Residential Vertical Rent Gradients in the City*

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Abstract

We analyze the determinants of the bid-rent function for vertical locations within residential buildings using rooftop quality geocoded rental price data. We find that residential bidders value the ease of access that is intrinsically offered on the ground floor by paying between 1.5-3% ground floor premium. Our analysis shows that the ground floor premium is indeed a valuation of access similar to the valuation of access to the Central Business District (CBD) in a monocentric setting and that the ground floor premium is equivalent to moving between 250-450 meters closer to the CBD in the cities in our sample. Our empirical framework provides a starting point for the analysis of vertical residential sorting. More precisely, we find evidence of heterogeneous house price spillovers at different vertical locations that manifest via gentrification.

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1 Introduction

Since its origin, a key concern of the standard model of urban economics as developed by Alonso (1964), Mills (1967) and Muth (1969) has been the analysis of house price patterns at different locations within a metropolitan area.[1] However, the model only allows for a very limited treatment of verticality and in essence implicitly assumes the existence of only one house price at a given location within a city.[2] In practice, this is not the case as the possibility of vertical housing implies a distribution of prices at any horizontal location in the city. This paper addresses this gap by analysing the bid-rent function for vertical locations within residential buildings. We find rental prices within buildings to follow a non-monotonic gradient, in which higher floors command increasingly higher prices, with the ground floor being the exception as it is valued with a premium paid for the easy access to the road it exclusively provides.

In this paper, identification comes from *within* building variation of rental prices per square meter. In particular, the analysis controls for any time-invariant building-specific characteristics, such as construction year, that could influence the variation in rental prices. Furthermore, we restrict the sample of buildings to those that were built prior to the start of rental price sample period in order to avoid the simultaneity bias that results from newly developed or renovated buildings commanding higher prices. To complement the within building identification, we include both grid-year and municipality-year fixed effects. On the one hand, the 100x100m grid-year cell fixed effects control for very local neighborhood characteristics that are time varying, e.g. improvements to the local park that makes the environment more attractive, putting upward pressure on rental prices. On the other hand, municipality-year fixed effects account for local policies at the municipal level that have an impact on rental prices, i.e. municipalities enjoy fiscal autonomy on both public expenditures and tax revenues. These factors are likely to be capitalized into local rental prices (Oates (1969); Black (1999); Bayer, Ferreira and McMillan (2007); Fack and Grenet (2010); Gibbons, Machin and Silva (2013)).

Our analysis yields three main results. First, the ground floor premium is driven by upper floor access costs (lack of a lift) rather than ground floor amenities (e.g. a garden). More precisely, a building that has no lift will exhibit a ground floor premium, while a building that that hosts a lift service will display a greatly reduced ground floor premium. Second, the ground floor premium ranges between 1.5% and 3%, which is in line, in terms of statistical significance, with estimates provided by Liu, Rosenthal and Strange (2015) in an analysis of commercial buildings.[3] In

[1]See Brueckner (1987) for an excellent unification of the models.

[2]Residential development can employ varying levels of capital-to-land at different locations within the city, which functions as a proxy for building height.

[3]Liu et al. (2015) find ground floor premia that range between 30-50%.

comparison to the standard urban model, the ground floor premium corresponds to a consumer locating approximately 250 to 450 meters closer to the central business district (CBD). Third, the vertical rent gradient is indeed convex, i.e. upper floors command higher prices per square metre. Intuitively, this result can be explained by amenities (e.g. views) that compensate consumers for the lack of easy access to the street, which is similar to the result in Liu et al. (2015) that produces sorting within a commercial building where access-oriented retailers bid for lower floors and amenity-oriented firms bid for upper floors.

