoning is a binding regulation in these regions. Overall, policymakers seeking to use upzoning policies as a way to increase housing affordability should first identify which regulation is a binding constraint in their constituencies and how different regulations interact with each other. Our results also suggest that small-scale upzoning policies, such as Massachusetts' recent Chapter 40A law, could reduce rents and sales prices, particularly in suburban towns with high levels of current zoning regulations.

[33] Anenberg and Kung (2020) also find limited effects of relaxing zoning on neighborhood rents.

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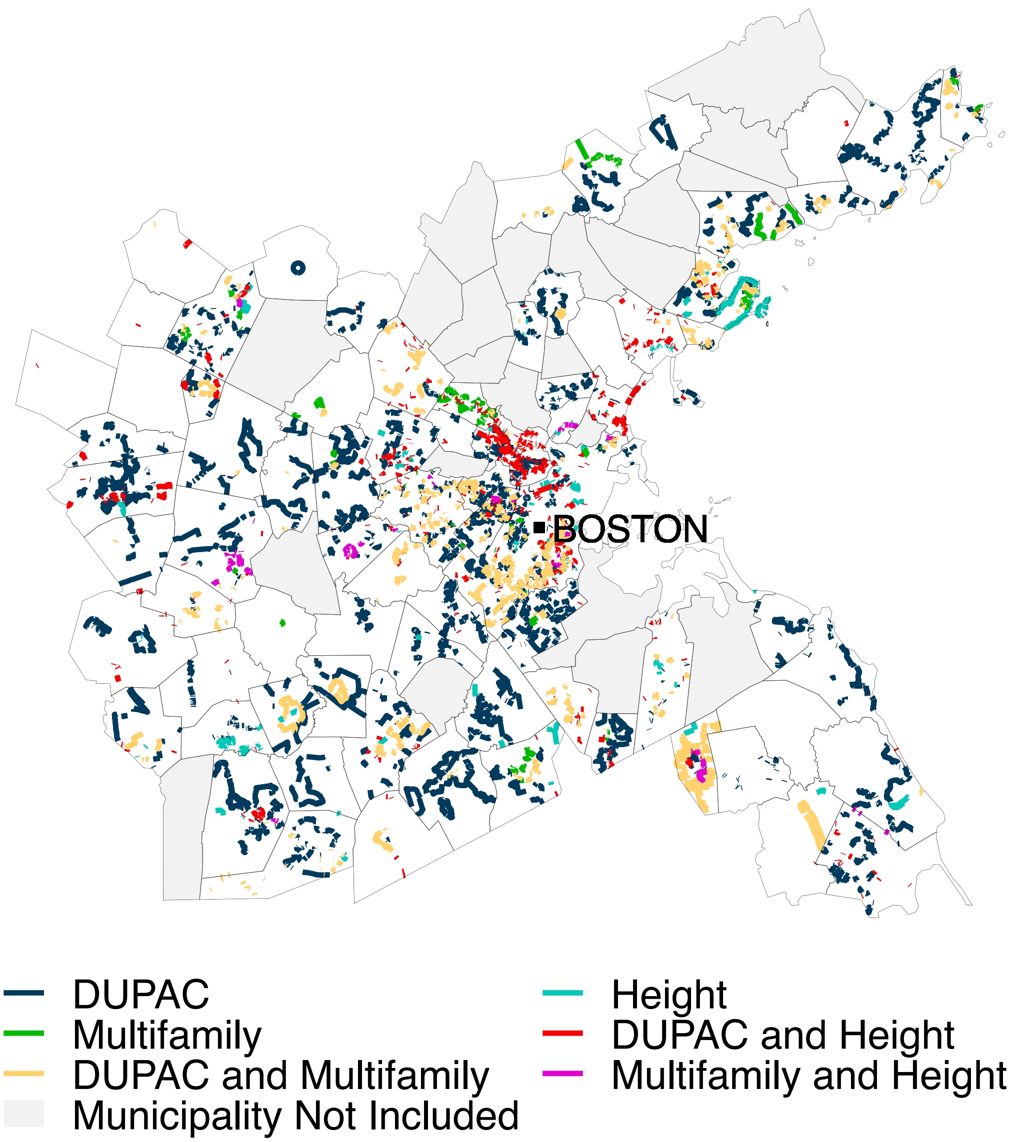
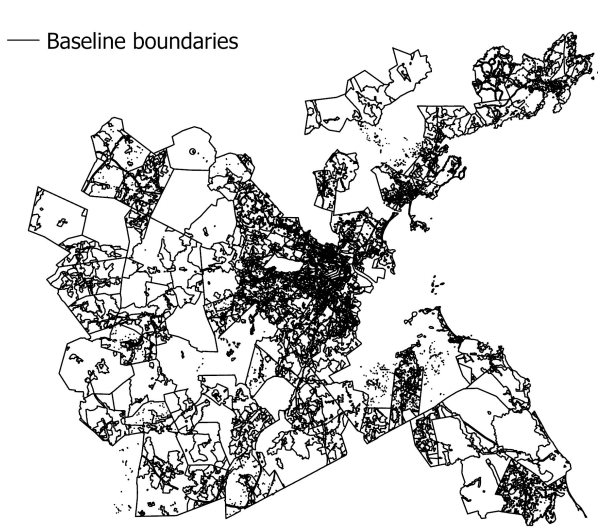
Figure 1: RD boundaries where zoning regulations change

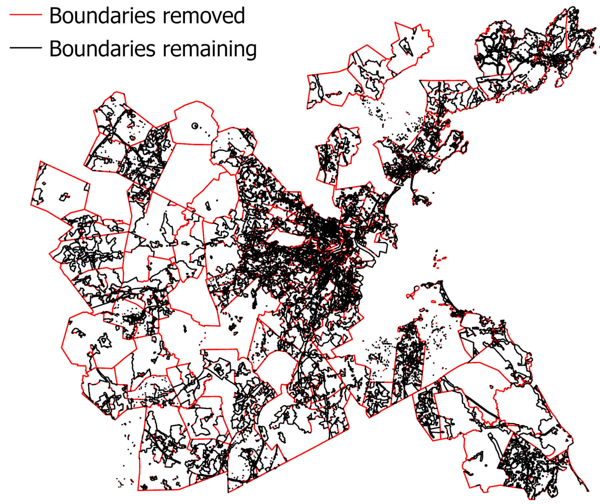


Note: This map shows the boundaries where multifamily (MF) regulation, maximum height restrictions, and dwelling units per acre (DUPAC) changes either by itself or in combination with another regulation change. “Changes”refers to cross-sectional differences in the regulations on either side of the boundary. The figure plots the final sample of boundaries which excludes regulation boundaries that overlap with water bodies, large roads municipality boundaries and elementary school attendance area boundaries. Only boundaries within areas that are either residential or mixed-use zoning are considered. These do not include regulations boundaries that overlap with major roads or geographic features. The base maps for these boundaries can be found in Appendix Figures C.1, C.2, and C.3. * denotes city of Boston.

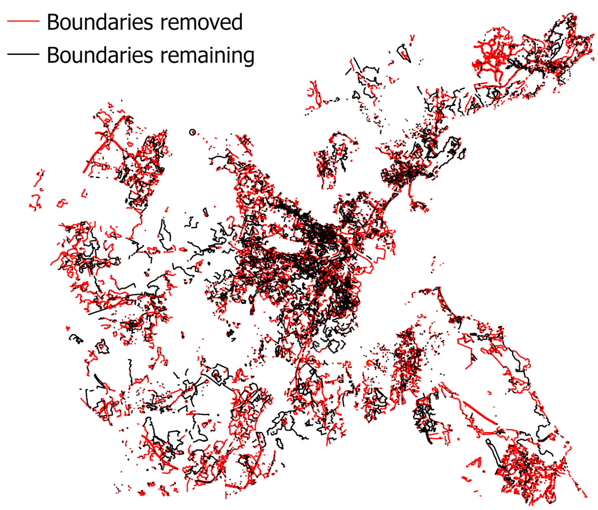
Figure 2: Step-by-step RD regulation boundary selection



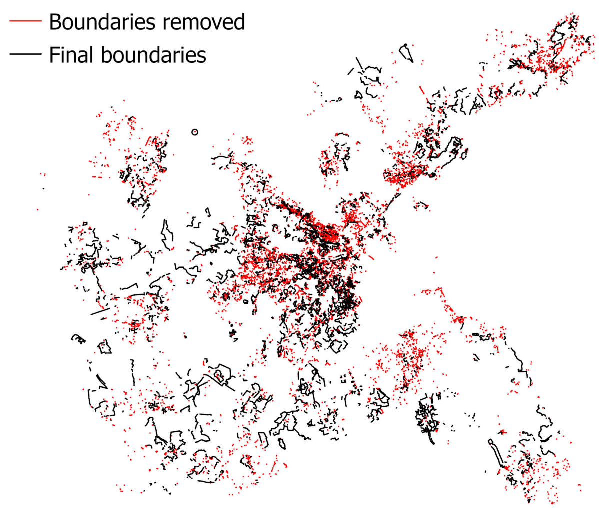
(a) Baseline



(b) Removing roads, municipal, and natural boundaries



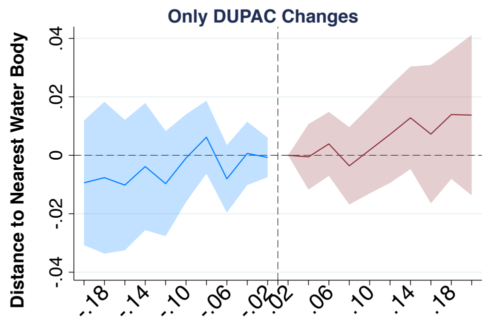
(c) Removing school and broad-use zoning boundaries



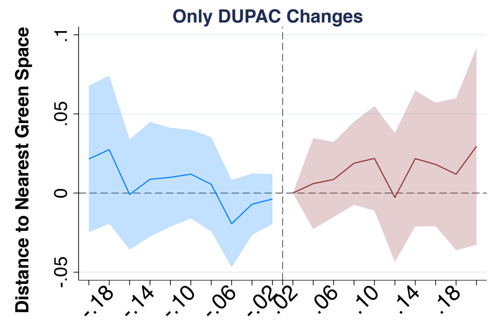
(d) Keeping boundaries with straight line segments

Note: This figure displays the step by step removal of boundaries to arrivae at the final set of boundaries in Figure 1 (Appendix Figure C.6) shows the boundaries without separating regulation scenarios). Figure 2a plots the baseline map of all zoning regulation boundaries. Figure 2b plots in red the zoning boundaries removed because they overlap with major roads, municipal boundaries, or water bodies like lakes and rivers. Figure 2c plots in red the boundaries removed because they overlap with school district boundaries, elementary school attendance zone boundaries, or broad-use zoning (residential or mixed-use) boundaries. Figure 2d plots in red the boundaries removed because they do not have s straight-line segment.

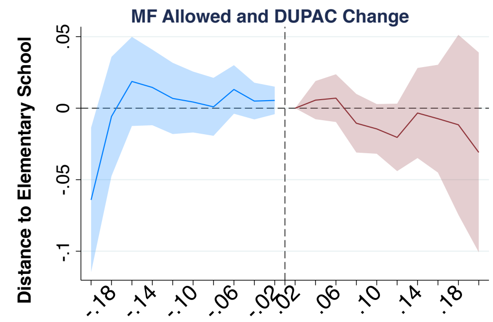
Figure 3: Neighborhood amenities and parcel attributes at regulation boundaries



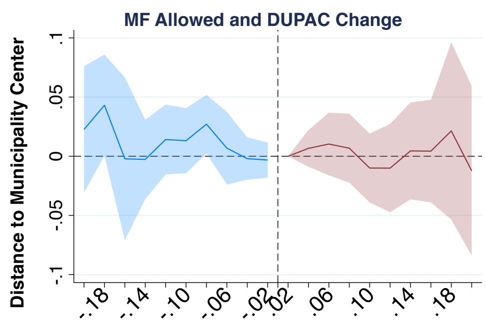
(a) RD est. = -0.001 (0.003), n= 42,702



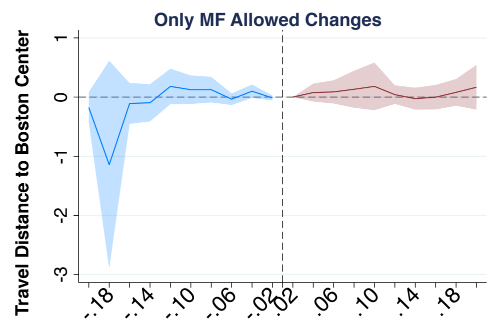
(b) RD est. = -0.004 (0.008), n=42,702



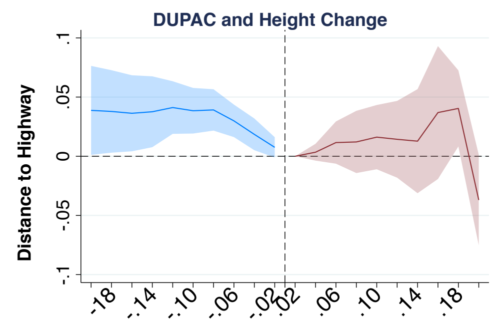
(c) RD est. = 0.006 (0.005), n=17,184



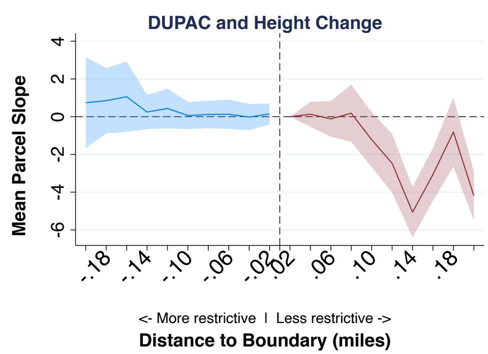
(d) RD est. = -0.003 (0.008), n=17,184



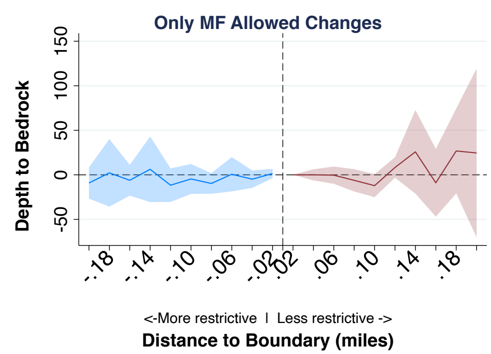
(e) RD est. = -0.015 (0.022), n=2298



(f) RD est. = 0.008 (0.004), n=4,570



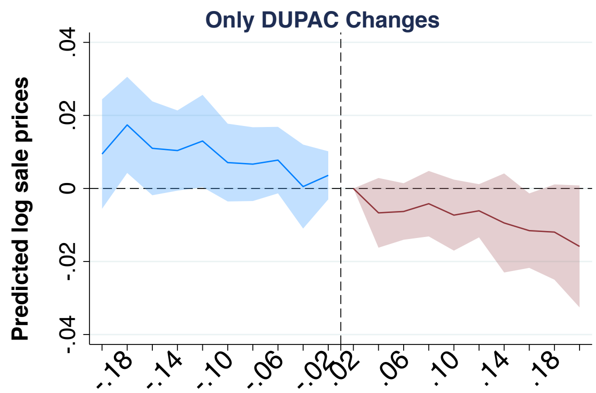
(g) RD est. = 0.144 (0.280), n=3941



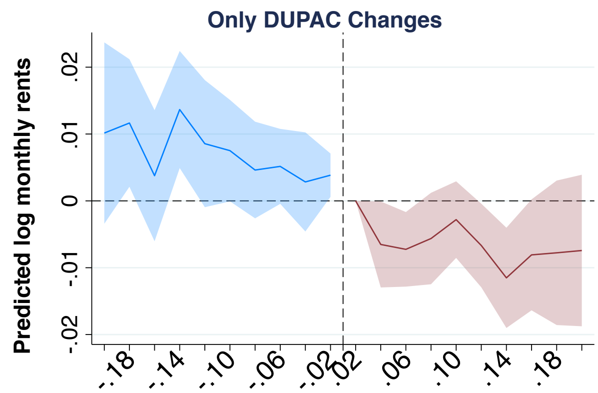
(h) RD est. = 1.475 (2.601), n=1941

Note: Figures are created by plotting coefficient from regressing distance to nearest amenities or parcel attributes on boundary fixed effects and distance to boundary (bins of 0.02 miles). Negative distances indicate more regulated side. Bin closest to boundary on less regulated side (0-0.02 miles) is normalized to 0. 95% confidence intervals are shown. Standard errors are clustered at boundary segment level. The coefficient and standard error on -0.02-0 bin on the restricted side is reported. DUPAC is Dwelling units per acre and MF is multifamily zoning. * p<0.05, ** p<0.01, *** p<0.001.

