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The local effects of relaxing land use regulation on housing supply and rents

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Abstract

We examine the effect of relaxing land use regulation on housing supply and rents at the local level. To this end, we develop a spatial equilibrium framework that compares a city with varying floor-to-area (FAR) restrictions. The framework shows that upzoning leads to higher local housing supply and lower rents across the entire city, with no difference in rents between upzoned and non-upzoned parcels. To bring our conceptual framework to the data, we use detailed geo-coded data from the Canton of Zurich in Switzerland from 1995 to 2020. Running changes-on-changes, doubly robust, staggered difference-in-difference, and geographically weighted regressions, we find that a 10% increase in zoning leads to a local 1.2% increase in housing supply in the subsequent five years. Furthermore, changes in zoning lead to a negligible difference in rents between upzoned and non-upzoned parcels, confirming the predictions of our framework. Thus, our findings show that upzoning is an effective policy for increasing housing supply, which, all else equal, leads to lower rents in the entire city. Keywords: Land use regulation, upzoning, housing supply, rents.

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1. Introduction

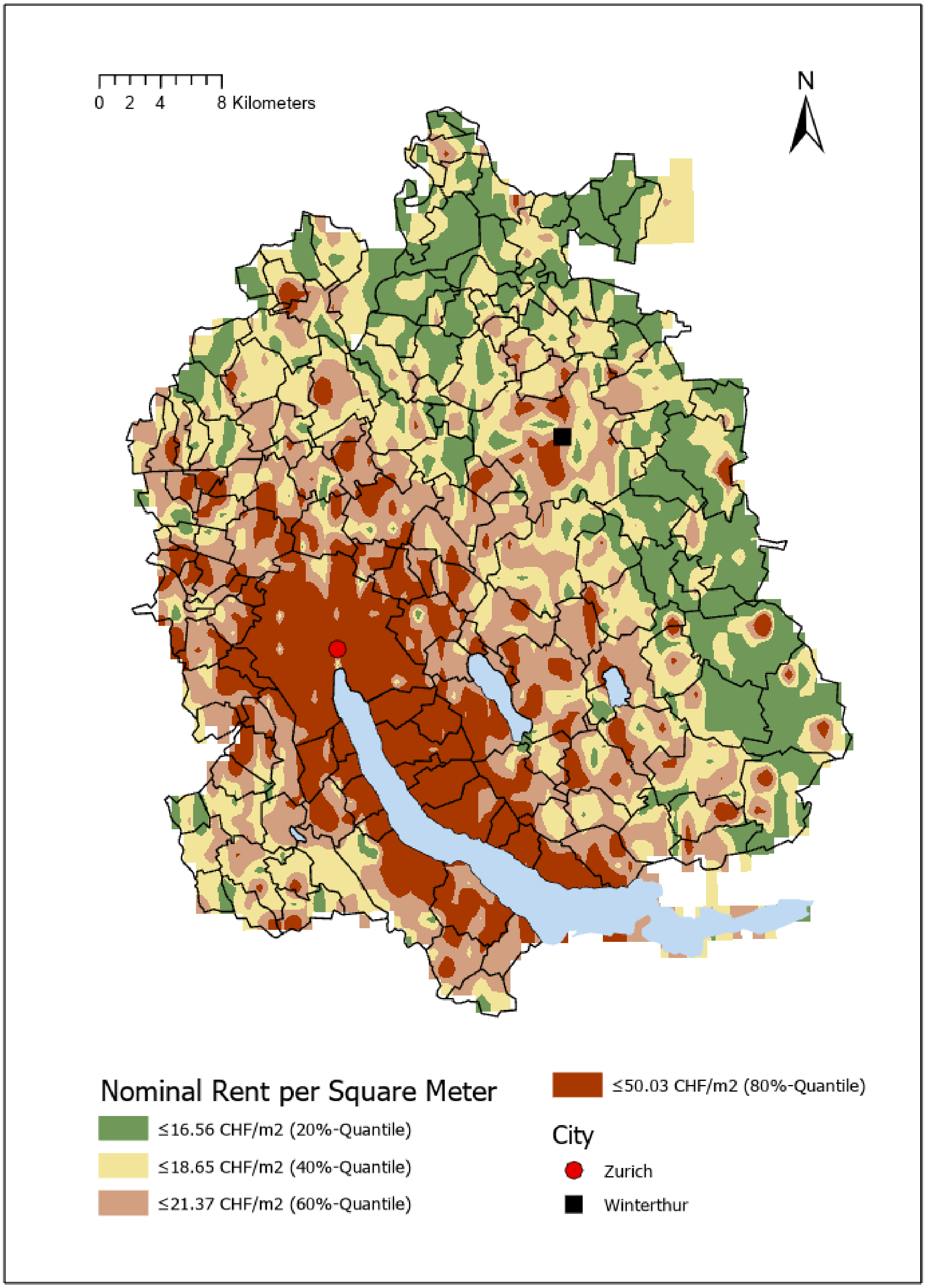
As the world continues to urbanize, cities across the globe have been confronted with the critical challenge of steeply rising rents and subsequent housing affordability problems (see, e.g., Gyourko et al., 2013; Knoll et al., 2017). One key policy, frequently applied by local governments to improve housing affordability, is *"upzoning"*, which refers to relaxing local land use regulations on a parcel to allow for more housing construction (see Freemark, 2020). Upzoning has become a popular policy since extensive literature suggests that tight land use regulations and the resulting inability of housing supply to react to increases in demand are crucial reasons for cities' current housing affordability problems.[1] However, despite the widespread use of upzoning, little is known about its local intra-city effects. This paper investigates the effects of upzoning on housing supply and rents at the micro-level and how these effects vary across space.

We start by developing a spatial equilibrium framework based on the monocentric-city model, comparing different scenarios of varying floor-to-area ratio (FAR) regulations. We show that upzoning a parcel, i.e., increasing the allowed FAR, leads to increased housing supply in the upzoned parcel. However, assuming a non-segregated city, the upzoning effect on rents dissipates across all parcels. Thus, all else equal, upzoning some areas in the city leads to a lower rent across the entire city.

Next, we bring our conceptual framework to the data and estimate how a local change in zoning affects the local housing supply and rents in the subsequent five years. To do so, we use detailed zoning, housing characteristics, and rent data for the Canton of Zurich in Switzerland from 1995 to 2020. More specifically, we run changes-on-changes, doubly robust, staggered difference-in-difference, and geographically weighted regressions. We find that upzoning significantly increases the housing supply on upzoned parcels. A 10% increase in zoning leads to a 1.2% increase in local housing supply in the subsequent five years. If a parcel is upzoned by 20% or more in a given year, housing supply increases by 9.6% to 15.5% on treated parcels compared to non-treated ones in the five years following the upzoning. Moreover, the housing supply response to upzoning is stronger in urban areas. As predicted

[1]See Gyourko and Molloy (2015) for a literature review.

Figure 1: Distribution of rents



This figure shows the pattern of nominal rents across the Canton in 2010, using Inverse Distance Weighting. Rents are higher in the City of Zurich and along the lake compared to other regions of the Canton. *Source:* Geocoded nominal rents per square meter from Meta-Sys.

by our conceptual framework, we find a small to non-existent negative effect of upzoning on local hedonic rents, likely attributable to a small disutility in density. Since the upzoning effect on rents dissipates across all the parcels, regressions estimating partial effects do not capture the general effect on rents. Thus, our results show that upzoning is an effective policy for increasing housing supply, which according to our model, leads to lower rents in the entire city and only a negligible difference in rents between upzoned and non-upzoned parcels.

The Canton of Zurich offers an ideal setting to study the effects of upzoning empirically. First, the Canton of Zurich has undergone different changes in upzoning across space and time, especially regarding the number of floors allowed to be built. Second, it contains both highly urbanized and costly areas, such as the City of Zurich, as well lower-price areas at the urban fringe. Figure 1 shows the heterogeneity in rents across the canton, with very high rents in the tight housing markets in and around the City of Zurich and the wealthy suburbs along the lake. Third, with more than 70% of renters and one dominant city, the Canton of Zurich corresponds well to the assumptions of our conceptual framework well, facilitating estimating the effects of upzoning. Fourth, the highly detailed zoning, housing, and rent panel data allow us to study the local variations in the effects of upzoning over time.

We contribute to the literature connecting land use regulation with housing supply, rents, and house prices. First, our paper is related to theoretical work by Bertaud and Brueckner (2005) and Brueckner and Singh (2020), that uses the monocentric-city model for developing a theoretical understanding of how land use regulations affect density, house prices, and welfare. It also relates to Wheaton (1998), who looks at density in a monocentric-city with varying congestion. Empirically, numerous studies document that stricter land use regulation constraining new housing supply is a critical reason why housing prices are high in booming urban areas (see, e.g., Gyourko et al., 2013; Glaeser and Ward, 2009; Hilber and Vermeulen, 2016). Nevertheless, most of these papers study US housing markets, and they analyze the regional level. This is because it is difficult to obtain detailed, comparable data on local zoning plans. Yet, as local spatial planning departments usually only change land use regulations on some parcels and not in the entire jurisdiction, this leaves open questions about whether land use changes are beneficial at the local level on the parcels where they occur.

However, there is emerging literature on the local intra-city effects of changes in land use and new housing construction, seeking to answer these questions. A new study by Anagol et al. (2021) estimates the effects of upzoning in São Paulo using a general equilibrium framwework. They find that upzoning leads to a 1.4% increase in new housing construction and a 0.4% to 0.9% decrease in rents. Using a boundary discontinuity design, Chiumenti et al. (2021) find that relaxing density restrictions or additionally allowing for multi-family zoning would increase the housing supply and reduce the housing cost the most in the Greater Boston Area. Dong (2021) documents that upzoning in Portland increased housing supply on the treated parcels. Contrarily, Freemark (2020) finds that upzoning in Chicago did not affect housing supply within the first five years. Moreover, Asquith et al. (2021), Pennington (2021), and Damiano and Frenier (2020) study the effects of new housing construction within cities on rents. Except for Damiano and Frenier (2020), all of these studies find that new housing construction decreases rents. Our paper is also related to Krause and Seidl (2021), who study the effect of geographic constraints on developable land within cities. They show that less developable land at a given distance of the city center leads to more housing supply and higher densities on those parcels where developers can still build. Our paper documents an analogous effect for regulatory FAR restrictions within cities.