This paper contributes to the literature in various ways. First, we are among the first to study the vertical rent gradient within residential buildings using detailed geocoded micro data on observed rental prices. Second, we show that the vertical rent gradient exists at varying horizontal locations within the city, but becomes less pronounced at further horizontal locations from the CBD. That said, the ground floor premium, may not necessarily appear at all horizontal locations within the city. Finally, in line with Guerrieri, Hartley and Hurst (2013), we find empirical results that are consistent with residential sorting manifesting through gentrification of cheaper rental price areas.[4] More precisely, we find that the rental prices of upper floor apartments experience higher growth, on average, the closer the municipality is to relatively more expensive municipalities. In a similar fashion, lower floor apartments tend to benefit from being closer to the CBD. In summary, the rental price growth patterns are consistent with the gentrification story proposed in Guerrieri et al. (2013) as well as the access versus amenity trade-off in urban resident bidding functions.

The remainder of the paper is structured as follows. Section 2 briefly covers relevant literature as well as a theoretical framework that underpins our empirical analysis of the vertical rent gradient. Section 3 describes the data we use. Sections 4 and 5 explain our empirical framework and ensuing results. Finally, section 6 concludes.

2 Literature Review

In a unified analysis of spatial economic regularities, Brueckner (1987) discusses patterns of urban land-use throughout real-world cities.[5] Notably, *within* cities, buildings tend to be taller towards the center compared to those found in more distant suburban areas. House prices also decrease as one moves further away from the city center in order to compensate commuting costs, which is also known as the horizontal rent gradient. However, the standard monocentric model neglects the verticality of house

[4] Brueckner and Rosenthal (2009) provide an analysis on how the age of the build stock affects the process of gentrification. They find that due to the fact that high-income households have high demand for housing services, they tend to be drawn to areas where the housing stock is relatively young.

[5] See Wheaton (1974) for an earlier comparative static anaylsis. For a recent survey of the literature, see Duranton and Puga (2015).

prices within cities at a given location. In an extension of the monocentric model, Wright (1971) shows that by introducing vertical location preferences, one can derive both a horizontal and a vertical rent gradient.

We borrow the simple theoretical framework developed by Wright (1971) to provide an example of a model that allows for the existence of a vertical rent gradient as a third dimension of the standard monocentric model.[6,7] After some simplifying modifications, identical urban residents have the following utility function

$$u = (x, s, d, h, t_d(d), t_h(h)) \ ,$$

where x is the consumption of the composite good, s is the amount of housing space consumed, d represents the commuting distance from central business district (CBD), h is the height (i.e. floor level) at which one lives and t_d and t_h are travel functions of time spent in horizontal or vertical transportation.[8] The functions have the following characteristics $\partial t_d / \partial d = t'_d(d) > 0$ and $\partial t_h / \partial h = t'_h(h) > 0$, i.e. further locations (horizontally or vertically) are time consuming and might demand physical effort (especially vertical transportation in the absence of a lift), combined with the usual assumption that $t''_d(d) \leq 0$ and $t''_h(h) \leq 0$. In addition, $\partial u / \partial t_d = u_{t_d} < 0$ and $\partial u / \partial t_h = u_{t_h} < 0$, signifying disutility from both types of transport. Note that urban resident housing location also enters the utility function both in terms of disutility coming from travel time as well as in terms of pure locational preference.

The urban resident's budget constraint is given by

$$w - \tau_d(d) - \tau_h(h) = x + R\,(s, d, h) \ ,$$

where w is the wage earned in the CBD, $\tau_d(d)$ is the horizontal commuting cost per round-trip, $\tau_h(h)$ is the vertical commuting cost per round-trip, and $R\,(s, d, h)$ is total rental cost bid-rent function.[9] In this simple setup utility maximization yields both a horizontal and a vertical rent gradient:

$$R_d = \left[u_{t_d} t'_d(d) - \tau'_d(d) + u_d \right] \ , \tag{1}$$

$$R_h = \left[u_{t_h} t'_h(h) + u_h \right] \ , \tag{2}$$

where $\tau'_d(d) > 0$, $\tau''_d(d) \leq 0$ and we assume that vertical transportation, in a resi-

[6]We refer to the model presented in section III of Wright (1971). More precisely, we abstract from heterogeneous agents, which results in both a representative vertical and a horizontal rent gradient. In addition, we simplify to model by assuming a fixed exogenous wage.