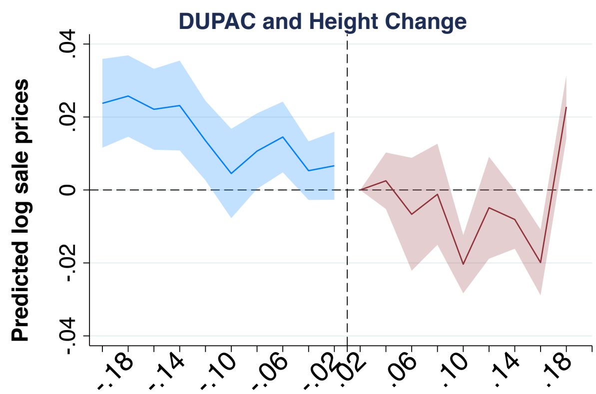
Figure 4: Unobserved location quality across regulation boundaries



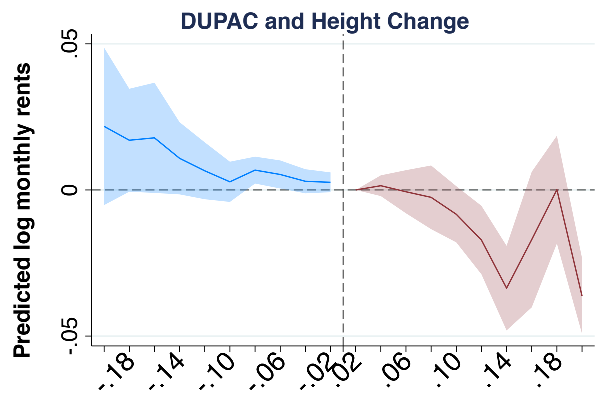
(a) RD est. = 0.004 (0.003), n=44,053



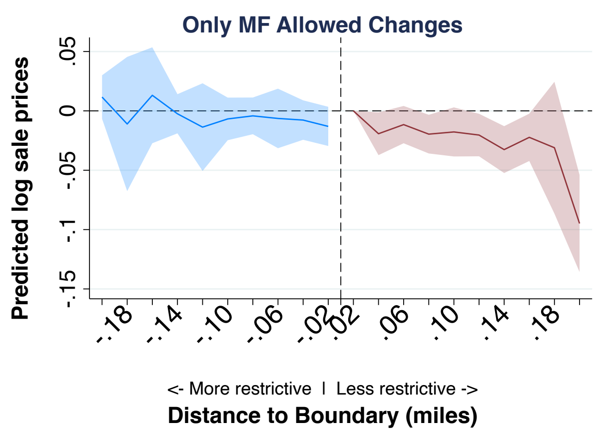
(b) RD est. = 0.004 (0.002)*, n=305,229



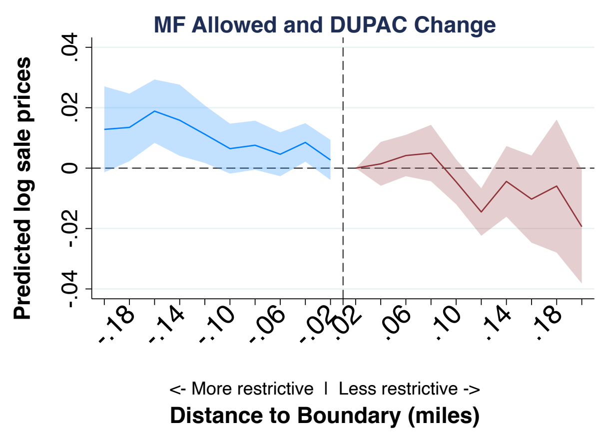
(c) RD est. = 0.007 (0.005), n=2,669



(d) RD est. = 0.003 (0.002), n=35,157



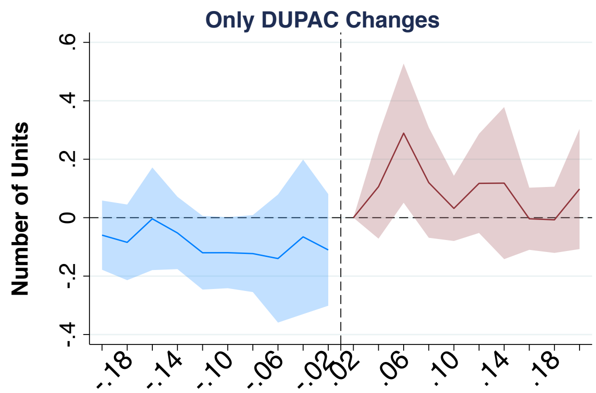
(e) RD est. = -0.013 (0.008), n=1,824



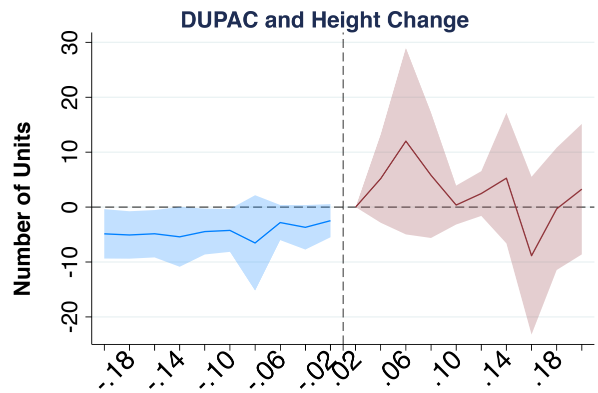
(f) School RD est. = 0.001 (0.004), n=15,031

Note: Figures are created by plotting coefficient of predicted log sale prices and rents in 0.02 distance to boundary bins. The model regresses log prices and rents on observed amenities, parcel attributes and boundary fixed effects. Negative distances indicate more regulated side. Bin closest to boundary on less regulated side (0-0.02 miles) is normalized to 0. 95% confidence intervals are shown. Standard errors are clustered at boundary segment level. The coefficient and standard error on -0.02-0 bin on the restricted side is reported. DUPAC is Dwelling units per acre and MF is multifamily zoning. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

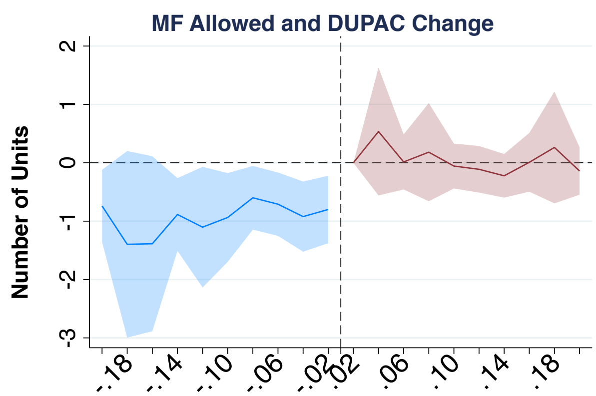
Figure 5: Effect of regulations on number of units



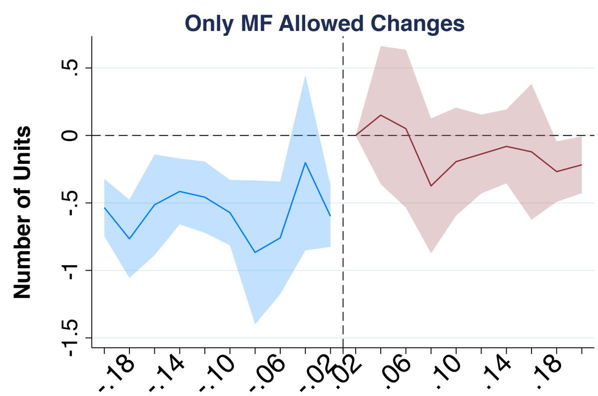
(a) RD est = -0.110 (0.097) [0.075], n = 33,940



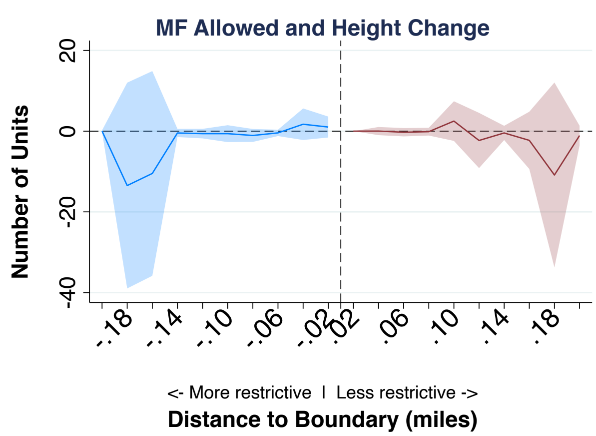
(b) RD est = -2.474 (1.532) [1.075]*, n = 1,806



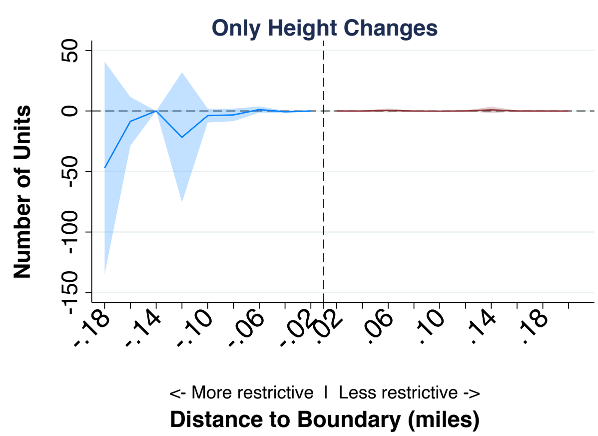
(c) RD est = -0.799 (0.294)* [0.253]**, n = 11,541



(d) RD est = -0.598 (0.114)*** [0.08]***, n = 1,535



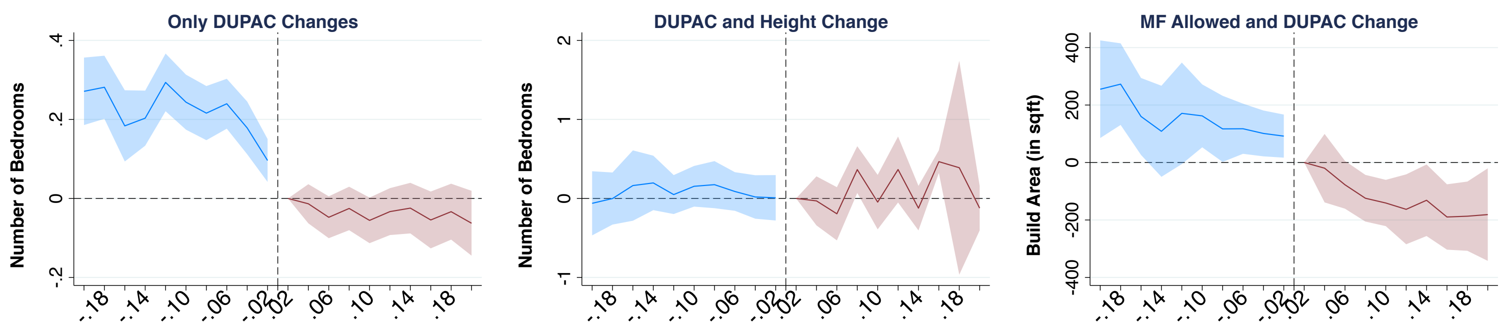
(e) RD est = 1.022 (1.268) [1.109], n = 504



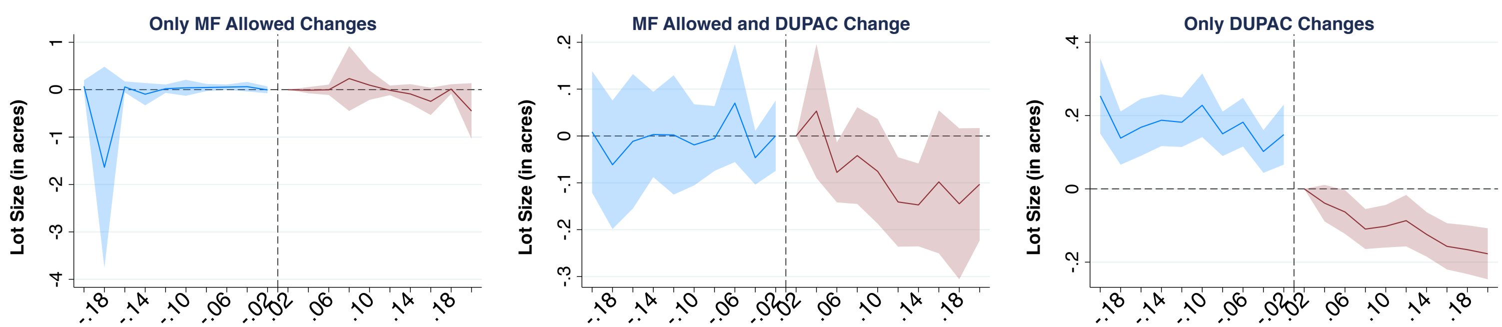
(f) RD est = -0.063 (0.293) [0.208], n = 1,854

Note: Plots are created by regressing number of units in 2018 on boundary fixed effects and distance to boundary (bins of 0.02 miles). All buildings are built after 1918. Negative distances indicate the more regulated side. The bin closest to boundary on the less regulated side (0-0.02 miles) is normalized to 0. 95% confidence intervals are shown with clustered standard errors at boundary segment level. The coefficient, clustered standard error in parenthesis, and robust standard error in square brackets is reported on -0.02-0 bin on the restricted side. DUPAC is Dwelling units per acre and MF is multifamily zoning. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

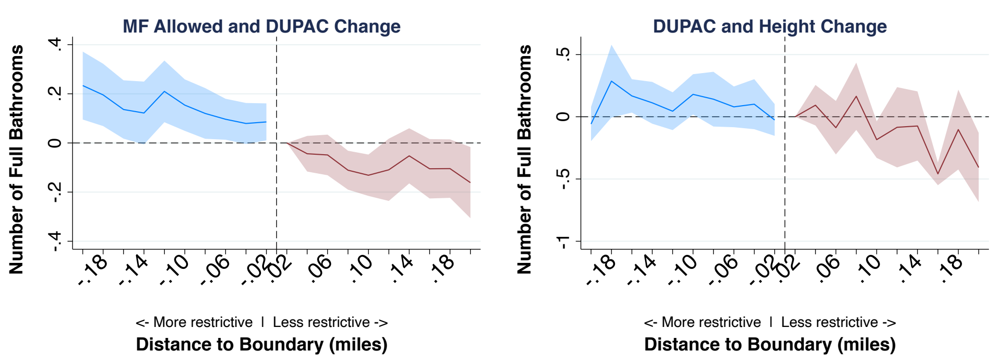
Figure 6: Housing characteristics at regulation boundaries



(a) RD est. = 0.096 (0.028)*** [0.021]*** (b) RD est. = 0.008 (0.146) [0.107] (c) RD est. = 91.85 (38.16)* [29.04]**



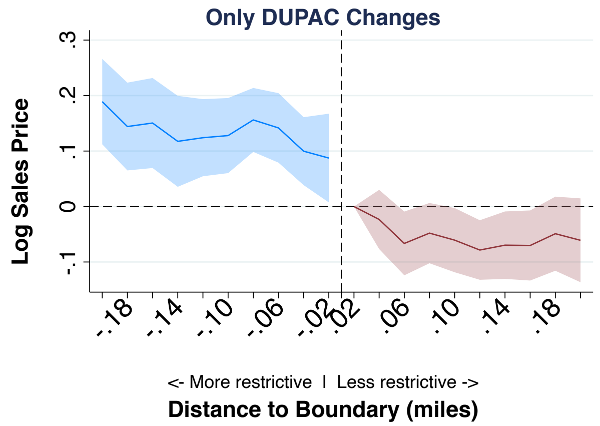
(d) RD est. = -0.005 (0.036) [0.029] (e) RD est. = 0.001 (0.038) [0.035] (f) RD est. = 0.148 (0.042)*** [0.029]***



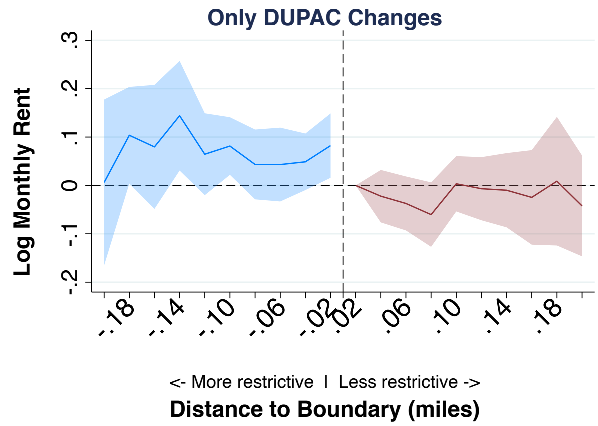
(g) RD est. =0.086 (0.038)* [0.029]** (h) RD est. = -0.025 (0.064) [0.070]

Note: This figure plots building characteristics across regulation boundaries in 2018. Plots are created by regressing unit characteristics on boundary fixed effects and distance to boundary (bins of 0.02 miles). Coefficients on distance bins are plotted. Negative distances indicate more regulated side. Bin closest to boundary on less regulated side (0- 0.02 miles) is normalized to 0. 95% confidence intervals are shown. DUPAC is Dwelling units per acre and MF is multifamily zoning. Standard errors are clustered at the boundary segment level.

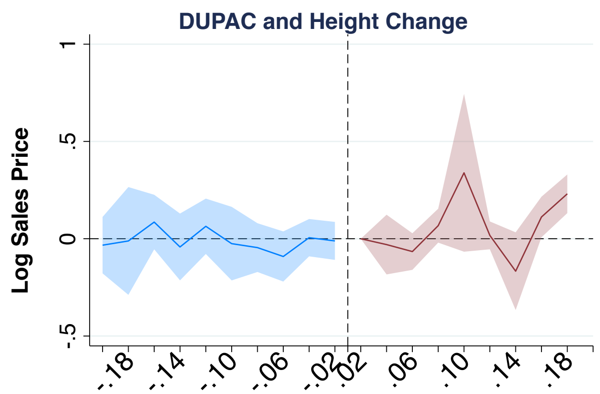
Figure 7: Effects of regulations on multifamily rents and single-family sale prices



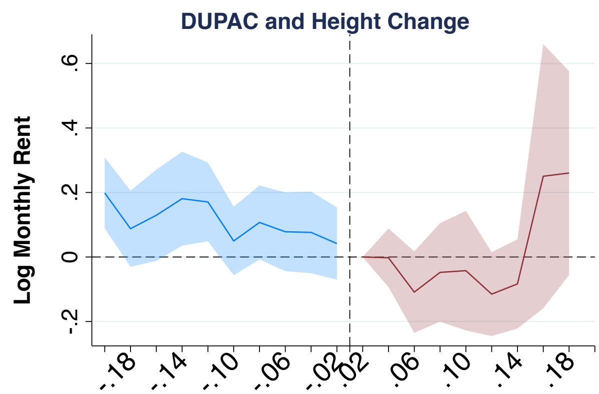
(a) RD est. = 0.044 (0.02)* [0.01]***, n = 56,561



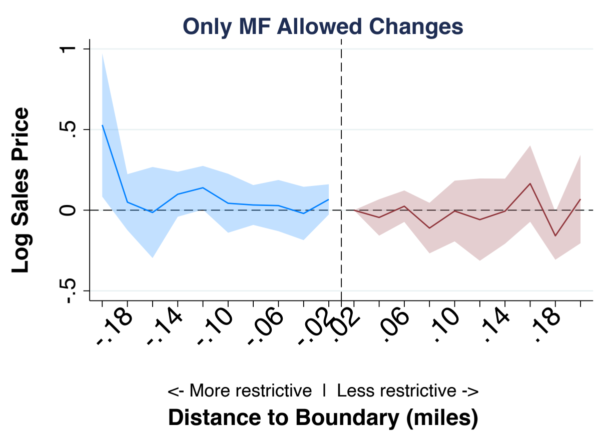
(b) RD est. = 0.069 (0.03)** [0.01]***, n = 50,374