We contribute to the above literature along several interrelated dimensions. First, we develop a spatial equilibrium framework that documents the effects of varying FAR restrictions. Second, our detailed data allows us to construct a panel data set on upzoning, housing supply, and rents to analyze the effect of intra-municipality upzoning over time. As far as we know, we are the first paper to study upzoning at a micro level over a 25-years period. This allows us also to identify the long-run effects of upzoning, which may be interesting as housing stock is a variable that is very slow to respond to policy changes. Third, we quantify the impact of upzoning on local housing supply and rents. Finally, we investigate these effects in a European country, thereby adding to the scarce literature outside the US.

The remainder of this paper is structured as follows. Section 2 derives theoretical expectations about the impact of upzoning on housing supply and rents. Section 3 outlines the institutional background. Section 4 describes the data and variable construction. Section 5 explains the empirical strategy. Section 6 discusses the results and Section 7 concludes.

2. Conceptual Framework

The conceptual framework derives theoretical expectations about the impact of upzoning on housing supply and rents. Therefore, we want to model the loosening of FAR restrictions on some parcels of urban land while leaving FAR restrictions in the rest of the city unchanged, as this is how upzoning in real-world cities usually takes place (see, e.g., Dong, 2021). Specifically, we are interested in the effects on housing supply and rents.

We proceed as follows. First, using the monocentric-city model developed by Alonso (1964), Muth (1967), and Mills (1967), and extended by Wheaton (1974) and Brueckner et al. (1987), we derive spatial equilibria of three different zoning regulation scenarios: (1) a city without FAR restrictions, (2) a city with a uniform FAR regulation (see Bertaud and Brueckner, 2005) and (3) a city with varying FAR regulations for parcels at the same distance d of the central business district (CBD). Figure 2 depicts a possible scenario of spatially varying FAR, where half of all parcels at a given distance from the CBD are subject to a FAR restriction, while the other half are not. Second, we compare housing supply, rents, and household utility across the different scenarios. Specifically, we are interested in the effects of moving from a city with a uniform FAR (scenario 2) to a city with a spatially varying FAR (scenario 3), as this allows us to assess the impact of upzoning.

2.1. The unregulated city

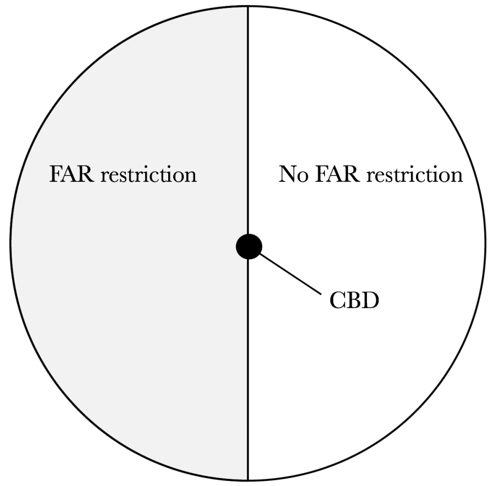
We start from the classic monocentric-city model [2], where N residents inhabit a monocentirc city. All residents work in the CBD and commute to work from their homes on a dense radial road network. They pay t per round-trip mile and earn income y per period. Thus, the disposable income of a household residing at distance d from the CBD equals $y - td$.

On the demand side, households' utility function $u(c, q)$, depends on the consumption of a numeraire nonhousing good c and housing space q. All households are renters. They rent housing space from absentee landlords at rent r per square meter. Thus, the household's budget constraint is

$$c + rq = y - td. \tag{1}$$

[2] For a detailed review of the monocentric-city model see, e.g., Wheaton (1977) or Brueckner et al. (1987).

Figure 2: Monocentric city with FAR restrictions in half of the territory



This figure shows a simple model of a city with spatially varying FAR restriction, where different parcels with the same distance of the CBD have a different FAR restriction. We depict a city where one half of parcels are regulated. However, note that our analysis extends to any other fraction of regulated land $0 \leq a \leq 1$.

Using the budget constraint we can rewrite the utility function as

$$u(y - td - rq, q). \tag{2}$$

Households maximize utility over housing space q, taking r as given. Note that in locational equilibrium, the utility must be equalized across households, regardless of where they chose to locate. Otherwise households would have an incentive to move. Thus, the spatial equilibrium requires that

$$u(y - td - rq, q) = \bar{u}, \tag{3}$$

where $\bar{u}$ is the uniform equilibrium utility level. It follows that housing consumption q and rents r are functions of d and u, i.e. $q(d, \bar{u})$ and $r(d, \bar{u})$.

As households must be indifferent across locations, r decreases with increasing distance from the CBD to offset higher commuting costs td. Therefore, the partial derivative of r with respect to d is negative $r_d < 0$. Conversely, dwelling size increases with d, and hence the derivative is positive $q_d > 0$.

Regarding the effects of parametric changes in the equilibrium utility level $\bar{u}$, an increase in the $\bar{u}$ affects both r and q. An increase in $\bar{u}$, i.e., moving to a higher indifference curve while holding disposable income constant means that households must be able to consume more housing. Therefore, r must fall to allow for higher consumption and hence higher utility, i.e., $r_{\bar{u}} < 0$. As long as housing is a normal good, this also leads to a rise in q, and hence $q_{\bar{u}} > 0$.

On the supply side, housing is supplied by developers who borrow capital and land from absentee landlords.[3] Developers take rents r as given. We assume that developers produce housing with a constant returns to scale production function $h(S)$, where S is the capital to land ratio, also referred to as structural density. In other words, $h(S)$ is the amount of housing supply per unit of land. The developer's profit per unit of land is

$$\pi = r(d, \bar{u})h(S) - l(d, \bar{u}) - iS, \tag{4}$$

where $l(d, u)$ is the highest price developers are willing to pay for a unit of land at a given distance d and i is the cost of capital. Developers maximize their profit over capital to land ratio S. Normalizing the cost of capital to one, the zero-profit condition implies that optimal capital to land ratio is given by

$$S^{\star} = h_s^{-1}\left(\frac{1}{r(d, \bar{u})}\right). \tag{5}$$

The optimal capital to land ratio depends only on r, which in turn is determined by the distance to the CBD d and utility level $\bar{u}$. Thus, S itself also is a function of these parameters, i.e., $S(d, \bar{u})$. First, the capital to land ratio decreases with higher utility as this implies lower rents, i.e., $S_{\bar{u}}' < 0$. Second, the incentive for housing construction declines with distance from the CBD as rents decrease, i.e., $S_d' < 0$. Thus, structural density declines with distance to the CBD.

Combining the supply and the demand side, we obtain functional expressions for the key variables of interest: housing supply per unit of land and rents

[3] In this simple model, absentee landlord's earnings disappear and do not impact equilibrium values.

$$h(S(d,\bar{u})), \;\; r(d,\bar{u}). \tag{6}$$

When examining parcels at a fixed distance d from the CBD, we can see that differences in housing supply and rents across the different scenarios of FAR regulation must come from equilibrium differences in household utility. Specifically, a higher equilibrium utility $\bar{u}$ results in a lower housing supply per land and lower rents.

To obtain the equilibrium utility level of the monocentric-city model without FAR restriction, we require two conditions. The first condition, given by Equation (7), requires that the land price $l(d,\bar{u})$ at the fringe of the city equals the land price for agricultural land l_A, thereby determining the size of the city. The second condition requires that the population N fits in the city, thereby determining the dwellings per unit of land and thus also population density. Together, these conditions determine the distance of the CBD to the edge of the city $\bar{d}$ and the uniform utility level $\bar{u}$.

$$l(\bar{d}_1,\bar{u}_1) = l_A \tag{7}$$

$$\int_0^{\bar{d}_1} 2\pi d \frac{h(S(d,\bar{u}_1))}{q(d,\bar{u}_1)} \,\mathrm{d}d = N \tag{8}$$

The subscript 1 denotes equilibrium values of scenario 1, i.e., the unregulated city.

2.2. City with uniform FAR

Next, we introduce a FAR restriction by limiting the housing supply to $h(S) \leq \hat{h}$ across the entire city following Bertaud and Brueckner (2005). The FAR restriction alters developers' maximization problem by setting an upper bound to the amount of housing they can supply per unit of land. This restriction is binding in areas where the developers would supply $h(S) > \hat{h}$. As shown by Bertaud and Brueckner (2005), the FAR restriction leads to less housing supply in areas where it binds. To still fit the population N, the city must expand spatially. Therefore, the equilibrium distance of the city's fringe will be further away from the CBD than in the unregulated city. This results in an average increase in transportation costs td for households, which in turn lowers disposable income. Thus, a city with binding

FAR restrictions will have a lower equilibrium level of utility $\bar{u}$ and a greater distance of the fringe to the CBD.

Let $\bar{d}_2$ denote the distance to the fringe of the city and $\hat{d}_2$ the distance to the CBD where the land use regulations stops binding. The subscript 2 denotes equilibrium values from scenario 2, the city with a uniform FAR. Then, equilibrium conditions are given by

$$l(\bar{d}_2, \bar{u}_2) = l_A \tag{9}$$

$$h(S(\hat{d}_2, \bar{u}_2)) = \hat{h} \tag{10}$$

$$\int_0^{\hat{d}_2} 2\pi d \frac{\hat{h}}{q(d, \bar{u}_2)} dd + \int_{\hat{d}_2}^{\bar{d}_2} 2\pi d \frac{h(S(d, \bar{u}_2))}{q(d, \bar{u}_2)} \, \mathrm{d}d = N \tag{11}$$

2.3. City with spatially varying FAR

Next, we consider the case of spatial variation in FAR restrictions within the city, as it is the case for most real-world cities. We assume that in one half of the city, an FAR restriction limits housing supply to $h_R(S) = \hat{h}$ while developers can freely choose S in the other half (see Figure 2). Our analysis is not specific to the choice of regulating half of the city, but would extend to regulating any other fraction of the city.