[7]See Brueckner (1983) for a model that includes a third dimension that corresponds to yard space.

[8]In this very naive model, these two terms could as well be summarised into one single variable capturing overall travel time. However, in a model with heterogeneous agents it would be easy to assume that people differ with respect to their valuation of vertical vs. horizontal travel time.

[9]The price of composite good x has been normalized to one, as is done in the literature.

dential setting, does not have material monetary costs, i.e. $\tau_h(h) = 0$.[10] Equation (1) represents the well-known horizontal rent gradient that decreases with distance from the CBD (McMillen (1996)). Albouy and Lue (2015) provide evidence that horizontal rent gradients are determined by wage opportunities and commuting costs, regardless of whether or not the gradients are monocentric. Therefore, while the monocentric model framework provides a useful setting, our estimations do not rely on the monocentric nature of a city. Gibbons and Machin (2005) document that urban residents do indeed value the ease access to CBD, using a quasi-experimental approch to study the effect on local house prices after the construction of new railway stations in London in the 1990's. Furthermore, Ahlfeldt and Wendland (2013) show that innovations in transport technology in early 20th century Berlin led to flatter housing price gradients.

The vertical rent gradient, given by equation (2), is at the center stage of this paper. Without locational preferences the vertical rent gradient would be negative since time spent in transportation provides disutility to urban residents. However, it is reasonable to assume the existence of positive locational preference, e.g. through the valuation of views on higher locations.[11] Therefore, the interplay between vertical time transportation costs and vertical locational preferences, i.e. if $|u_{t_h} t'_h(h)| \geq u_h$ for some $h \in [0, \underline{h}]$ and $|u_{t_h} t'_h(h)| < u_h$ for some $h \in \left(\underline{h}, \overline{h}\right]$, where $\underline{h} < \overline{h}$, will produce a non-monotonic vertical rent gradient. Helsley and Strange (2008) provide a game-theoretical analysis of why there is an inherent value in a building being classified as the tallest. This suggests that there is an intrinsic value associated with verticality and vertical location, a feature discussed in Liu et al. (2015).

Recent empirical work by Ahlfeldt and McMillen (2015) and Liu et al. (2015) address two notable elements of the standard monocentric model. On the one hand, Ahlfeldt and McMillen (2015) document a robust relationship between building height and land rent. They find that developers indeed respond to higher land prices by producing taller buildings. More precisely, in 2000, the elasticity of building height with respect to land price is approximately 45% for tall commercial structures and around 30% for residential structures. On the other hand, Liu et al. (2015) take the first step to enrich the standard model by accounting for price patterns at a given location *within* commercial buildings.[12] First, they conclude that pricing and spatial structure vary vertically in ways that standard urban models fail to capture. Second, vertical rents gradients are non-monotonic due to the presence of forces driven by access and

[10] It could be argued that vertical transportation has opportunity costs if some goods cannot easily be transported to higher floors. For the sake of simplicity, we abstract from this argument.

[11] Ng (2008) shows that, in theory, differences in household preferences over amenities generate various types of horizontal location patterns in housing prices. In other words, households may be willing to accept longer commutes in order to locate closer to amenities.

[12] As noted by Wong, Chau, Yau and Cheung (2011), the real estate literature has rarely studied the variation in price per square meter *within* buildings has rarely been the main focus.

amenities. These forces produce sorting within a commercial building where access-oriented retailers bid for lower floors and amenity-oriented firms bid for upper floors. This bid-rent function generates a non-monotonic vertical rent gradient that exhibits a ground floor premium.

3 Data

Our empirical analysis makes use of two main sources of data, which are discussed in detail below. On the one hand we use geocoded data on the location and building characteristics of all residential buildings in Switzerland in the period 2004-2014. On the other hand, we use geocoded rental price data for the same observation period. We obtain our final dataset by spatially matching rental prices to the corresponding buildings.