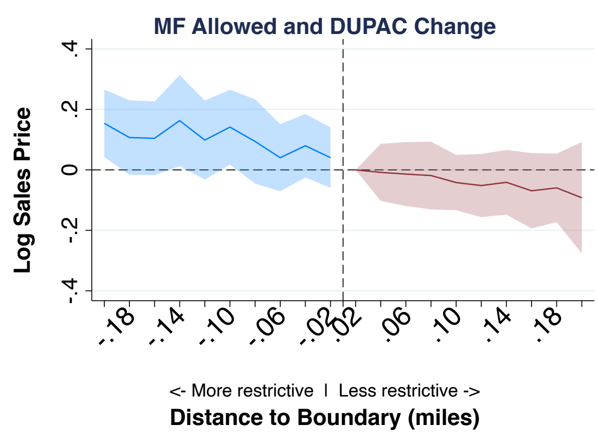
(c) RD est. = -0.011 (0.049) [0.02], n = 3,117



(d) RD est. = 0.042 (0.057) [0.01]***, n = 21,907



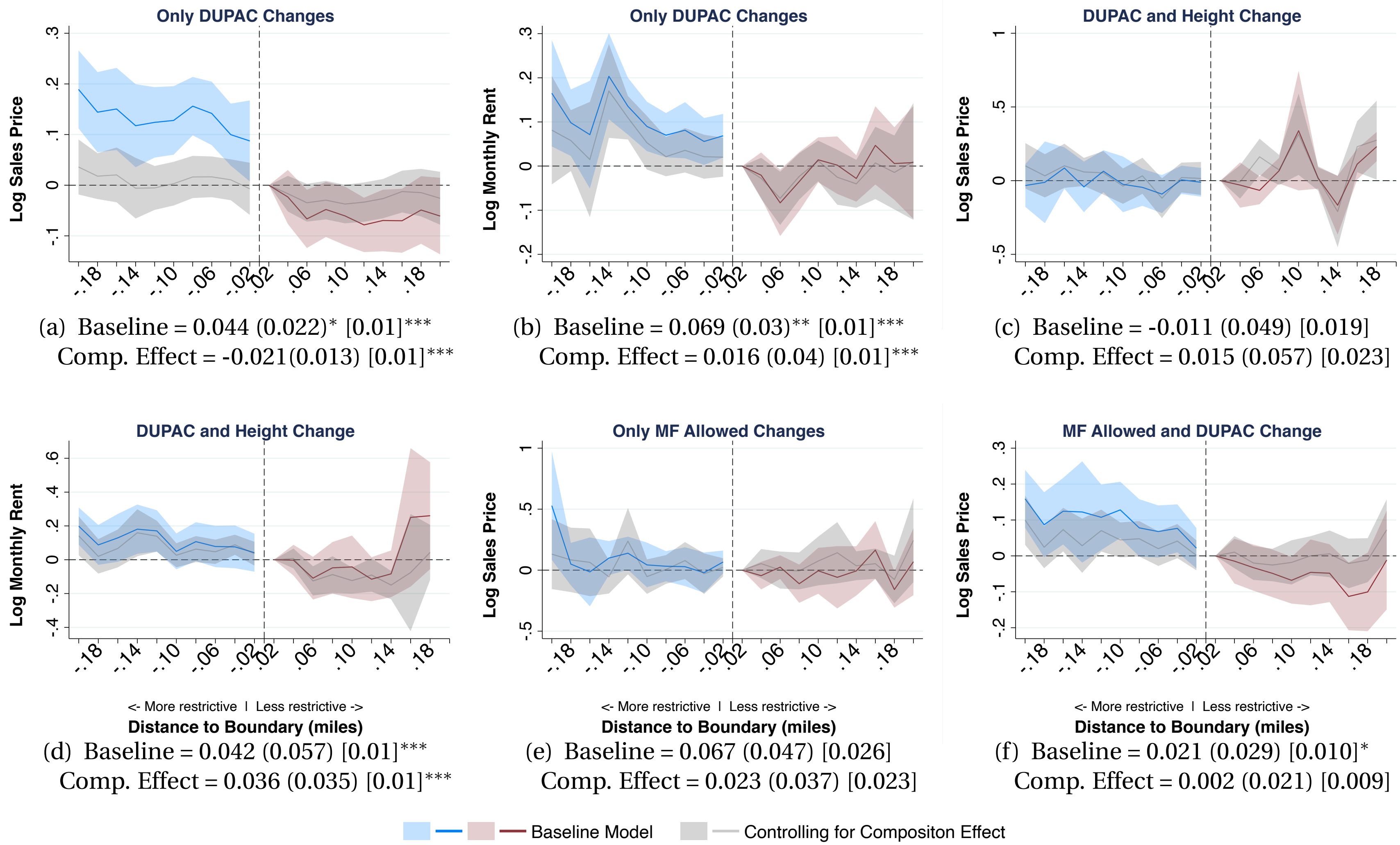
(e) RD est.= 0.067 (0.047) [0.03]*, n = 2,174



(f) RD est. = 0.022 (0.0286) [0.01]*, n = 18,815

Note: Plots are created by regressing log single-family sale prices or log multifamily monthly rents on boundary fixed effects, sale year/rent year fixed effects [2010-2018], and 0.02 miles bins of distance to boundary. Coefficients on distance bins are plotted. Negative distances indicate the more regulated side. The bin closest to boundary on the less regulated side (0-0.02 miles) is normalized to 0. 95% confidence intervals are shown with clustered standard errors at boundary segment level. The coefficient, clustered standard error in parenthesis, and robust standard error in square brackets is reported on -0.02-0 bin on the restricted side. DUPAC is Dwelling units per acre and MF is multifamily zoning. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Figure 8: Mechanisms behind equilibrium price effects



(a) Baseline = 0.044 (0.022)* [0.01]***
Comp. Effect = -0.021(0.013) [0.01]***

(b) Baseline = 0.069 (0.03)** [0.01]***
Comp. Effect = 0.016 (0.04) [0.01]***

(c) Baseline = -0.011 (0.049) [0.019]
Comp. Effect = 0.015 (0.057) [0.023]

(d) Baseline = 0.042 (0.057) [0.01]***
Comp. Effect = 0.036 (0.035) [0.01]***

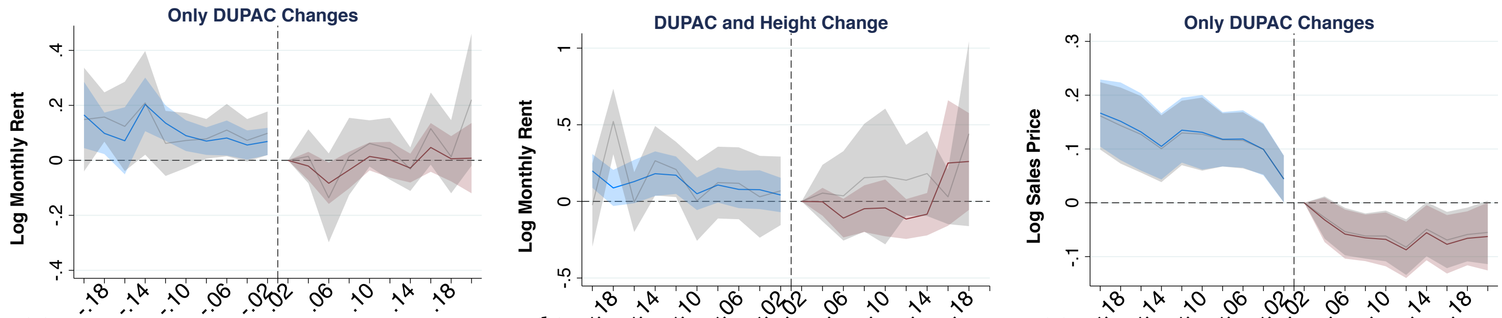
(e) Baseline = 0.067 (0.047) [0.026]
Comp. Effect = 0.023 (0.037) [0.023]

(f) Baseline = 0.021 (0.029) [0.010]*
Comp. Effect = 0.002 (0.021) [0.009]

Note: Plots are created by regressing log single-family sale prices or log multifamily monthly rents on boundary fixed effects, sale year/rent year fixed effects [2010-2018], and 0.02 miles bins of distance to boundary. Compared to the baseline model, composition effect (Comp. Effect) model controls for housing units characteristics. The 0-0.2 mile bin is normalized to 0. 95% confidence intervals are shown with clustered standard errors at boundary segment level. The coefficient, clustered standard error in parenthesis, and robust standard error in square brackets is reported on -0.02-0 bin on the restricted side. DUPAC is Dwelling units per acre and MF is multifamily zoning. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Figure 9: Robustness tests on rent and sale price effects

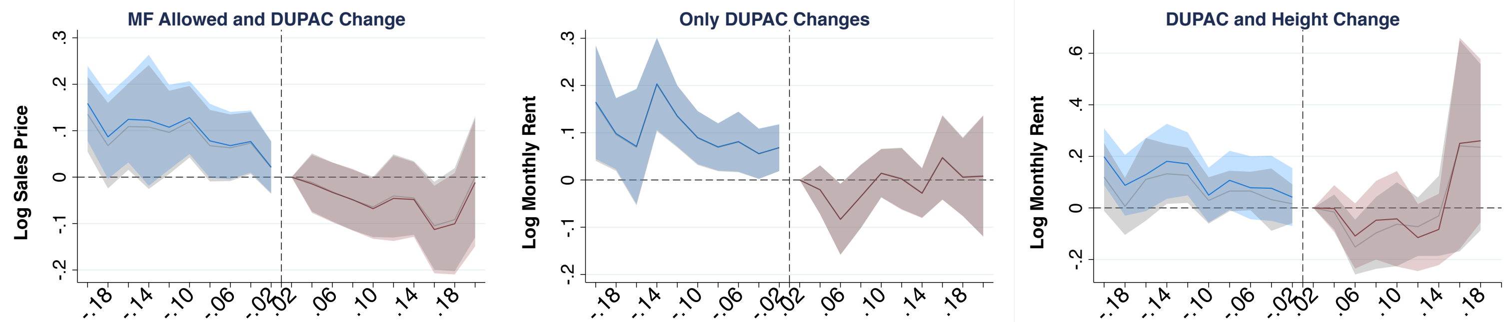
Panel A: Baseline and robustness models



(a) Baseline = 0.068 (0.025)** [0.006]***
Robustness = 0.098 (0.040)* [0.0105]***

(b) Baseline = 0.042 (0.057) [0.0104]***
Robustness = 0.069(0.113) [0.023]**

(c) Baseline = 0.044 (0.022)* [0.007]***
Robustness = 0.044 (0.022)* [0.007]***



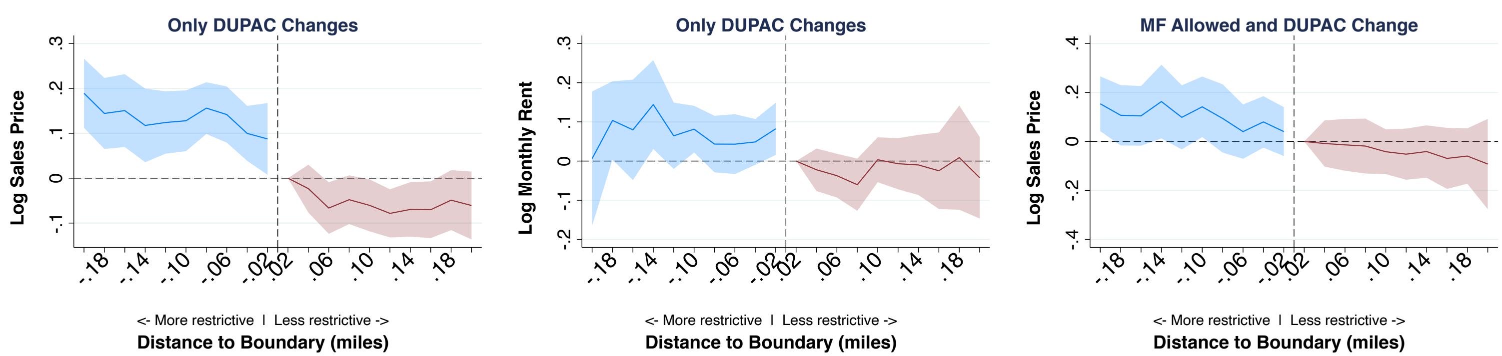
(d) Baseline = 0.022 (0.029)* [0.010]*
Robustness = 0.020 (0.029)* [0.010]*

(e) Baseline = 0.069 (0.025) [0.006]***
Robustness = 0.068 (0.025)** [0.006]***

(f) Baseline = 0.042 (0.057) [0.010] ***
Robustness = 0.016(0.038) [0.009]

Baseline Model   Robustness Model

Panel B: Keeping boundaries with no roads



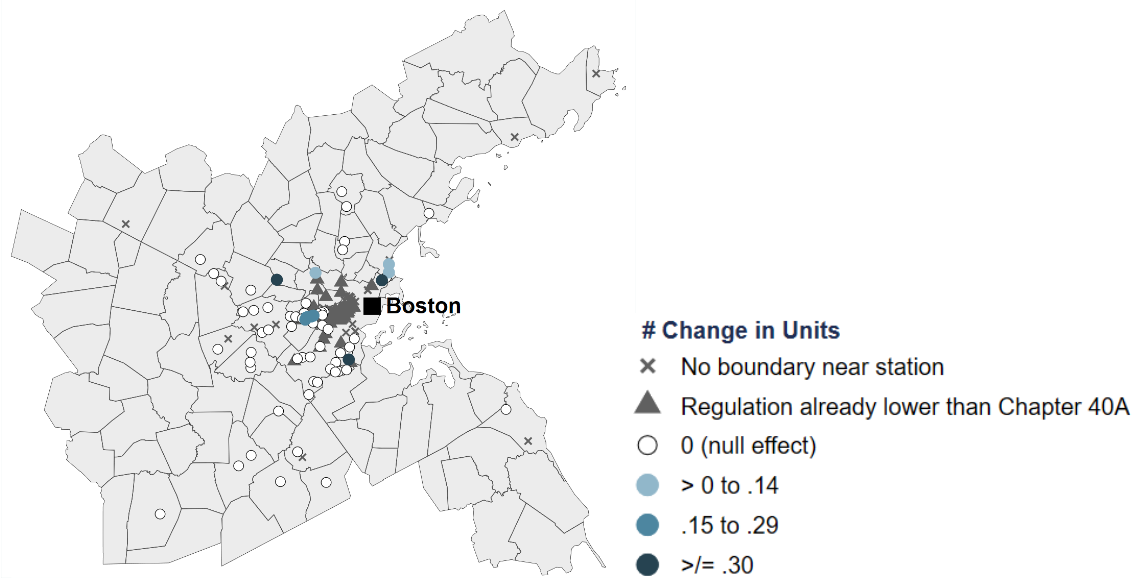
(g) Baseline = 0.087 (0.041)* [0.012]***

(h) Baseline = 0.082 (0.034)* [0.011]***

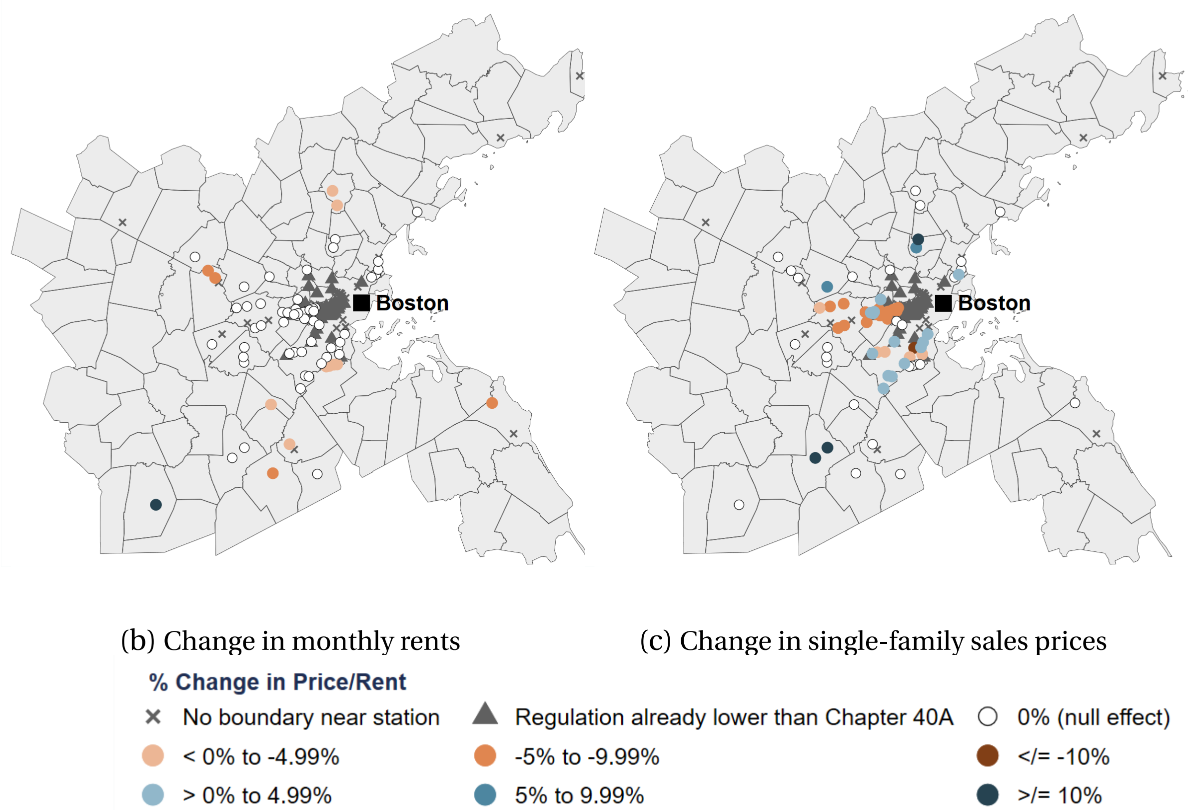
(i) Baseline = 0.041 (0.051) [0.019]*

Note: Figures 9a and 9b show effects excluding rents $500-$1400. Figures 9c, 9d, and 9e, and 9f show effects after controlling for distance to highway, mean parcel slope, and/or parcel depth to bedrock. Figures 9g, 9h, and 9i show effects for boundaries that not overlapping with any roads. The coefficient, clustered standard error in parenthesis, and robust standard error in square brackets is reported on -0.02-0 bin. DUPAC is Dwelling units per acre and MF is multifamily zoning. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Figure 10: Policy effects of Chapter 40A: relaxing regulations near transit stations



(a) Change in number of units



(b) Change in monthly rents

(c) Change in single-family sales prices

This figure plots the average change in number of housing units per lot, percent monthly multifamily rents, and percent single-family sale prices from relaxing regulations under Chapter 40A near transit stations. Chapter 40A allows multi-family housing in places where it's not currently allowed and increases allowed dwelling units per acre (DUAPC) up to 15 units. For the counterfactual calculations we focus on boundaries that lie within 0.5-mile of a given commuter rail or metro station. Stations that don't have boundaries within 0.5-mile radius are marked with an X on the map. Stations marked with a grey triangle are excluded from analysis because Chapter 40A has no effect (density is already higher than 15 dwelling units per acre and multi-family buildings are allowed).