On the supply side, developers of parcels in the part of the city where the FAR restriction is binding will supply $h_R(S) = \hat{h}$. However, developers of parcels without FAR restriction will solve the following maximization problem:

$$\max_S \pi = r(d, \bar{u}_3)h(S) - l(d, \bar{u}_3) - S \tag{12}$$

where the $\bar{u}_3$ denotes the equilibrium utility level with spatially varying FAR. Note that this profit maximization is almost identical to Equation (4) of the unregulated city.

However, housing supply on the unregulated parcels of the city with varying FAR restrictions will be higher than in an unregulated city, resulting in a "supply compensation" on unregulated parcels for the lower supply on the regulated parcels. To see this note that in

Equation (12), if $\bar{u}_3 \neq \bar{u}_1$, then $r(d, \bar{u}_3) \neq r(d, \bar{u}_1)$. This difference in rents changes developers' maximization problem, causing them to produce a different amount of housing on an unregulated parcel at distance d from the CBD than they would in the completely unregulated city of scenario 1. Specifically, as $r_{\bar{u}} < 0$, rents will be lower in the city with the higher equilibrium utility. We compare the different levels of utility in section 2.4.

Furthermore, note that the condition of spatially equal household utility requires that rents are identical in the regulated and the unregulated part of the city for parcels at the same distance from the CBD.[4] Conversely, housing supply and structural density will vary between the regulated and the unregulated part of the city as $h(S) > \hat{h}$ where the FAR restriction binds.

The equilibrium conditions for the city with varying FAR restrictions are the following:

$$l(\bar{d}, \bar{u}_3) = l_A \tag{13}$$

$$h_R(S(\hat{d}_3, \bar{u}_3)) = \hat{h} \tag{14}$$

$$\int_0^{\bar{d}_3} \pi d \frac{h(S(d, \bar{u}_3))}{q(d, \bar{u}_3)} \mathrm{d}d + \int_0^{\hat{d}_3} \pi d \frac{\hat{h}}{q(d, \bar{u}_3)} \mathrm{d}d + \int_{\hat{d}_3}^{\bar{d}_3} \pi d \frac{h(S(d, \bar{u}_3))}{q(d, \bar{u}_3)} \, \mathrm{d}d = N \tag{15}$$

where the subscript 3 stands for the third scenario, $\bar{d}_3$ stands for the distance of the fringe to the CBD, and $\hat{d}_3$ for the distance where the FAR restriction would bind, and h_R stands for the housing supply per unit of land in the regulated half or the city.

2.4. Comparison

In this subsection, we compare the housing supply and rents of the three different scenarios of FAR restrictions to understand how upzoning, i.e., changing the FAR restrictions, affects housing supply and rents. Both housing supply $h(S(d, \bar{u}))$ and rents $r(d, \bar{u})$ are functions of

[4]Moreover, the fact that r is uniform across the regulated and unregulated part of the city results in unregulated land being more expensive than regulated land. This is the case because developers take prices as given and bid for land until they make zero profits. Therefore, we can solve for the price of land as $l_{unregulated}(d, u) = r(d, u_3)h(S) - S$ and $l_{regulated}(d, u) = r(d, u_3)\hat{h}(S) - \hat{S}$. Since r is equal in both cases, for any class of functions $h(S) = S^\alpha$ with $0 < \alpha < 1$, $l_{unregulated}(d, u_3) > l_{regulated}(d, u_3)$ if $\hat{S} < S$, i.e., the FAR restriction is binding. This has also been documented empirically by, e.g., Ihlanfeldt (2007).

$\bar{u}$. To allow for comparison, we, therefore, need to determine the relative values for $\bar{u}$ across the different scenarios.

To compare equilibrium utility, we first assume that the equilibrium household utility in the completely unregulated city equals $\bar{u}_1$. Then, as shown in Bertaud and Brueckner (2005), a city with the same number of inhabitants N and a uniform FAR restriction as in scenario 2 has a lower equilibrium utility, $\bar{u}_2 < \bar{u}_1$. This is because, to fit the same number of inhabitants N, the regulated city needs to extend more in space, resulting in higher average commute times and, therefore, more money spent on transport and hence lower utility.

Next, let us consider the equilibrium utility in a city with a spatially varying FAR, $\bar{u}_3$. First, in comparison to the utility of a completely regulated city, $\bar{u}_2$, we can see that $\bar{u}_3 > \bar{u}_2$. This is because, in the unregulated part of the city, developers will choose to supply $h(S) > \hat{h}$. Therefore, the spatial extension of the partly regulated city will be smaller than that of the completely regulated city, $\bar{d}_2 > \bar{d}_3$. This implies that $\bar{u}_2 < \bar{u}_3$.

Further, let us compare $\bar{u}_3$ to the utility of an unregulated city $\bar{u}_1$. Again the utility will depend on the spatial expansion of the city. The relative spatial expansion of the partly regulated city is determined by the housing supply $h(S(d, u))$ on the unregulated parcels and by whether it compensates for the supply restriction in the regulated part of the city. Thus, it could be that $\bar{u}_1 = \bar{u}_3$ if the housing supply on the unregulated parcels is sufficiently high to compensate for all the housing not built on the regulated parcels. This would imply that $\bar{d}_1 = \bar{d}_3$. However, this is not possible as $\bar{u}_1 = \bar{u}_3$ implies that $r_1(d, \bar{u}_1) = r_3(d, \bar{u}_3)$. Yet, in this case, developers on unregulated parcels would only supply the same amount of housing as in the unregulated city and hence not make up for the restricted parcels. Thus, this results in a contradiction, ruling out $\bar{u}_1 = \bar{u}_3$. Thus, the partly regulated city will be larger $\bar{d}_1 < \bar{d}_3$, and utility will be lower $\bar{u}_1 > \bar{u}_3$.

Overall, utility compares as

$$\bar{u}_1 > \bar{u}_3 > \bar{u}_2 \tag{16}$$

This implies that

$$\bar{r}_1(d, \bar{u}_1) < \bar{r}_3(d, \bar{u}_3) < \bar{r}_2(d, \bar{u}_2) \tag{17}$$

and

$$h(\bar{S}_1(d, \bar{u}_1)) > h(\bar{S}_3(d, \bar{u}_3)) > h(\bar{S}_2(d, \bar{u}_2)) \tag{18}$$

for all d where the FAR restriction is binding.

Regarding housing supply, it is also interesting to consider not only the total supply of housing on the ring with distance d to the CBD, but also the housing supply in the unregulated parts of the partly regulated city (i.e., the right half of Figure 2). We can show that there will be a "compensation" in the form of a higher housing supply than $h(S_1(d, \bar{u}_1))$. To see this, note that the case in which developers supply only $h(S_1(d, \bar{u}_1))$ on the unregulated parts of the partly regulated city results in a contradiction. Specifically, $r_1(d, \bar{u}_1) < r_3(d, \bar{u}_3)$ implies that $h_{3,unregulated} > h_1$ as the higher equilibrium rent will induce developers to provide more housing. Thus, housing supply and structural density S will be the highest on the unregulated parcels of the partly regulated city.

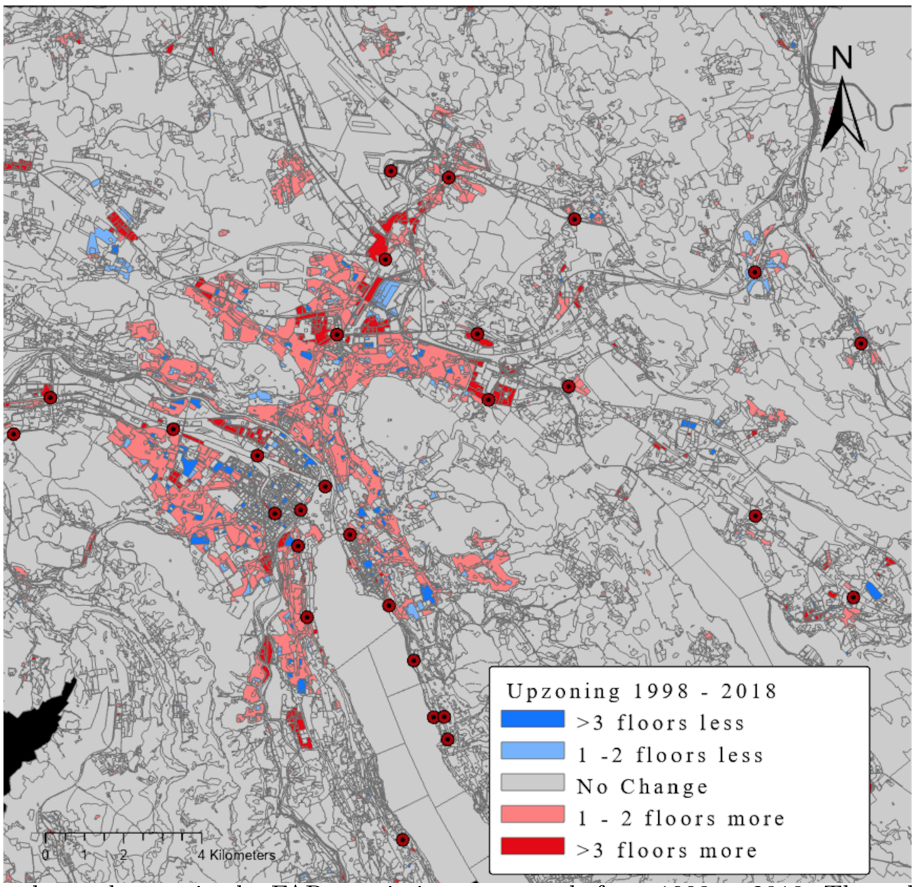
In sum, upzoning, i.e., removing FAR restrictions in some parts of the city, is equivalent to a move from scenario 2 to scenario 3. Thus, for our empirical analysis, we expect that upzoning will:

1. increase the housing supply on the upzoned parcels. Specifically, there will be a compensation reaction where developers make up for the FAR restriction by building more housing on the unregulated parcels than they would in a completely unregulated city.

2. decrease rents across the entire city by the same magnitude.