3.1 Residential Buildings

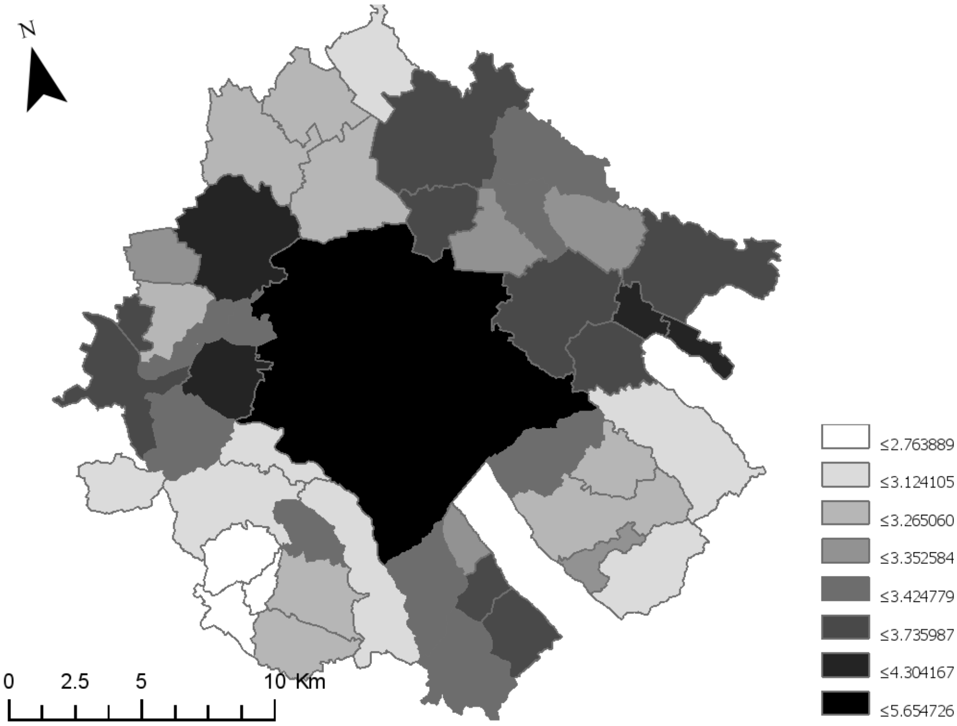
The first panel data set covers an exhaustive record of geocoded residential building data.[13] In particular, we observe the number of floors within a building, the building period as well as characteristics such as the number of individual housing units within the building and the total number of inhabitants in the building. We restrict our sample to the five biggest cities in Switzerland, namely, Zurich, Geneva, Basel, Lausanne and Bern.[14] Furthermore, we restrict the sample of buildings to those that were built prior to the start of rental price sample period and that were not renovated during the observation period. This avoids problems of variation of prices within building due to changes in overall quality of the building. Lastly, we eliminate all buildings that host some kind of commercial activity.[15]

[13] The confidential data were kindly provided by Swiss Federal Registry of Buildings and Housing.

[14] Cities in our context are monocentric circles of 10km radius around the main train station, which acts as the CBD.

[15] Since these exist predominantly on the ground floor and since taxe advantages for the usage of office space (for example for lawyers etc.) are capitalized into prices, keeping those semi-commercial buildings would bias our estimate of the ground floor premium upwards.