Table 1: Zoning regulation scenarios

	(1)	(2)	(3)	(4)	(5)	(6)
Regulation Scenarios (Sc.)	Sc. 1	Sc. 2	Sc. 3	Sc. 4	Sc. 5	Sc. 6
Panel A: Summary statistics across regulation scenarios						
Multifamily Changes	X			X	X	
Height Changes		X		X		X
DUPAC Changes			X		X	X
Mean DUPAC	9.34	7.92	13.87	11.89	11.20	38.58
Mean Height (10 feet)	3.51	4.13	3.39	3.50	3.45	4.33
Mean Multifamily	0.50	0.50	0.63	0.51	0.51	0.82
No. of Boundaries	161	124	1557	61	775	426
Mean Housing Units	1.44	1.66	1.26	1.77	1.48	3.58
(Obs.)	(1,535)	(1,854)	(33,940)	(504)	(11,541)	(1,806)
Mean Multifamily	1,203	1,032	1,370	1,116	1,507	1,220
Rent (Obs.)	(7,297)	(3,610)	(50,435)	(1,369)	(42,705)	(21,950)
Mean Single-family	589,852	708,097	596,585	656,608	546,947	515,845
Sale Prices (Obs.)	(2,178)	(3,140)	(56,561)	(990)	(18,815)	(3,177)
Panel B: T-test mean difference with regulation scenario 3						
Mean Share $\leq$ 18	0.210	0.205	0.220	0.235	0.223	0.185
(Difference) [t-stat]	(-0.119)	(-0.015)	-	(0.015)	(0.003)	(-0.036)
	[-1.196]	[-1.524]	-	[1.056]	[0.574]	[-6.011]
Mean Share $\geq$ 65	0.142	0.132	0.139	0.140	0.144	0.115
(Difference) [t-stat]	(0.003)	(-0.007)	-	(0.001)	(0.005)	(-0.024)
	[0.389]	[-0.755]	-	[0.087]	[0.574]	[-4.440]
Mean Share Black	0.060	0.063	0.049	0.088	0.124	0.089
(Difference) [t-stat]	(0.11)	(0.014)	-	(0.039)	(0.075)	(0.040)
	[0.784]	[0.995]	-	[1.920]	[7.747]	[4.564]
Dist. to Municipality Center	1.401	1.495	1.643	1.374	1.949	1.289
(miles) (Difference) [t-stat]	(-0.242)	(-0.149)	-	(-0.269)	(0.305)	(-0.354)
	[-2.056]	[-1.202]	-	[-1.527]	[4.431]	[-5.116]
Mean Transit Dist. to Central	14.48	18.83	16.55	16.38	14.49	10.74
Boston (Difference) [t-stat]	(-2.070)	(2.280)	-	(-0.169)	(-2.060)	(-5.813)
	[-1.721]	[1.723]	-	[-0.091]	[-3.430]	[-7.869]
No. of Boundaries	91	77	906	37	445	277

Note: This table represents all zoning regulation scenarios where one or two of the three main regulations (DUPAC, height, allowing multifamily) change at RD boundaries. DUPAC is maximum dwelling units per acre. In Panel A, the mean number of units is reported for 2018 housing units built after 1918, while 2010-18 multifamily rents and single-family house sale prices are reported for all housing units. Panel B reports the mean regulation scenario characteristics, t-test difference with scenario 3 in parenthesis and t-stat in square brackets.

Table 2: Step-by-step RD boundary selection

Removal Step	Mean Boundary Length (miles)	Remaining Boundaries
Main Sample		
Baseline	0.20	26,306 (100%)
Removing municipal boundaries	0.18	24,475 (93.0%)
Removing water bodies	0.17	24,300 (92.4%)
Removing major roads	0.17	21,328 (81.1%)
Removing elementary school attendance areas	0.17	20,922 (79.5%)
Removing school district boundaries	0.17	20,863 (79.3%)
Removing broad-use zoning boundaries	0.11	9,674 (36.8%)
Keeping boundaries with straight-line segments	0.35	2,835 (10.8%)
Robust Sample		
Boundaries that don't overlap with minor roads	0.37	1,473 (5.6%)

Note: This table displays the step-by-step procedure for final regulation RD boundary selection. It also reports the mean boundary length (in miles) and number and percent of boundaries at each step. Figure 2 shows this process spatially on a map.

Table 3: Supply: types of buildings across regulation boundaries (built after 1918)

	2-3 units (Gentle-Density)						4+ units (High-Density)					
	Only MF	Only H	Only DU	MF & H	MF & DU	H & DU	Only MF	Only H	Only DU	MF & H	MF & DU	H & DU
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
MF allowed	0.478			-0.214	0.005		0.016			-0.138	0.006	
	(0.098)***			(0.757)	(0.025)		(0.012)			(0.252)	(0.015)	
	[0.027]***			[410]	[0.013]		[0.009]			[0.225]	[0.009]	
Height (H)		0.025		-0.087		-0.029		-0.021		-0.060		-0.047
		(0.025)		(0.197)		(0.025)		(0.022)		(0.085)		(0.029)
		[0.022]		[0.112]		[0.023]		[0.020]		[0.076]		[0.022]*
DUPAC (DU)			0.001		-0.004	-0.102			0.001		0.001	-0.009
			(0.001)		(0.004)	(0.051)*			(0.001)		(0.001)	(0.004)*
			[0.0005]*		[0.001]**	[0.003]**			[0.0003]**		[0.001]	[0.003]**
MFXDU					0.016						0.002	
					(0.003)***						(0.002)	
					[0.001]***						[0.001]	
HXDU						0.001						0.001
						(0.0004)*						(0.0003)**
						[0.0003]***						[0.0004]***
MFXH				0.119						0.049		
				(0.209)						(0.077)		
				[0.118]						[0.069]		
N	1,495	1,760	33,071	485	11,264	1,587	1,165	1,172	31,835	437	9,477	1,163
R^2	0.539	0.381	0.435	0.284	0.389	0.454	0.598	0.493	0.565	0.070	0.309	0.564
$\mathbb{E}(y)$	0.231	0.041	0.045	0.116	0.171	0.350	0.013	0.021	0.008	0.007	0.015	0.113

Note: This table presents the results from a linear probability model (Equations 3 and 4) where dependant variable value of 0 is a single-family house and value of 1 is either a 2-3 unit building or 4 or more unit building 0-0.2 miles on either side of the boundary in 2018. All buildings are built after 1918. Linear polynomial in distance to boundary is used. Only MF are boundaries where only multifamily (MF) regulation changes, Only H are boundaries where only height (H) changes, and only DU are boundaries where only dwelling units per acre (DUPAC) regulation changes. MF & H, MF & DU, and H & DU are boundaries where MF and height, MF and DUPAC, and height and DUPAC change, respectively. The unit on height is in 10 feet and DUPAC is in 1 housing unit. Standard errors are clustered at the boundary level(in parenthesis) and robust standard errors in square brackets. * p< 0.05, ** p< 0.01, *** p< 0.001.

How to Increase Housing Affordability? Understanding Local Deterrents to Building Multifamily Housing

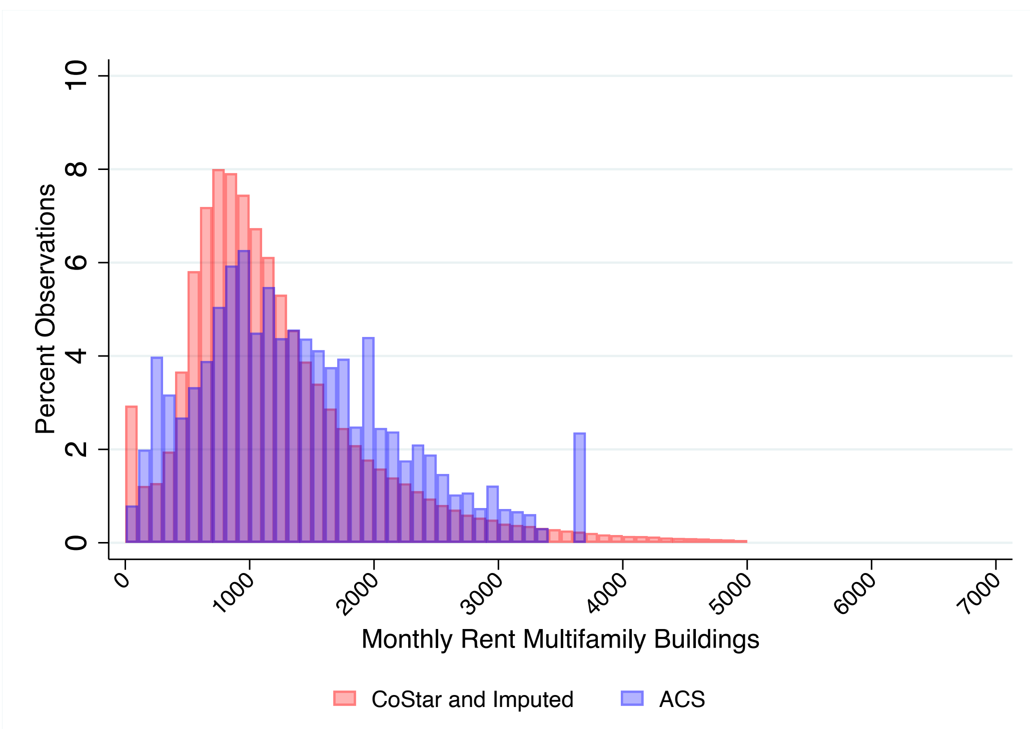
by Amrita Kulka, Aradhya Sood, and Nicholas Chiumenti

ONLINE APPENDIX

A. Data appendix and rent imputation

For the buildings that have CoStar market rent available [18,536 buildings from 2010-2018], we use market rent per unit directly. CoStar uses websites like Apartment.com and field visits and surveys to get market rental data. For the remaining 112,992 buildings, we impute rent by calculating the owner cost of housing following Bureau of Economic Analysis (BEA) methodology (Katz et al., 2017), taking the assessed value of the property and multiplying it by 0.629% to get the annual owner cost of housing. We then divide this number by 12 to get a monthly rent estimate. The distribution of CoStar market rent and imputed rent values combined is shown in red in Figure A.1 and plotted against the 2018 ACS block-group level rent (blue). The baseline results use CoStar market rent data and BEA imputation for the remainder of properties.

Figure A.1: Rent imputation for multifamily buildings



Note: This figure plots the rental data from CoStar and imputed rental values (red) against the ACS block group (2018) rental distribution (blue).

B. Details on policy counterfactual

This section describes how we simulate Massachusetts' Chapter 40A upzoning policy counterfactual using our semiparametric estimates. In particular, we explain how we calculate θ_i in Equation 5. The Chapter 40A upzoning policy will allow for DUPAC= 15 units and multi-family housing within a half-mile radius of transit stops. Our estimates are local average treatment effects at the boundary and, therefore, cannot be applied to large changes in regulation or changes further away from the boundary.

We first identify all boundaries in our final boundary sample that lie within half a mile radius of all metro and commuter rail stations in Greater Boston. We then exclude boundaries for which only one side of the boundary lies within 0.5 miles, but the other does not. Stations for which we do not find a regulation boundary with both sides within a 0.5-mile radius are marked with an X in Figure 10. We have at least one regulation boundary (possibly multiple boundaries) within half a mile for the remainder of the transit stations. Note that by design at a given boundary, $z_0(x)\ \forall x < 0 \neq z_0(x)\ \forall x \geq 0$. We calculate the effects θ_{ik} of Chapter 40A separately on either side $k \in L, R$ of the boundary and take the unweighted average to arrive at θ_i for boundary scenario i.

We now describe how we calculate the average sale price, monthly rent, and housing unit effects for the relaxed and strict side of the four regulation scenarios with non-null semiparametric estimates (Tables C.4 and C.5).[1] We calculate regulation effects θ_i relative to the average of the dependent variable $\bar{Y}$ at a given boundary (note Y is either the number of units, log sale price for single-family homes, or log monthly rent for multi-family houses from Section 3.4). The average of dependent variables is calculated at the municipality level to avoid noise from small sample sizes near a given station.[2]

Scenario 1: Allowing multifamily housing

For this regulation scenario, the counterfactual effect occurs only on the strict side of the boundary, which does not allow multi-family houses before the Chapter 40A policy. θ_1 is given below where $\hat{\rho}$ is from Equation 3.

$$\theta_1 = \frac{1 * \hat{\rho}_{MF}}{\bar{Y}}.$$

[1] We show price and rent results in percentage terms. Since sales prices and rents are estimated as log-level specifications, we multiply all expressions by 100 to show percentages.

[2] At a given station, there may be only very few sales occurring within 2010-2018.

Scenario 3: Only density changes

For this regulation scenario, the counterfactual effect occurs on strict L and relaxed R sides of the boundary, i.e., DUPAC (DU_{40A}) increases to 15 housing units if the existing DUPAC (DU_0) is lower than 15. The effect θ_{3k} for $k \in L, R$ is given by

$$\theta_{3k} = \frac{(\max[0, DU_{40A} - DU_{0k}] * \hat{\rho}_{DU})}{\bar{Y}}.$$

Scenario 5: Relaxing density and multi-family housing

For this regulation scenario, on the strict side of the boundary, Chapter 40A manifests through allowing multi-family houses and increasing DUPAC (DU_{40A}) to 15 if not already the case, i.e., if $DU_0 < 15$. On the other hand, on the relaxed side of the boundary, the effect of Chapter 40A comes only through allowing the density to 15 DUPAC if $DU_0 < 15$.

Strict side L

$$\theta_{5L} = \frac{(\max[0, DU_{40A} - DU_{0L}] * \hat{\rho}_{DU} + 1 * \max[0, DU_{40A} - DU_{0L}] * \hat{\rho}_{MFXDU})}{\bar{Y}} + \frac{1 * \hat{\rho}_{MF} + \hat{\rho}_{MFXDU} * DU_{0L}}{\bar{Y}}.$$

Relaxed side R

$$\theta_{5R} = \frac{(\max[0, DU_{40A} - DU_{0R}] * \hat{\rho}_{DU} + 1 * \max[0, DU_{40A} - DU_{0R}] * \hat{\rho}_{MFXDU})}{\bar{Y}}.$$

Scenario 6: Relaxing density and height Since the Chapter 40A upzoning policy does not change height (H) regulations, the only change at these boundaries occurs through a change in DUPAC. Again, the counterfactual effect occurs on both sides $k \in L, R$ of the boundary by increasing DUPAC (DU_{40A}) to 15 housing units if the existing DUPAC (DU_0) is lower than 15.

$$\theta_{6k} = \frac{\max[0, DU_{40A} - DU_{0k}] * (\hat{\rho}_{DU} + \hat{\rho}_{DUXH} * H_{0k})}{\bar{Y}.}$$

Calculation of counterfactual effects

For the baseline effects, $\hat{\rho}_1, \hat{\rho}_2, \hat{\rho}_3$ are estimated from semiparametric models with a linear polynomial in the distance to boundary variable (Table C.4). However, as can be seen from Table C.5, the estimates are not significantly different if a cubic polynomial is used in the distance to the boundary variable. For the regulation scenario with the most observations (only DUPAC changes, scenario 3), we select a bandwidth of 0.02 miles. For all other regulation scenarios, a bandwidth of 0.2 miles is chosen. After calculating θ_i for $i = 1, 3, 5, 6$, we plot the counterfactual effects in Figure 10 using Equation 5. Stations marked with a gray X are not considered in our analysis because there are no regulation boundaries within 0.5 miles of the station. The Chapter 40A law will have no effect near stations marked with gray triangles because density is already at or above the suggested maximum value of DUPAC = 15 or multi-family zoning already exists. Among the remaining stations with multiple regulation scenarios, we plot scenarios that result in price decreases over scenarios that result in price increases. In addition, if multiple boundaries are present at a station, we select the largest effects, i.e., the largest increase in the number of units and the largest decrease in prices or rents. Null effects are plotted as white dots.

C. Additional tables and figures

Table C.1: Adoption of first zoning laws across municipalities

Town	Year	Town	Year
ARLINGTON	1924-8-30	MEDFORD	1925
BEDFORD	1928	MELROSE	1924-5-6-7-8
BELMONT	1925-6-7	MILTON	1022-6
BOSTON	1918-23-4-9-30-1-2-56	NATICK	1931
BROOKLINE	1922-4-8	NEEDHAM	1925-6-31
CAMBRIDGE	1924-5-6-7-8-9-30-56	NEWTON	1922-5-6-9
CHELSEA	1924	REVERE	1925-9
CONCORD	1928	SALEM	1925-7-8-9
DEDHAM	1924	SOMERVILLE	1925-9
EVERETT	1926-8	STONEHAM	1925-6-7-8-9-30-31-32
FRANKLIN	1930	SUDBURY	1931
GLOUCESTER	1926-7	SWAMPSCOTT	1924
HUDSON	1927	WAKEFIELD	1925-7-9
HULL	1931-2	WALPOLE	1925-8
LEXINGTON	1924-9	WALTHAM	1925-8-9
LINCOLN	1929	WATERTOWN	1026-7-9-30-1
LYNN	1924-5-6-9	WELLESLEY	1925
MALDEN	1923-6-32	WESTON	1928
MARBLEHEAD	1927-8-30	WESTWOOD	1929
MARLBOROUGH	1927	WINTHROP	1922-8-9
MARSHFIELD	1926	WOBURN	1925

Note: This table provides the date of first height or land-use zoning adoption across municipalities in Greater Boston Area. Data is from Knauss (1933).