Note that in this conceptual framework, the population is fixed. In a city where the rate of redevelopment is lower than population growth, rents would continuously increase. In such a case, upzoning would lead to a lower increase in rents. Moreover, in our framework, upzoning leads to a smaller city, i.e., a shorter distance from the periphery to the CBD $\bar{d}$. This implies that housing is demolished. However, in reality, demolishing housing is costly, and it is only done if economically worthwhile. Thus, introducing demolishing costs would lead to vacancies, which in turn would depress rents even further.

Figure 3: Upzoned areas in Zürich, 1998-2018



This figure shows changes in the FAR restrictions on parcels from 1998 to 2018. The red dots are train stations. Red areas are areas where upzoning occurred *Source:* Historic zoning plans from the Statistical Office of the Canton of Zürich.

3. Institutional Background

We test the predictions of our theoretical framework empirically, using the Canton of Zurich as a study area. The Canton of Zurich is a suitable case to test our model for at least three reasons. First, the Canton of Zurich collects parcel-level zoning regulations and FAR restrictions since 1995 and harmonizes them across municipalities. Moreover, it has excellent micro-level housing characteristics and rent data. Second, the Canton Zurich matches well with the assumptions made in our model. In particular, an exceptionally high number of households are renters, and the Canton has one major central business in the city of Zurich that households commute to. Third, the Canton of Zurich also is Switzerland's biggest metropolitan area with 1.5 million inhabitants in 2019 (Kanton Zürich, 2021). As a major tech and finance hub, with firms such as Google, Facebook, Microsoft, and the headquarters of several international banks, the metropolitan area of Zurich is experiencing strong population and house price growth. Therefore, lessons from the metropolitan area of Zurich may be generalizable to other major cities in the world, such as San Francisco, New York, or London.

3.1. Upzoning in the Canton of Zurich

The zoning system in Switzerland works as follows. The urban planning department of each municipality sets a zoning plan that regulates the by-right land use regulations on each parcel in the city (Kanton Zurich, 2015). When elaborating the plan, the *Kantonaler Richtplan*, a "masterplan" of the Canton of Zurich sets out basic regulations to be respected (Schmid et al., 2021). The city council then passes the zoning plan. Since Switzerland has a direct democratic system, large cities, such as Zurich, also sometimes let citizens vote on whether or not to accept the new zoning plan.

Therefore, upzoning in Zurich's context can be defined as a change in the FAR restrictions, such that the landowner can build more housing on the parcel of land than before (see Figure 3). Upzoning only takes place when a new zoning plan is passed. Zurich's 168 different municipalities only change their zoning plans infrequently (approximately every 15 to 20 years). When they upzone, they try to identify areas suitable for higher densities, such as areas close to train stations with good access to public transit. Furthermore, most cases of upzoning are relatively small changes in the allowed FAR ratio, e.g., by adding one or two more floors to the building.

4. Data and variable construction

To estimate the effects of upzoning, we rely on several data sources. Using these data, we construct a detailed data set that covers the Canton of Zurich[5] in Switzerland from 1995 to 2020.

4.1. Independent variable: Upzoning

The independent variable in our study is upzoning, i.e., changes in the floor to area ratio (FAR) that allow for more housing construction. To detect upzoning, we use detailed annual zoning plans from 1995-2018 in GIS, obtained from the Statistical Office of the Canton of Zurich. For residential areas, the zoning plans contain 76 different zoning codes. For operationalization, we convert these zoning codes into a variable that increases with higher FAR allowed. The methodology of converting the zoning codes into a numerical variable is described in Appendix A.

Using GIS, we then calculate the annual zoning change for each raster cell. Besides using this continuous variable, we also use a dummy for upzoning that equals one if a raster cell is upzoned by at least 20% and zero otherwise. We use the cut-off of 20% to account that sometimes only a small fraction of a raster cell is upzoned, meaning that the cell does not really qualify as treated.

4.2. Dependent variables: Housing supply and rents

We use two dependent variables: housing supply and rents. We measure housing supply as the change in square meters of living space on raster cell i in year t. To calculate the housing stock on each raster cell, we use data from the Federal Register of Buildings and Habitations published by the Swiss Federal Statistical Office (FSO). Changes in the housing

[5]For our empirical analysis to fit to our mono-centric city model, we would ideally focus on the agglomeration of the City of Zurich instead of the Canton of Zurich. However, approximately 19% of the agglomeration of Zurich lies not in the Canton of Zurich, but in the neighbouring Canton of Aargau (Bundesamt für Statistik, 2005). We have recently received the zoning data of the Canton of Aargau, and a next version of this paper will include the entire agglomeration of Zurich in accordance with our model.

stock are measured every five years. Up to 2020, the register contains approximately 850,000 housing units for the whole Canton of Zurich, 29.2% of which were built between 1995 and 2020. Using GIS, we calculate the five-year change in the square meters of living space on each raster cell.

For rents, we use detailed geo-coded web-scraped asking rents data from the data provider Meta-Sys. The data set contains approximately 600,000 postings of rental properties for the Canton Zurich from 2004 to 2020. In addition to asking rents, the data set includes comprehensive information on housing characteristics. Using these data, we calculate the average yearly hedonic and nominal rent per square meter for raster cell i in year t. For the hedonic rents, we control for the size, the number of rooms, and building age, as described in Appendix A.[6]

Since the housing stock is measured every five years, and zoning plans are only changed infrequently, we aggregate our data to five-year periods 1995, 2000, 2005, 2010, 2015, and 2020. Furthermore, we restrict our analysis to raster cells that have been zoned as residential in 1995. We do so because upzoning refers specifically to increasing density on parcels already zoned as residential and not to re-zoning, e.g., farmland for residential purposes (Freemark, 2020). To deal with possible spatial spillovers of the upzoning on nearby parcels, which is found by Asquith et al. (2021), we exclude raster cells that lie with more than 50% of their surface inside a 100 meter band around the upzoned units.

[6]As robustness, we compute an alternative hedonic rent, where we additionally control for whether a dwelling is a single-family home, has a garden, a balcony, parking, a garage, an elevator, a terrace, a chimney, a conservatory, or a view on the lake of Zurich.

Table 1: **Summary statistics of main variables**

	Mean	SD	Min	Max	N
Zoning	2.39	1.01	0	7.25	151,727
Dummy upzoning	0.04	0.20	0	1	151,727
Δ Zoning	0.01	0.15	-4.19	4.50	122,640
Floorspace	2,037	1,879	0	24,747	151,727
Δ Floorspace	0.06	0.27	-1.94	4.72	147,200
Nominal rent	22.05	6.39	5.14	60	37,187
Hedonic rent	3.28	0.26	1.88	4.63	36,971
Δ Hedonic rent	0.03	0.06	-0.52	0.61	19,486
Hist. rent	13.03	1.63	8.63	17.71	151,727
Buildings	6.87	5.23	1	67	151,727
Flats	23.21	25.91	1	190	151,727
Hist. flats	3.35	10.64	0	331.00	151,727
Dist. CBD	10.20	6.28	0.05	30.76	151,727
Dist. train	2.84	2.94	0	20.07	151,727
Age	71	50	3	1013	151,727
Right	0.47	0.10	0	0.72	151,727
Center	0.10	0.03	0	0.24	151,727
Left	0.24	0.06	0	0.35	151,727
Tax rate	0.11	0.01	0.09	0.12	151,727
Prop. tax share	0.12	0.05	0.02	0.34	151,727
Hist. own. rate	0.31	0.19	0.07	0.77	151,727
Supply elasticity	0.46	0.09	0.25	0.52	151,727

Notes: *Zoning* = numerical zoning indicator. *Dummy upzoning* = Dummy that equals 1 if a raster cell is upzoned by at least 20%. Δ *Zoning* = 5-year change in zoning. *Floorspace* = Total living surface in sqm. in a raster cell. Δ *Floorspace* = 5-year change in total living surface *Nominal rent* = Average rent per sqm. in a raster cell. *Hedonic rent* = Rents that are quality-adjusted for the living surface, the number of rooms, age, age squared, and building type. Δ *Hedonic rent* = 5-year change in hedonic rents. *Hist. rent* = Average municipality rent per sqm. in 1919. *Buildings* = Number of buildings in a raster cell. *Flats* = Number of flats in a raster cell. *Hist. flats* = Number of flats in a raster cell in 1919. *Dist. CBD* = Distance in km. from the centroid of each raster cell to the nearest CBD, either Zurich or Winterthur. *Dist. train* = Distance in km. from the centroid of each raster cell to the nearest train station. *Age* = Average age in years of the buildings in a raster cell. *Right*, *Center*, and *Left* = The share who voted for right, center, and left-wing parties in the 1991 Swiss national elections, respectively. *Tax rate* = Tax rate for single with a taxable income of 80,000. *Prop. tax share* = Property tax share of total municipal tax income. *Hist. own. rate* = Municipality ownership rate in 1980. *Supply elasticity* = Municipality price housing supply elasticity from Büchler et al. (2021).

4.3. Control variables

Furthermore, we use several control variables. First, we use the Federal Register of Buildings and Habitations to retrieve the number of buildings, the number of flats, the average age of the buildings, and the average floor that people live on for each raster cell. This allows us to control for the current built density level and the housing stock's age on a raster cell. Both are crucial variables regarding whether a parcel is selected for upzoning or not according to the Canton of Zurich (Kanton Zurich, 2015). For instance, parcels that are located in densely constructed neighborhoods are upzoned more often than those located in low-density single-family home neighborhoods. To further control for this, we also use the historical density of 1919 of each parcel, which corresponds to the first wave of the building census in Switzerland.

Second, we use the location of the raster cell as a control variable. Specifically, we calculate the distance of the raster cell centroid to the central train station of Zurich, which we define as the location of the central business district. Second, we also use the distance to the nearest 54 second-tier train stations served by at least two regional lines. These location measures capture whether the parcel is located close to public transit and close to the main employment centers of the canton. Both variables are necessary measures, as the Canton of Zurich intends to densify areas close to public transit and the urban employment centers to the environment (Kanton Zurich, 2015).