Figure 1: Average Building Height (Floors) Variation across Locations in Zurich*



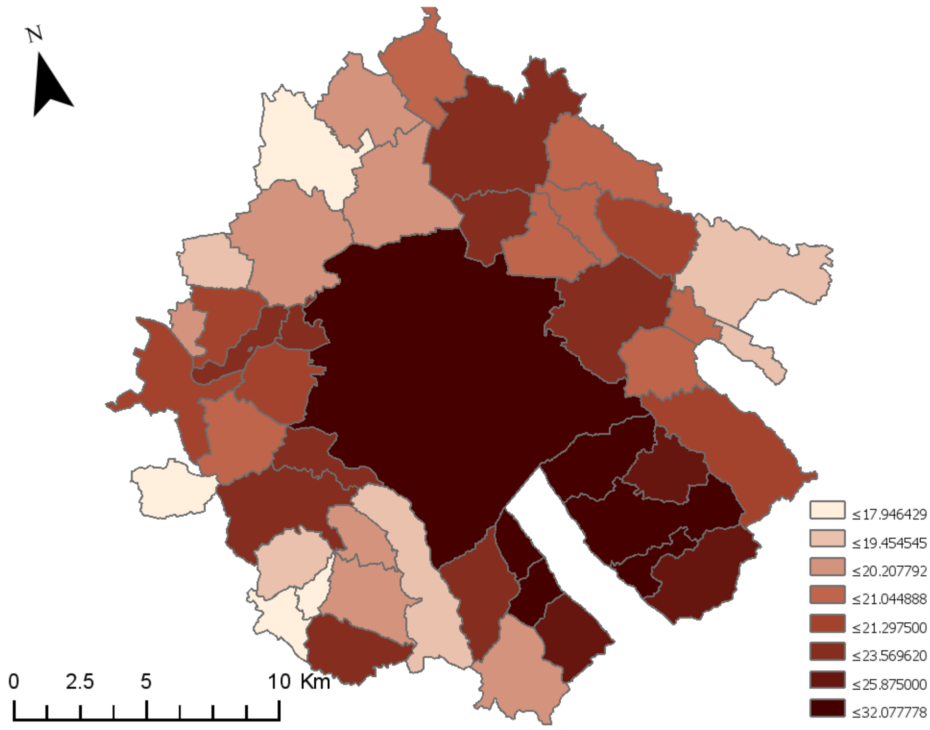
*The figure is constructed by taking all building level observations and calculate the average building height (in number of floor levels) per municipality. Dark regions represent municipalities with tall buildings, on average, and lighter regions represent municipalities with smaller buildings, on average. Gray lines represent municipal administrative borders.

Figure 1 displays the average building height per municipality throughout the city of Zurich for illustrative purposes. The CBD is located in the central municipality, where we find the tallest buildings. As one moves away from the central municipality, average building height decreases, which is a well-known result of the standard urban monocentric model. This feature is driven by the decrease in land prices at further locations from the CBD. In turn, the capital-to-land ratio, or in other words, building height decreases. Figure 1 also indicates that large city areas may indeed polycentric. For example, to the northeast of the relief map, one starts to get closer to a relatively smaller city (Winterthur), which hosts its own CBD. As a result, building height does not decrease as much as other directions that truly represent the city periphery.

3.2 Rental Prices

The second panel data set contains annual advertised rental prices spanning 2004-2014. It contains the structural attributes, namely the rental price per square meter, of approximately 1,200,000 rental objects as well as their corresponding rooftop quality coordinates.[16] More precisely, the dwelling characteristics include: floor level, the number of rooms and the existence of a balcony, view, parking spot or garage. Roughly one quarter of these observations take place in the top 5 cities. The high quality geocoding ensures that the localization of the rental objects within the city provides reliable matching of rental prices to buildings as well as accurate distances to the central point of the city.

Figure 2: Average Rental Price (CHF/m^2) Variation across Locations in Zurich*



*The figure is constructed by taking all rental price posting level observations and calculate the average (over the whole sample period 2004-2014) rental price per square metre (CHF) per municipality. Dark regions represent expensive municipalities, on average, and lighter regions represent cheaper municipalities, on average. Gray lines represent municipal administrative borders.

Figure 2 portrays the average rental price per square meter per municipality throughout the city of Zurich. The central municipality hosts the main train station, which is considered to be the CBD in our setting. Dark red zones indicate high rental prices and the lighter municipalities depict lower rental prices. Moving away from the central municipality, we notice a decreasing rental price (except at the lake shores in the South East of the city), which is a typical feature of the standard urban monocentric model.