Table C.2: Supply: types of housing across regulation boundaries (built after 1918, cubic polynomial in distance)

	2-3 units (Gentle-Density)						**4+ units (High-Density)**					
	Only MF	Only H	Only DU	MF & H	MF & DU	H & DU	Only MF	Only H	Only DU	MF & H	MF & DU	H & DU
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
MF	0.455			-0.357	0.001		0.014			-0.140	-0.003	
	(0.102)***			(0.752)	(0.029)		(0.011)			(0.251)	(0.016)	
	[0.038]***			[0.429]	[0.016]		[0.009]			[0.225]	[0.010]	
H		0.028		-0.093		-0.063		-0.018		-0.060		-0.080
		(0.026)		(0.200)		(0.029)*		(0.016)		(0.084)		(0.034)*
		[0.024]		[0.118]		[0.026]*		[0.016]		[0.075]		[0.025]**
DU			0.001		-0.004	-0.012			0.001		0.001	-0.010
			(0.001)		(0.004)	(0.005)**			(0.001)		(0.001)	(0.004)**
			[0.0005]		[0.001]*	[0.003]***			[0.0003]**		[0.001]	[0.003]***
MFXDU					0.016						0.002	
					(0.002)***						(0.002)	
					[0.001]***						[0.001]	
HXDU						0.001						0.001
						(0.0004)**						(0.0004)**
						[0.0003]***						[0.0003]***
MFXH				0.136						0.047		
				(0.211)						(0.076)		
				[0.123]						[0.068]		
N 1,495	1,760	3,3071	485	1,1264	1,587	2,538	1,165	1,722	3,1835	431	9,477	1,163
R^2	0.542	0.382	0.435	0.316	0.389	0.457	0.598	0.494	0.565	0.071	0.310	0.570
$\mathbb{E}(y)$	0.231	0.041	0.045	0.116	0.171	0.350	0.013	0.021	0.008	0.007	0.015	0.113

Note: This table presents the results from a linear probability model (Equations 3 and 4) where dependant variable value of 0 is a single-family house and value of 1 is either a 2-3 unit building or 4 or more unit building 0-0.2 miles on either side of the boundary in 2018. All buildings are built after 1918. Cubic polynomial in distance to boundary is used. Only MF are boundaries where only multifamily (MF) regulation changes, Only H are boundaries where only height (H) changes, and only DU are boundaries where only dwelling units per acre (DUPAC) regulation changes. MF & H, MF & DU, and H & DU are boundaries where MF and height, MF and DUPAC, and height and DUPAC both change, respectively. The unit on height is in 10 feet and DUPAC is in 1 housing unit. Standard errors are clustered at the boundary level. Clustered standard errors are in parenthesis and robust standard errors in square brackets. * p< 0.05, ** p< 0.01, *** p< 0.001.

Table C.3: Supply: types of housing across regulation boundaries (built after 1956)

	2-3 units (Gentle-Density)						**4+ units (High-Density)**					
	Only MF	Only H	Only DU	MF & H	MF & DU	H & DU	Only MF	Only H	Only DU	MF & H	MF & DU	H & DU
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
MF allowed	0.264			-1.575	0.0246		0.030			0.193	-0.010	
	(0.084)**			(0.757)	(0.025)		(0.026)			(0.075)*	(0.024)	
	[0.058]***			[0.540]**	[0.017]		[0.019]			[0.264]	[0.014]	
Height (H)		0.036		-0.668		0.096		-0.036		0.043		-0.013
		(0.015)*		(0.357)		(0.056)		(0.037)		(0.029)		(0.054)
		[0.030]		[0.216]**		[0.048]*		[0.024]		[0.070]		[0.040]
DUPAC (DU)			0.001		0.010	-0.007			0.001		0.001	-0.005
			(0.001)		(0.003)**	(0.004)			(0.001)		(0.003)	(0.005)
			[0.001]		[0.002]***	[0.004]			[0.0004]*		[0.002]	[0.005]
MFXDU					0.007						0.006	
					(0.003)*						(0.003)	
					[0.002]***						[0.002]*	
HXDU						0.000						0.0005
						(0.0005)						(0.001)
						[0.0005]						[0.0004]
MFXH				0.587						-0.049		
				(0.319)						(0.026)		
				[0.182]**						[0.074]		
N	482	1,029	21,108	193	5,075	621	454	1,026	20,789	177	4,765	511
R^2	0.535	0.365	0.291	0.405	0.400	0.524	0.821	0.632	0.477	0.068	0.432	0.741
$\mathbb{E}(y)$	0.078	0.028	0.019	0.090	0.075	0.264	0.020	0.026	0.004	0.011	0.015	0.105

Note: This table presents the results from a linear probability model (Equations 3 and 4) where dependant variable value of 0 is a single-family house and value of 1 is either a 2-3 unit building or 4 or more unit building 0-0.2 miles on either side of the boundary in 2018. All buildings are built after 1956. Linear polynomial in distance to boundary is used. Only MF are boundaries where only multifamily (MF) regulation changes, Only H are boundaries where only height (H) changes, and only DU are boundaries where only dwelling units per acre (DUPAC) regulation changes. MF & H, MF & DU, and H & DU are boundaries where MF and height, MF and DUPAC, and height and DUPAC both change, respectively. The unit on height is in 10 feet and DUPAC is in 1 housing unit. Standard errors are clustered at the boundary level. Clustered standard errors are in parenthesis and robust standard errors in square brackets. * $p< 0.05$, ** $p< 0.01$, *** $p< 0.001$.

Table C.4: Semi-parametric effects of regulation on supply and prices

	Number of units				Single-family sales price				Multifamily rent	
	Only MF	Only DU	MF & DU	DU & H	Only MF	Only DU	MF & DU	DU & H	Only DU	DU & H
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A: Inner Core Municipalities										
MF allowed	0.620***		-7.958		0.069		-0.300*			
	(0.133)		(7.046)		(0.060)		(0.124)			
Height (H)				0.058				0.041		0.016
				(0.481)				(0.029)		(0.027)
DUPAC (DU)		0.062*	0.060	0.119		0.009***	-0.011*	0.001	0.002	-0.002
		(0.028)	(0.076)	(0.063)		(0.002)	(0.005)	(0.002)	(0.002)	(0.002)
MFXDU			0.570				0.015*			
			(0.447)				(0.007)			
HXDU				-0.010				0.000		0.000
				(0.006)				(0.000)		(0.000)
N	7,281	1,584	5,113	1,128	10,193	1,762	5,862	1,139	36,229	17,341
Panel B: Mature Suburb Municipalities										
MF allowed	-0.157		0.050		-0.038		-0.020			
	(0.412)		(0.457)		(0.099)		(0.062)			
Height (H)				-8.968				-55.560***		7.640 ***
				(8.934)				(11.900)		(1.593)
DUPAC (DU)		0.009	-0.799*	2.067		-0.001	0.017	-13.033***	-0.005***	-0.312***
		(0.005)	(0.354)	(4.836)		(0.002)	(0.033)	(2.650)	(0.001)	(0.055)
MFXDU			0.566*				-0.011			
			(0.239)				(0.021)			
HXDU				-0.535				0.000†		0.000†
				(1.165)				(0.000)		(0.000)
N	518	15,394	3,951	330	656	25,352	5,994	492	6,773	177

Continues...

Table C.4: Continued

	Number of units				Single-family sales price				Multifamily rent	
	Only MF	Only DU	MF & DU	DU & H	Only MF	Only DU	MF & DU	DU & H	Only DU	DU & H
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Panel C: Developing Suburb Municipalities									
MF allowed	-0.267**		-0.821		-0.517***		-1.448***			
	(0.083)		(0.724)		(0.139)		(0.390)			
Height (H)				-0.947*				-0.490		0.552**
				(0.382)				(0.530)		(0.187)
DUPAC (DU)		0.039	-0.427	-1.176*		-0.012	-0.501***	-0.634	0.107***	0.504***
		(0.075)	(0.381)	(0.536)		(0.044)	(0.139)	(0.734)	(0.021)	(0.055)
MFXDU			0.430				0.602***			
			(0.378)				(0.163)			
HXDU				0.300*				0.154		-0.127***
				(0.134)				(0.182)		(0.014)
N	180	6,346	3,319	177	339	9,721	4,063	269	2,243	461

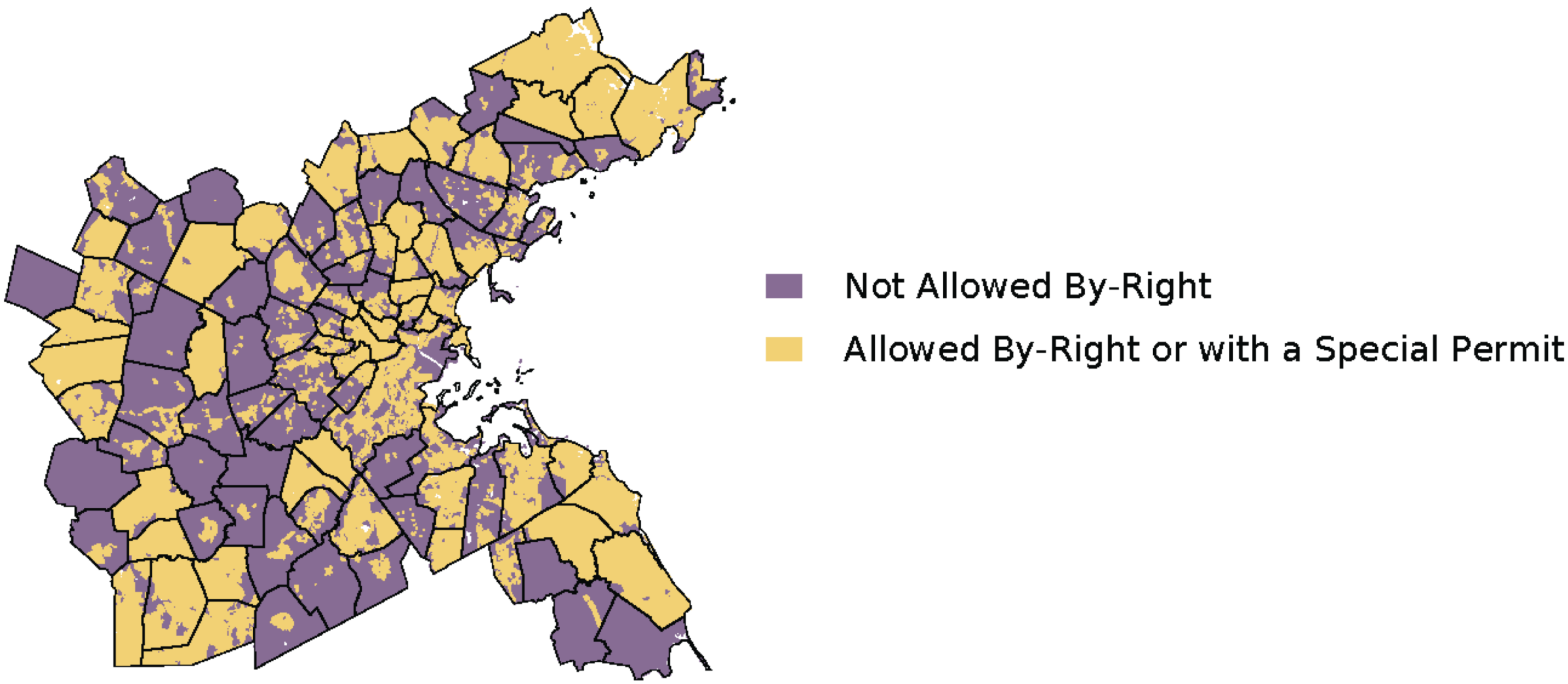
Note: This table presents the results from Equation 3 where the dependent variable is either log of monthly owner cost of housing or monthly rent 0-0.2 miles around the boundary. Boundary fixed effects and year fixed effects are included [2010-2018]. Only MF are boundaries where only multifamily (MF) regulation changes and only DU are boundaries where only dwelling units per acre (DUPAC) regulation changes. MF & DU and H & DU are boundaries where MF and DUPAC both change and height and DUPAC both change, respectively. Since there are no renters on one side of a boundary where allowing multifamily homes changes, we do not show results on rents for that type of boundary. The unit on height is in 10 feet and DUPAC is in 1 housing unit. Standard errors are clustered at the boundary level. * p<0.05, ** p<0.01, *** p<0.001. † implies coefficient cannot be calculated due to multi-collinearity.

Table C.5: Semi-parametric effects of regulation on supply and prices (cubic polynomial in distance)

	Number of units				Single-family sales price				Multifamily rent	
	Only MF	Only DU	MF & DU	DU & H	Only MF	Only DU	MF & DU	DU & H	Only DU	DU & H
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A: Inner Core										
MF allowed	0.522**		-8.482		0.062		-0.247*			
	(0.191)		(7.007)		(0.053)		(0.110)			
Height (H)				-1.790				0.034		0.018
				(1.108)				(0.032)		(0.032)
DUPAC (DU)		0.053	0.059	-0.014		0.003	-0.012*	0.001	0.001	-0.002
		(0.027)	(0.075)	(0.100)		(0.002)	(0.005)	(0.002)	(0.001)	(0.003)
MFXDU			0.575				0.015*			
			(0.449)				(0.007)			
HXDU				0.007				0.000		0.000
				(0.010)				(0.000)		(0.000)
N	1,128	7,281	5,113	1,584	1,139	10,193	5,862	1,762	36,229	17,341
Panel B: Mature Suburbs										
MF allowed	0.193		0.154		0.015		0.007			
	(0.238)		(0.503)		(0.158)		(0.066)			
Height (H)				-11.819				-53.382***		13.173***
				(8.696)				(10.670)		(0.522)
DUPAC (DU)		0.002	-0.791*	1.589		0.002	0.013	-12.569***	-0.001	-0.767***
		(0.004)	(0.358)	(9.189)		(0.001)	(0.032)	(2.373)	(0.002)	(0.042)
MFXDU			0.561*				-0.009			
			(0.238)				(0.021)			
HXDU				-0.344				0.000†		0.000†
				(2.087)				(0.000)		0.000
N	518	15,394	3,951	330	656	25,352	5,994	492	6,773	177

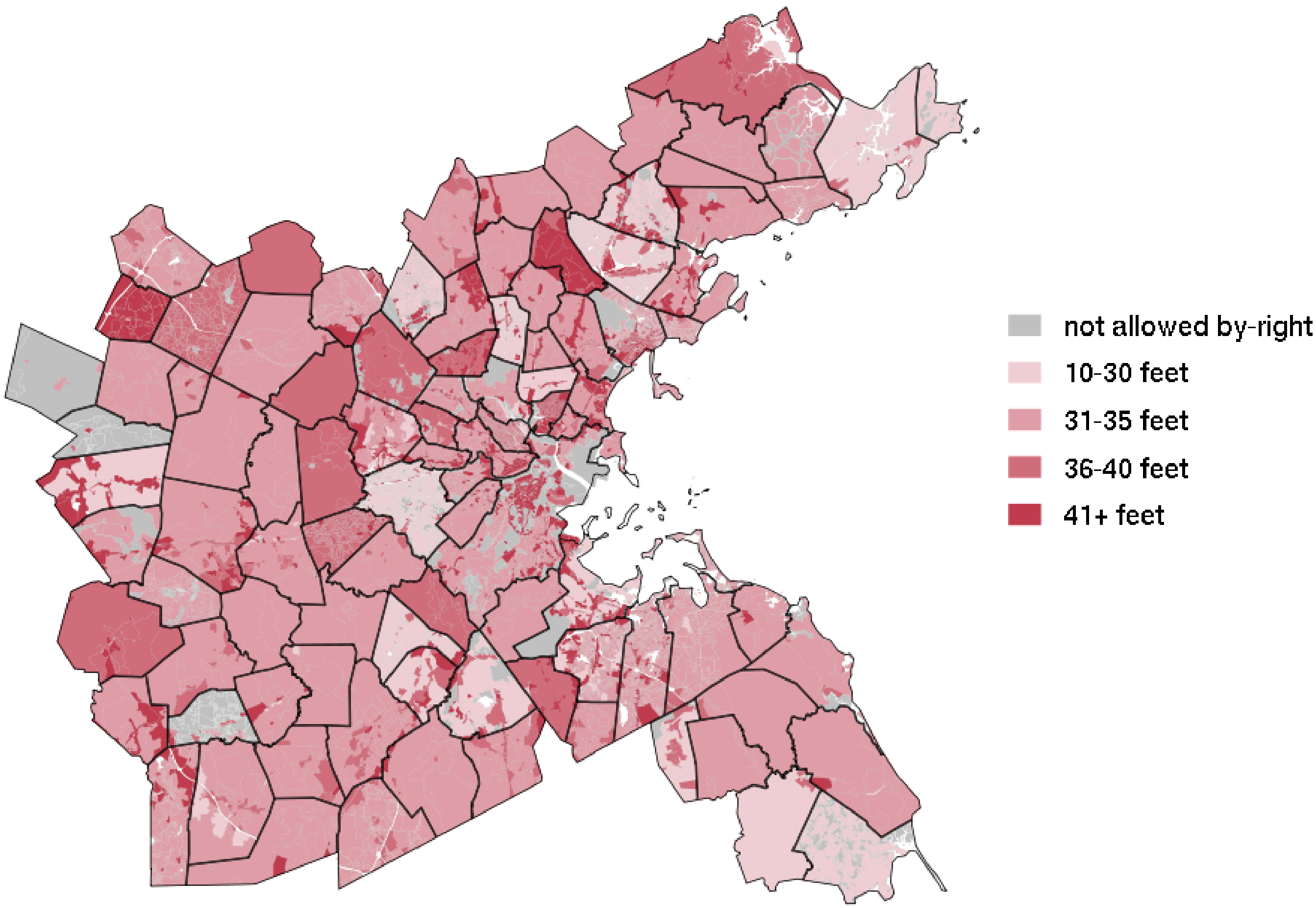
Note: This table presents the results from Equation 3 where the dependent variable is either log of monthly owner cost of housing or monthly rent 0-0.2 miles around the boundary. Boundary fixed effects and year fixed effects are included [2010-2018]. Only MF are boundaries where only multifamily (MF) regulation changes and only DU are boundaries where only dwelling units per acre (DUPAC) regulation changes. MF & DU and H & DU are boundaries where MF and DUPAC both change and height and DUPAC both change, respectively. Since there are no renters on one side of a boundary where allowing multifamily homes changes, we do not show results on rents for that type of boundary. The unit on height is in 10 feet and DUPAC is in 1 housing unit. Standard errors are clustered at the boundary level. * $p<0.05$, ** $p<0.01$, *** $p<0.001$. † implies coefficient cannot be calculated due to multi-collinearity.