Third, we use several socioeconomic variables at the municipality level provided by the Swiss Federal Statistical Office (FSO). First, we use vote shares for left, center, and right parties in the 1991 national election. We also use the property tax rate in 1994, the overall tax rate on households in 1998, and the homeownership rate of 1990. We also use the housing supply price elasticity from (Büchler et al., 2021). Next, we use these variables in a logit regression to obtain the likelihood of upzoning of each parcel. Finally, to account for the endogeneity of these variables, we use fixed values before our period of observation starting in 1995. The logic here is that upzoning today cannot influence socioeconomic characteristics before the upzoning. Table 1 summarizes the final data set.

5. Empirical framework

5.1. Identifying the effect of upzoning

This section derives the specifications to test the theoretical predictions from our conceptual framework empirically. Throughout our main analysis, we use 100x100 meter raster cells as our constant unit of analysis. To ensure the robustness of our findings to different estimation methods, we use four different estimation techniques: (1) changes-on-changes regressions with a continuous zoning variable and a upzoning dummy, (2) a doubly robust regression using propensity score weights (Funk et al., 2011), (3) staggered difference-in-difference regressions (Athey and Imbens, 2021), and (4) a geographically weighted regressions to investigate spatial differences in the housing supply response.

The main difficulty for causally estimating the effects of upzoning is the potential endogeneity of upzoning. Upzoning is likely endogenous as municipalities choose the most suitable parcels for upzoning, e.g., parcels with good access to public transit or with old housing stock (see, e.g., Pogodzinski and Sass, 1994; McMillen, 2008). While we observe some of the determinants of upzoning, there are many factors that we do not observe. Omitting these factors would lead to an omitted variable bias in a simple OLS regression. Of these unobserved factors, some are constant over time, such as the ruggedness of a parcel. Thus, we can account for them with our panel data, e.g., through first-differencing.

However, other types of unobservables complicate the endogeneity problem. First, parcels may experience different unobserved trends over time. For instance, of two similar parcels, one could be located in a gentrifying neighborhood and hence, experience a stronger increase in rents than the other parcel. To address this problem, we implement a staggered difference-in-difference (DiD) estimation. Second, parcels' amenities may change over the 25 years of our analysis. For example, a new playground built next to the parcel increases rents and housing supply irrespective of changes in zoning (see, e.g., Gibbons and Machin, 2008). We do not have data on all such changes in amenities and therefore assume that changes in amenities over time are idiosyncratic rather than systematic. This means, e.g., that the construction of playgrounds does not follow a systematic pattern but is random across our sample. This assumption is plausible as our sample is extensive, encompassing thousands of parcels in 168 different municipalities. Thus, it is unlikely that there is a unified system of changes in amenities.

5.2. Changes-on-changes estimation

We begin our empirical analysis by exploiting the panel structure of our data to account for constant parcel-specific unobservables. Specifically, we use the following changes-on-changes specification to estimate the effect of upzoning on housing supply and rents:

$$\Delta_{t+1,t}\log\tau_i = \beta_0 + \beta_1(\Delta_{t+1,t}U_i) + \beta_2 C^{'}_{i,t} + \epsilon_{it}, \quad \tau = H,\, R, \tag{19}$$

where $\Delta_{t+1,t}\log\tau_i$ is either the change in log square meters of living space (H) or log hedonic rent per square meter (R) on raster cell i from period t to $t+1$. $\Delta_{t+1,t}U_i$ is the change in zoning, i.e., the change in the FAR code, on raster i from period t to $t+1$. $C^{'}_{i,t}$ is a vector of controls. Since we use a changes-on-changes specification, i.e., a type of first-differencing method, time-constant raster cell characteristics, such as the location or geography of the raster cell, are differenced out. Therefore, we only control for raster cell characteristics that could change. Thus, $C_{i,t}$ contains the average building age, age squared, and the number of buildings on the raster.[7] These variables are likely to change as houses may be built in areas that were not upzoned during our 25-year observation period. Standard errors are clustered at the municipality level, allowing for correlation in the error term of parcels within the same municipality over time. Column (1) of Tables 3 and 4 show the results of these regressions, providing a first benchmark of the effects of upzoning on housing supply and rents. We also estimate equation (19) using a dummy $T_{i,t}$ that equals one if a raster cell is upzoned by more than 20% from period t to $t+1$, instead of $\Delta_{t+1,t}U_i$. Column (2) of Tables 3 and 4 show the results of these regressions.

5.3. Doubly robust estimation

Second, we use a doubly robust regression specification (for more details see Funk et al., 2011; Wooldridge, 2010; Sant'Anna and Zhao, 2020). This method combines a form of outcome regression (i.e., changes-on-changes) with a model for the exposure (i.e., the propensity

[7] We chose our controls using the "post-double-selection" (PDS) methodology of Belloni et al. (2014).

score) to estimate the causal effect of an exposure on an outcome. The doubly robust estimation has the advantage that only one of the two regression models, either the logit (exposure) or the changes-on-changes regression (outcome), needs to be correctly specified to yield consistent estimates. Since in the Canton of Zurich parcels are upzoned based on observable factors such as location, proximity to train station, and age of the buildings, we can develop a reliable model to estimate the probability that a parcel is upzoned. Thus, we run a logit regression to estimate the likelihood of a raster cell being upzoned and calculate propensity scores p_i. Specifically, we estimate the following logit model:

$$Pr(U_{i,t} = 1|D_{i,t}, X_{i,t}, S_{i,t}) = \Phi(\theta_0 + \theta_1 D_{i,t} + \theta_2 X_{i,t} + \theta_3 S_{i,t}), \tag{20}$$

where Φ is the cumulative standard normal distribution function, and $U_{i,t}$ is a dummy that equals one if a raster cell is upzoned by more than 20% from period t to $t+1$. $D_{i,t}$ is a vector of variables, capturing the distance of the raster cell to the CBD and the nearest train station. $X_{i,t}$ is a vector of controls that change over time. It includes the number of flats on the raster cell, historical density, the average age of buildings on the raster cell, and age squared. S_i is a vector of socioeconomic variables, i.e., the share of center and left-wing voters in the 1991 national election, the tax rate, the property tax share, the homeownership rate, housing supply price elasticity, and a dummy for urban and suburban locations. To avoid reverse causality issues, we take all socioeconomic variables as constant values before our observation period, which starts in 1995. All socioeconomic variables are available at the municipality level only, while all other variables are at the raster cell level. We choose these covariates based on the Canton of Zurich documents that state that parcels for upzoning are chosen according to their location and housing stock (Kanton Zurich, 2015).

Column (1) of Table 2 shows the average marginal effects of the standardized coefficients of this logit regression. These estimates show which factors predict the upzoning in the Canton of Zurich and thus, contribute to the literature on understanding the determinants of land use regulation (see, e.g., Glaeser and Ward, 2009; Parkhomenko, 2020). Our estimation shows that the most important predictors of upzoning are the distance to the CBD, the municipality-level tax rate, the price housing supply elasticity, and whether the parcels are in an urban or suburban location. Regarding the distance to the CBD, our results indicate that most upzoning happens neither directly in the city center nor at the urban fringe. Rather it happens somewhere between, as indicated by the statistically significant square term of distance to the CBD. Moreover, municipalities with high tax rates upzone more. This is consistent with Schmidheiny (2006a) and Schmidheiny (2006b) who find that rich low-density municipalities set lower tax rates. Lastly, urban parcels are more likely to be upzoned.

Next, we re-estimate equation (20), but using municipality fixed effects instead of constant raster characteristics. Thus, we estimate:

$$Pr(U_{i,t} = 1|D_{i,t}, X_{i,t}, \zeta^j) = \Phi(\theta_0 + \theta_1 D_{i,t} + \theta_2 X_{i,t} + \zeta^j), \tag{21}$$

where Φ is the cumulative standard normal distribution function, and $U_{i,t}$ is a dummy that equals one if a raster cell is upzoned by more than 20% from period t to $t+1$. $D_{i,j}$ is a vector of distance variables, and $X_{i,j,t}$ is a vector of raster cell specific housing characteristics of raster cell i in municipality j in period t. ζ^j denotes municipality fixed effects. Column (2) of Table 2 shows the average marginal effects.

Note that the municipality-specific time-constant attributes of vector $S_i^{'}$ are accounted for by the municipality fixed effect. Thus, this specification leads to superior propensity scores than Equation (20) as the fixed effects account for unobserved municipality-specific confounders. For the calculation of the propensity score, we, therefore, use these estimates.

We use the propensity scores p_i to obtain inverse probability weights, calculated as $(1/p_i)$ for treated units and $1/(1-p_i)$ for untreated units (Li et al., 2018). Then, we use these weights as probability weights to re-estimate Equation (19). However, we substitute $U_{i,t}$ with the zoning dummy $T_{i,t}$, as we need a binary zoning variable to estimate the logit models. Standard errors are clustered at the municipality level. Column (3) of Tables 3 and 4 show the results of these regressions.

Table 2: **Logit regression, average marginal effects, 100m raster**

	(1)	(2)
Flats	0.004***	0.004***
Hist. flats	-0.003***	-0.002***
Dist. CBD	0.043***	0.063***
Dist. CBD sq.	-0.017***	-0.074***
Dist. train	-0.008***	-0.009
Dist. train sq.	0.005**	-0.001
Age	-0.011***	-0.012***
Age sq.	0.005**	0.006***
Center	-0.012***	
Left	-0.007***	
Tax rate	0.011***	
Prop. tax share	-0.005***	
Hist. rent	0.013***	
Hist. own. rate	-0.006***	
Supply elasticity	-0.023***	
Suburb	0.029***	
Urban	0.046***	
Municipality FE	No	Yes
Observations	151,727	151,727

Notes: *** p<0.01, ** p<0.05, * p<0.1. Dependent variable: The dependent variable is a dummy, equaling 1 if a raster cell is upzoned by at least 20%. *Flats* = Number of flats in a raster cell. *Hist. flats* = Number of flats in a raster cell in 1919. *Dist. CBD* = Distance in km. from the centroid of each raster cell to the nearest CBD, either Zurich or Winterthur. *Dist. train* = Distance in km. from the centroid of each raster cell to the nearest train station. *Age* = Average age in years of the buildings in a raster cell. *Age Sq.* = average age squared. *Hist. rent* = Average municipality rent per sqm. in 1919. *Right*, *Center*, and *Left* = The share who voted for right, center, and left-wing parties in the 2015 Swiss national elections, respectively. *Tax rate* = Tax rate for single with a taxable income of 80,000. *Prop. tax share* = Property tax share of total municipal tax income. *Hist. own. rate* = Municipality ownership rate in 1980. *Supply elasticity* = Municipality price housing supply elasticity from Büchler et al. (2021). *Suburban, Urban* = Categorical dummy for whether the municipality is in the urban center, suburban, or rural.