The third data set complements the building and rental price data with information regarding exogenous topographical features of the city's landscape, such as

[16]For more information on rental object characteristics, refer to Table A.2 in appendix. Source: Purchased from Meta-Sys (`http://meta-sys.ch/`), who collected postings from online internet platforms.

elevation, slope and the presence of local exogenous amenities (e.g. lakes).[17]

4 Empirical Framework

Our baseline estimation strategy entails regressing the rental prices per square meter on the floor level of an apartment. In order to allow for the potential non-monotonicity in the vertical rent gradient, we include a dummy variable that takes the value one if the apartment is on the ground floor and zero otherwise, as well as an equivalent dummy variable for the top floor.

Identification of the ground floor premium necessitates controls on three different dimensions. First, time-invariant building-specific characteristics that could influence rental price patterns over different floor levels in a building such as building age, are captured by building fixed effects. As a result, identification comes from *within* building variation of the rental price per square meter over time. Furthermore, we restrict our sample of buildings to those that were built prior to our sample period and experienced no renovations during the sample period. Second, local house prices are likely to be driven by neighbourhood characteristics that vary over time (e.g. the neighbourhood becoming more or less attractive over time). We control for very local time varying neighbourhood characteristics by using grid-cells measuring 100x100 meters as grid-year fixed effects. Third, local policy at the municipality level will affect house prices in various ways. For example, among others, Swiss municipalities enjoy full fiscal autonomy in levying and deploying tax revenues, which will capitalize into house prices.[18] We include municipality-year fixed effects to account for these features.

Inspired by Liu et al. (2015), let $\ln P_{ibgmt}$ represent the log per square meter rental price of apartment i in building b, grid-cell g, municipality m and year t. GF is a dummy variable for the apartment being on the ground floor or not, FL is the floor level, TF is a dummy for the top floor and BH_b is the building height of building b. Z is a vector controlling for a variety of dwelling controls such as apartment size, the presence of a balcony and/or a view.[19] The full battery of building, grid-year and municipality-year fixed effects are δ_b, δ_{gt} and δ_{mt}, respectively.[20] Our baseline

[17] The Digital Height Model (DHM25) data, a product of the Swiss Federal Statistics Office, are confidential and provided by Alexandre Hirzel from the Graphic Information System (GIS) department at the University of Lausanne.

[18] Schmidheiny (2006) shows how differences in municipal income taxation in the city of Basel influence household location choices and provide a channel for income segregation within a city. Brülhart, Bucovetsky and Schmidheiny (2015) discuss how most cities are divided into 74 municipalities, on average, which enjoy varying degrees of fiscal autonomy.

[19] Following Liu et al. (2015), we use the floor level as a continuous variable. In the log-log specification, we recode floor level to be floor level + 1 to avoid missing values.

[20] We also explore specifications including a log-linear inclusion of floor level as well as a log-linear version using dummy variables for each floor level. In addition, we also run log-linear specifications with up to second order polynomials to capture the convex nature of the vertical rent gradient.

specification then takes on the following form:

$$\ln P_{ibgmt} = \beta_1 GF_i + \beta_2 GF_i \times BH_b + \gamma_1 \ln FL_i + \gamma_2 \ln FL_i \times BH_b \\ + \theta_1 TF_i + \theta_2 TF_i \times BH_b + \mu Z_i + \delta_b + \delta_{gt} + \delta_{mt} + u_{ibgmt}\,, \tag{3}$$

A positive β_1 coefficient should be interpreted as a premium paid for ease of access that the ground floor apartment enjoys *compared to the price of all other floors in the building*. We allow for the ground floor premium to vary with building height. Similarly, γ_1 measures the value of moving up a floor within a building, which may also vary with building height. Finally, for completeness, θ_1 accounts for a top floor premium that may be associated with apartments located at the top of a building, which is also allowed to vary with building height.