Figure C.1: Multifamily zoning in greater Boston area



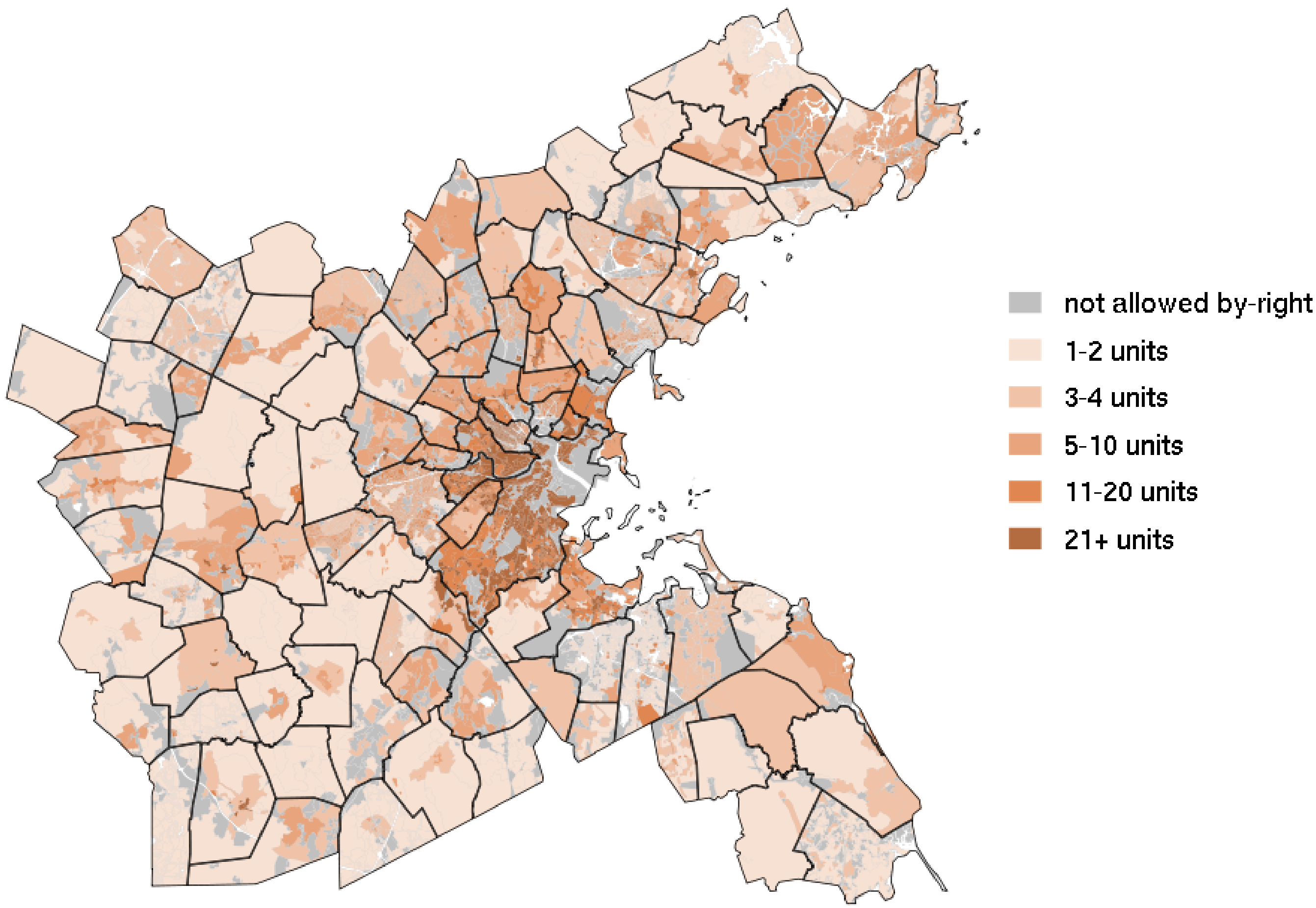
Note: This figure plots the multifamily zoning in greater Boston area. Allowed includes areas where multifamily construction is allowed by right and by special permit.

Figure C.2: Maximum height restrictions in greater Boston area



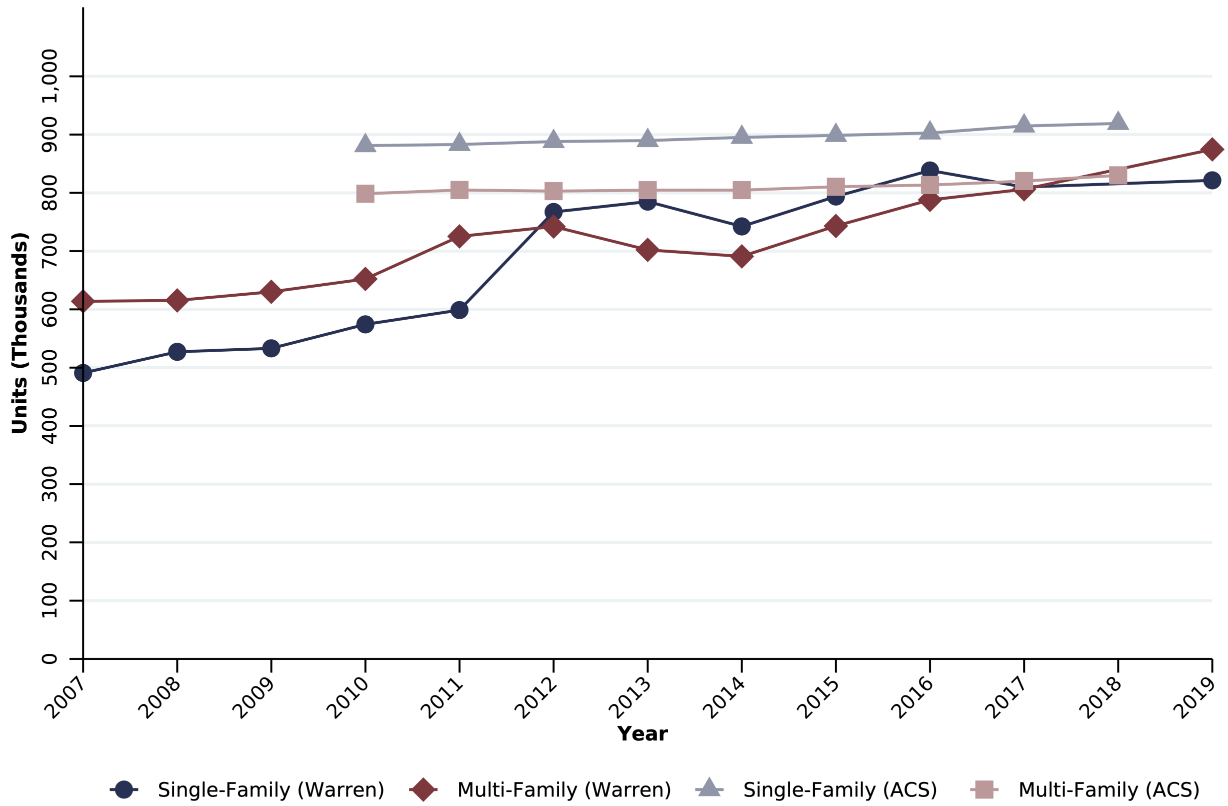
Note: This figure plots the maximum height restrictions in greater Boston area in feet.

Figure C.3: Maximum density (DUPAC) restrictions in greater Boston area



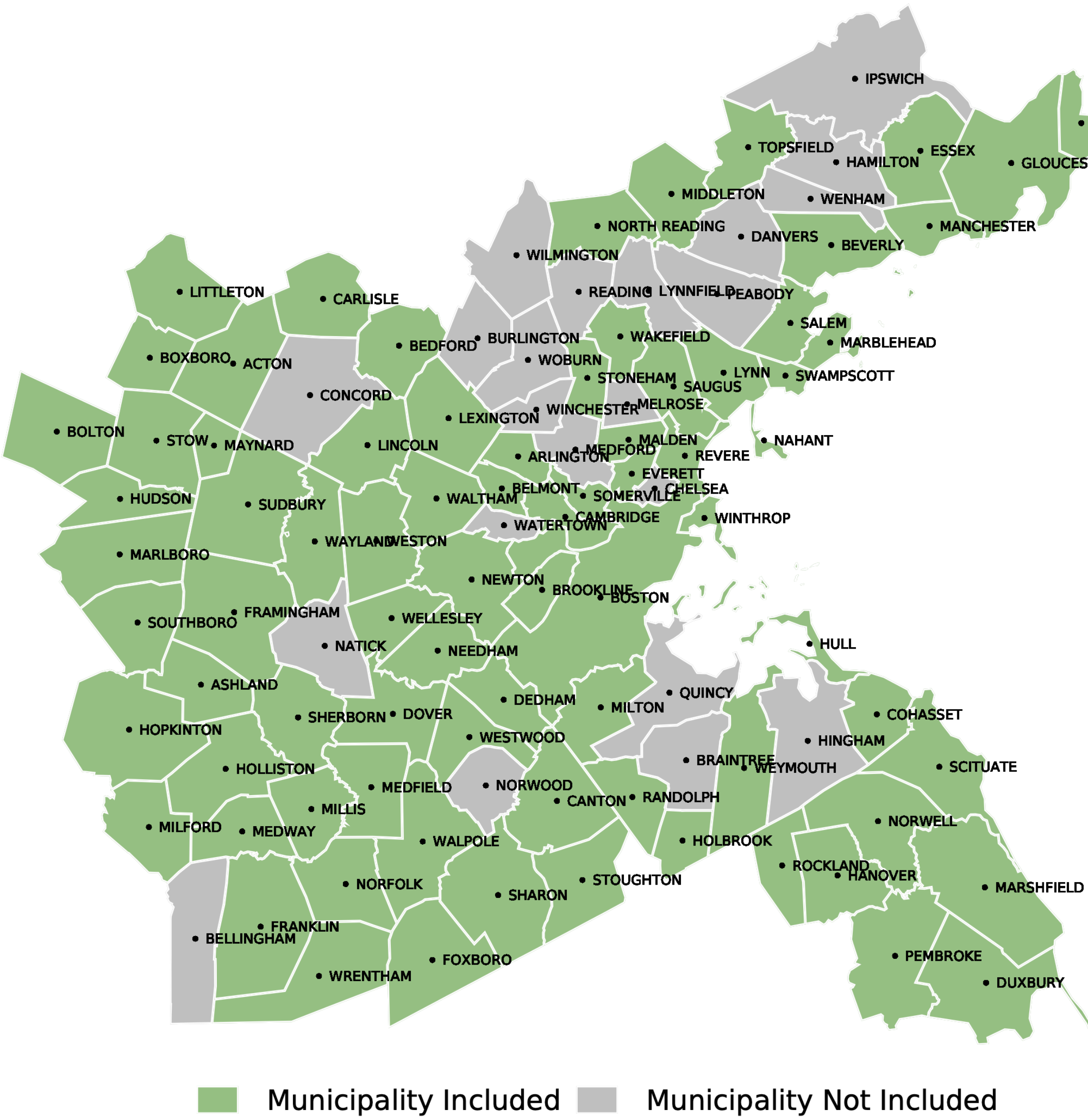
Note: This figure plots the maximum DUPAC (dweelng units per acre) restrictions in greater Boston area.

Figure C.4: Total units by housing type: Warren and ACS data



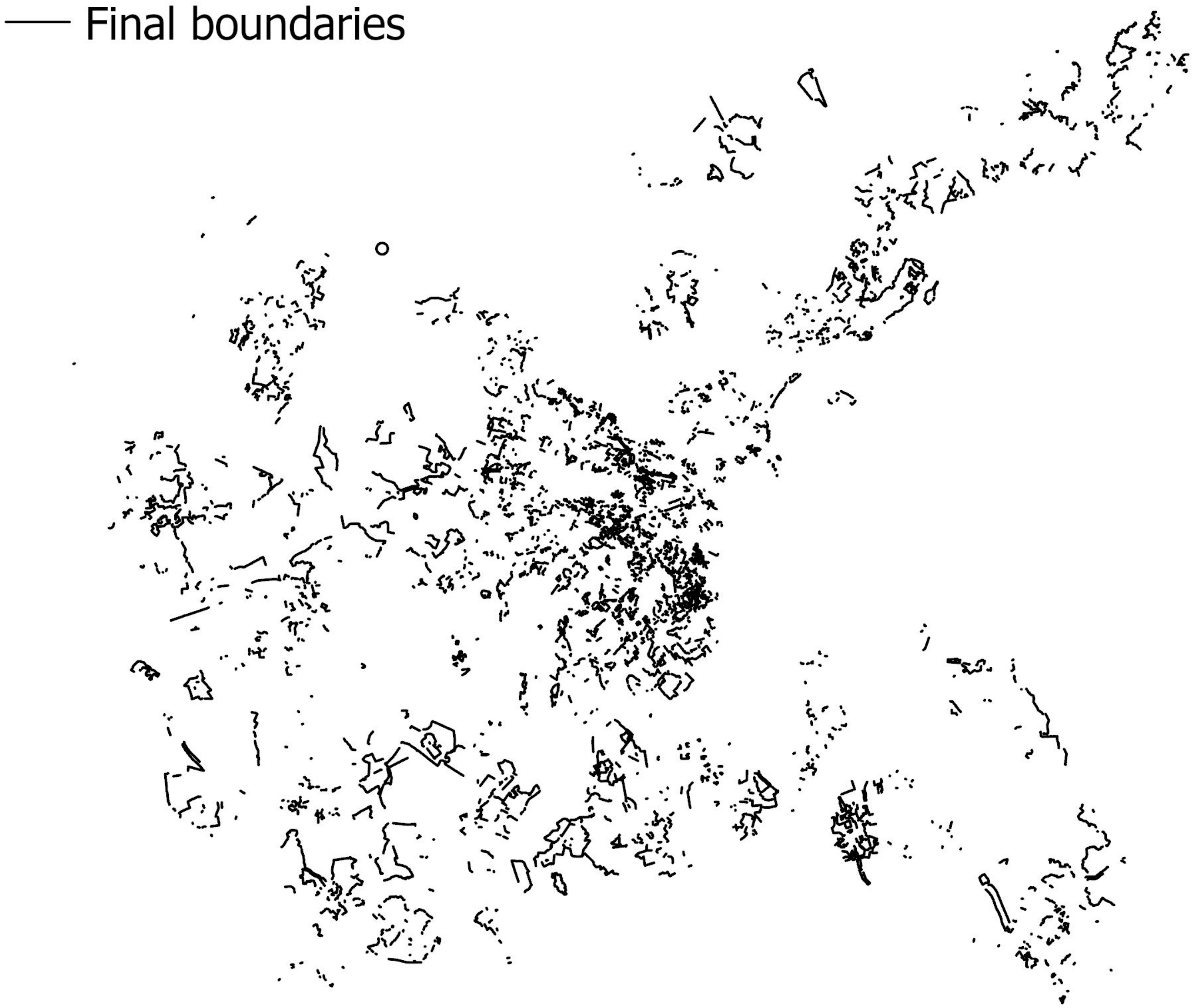
Notes: Single-family units from ACS include all 1 unit housing units (attached and detached). Single-family units in Warren include property addresses with 1 unit listed. All other types counted as multifamily. Counts only Massachusetts counties for the Boston-Cambridge-Newton MSA (2007-2019).

Figure C.5: Towns included in sample



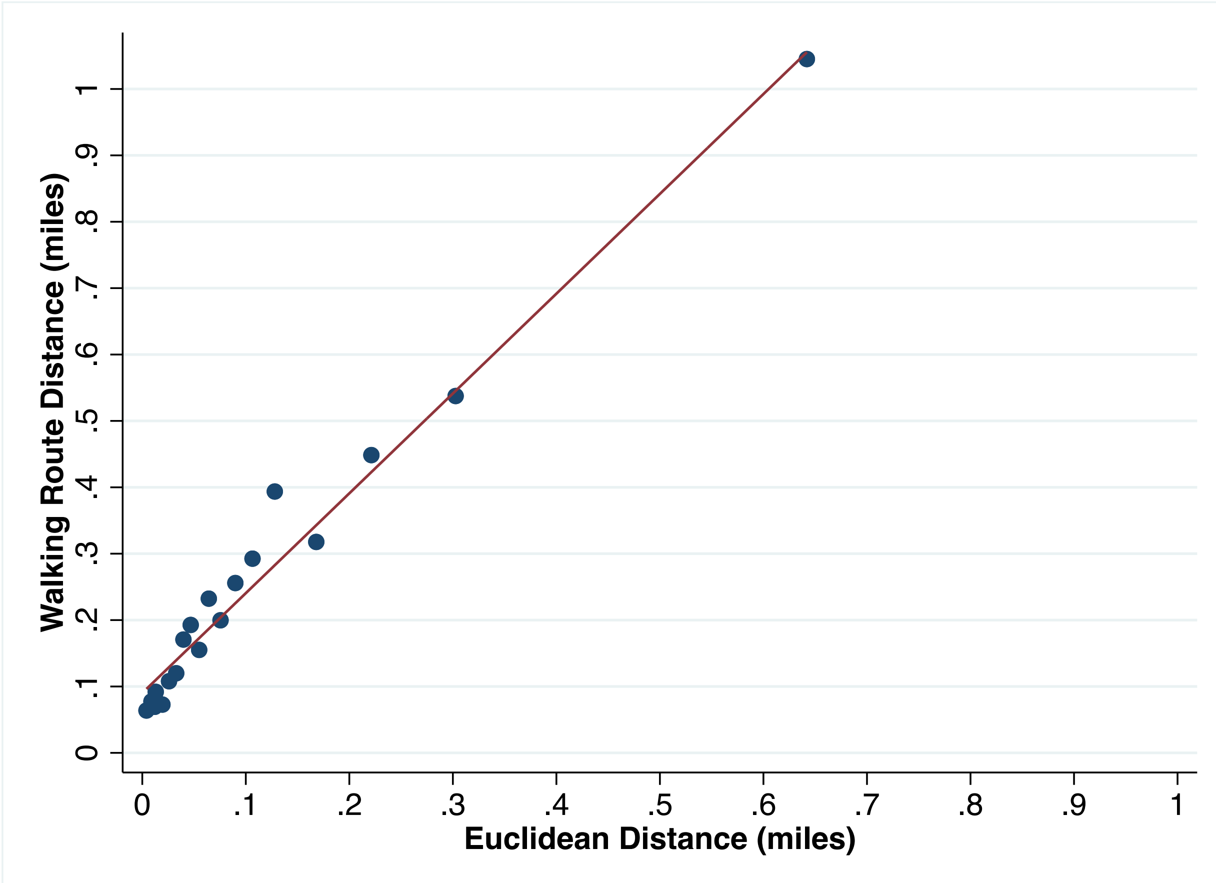
Note: Municipalities are included if they either had open enrollment school attendance policies or had elementary school attendance boundary data included in the 2016 School Attendance Boundary Survey (SABS). Municipalities were excluded if they lacked school attendance boundary data and did not have open enrollment.