5.4. Staggered difference-in-difference estimation

Third, we use a staggered difference-in-difference estimation strategy, following Athey and Imbens (2021). This approach allows us to identify the effect of upzoning by comparing similar parcels, some of which were upzoned while others were not. This approach works well because we have data from 168 different municipalities, which upzone[8] in different periods independently, resulting in an exogenous variation in the treatment assignment (see also Callaway and Sant'Anna, 2020; Goodman-Bacon, 2021). We estimate the following model:

$$\log\tau_{i,t} = \beta_0 + \beta_{\mathbf{1}}\mathbf{D_{i,t}} + \zeta^t + \zeta^i + \epsilon_{it},\ \tau = H,\ R, \tag{22}$$

where $\log\tau_{i,t}$ is the five-year lead log-level of the square meters of living space or the average hedonic rent per square meter on raster cell i. The variable of interest $\mathbf{D_{i,t}}$ is a dummy equal to one in all periods after the raster cell has been upzoned by 20% or more, and zero otherwise. ζ^t are period-fixed effects and ζ^i are raster cell fixed effects, accounting for all constant period and raster-specific effects. Standard errors are clustered at the municipality level. Column (4) of Tables 3 and 4 shows the results

However, this specification has the potential problem that the control group may not be suitable for the treated units since the control group contains all non-upzoned parcels. Thus, our DiD model in Equation (22) may overestimate the effect of upzoning. To account for this problem, we follow Callaway and Sant'Anna (2020). Theuy use propensity score matching to construct control groups for treated units when the parallel trends assumption holds when controlling for observables. The intuition is to use units with a similar likelihood of being treated as control group, i.e., units with similar propensity scores to the treated ones.

Therefore, we use the propensity score to select the control group. Specifically, we exclude all observations whose propensity score is lower than the 10^{th}-percentile of the distribution of the propensity score of the treated units, which is a propensity score of 0.03. This significantly reduces our sample but makes the control group more suitable for the treated units. Column (5) of Tables 3 and 4 show the results of these regressions.

[8]Note that we also have municipalities that downzone. However, they account for less than 5% of our observations.

5.5. *Geographically weighted estimation*

Our model predicts that the effect of upzoning on housing supply within the metropolitan area will vary across locations, depending on their proximity to the CBD. Thus, to see how the effect of upzoning on housing supply varies across space, we use geographically weighted regressions (GWR). GWR is a form of kernel-weighted regression, allowing coefficients to vary across space (Brunsdon et al., 1998). It estimates coefficients as:

$$\hat{\beta}_i = (X^T W_i X)^{-1} X^T W_i y, \tag{23}$$

where Wi is a weight matrix calibrated separately for each location i. Using ArcGIS, we use this technique to estimate the changes-on-changes regression for housing supply in Equation (19) using ArcGIS. As bandwidth, we choose a 10 km distance band. This value minimizes the Akaike and guarantees the inclusion of observations from different municipalities in the weight matrix.[9] Figure 4 depicts the results.

6. Results

6.1. *Housing Supply*

Table 3 summarizes the results of the effects of upzoning on housing supply. Column (1) shows the results of regressing the 5-year change in zoning on the lead 5-year change square meters of total living surface on each raster. We find that a 10% increase in zoning leads to a 1.2% increase in housing supply in the subsequent five years. Column (2) shows the results of regressing our zoning dummy, which equals one if a raster cell is upzoned by at least 20% and zero otherwise, on the lead 5-year change in total living surface. As can be seen, housing supply increases by 6.6 percentage points more in an upzoned parcel compared to a non-treated one. Column (3) shows the results of regressing our zoning dummy on the lead 5-year change in total living surface weighted by the propensity scores computed with the logit regression. The doubly robust estimate is even larger, showing that housing supply increases by 9.5 percentage points more in an upzoned parcel compared to a non-treated one. In these regressions, we control for the initial number of buildings, the average age of

[9] Note that varying the bandwidth between 5 km and 20 km does not substantially change the results.

Table 3: **Housing supply results, changes 1995-2020 100m raster**

	(1)	(2)	(3)	(4)	(5)
	Δ on Δ	Dummy	Doubly robust	DiD	PSM DiD
Δ Zoning	0.123***				
	(0.034)				
Dummy upzoning		0.066***	0.095***		
		(0.018)	(0.030)		
DiD treatment				0.155***	0.096***
				(0.027)	(0.030)
Buildings	-0.008***	-0.008***	-0.094***		
	(0.001)	(0.001)	(0.010)		
Age	0.005***	0.005***	0.061***		
	(0.001)	(0.001)	(0.009)		
Age sq.	-0.000**	-0.000***	-0.001***		
	(0.000)	(0.000)	(0.000)		
Raster cell FE	No	No	No	Yes	Yes
Period FE	No	No	No	Yes	Yes
Observations	99,929	99,929	99,929	99,929	16,036

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable in columns (1)-(3) is the lead 5-year log change in square meters of living space on raster i from period t to $t+1$. The dependent variable in columns (4) and (5) is the lead 5-year log-level sum of square meters of living space on raster i. Δ *Zoning* is the first difference of the continuous zoning variable, i.e. the change in zoning. *Dummy upzoning* is a dummy that equals one if the raster is upzoned by 20 percent or more in period t and zero otherwise. *DiD treatment* is a dummy that equals one in the period when the raster is upzoned by 20 percent or more and in all subsequent periods. *Buildings* is the number of buildings on raster i, measured in hundreds of buildings. *Age* is the average building age on raster i in periods t, measured in decades. Standard errors are clustered at the municipality level.

the buildings, and the squared average age of buildings in a raster cell, as these factors may change over time.

Columns (4) and (5) show the staggered difference-in-difference estimation results. When using all never-upzoned units as the control group, we find that upzoning a raster cell by 20% or more leads to an average increase of 15.5% in the housing supply. When using our restricted control group, upzoning a raster cell by 20% or more leads to an average of 9.6% more housing supply. This slightly smaller coefficient is expected as we only consider raster cells with similar observable features with the treatment group. Overall, our results are very robust across the different estimation techniques. These results show that upzoning increases housing supply locally in an economically and statistically significant manner in the subsequent five years.

Our findings are thus in line with Anagol et al. (2021), Chiumenti et al. (2021), and Dong (2021), who also finds that upzoning increases local housing supply, and contradict Freemark (2020), who found no effect of upzoning on housing supply. Our results show that upzoning is an effective policy to increase the local housing supply.

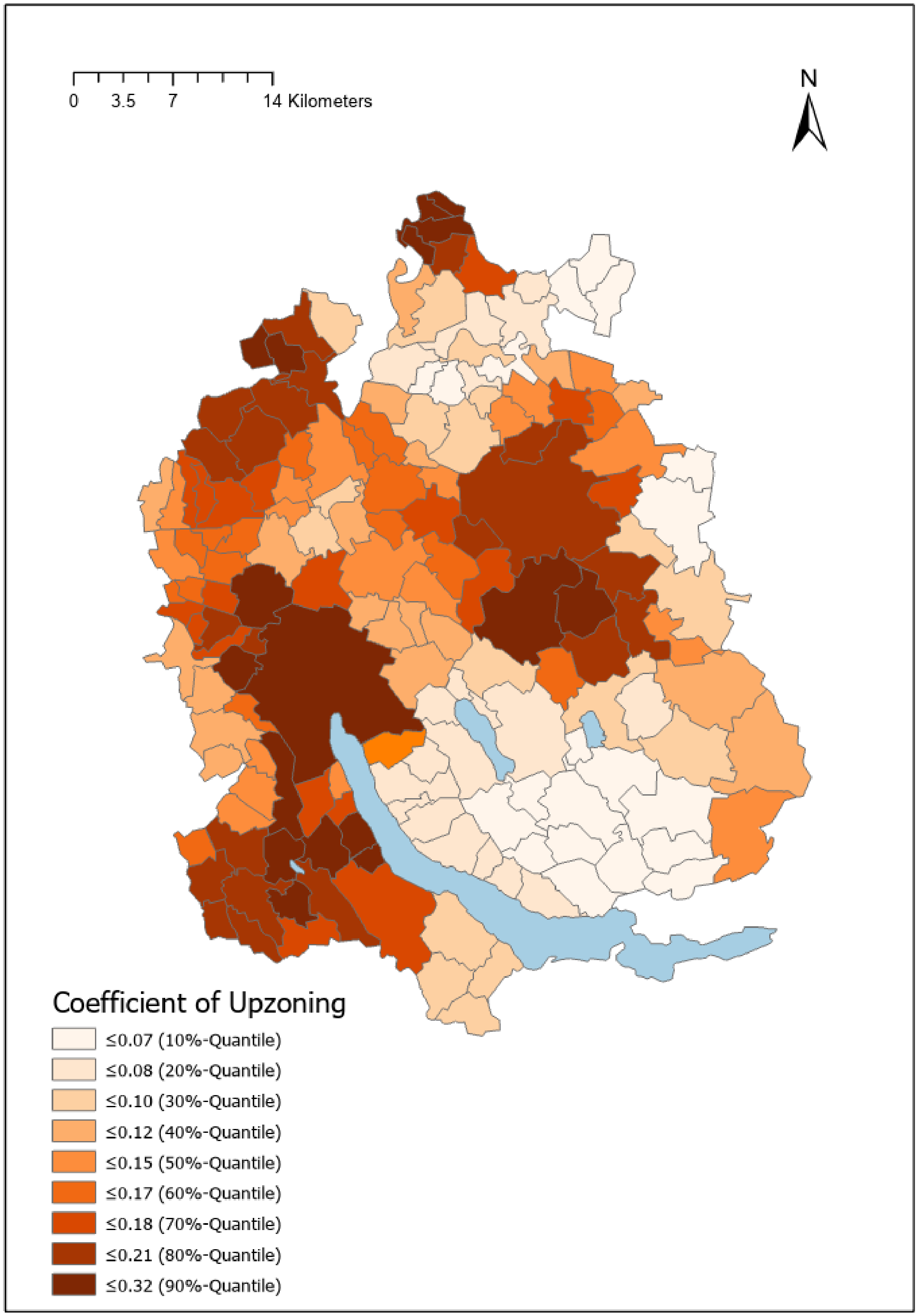
The results of the GWR estimation show that the response to upzoning varies strongly across space. If a raster cell is upzoned by at least 20%, this leads to an increase of housing supply between one percentage point to 42 percentage points. Since GWR produces different coefficients for each raster cell, coefficients cannot be shown in a table but are aggregated at the municipality level and then visualized in a map. As shown in Figure 4, the housing supply response to upzoning tends to be higher in urban areas, such as Zurich or Winterthur. This finding is in line with economic theory, as housing demand may be higher in these central locations. Furthermore, the coefficients of upzoning are statistically significant at least at the 10% level in over 95% of cases, further demonstrating the positive effect of upzoning on housing supply across different types of municipalities.

6.2. Rents

Table 4 shows the effects of upzoning on rents. Similar to Table 3, Columns (1), (2), and (3) show the results of regressing the 5-year change in zoning, our zoning dummy, the weighted zoning dummy, on the lead 5-year change in hedonic rents. Columns (4) and (5) show the staggered difference-in-difference estimation results. Since the Canton of Zurich is an integrated housing market, our spatial equilibrium framework predicts that the local increase in housing supply following an upzoning leads to a hedonic rent decrease in the entire housing market. In other words, the local rent effect dissipates in the whole housing market. Thus, to estimate the effect of upzoning for the whole housing market, we would need a general equilibrium model, which lays outside the scope of this paper.[10] One way to find a significant difference in rent effect between upzoned and non-upzoned rasters using partial analysis is if household utility decreases (or increases) with density. If households dislike density, then upzoning, which leads to higher density (see Section 2), can cause lower

[10]Note that we would also need data for all of Switzerland since the housing markets are very connected in such a small country. Unfortunately, this data is currently not available.

Figure 4: Spatial Variation of Effect of Upzoning on Housing Supply



This figure shows the average coefficient of upzoning on housing supply at the municipality-level estimated with GWR described in section 5. A darker color shows a larger coefficient.

Table 4: **Hedonic rents Results, 1995-2020 100m raster**

	(1)	(2)	(3)	(4)	(5)
	Δ on Δ	Dummy	Doubly robust	DiD	PSM DiD
Δ Zoning	-0.004				
	(0.003)				
Dummy upzoning		-0.005**	-0.010		
		(0.003)	(0.018)		
DiD treatment				-0.002	-0.014
				(0.005)	(0.010)
Buildings	-0.000	-0.000	0.002		
	(0.000)	(0.000)	(0.002)		
Age	0.002***	0.002***	0.010***		
	(0.000)	(0.000)	(0.004)		
Age sq.	-0.000***	-0.000***	-0.000		
	(0.000)	(0.000)	(0.000)		
Raster cell FE	No	No	No	Yes	Yes
Period FE	No	No	No	Yes	Yes
Observations	20,102	20,102	20,102	20,102	4,890

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable in columns (1)-(3) is the lead 5-year log change in hedonic rent per square meter of living space on raster i from period t to $t+1$. The dependent variable in columns (4) and (5) is the lead 5-year log-level average hedonic rent per square meter of living space on raster i. Δ *Zoning* is the first difference of the continuous zoning variable, i.e. the change in zoning. *Dummy upzoning* is a dummy that equals one if the raster is upzoned by 20 percent or more in period t and zero otherwise. *DiD treatment* is a dummy that equals one in the period when the raster is upzoned by 20 percent or more and in all subsequent periods. *Buildings* is the number of buildings on raster i, measured in hundreds of buildings. *Age* is the average building age on raster i in periods t, measured in decades. Standard errors are clustered at the municipality level.

hedonic rents in upzoned rasters compared to non-upzoned ones. Our findings show that the density disutilty is small to non-existent. A 10% increase in zoning leads to only a 0.04% decrease in local rents and the estimate is not statistically different from zero. Rents decrease by 0.5 to 1 percentage points more in an upzoned parcel compared to a non-treated one in the five years following an upzoning, but only the estimate in Column (2) is statistically significant.

The difference-in-difference estimation results confirm that upzoning does not lead to a significant difference in rents between upzoned and non-upzoned parcel cells. When using all never-upzoned units as the control group in Column (4), we find that upzoning a raster by 20% or more leads to a zero effect on rents. When using our restricted control group, our estimate in Column (5) shows that upzoning a raster by 20% or more leads to a decrease in rents of 0.1%. However, non of these effects is statistically significant. In sum, our results confirm the predictions of our theoretical framework that upzoning will not lower rents on the upzoned parcel cells compared to non-treated parcel cells within the same city.

7. Conclusion

This paper investigates the local effect of upzoning on housing supply and rents, as well as its variation in space. Building on the monocentric-city model, we develop a spatial equilibrium framework that compares a city with varying FAR restrictions. We bring the model to the data using a detailed geo-coded panel data set on zoning, housing characteristics, and rents from 1995 to 2020 on the Canton of Switzerland. We find that local upzoning, i.e., locally relaxing the FAR restriction, leads to a significant local increase in housing supply. Moreover, upzoning leads to a negligible difference in rents between upzoned and non-upzoned parcels since, as predicted by our framework, the rent effect dissipates across the entire city. Looking at these effects at the intra-municipality level, we address a gap in the literature that has focused on land use regulation at the regional level.

Our findings hold valuable lessons for public policies looking to increase the housing supply to help affordability. This study shows that upzoning is a viable policy instrument to increase the housing supply. All else equal, the additional housing supply helps to make housing more affordable. Thus, allowing the private market to supply more housing by relaxing land use regulations is essential in addressing the housing affordability crisis in many cities across the globe.

Furthermore, this paper adds a nuance to this general understanding. We show that upzoning leads to stronger housing supply responses in upzoned parcels than non-upzoned ones. This is because developers try to compensate for the strict regulations elsewhere. For the upzoned areas' inhabitants, this means that the density in their neighborhood may increase significantly. However, our theoretical and empirical analysis shows that the benefits of upzoning - which come in the form of lower rents - are relatively evenly distributed across the entire city and - controlling for density disutility - are not stronger in upzoned parcels. In conjunction, this may cause public acceptance problems for upzoning neighborhoods, a problem commonly known as NIMBYism (short for not-in-my-backyard). Thus, our study highlights the importance of research on how the costs and benefits of changes in land use regulations are shared among cities' households.

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Appendix A. Data

Appendix A.1. Construction of Zoning Variable

This section describes the conversion of the description of the zoning codes to numerical variables. The zoning codes in the Canton of Zurich describe the type of housing landowners can build on their land. The Statistical Office of the Canton of Zurich has harmonized these descriptions across all municipalities, allowing for a cross-municipality comparison. The numerical codes are short and contain information on the floor-to-area ratio, the height, and the type of housing landowners can build. For example, the code "one-story single-family home" means that landowners can build only single-family homes with a maximum of one story and must also adhere to parking lot requirements and minimum distances to the street and the next house. We code "one-story single-family home" as one, "two-story single-family home" as two, and so on. Thus, the lowest value of our numerical zoning variable is 0.75 for "low-density one-story single-family home", and the highest is 7.25 "high-density seven-story + apartment building". Whenever there are different zoning codes on one raster cell, we choose the weighted average of these zones.

To obtain a unit of analysis that is constant over time, we divide the entire surface of the Canton of Zurich into 100x100 meter raster cells. This is necessary because the polygons in the zoning plans change over time. We then calculate the weighted average zone on raster cell i in year t as:

$$Average\ Zone_{i,t} = \frac{Zone_{i,t} \cdot Shape\ Area_{i,t}}{10,000} \tag{A.1}$$

Appendix A.2. Hedonic Rent Estimation

Upzoning is likely to lead to construction of new housing units. These new housing units are likely to have higher nominal rents, as they are new buildings with new bathrooms and kitchens. To control for this difference in the quality of the housing stock on a raster cell prior and after the upzoning, we use hedonic rents. Hedonic rents control for quality of the housing stock, thereby providing an implicit price of housing (Rosen, 1974). We estimate the hedonic rents separately for all years from 2004 to 2020 as:

Table B.5: **Housing supply results, changes 1995-2020, 500m raster**

	(1)	(2)	(3)	(4)	(5)
	Δ on Δ	Dummy	Doubly robust	DiD	PSM DiD
Δ Zoning	0.100***				
	(0.030)				
Dummy upzoning		0.083***	0.055**		
		(0.019)	(0.024)		
DiD treatment				0.141***	0.081
				(0.029)	(0.053)
Buildings	-0.000***	-0.000***	-0.006***		
	(0.000)	(0.000)	(0.002)		
Age	0.003	0.003*	0.126***		
	(0.002)	(0.002)	(0.025)		
Age sq.	-0.000***	-0.000***	-0.004***		
	(0.000)	(0.000)	(0.001)		
Raster cell FE	No	No	No	Yes	Yes
Period FE	No	No	No	Yes	Yes
Observations	8,728	8,728	8,728	8,728	1,268

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable in columns (1)-(3) is the lead 5-year log change in square meters of living space on raster i from period t to $t+1$. The dependent variable in columns (4) and (5) is the lead 5-year log-level sum of square meters of living space on raster i. *Δ Zoning* is the first difference of the continuous zoning variable, i.e. the change in zoning. *Dummy upzoning* is a dummy that equals one if the raster is upzoned by 20 percent or more in period t and zero otherwise. *DiD treatment* is a dummy that equals one in the period when the raster is upzoned by 20 percent or more and in all subsequent periods. *Buildings* is the number of buildings on raster i, measured in hundreds of buildings. *Age* is the average building age on raster i in periods t, measured in decades. Standard errors are clustered at the municipality level.

$$R_{i,t} = \beta_0 + \beta_1 N_{i,t} + \beta_2 A_{i,t} + \beta_3 A2_{i,t} + \beta D'_{i,t} + \varepsilon_{i,t}, \tag{A.2}$$

where $R_{i,t}$ is the log rent per square meter for apartment i in year t. $N_{i,t}$ is the number of rooms. $A_{i,t}$ is the building age. We also include a square term, $A2_{i,t}$. $D'_{i,t}$ is a vector of dummy variables equalling one if the object is a single-family home, has a garden, a balcony, parking, a garage, an elevator, a terrace, a chimney, a conservatory or a view on the lake of Zurich. We use robust standard errors. We also try other regression specifications for hedonic rents, and our results remain largely unchanged.