Figure C.6: Final RD regulation boundaries



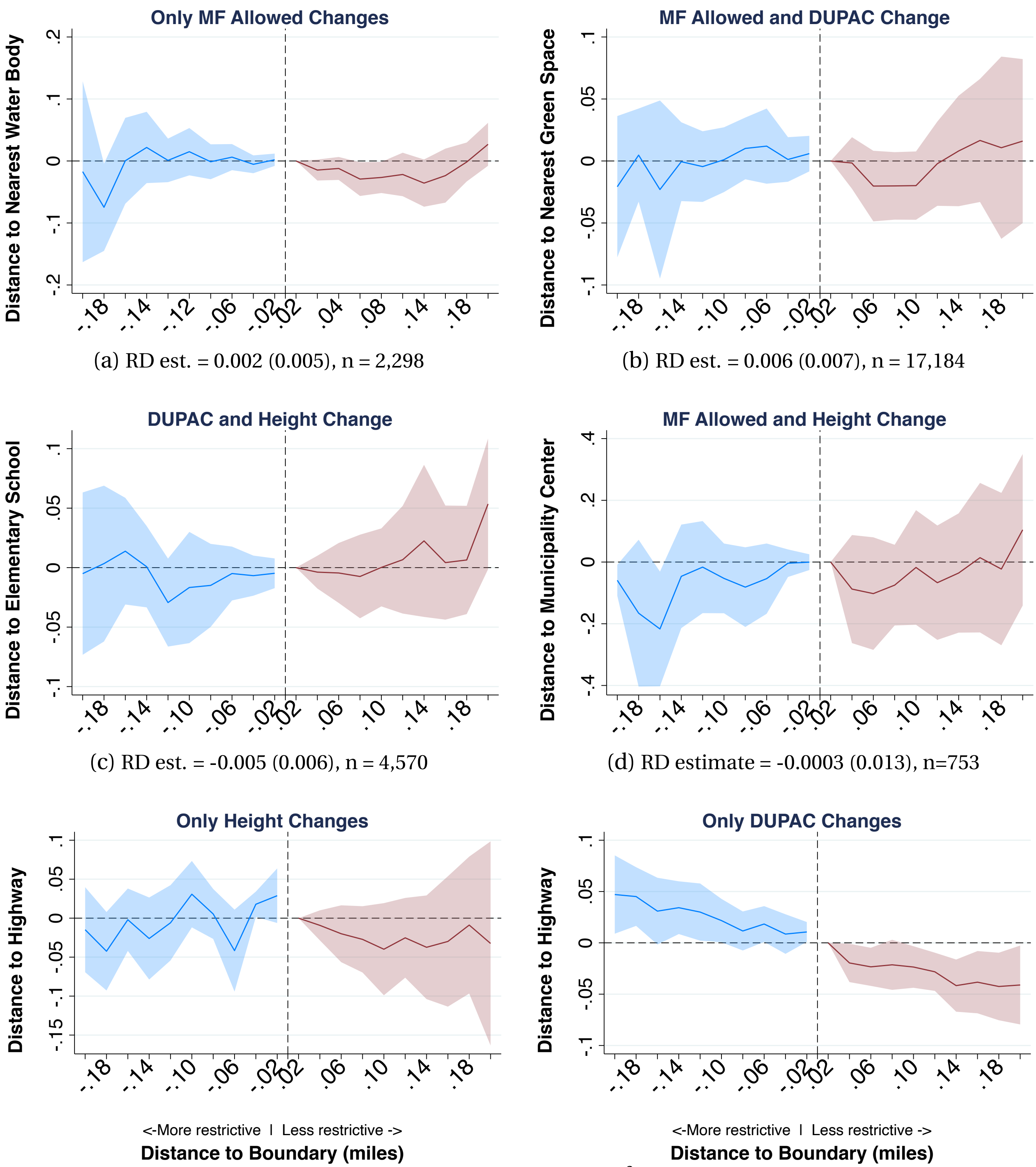
Note: This figure displays the RD regulation boundaries used in analysis in Greater Boston after the step by step boundary removal process highlighted in Figure 2 and Table 2.

Figure C.7: Correlation between straight line and walking distance



Note: This figure plots the Euclidean distance against the walking distance between the closest property on the less restrictive side of a regulation boundary and the closest property on more restrictive side. The Euclidean distance is the direct path between two properties (in miles), while the walking route distance is the shortest path using the local road and sidewalk network. Distances were calculated using the geographic coordinates for each of the closest properties. The walking route distance was calculated using Project OSRM's Open Source Routing Machine, which finds the shortest path between two points based on the road and sidewalk network of local area.

Figure C.8: Neighborhood amenities and parcel attributes at regulation boundaries (continued)



(a) RD est. = 0.002 (0.005), n = 2,298

(b) RD est. = 0.006 (0.007), n = 17,184

(c) RD est. = -0.005 (0.006), n = 4,570

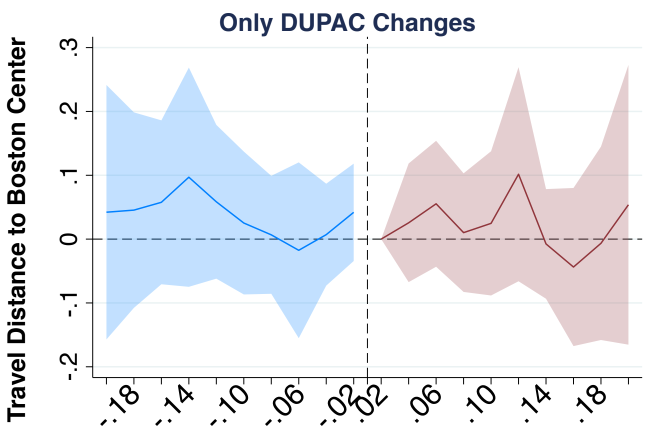
(d) RD estimate = -0.0003 (0.013), n=753

(e) RD est. = 0.029 (0.018), n = 2,593

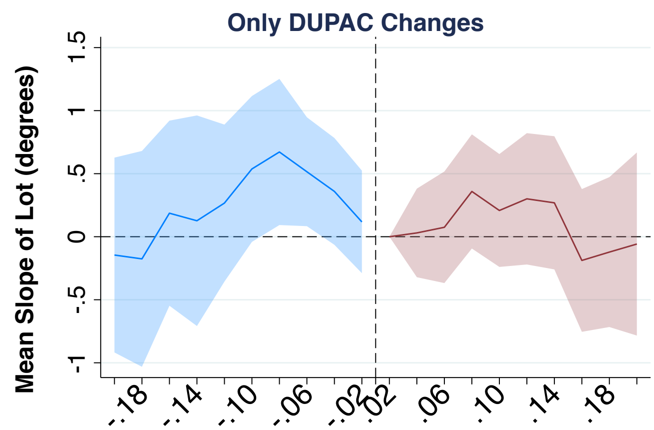
(f) RD est. = 0.011 (0.005)*, n = 42,702

Note: Figures are created by plotting coefficient from regressing distance to nearest amenities or parcel attributes on boundary fixed effects and distance to boundary (bins of 0.02 miles). Negative distances indicate more regulated side. Bin closest to boundary on less regulated side (0-0.02 miles) is normalized to 0. 95% confidence intervals are shown. Standard errors are clustered at boundary segment level. The coefficient and standard error on -0.02-0 bin on the restricted side is reported. DUPAC is Dwelling units per acre and MF is multifamily zoning. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

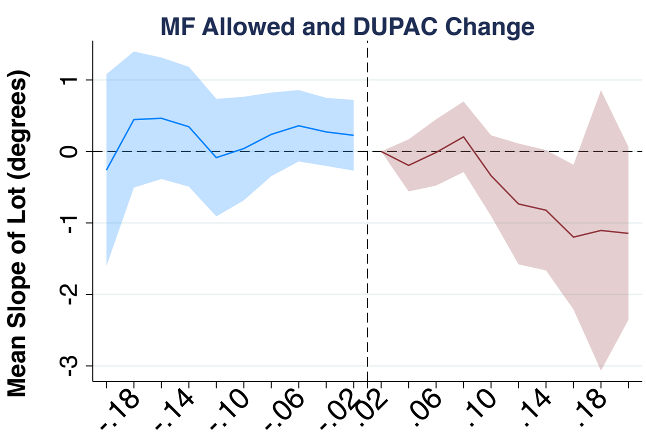
Figure C.9: Neighborhood amenities and parcel attributes at regulation boundaries (continued)



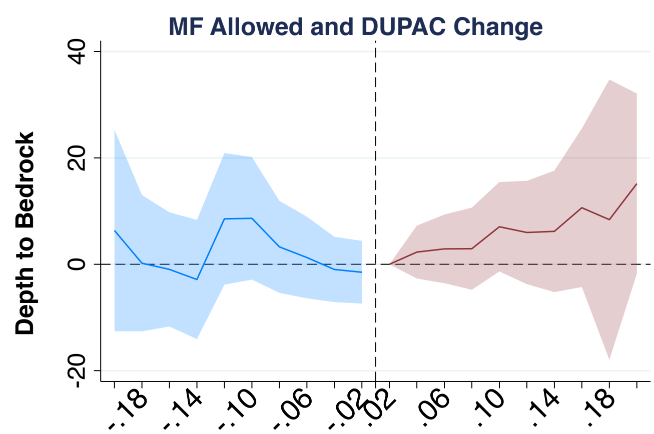
(a) RD est. = 0.042 (0.039), n = 42,438



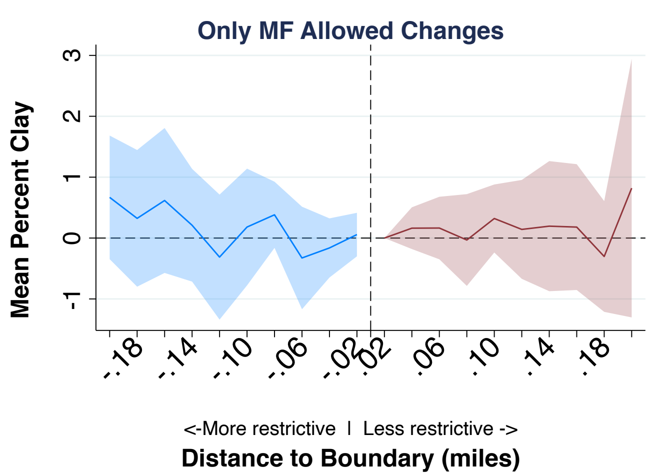
(b) RD est. = 0.117 (0.207), n = 34,172



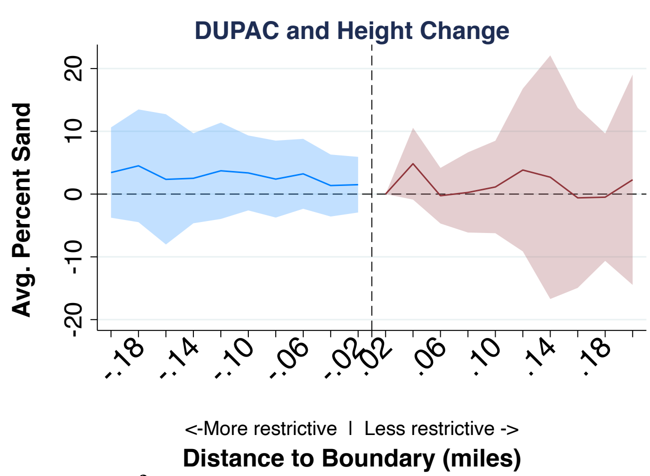
(c) RD est. = 0.226 (0.251), n = 14,484



(d) RD estimate = -1.493 (3.001), n=14,484



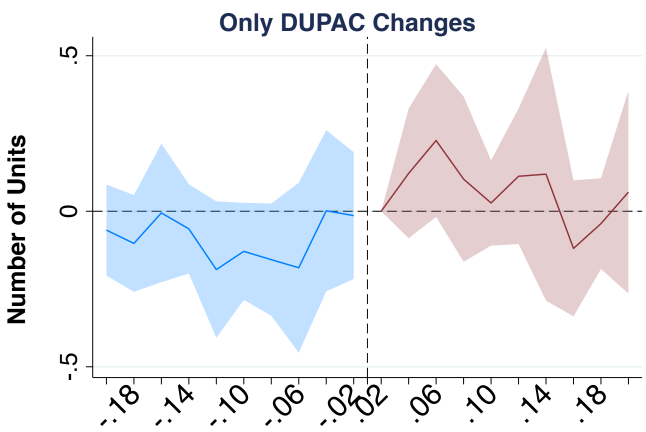
(e) RD est. = 0.057 (0.180), n = 1,941



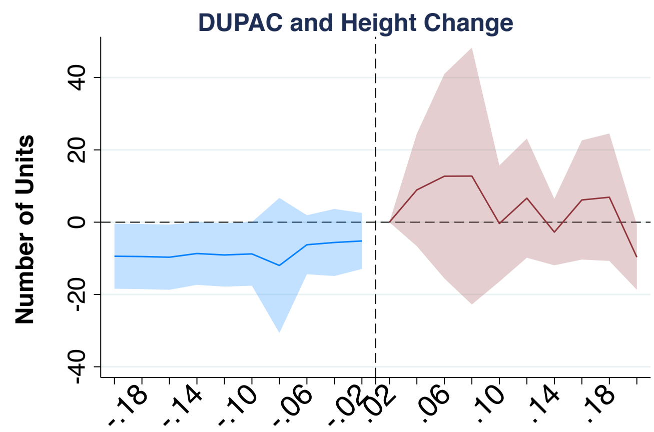
(f) RD est. = 1.499 (2.250), n = 3,941

Note: Figures are created by plotting coefficient from regressing distance to nearest amenities or parcel attributes on boundary fixed effects and distance to boundary (bins of 0.02 miles). Negative distances indicate more regulated side. Bin closest to boundary on less regulated side (0-0.02 miles) is normalized to 0. 95% confidence intervals are shown. Standard errors are clustered at boundary segment level. The coefficient and standard error on -0.02-0 bin on the restricted side is reported. DUPAC is Dwelling units per acre and MF is multifamily zoning. * p< 0.05, ** p< 0.01, *** p< 0.001.

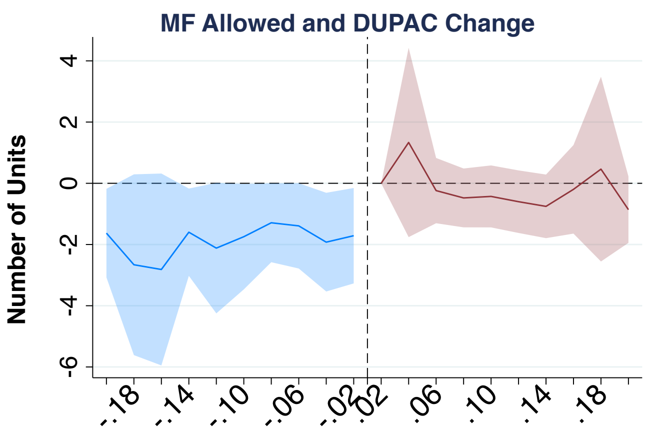
Figure C.10: Effect of regulations on number of units (buildings built after 1956)



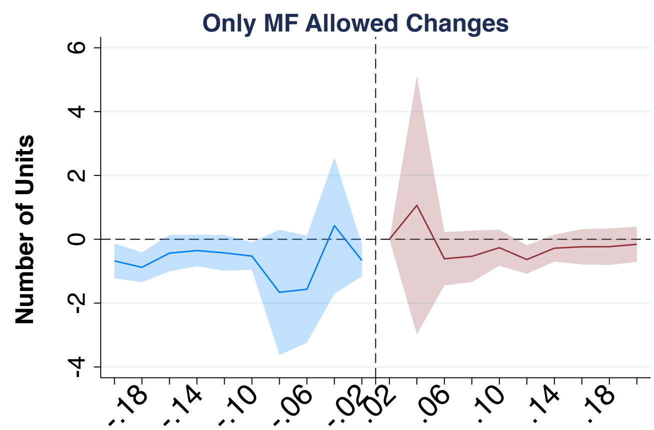
(a) RD est. = -0.014 (0.104) [0.095], n = 21,601



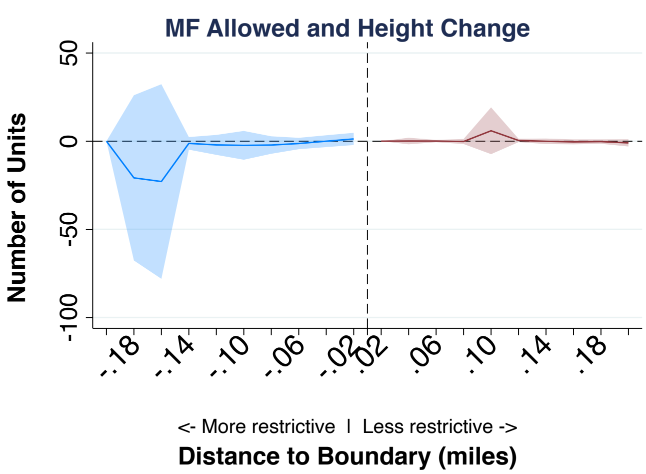
(b) RD est. = -5.194 (3.918) [2.913], n = 718



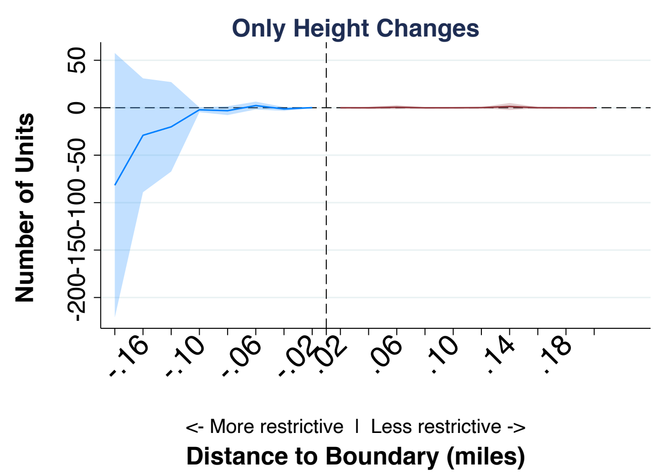
(c) RD est. = -1.712 (0.792)* [0.671]*, n = 5,223