Table B.6: **Hedonic rents results, changes 1995-2020, 500m raster**

	(1)	(2)	(3)	(4)	(5)
	Δ on Δ	Dummy	Doubly robust	DiD	PSM DiD
Δ Zoning	-0.004				
	(0.005)				
Dummy upzoning		-0.002	-0.004		
		(0.005)	(0.007)		
DiD treatment				-0.000	0.026***
				(0.006)	(0.003)
Buildings	0.000***	0.000***	0.000		
	(0.000)	(0.000)	(0.000)		
Age	0.002***	0.002***	0.016**		
	(0.000)	(0.000)	(0.008)		
Age sq.	-0.000***	-0.000***	-0.001		
	(0.000)	(0.000)	(0.001)		
Raster cell FE	No	No	No	Yes	Yes
Period FE	No	No	No	Yes	Yes
Observations	4,091	4,091	4,091	4,091	858

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable in columns (1)-(3) is the lead 5-year log change in hedonic rent per square meter of living space on raster i from period t to $t+1$. The dependent variable in columns (4) and (5) is the lead 5-year log-level average hedonic rent per square meter of living space on raster i. Δ *Zoning* is the first difference of the continuous zoning variable, i.e. the change in zoning. *Dummy upzoning* is a dummy that equals one if the raster is upzoned by 20 percent or more in period t and zero otherwise. *DiD treatment* is a dummy that equals one in the period when the raster is upzoned by 20 percent or more and in all subsequent periods. *Buildings* is the number of buildings on raster i, measured in hundreds of buildings. *Age* is the average building age on raster i in periods t, measured in decades. Standard errors are clustered at the municipality level.

Appendix B. Modifiable areal unit problem

According to Briant et al. (2010), the stability of our results might vary depending on the aggregation level and therefore suffer from the modifiable area unit problem. This is a common problem in geo-spatial analysis and can suggest that the model specification suffers from omitted variable bias. Thus, as a robustness check, we re-estimate our models using larger raster cell sizes. Specifically, as alternative raster sizes, we choose raster cells of 500x500 meters and 1x1 kilometers. Tables B.5 and B.6 and Tables B.7 and B.8 show the results for these specifications, respectively. Compared to the 100x100 meter estimations, the results only change minimally. This shows that our results are robust to the modifiable unit problem.

Table B.7: **Housing supply results, changes 1995-2020, 1000m raster**

	(1)	(2)	(3)	(4)	(5)
	Δ on Δ	Dummy	Doubly robust	DiD	PSM DiD
Δ Zoning	0.089***				
	(0.034)				
Dummy upzoning		0.070***	0.036**		
		(0.020)	(0.017)		
DiD treatment				0.077***	0.096
				(0.025)	(0.098)
Buildings	-0.000***	-0.000***	-0.000		
	(0.000)	(0.000)	(0.001)		
Age	-0.002	-0.002	0.160***		
	(0.002)	(0.002)	(0.031)		
Age sq.	-0.000	-0.000	-0.005***		
	(0.000)	(0.000)	(0.001)		
Raster cell FE	No	No	No	Yes	Yes
Period FE	No	No	No	Yes	Yes
Observations	3,112	3,112	3,112	3,112	466

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable in columns (1)-(3) is the lead 5-year log change in square meters of living space on raster i from period t to $t+1$. The dependent variable in columns (4) and (5) is the lead 5-year log-level sum of square meters of living space on raster i. Δ *Zoning* is the first difference of the continuous zoning variable, i.e. the change in zoning. *Dummy upzoning* is a dummy that equals one if the raster is upzoned by 20 percent or more in period t and zero otherwise. *DiD treatment* is a dummy that equals one in the period when the raster is upzoned by 20 percent or more and in all subsequent periods. *Buildings* is the number of buildings on raster i, measured in hundreds of buildings. *Age* is the average building age on raster i in periods t, measured in decades. Standard errors are clustered at the municipality level.

Appendix C. Nominal rents

This section shows the results of our estimations of the effect of upzoning on rents, using nominal instead of hedonic rents. The estimation strategy in Columns (1), (2), (3), (4), and (5) corresponds precisely to the one in our main results Table 4. We show the results of the nominal rents to investigate the hypothesis that upzoning leads to the construction of high-end, high-quality, and high-price housing units.[11] However, we find no significant effect of upzoning on nominal rents.

Table B.8: **Hedonic rents results, changes 1995-2020, 1000m raster**

	(1)	(2)	(3)	(4)	(5)
	Δ on Δ	Dummy	Doubly robust	DiD	PSM DiD
Δ Zoning	0.003				
	(0.009)				
Dummy upzoning		0.002	-0.000		
		(0.005)	(0.012)		
DiD treatment				-0.002	-0.001
				(0.005)	(0.003)
Buildings	0.000***	0.000***	0.000		
	(0.000)	(0.000)	(0.000)		
Age	0.000	0.000	0.020**		
	(0.001)	(0.001)	(0.009)		
Age sq.	-0.000	-0.000	-0.001		
	(0.000)	(0.000)	(0.001)		
Raster cell FE	No	No	No	Yes	Yes
Period FE	No	No	No	Yes	Yes
Observations	1,686	1,686	1,686	1,686	312

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable in columns (1)-(3) is the lead 5-year log change in hedonic rent per square meter of living space on raster i from period t to $t+1$. The dependent variable in columns (4) and (5) is the lead 5-year log-level average hedonic rent per square meter of living space on raster i. Δ *Zoning* is the first difference of the continuous zoning variable, i.e. the change in zoning. *Dummy upzoning* is a dummy that equals one if the raster is upzoned by 20 percent or more in period t and zero otherwise. *DiD treatment* is a dummy that equals one in the period when the raster is upzoned by 20 percent or more and in all subsequent periods. *Buildings* is the number of buildings on raster i, measured in hundreds of buildings. *Age* is the average building age on raster i in periods t, measured in decades. Standard errors are clustered at the municipality level.

Appendix D. Historical density

To investigate whether the effect of upzoning is different in areas that where historically dense (i.e., the historic centers of towns and villages), we interact our zoning variables with the number of flats in 1919 on a raster cell. The historic number of flats serves as a proxy for historical density. Table D.10 shows the results. We find that higher historical density lowers the effect of upzoning on housing supply. Although the effect is statistically significant, the magnitude is small. A 10% change in zoning leads to a 1.36% change in housing supply in raster cell at the 25$^{\text{th}}$ percentile of historical density, whereas it leads to a 13% change for one at the 75$^{\text{th}}$ percentile of historical density in the subsequent five years. Housing supply

[11] Note that our hedonic rent results abstract from rent increases driven by higher quality housing.

Table C.9: **Nominal rents results, changes 1995-2020, 100m raster**

	(1)	(2)	(3)	(4)	(5)
	Δ on Δ	Dummy	Doubly robust	DiD	PSM DiD
Δ Zoning	-0.013				
	(0.013)				
Dummy upzoning		-0.014	-0.021		
		(0.009)	(0.064)		
DiD treatment				-0.012	-0.066
				(0.017)	(0.038)
Buildings	0.000	0.000	0.004		
	(0.000)	(0.000)	(0.009)		
Age	0.009***	0.009***	0.032***		
	(0.001)	(0.001)	(0.012)		
Age sq.	-0.000***	-0.000***	-0.000		
	(0.000)	(0.000)	(0.000)		
Raster cell FE	No	No	No	Yes	Yes
Period FE	No	No	No	Yes	Yes
Observations	20,283	20,283	20,283	20,283	4,920

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable in is the lead 5-year log-change in nominal rents on raster i. We use a 5-year lead to account for the fact that it takes several years for rents to adjust to zoning changes. $\Delta_{t+1,t}$ is the first difference of the continuous zoning variable. Dummy zoning is a dummy that equals one if the raster was upzoned by 20 percent or more. Number of buildings is measured in hundreds of buildings and age in decades. Standard errors are clustered at the municipality level.

increases by 6.9-10.6 percentage points more in an upzoned parcel at the 25$^{\text{th}}$ percentile of historical and 6.6-9.7 percentage points more in an upzoned parcel at the 75$^{\text{th}}$ percentile of historical density compared to a non-treated one.

Table D.10: **Interaction with historical density, raster 1995-2020, 100m raster**

	(1)	(2)	(3)
	Δ on Δ	Dummy	Doubly robust
Δ Zoning	0.136***		
	(0.035)		
Dummy upzoning		0.069***	0.106***
		(0.019)	(0.033)
Hist flats $\times$ Δ zoning	-0.002***		
	(0.001)		
Hist flats $\times$ dummy upzoning		-0.001**	-0.003*
		(0.000)	(0.002)
Buildings	-0.007***	-0.008***	-0.093***
	(0.001)	(0.001)	(0.010)
Age	0.005***	0.005***	0.061***
	(0.001)	(0.001)	(0.009)
Age sq.	-0.000**	-0.000***	-0.001***
	(0.000)	(0.000)	(0.000)
Observations	99,929	99,929	99,929

Notes: *** p<0.01, ** p<0.05, * p<0.1. The dependent variable in columns (1)-(3) is the lead 5-year log change in square meters of living space on raster i from period t to $t+1$. Δ *Zoning* is the first difference of the continuous zoning variable, i.e. the change in zoning. *Dummy upzoning* is a dummy that equals one if the raster is upzoned by 20 percent or more in period t and zero otherwise. *DiD treatment* is a dummy that equals one in the period when the raster is upzoned by 20 percent or more and in all subsequent periods. *Buildings* is the number of buildings on raster i, measured in hundreds of buildings. *Age* is the average building age on raster i in periods t, measured in decades. Standard errors are clustered at the municipality level.