(d) RD est. = -0.663 (0.249)* [0.321]*, n = 501



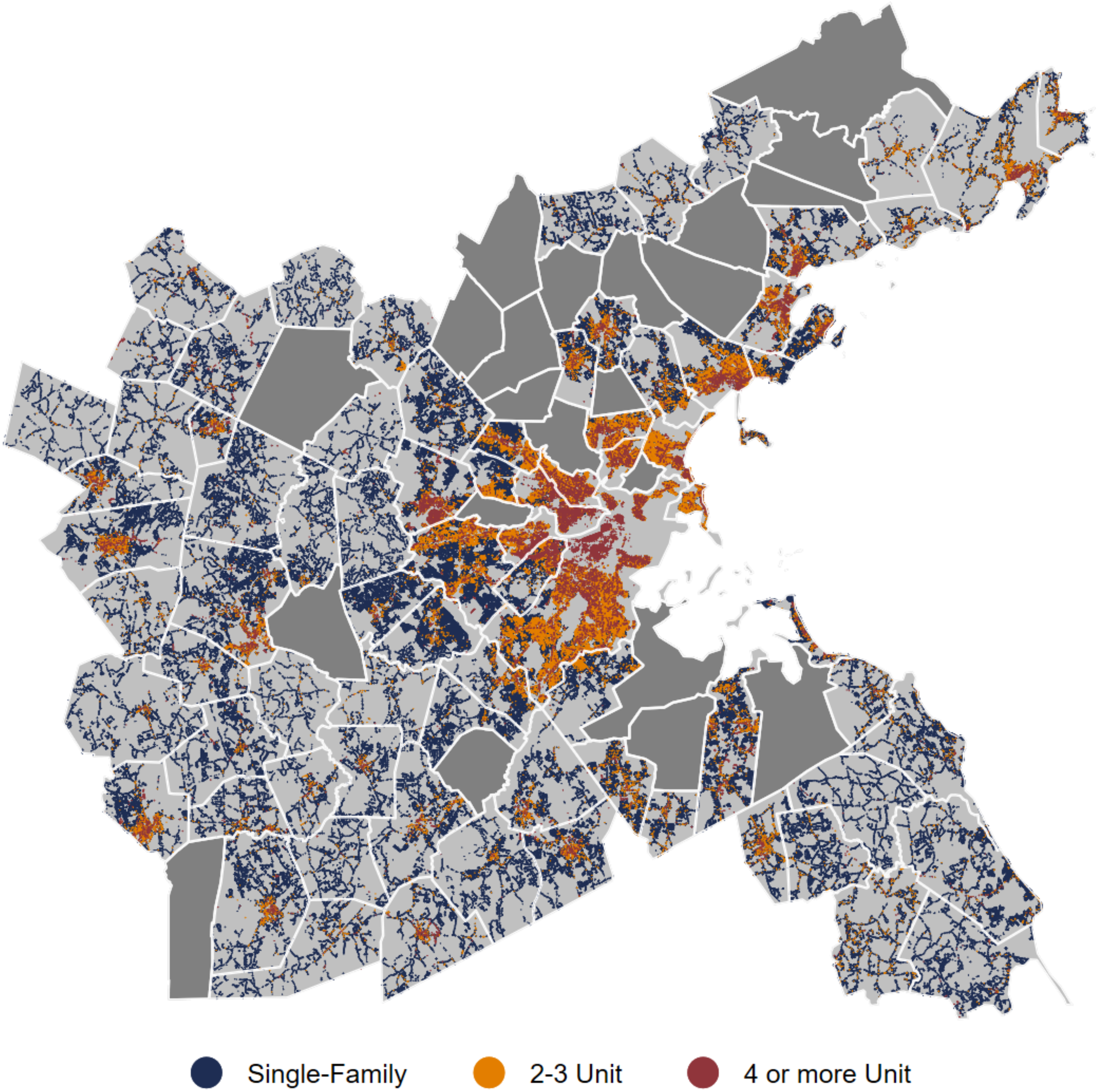
(e) RD est. = 1.271 (1.673) [1.645], n = 207



(f) RD est. = 0.128 (0.253) [0.234], n = 1,854

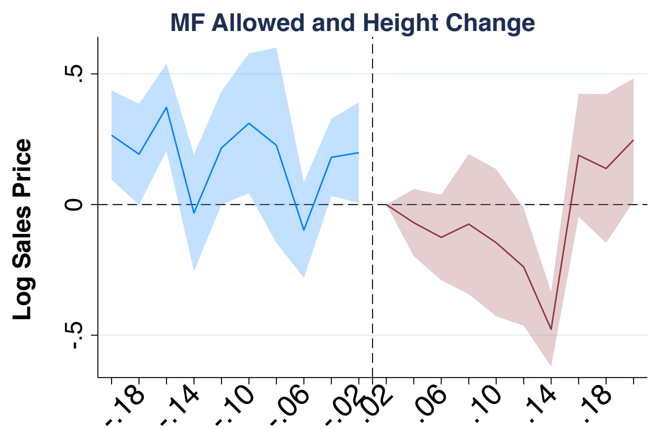
Note: Plots are created by regressing number of units in 2018 on boundary fixed effects and distance to boundary (bins of 0.02 miles). All buildings are built after 1956. Negative distances indicate the more regulated side. The bin closest to boundary on the less regulated side (0-0.02 miles) is normalized to 0. 95% confidence intervals are shown with clustered standard errors at boundary segment level. The coefficient, clustered standard error in parenthesis, and robust standard error in square brackets is reported on -0.02-0 bin on the restricted side. DUPAC is Dwelling units per acre and MF is multifamily zoning. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Figure C.11: Location of single-and multi-family properties in our sample



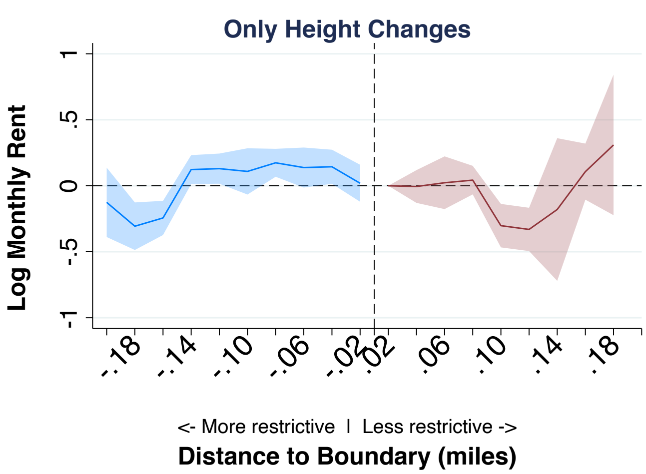
Note: This figure shows the location of single-family properties (in blue) as well as 2-3 unit properties (in orange) and 4+ unit properties (in red) in the Greater Boston Area for towns in our sample. Towns not in our sample are left in solid gray.

Figure C.12: Effects of height and multifamily regulation on housing costs

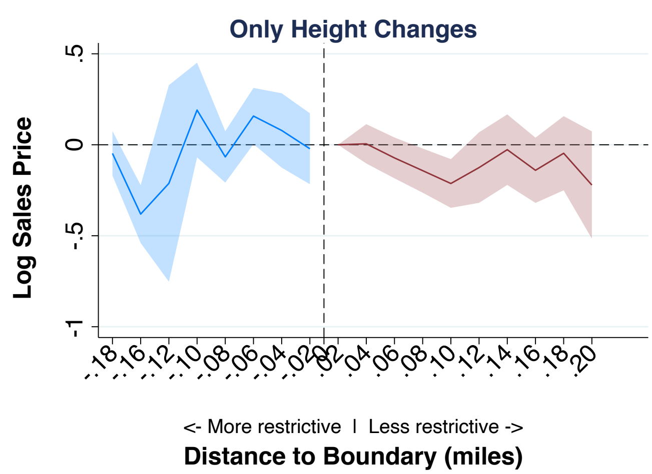


(a) RD est. = 0.198 (0.093)* [0.035]***, n = 990

Change in Only Multifamily or Multifamily and Height Regulation



(b) RD est. = 0.019 (0.070) [0.026], n = 3,609

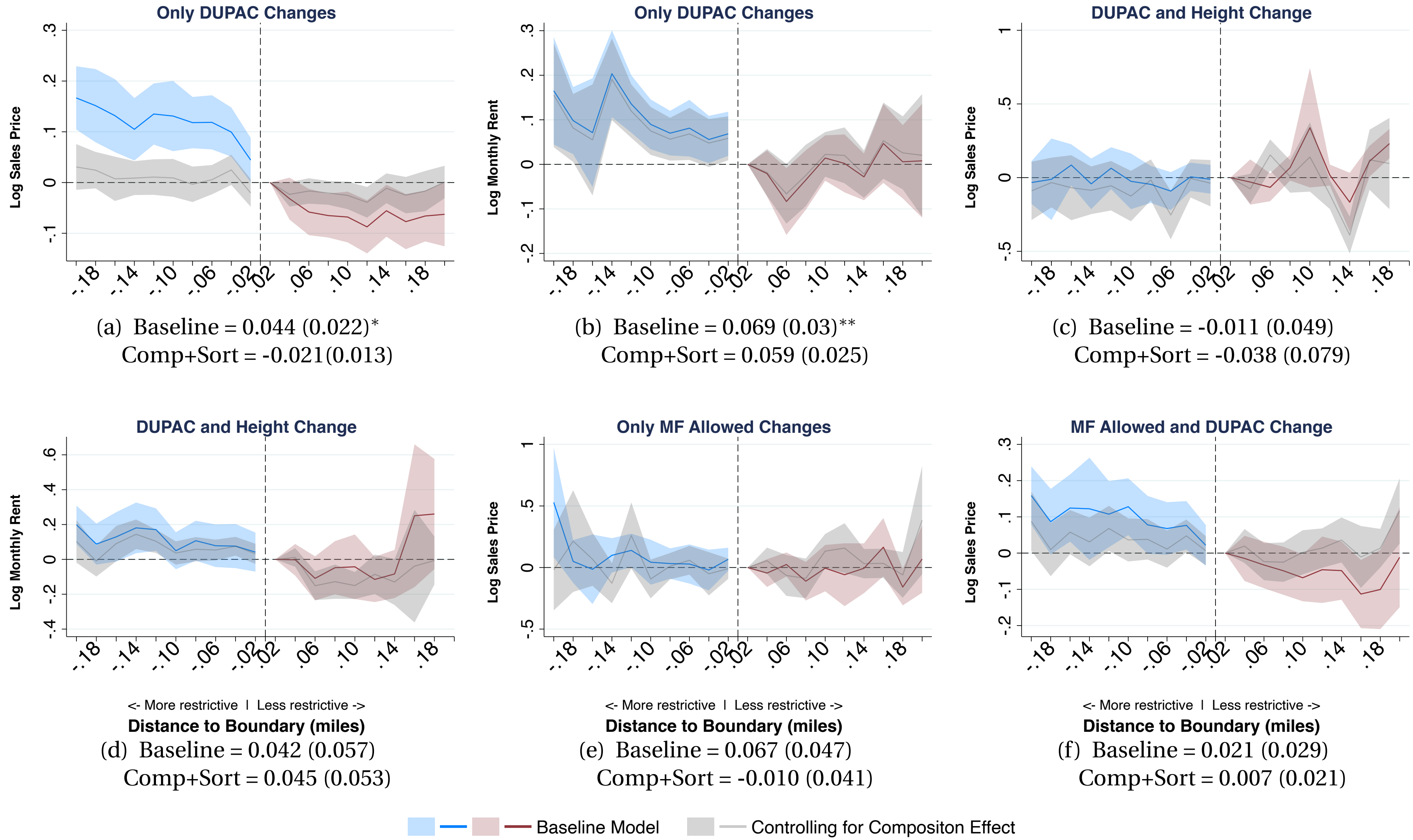


(c) RD est. = -0.022 (.097) [0.029], n = 3,140

Change in Only Height Regulation Boundaries

Note: Plots are created by regressing log prices on boundary fixed effects, year fixed effects [2010-2018], and 0.02 miles bins of distance to boundary. Coefficients on distance bins are plotted. Negative distances indicate the more regulated side of a boundary. The bin closest to boundary on less regulated side (0-0.02 miles) is normalized to 0. 95% confidence intervals are shown. The effects are on monthly rents for multifamily (MF) buildings or monthly owner cost of housing for single-family houses. Standard errors are clustered at the boundary level. Since there are no MF builings on one side of a boundary where allowing MF and Height changes, we do not show results on rents.

Figure C.13: Mechanisms behind equilibrium price effects (including sorting effect)



(a) Baseline = 0.044 (0.022)*
Comp+Sort = -0.021(0.013)

(b) Baseline = 0.069 (0.03)**
Comp+Sort = 0.059 (0.025)

(c) Baseline = -0.011 (0.049)
Comp+Sort = -0.038 (0.079)

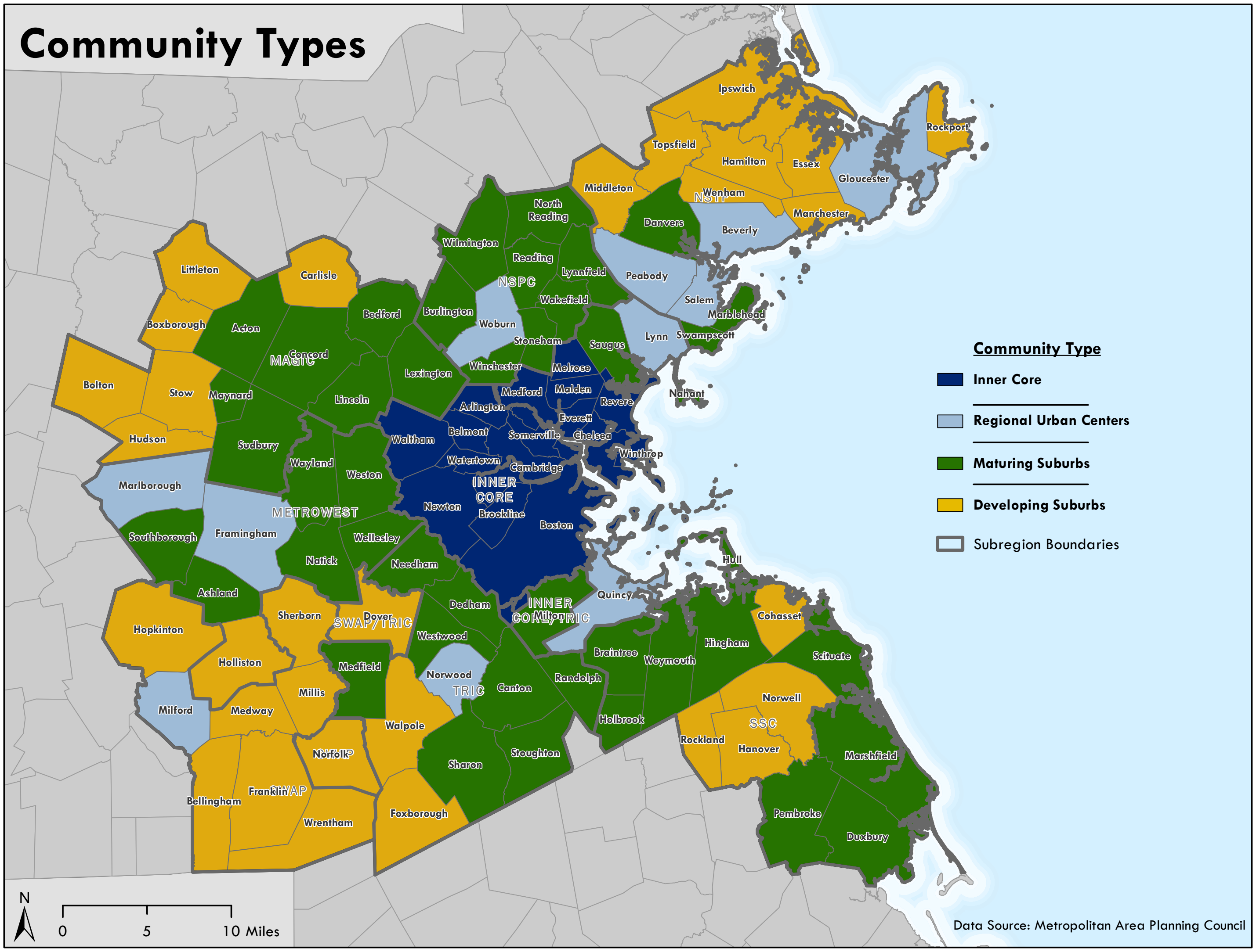
(d) Baseline = 0.042 (0.057)
Comp+Sort = 0.045 (0.053)

(e) Baseline = 0.067 (0.047)
Comp+Sort = -0.010 (0.041)

(f) Baseline = 0.021 (0.029)
Comp+Sort = 0.007 (0.021)

Note: Plots are created by regressing log single-family sale prices or log multifamily monthly rents on boundary fixed effects, sale year/rent year fixed effects [2010-2018], and 0.02 miles bins of distance to boundary. Compared to the baseline model, composition effect and sorting effect (Comp.+Sort) model controls for housing units characteristics and 2010 Census block controls. The 0-0.2 mile bin is normalized to 0. 95% confidence intervals are shown with clustered standard errors at boundary segment level. The coefficient, clustered standard error in parenthesis, and robust standard error in square brackets is reported on -0.02-0 bin on the restricted side. DUPAC is Dwelling units per acre and MF is multifamily zoning. * $p< 0.05$, ** $p< 0.01$, *** $p< 0.001$.

Figure C.14: Greater Boston area municipality types



Note: This figure highlights how the Metropolitan Area Planning Council (MAPC) divides towns in the Greater Boston Area into four distinct municipality types. Source: Metropolitan Area Planning Council community types. Towns classified as "Inner core" are high density inner cities and historic, high-density suburbs near the urban core. Towns classified as "Maturing Suburbs" are moderate density towns that are nearly built out or lower-density towns approaching buildout. Towns in the "Developing Suburbs" category are mixed density with well-defined town centers and room to grow or very low density with a country character and room to grow. Finally "Regional Urban Centers" are large, high-density urban centers not proximate to Boston or small and mid-sized urban downtowns with diverse neighborhoods. Since regional urban centers do not fit well into a monocentric city model, we exclude them for the purposes of our spatial heterogeneity analysis in Section 6.