It is worth noting that while equation (3) provides clean identification of the ground floor premium, there may still be characteristics at the building-year level that affect house prices, such as changes in ownership in parts of the building. To address this concern, we implement a within building-year (δ_{bt}) estimation given by:

$$\ln P_{ibt} = \beta_1 GF_i + \beta_2 GF_i \times BH_b + \gamma_1 \ln FL_i + \gamma_2 \ln FL_i \times BH_b \\ + \theta_1 TF_i + \theta_2 TF_i \times BH_b + \mu Z_i + \delta_{bt} + u_{ibt}\,. \tag{4}$$

This particular identification strategy has a significant drawback in that approximately 35% of our estimation sample come from building-years with only one observation and would therefore not contribute to the identification of the effect, with additional 40% of the remaining observations coming from building-years of two or three rental postings. In addition, the likelihood of having mutliple rental postings per building-year increases with building height (higher buildings contain more apartments), which means that the within building-year specification systematically changes the share between tall and small buildings in the estimated sample.

5 Results

5.1 Baseline Results

Table 1 displays the results of our baseline estimation of equations (3) and (4) with and without dwelling characteristics. Estimating equation (3) without dwelling controls in column (1), we find a premium for ground floor apartments of 3% compared to the average price per square meter in the rest of the building. Once dwelling controls are included in column (2), this premium drops slightly to 2.3%. This premium decreases with building height, which might reflect the disutility that ground floor

Globally, the qualitative interpretations of our log-log baseline model do not change.

Table 1: Baseline Estimations

Dependent variable:	Log Rental Price Per Square Meter			
	(1)	(2)	(3)	(4)
Ground Floor	0.030***	0.023***	0.037***	0.030***
	(0.005)	(0.004)	(0.005)	(0.005)
Ground Floor × Building Height	-0.001	-0.003***	-0.002	-0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
Log Floor	0.022***	0.013***	0.029***	0.024***
	(0.003)	(0.003)	(0.004)	(0.003)
Log Floor × Building Height	0.002***	0.002***	0.001**	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Top Floor	-0.004	-0.021**	-0.017	-0.030**
	(0.010)	(0.010)	(0.012)	(0.012)
Top Floor × Building Height	0.006**	0.009***	0.007**	0.009***
	(0.002)	(0.002)	(0.003)	(0.003)
Buildings	37,382	37,382	26,363	26,363
Observations	265,089	265,089	172,332	172,332
Building FE	YES	YES	NO	NO
Building-Year FE	NO	NO	YES	YES
Grid-Year FE	YES	YES	NO	NO
Municipal-Year FE	YES	YES	NO	NO
Dwelling controls	NO	YES	NO	YES

Standard errors clustered at building level in parentheses. The variable Log Floor is the log of floor level + 1, which removes the missing values created by log of zero. Ground floor is a binary variable that equals one when the floor level is the ground floor, and zero otherwise. Top floor is a binary variable that equals one when the floor level is the top floor of the building and zero otherwise. Dwelling characteristics include: the number of rooms and the existence of a balcony, view, parking spot or garage. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

apartments receive being located near to the building's thoroughfare to apartments on upper floors in taller buildings. However, the ground floor only starts to be cheaper than the average apartment in buildings of eight floors or more.[21] Concerning the vertical rent gradient, we find an elasticity of the per square meter price with respect to the floor level of 2.2% without controlling for dwelling characteristics and 1.3% once dwelling characteristics are included. This effect becomes more pronounced as the building height increases. Interestingly, there appears to be a top floor discount in smaller buildings, which is most likely associated with increase maintenance costs, such as heating due to the apartments location in the building.

Columns (3) and (4), report the building-year fixed effects results from the specification given by equation (4). The point estimates remain stable across the two columns in comparison to columns (1) and (2). This the assertion that changes in ownership of apartments or other factors that vary over time within a building-year have no systematic effect on the pattern of rental price across floor levels (except

[21] A noteworthy characteristic about the residential building stock in Switzerland, is that around 94% of the park of buildings have less than 5 floors. See the Federal Statistics Office publication *Construction and Housing* (2016), page 12.

Figure 3: The Vertical Rent Gradient*

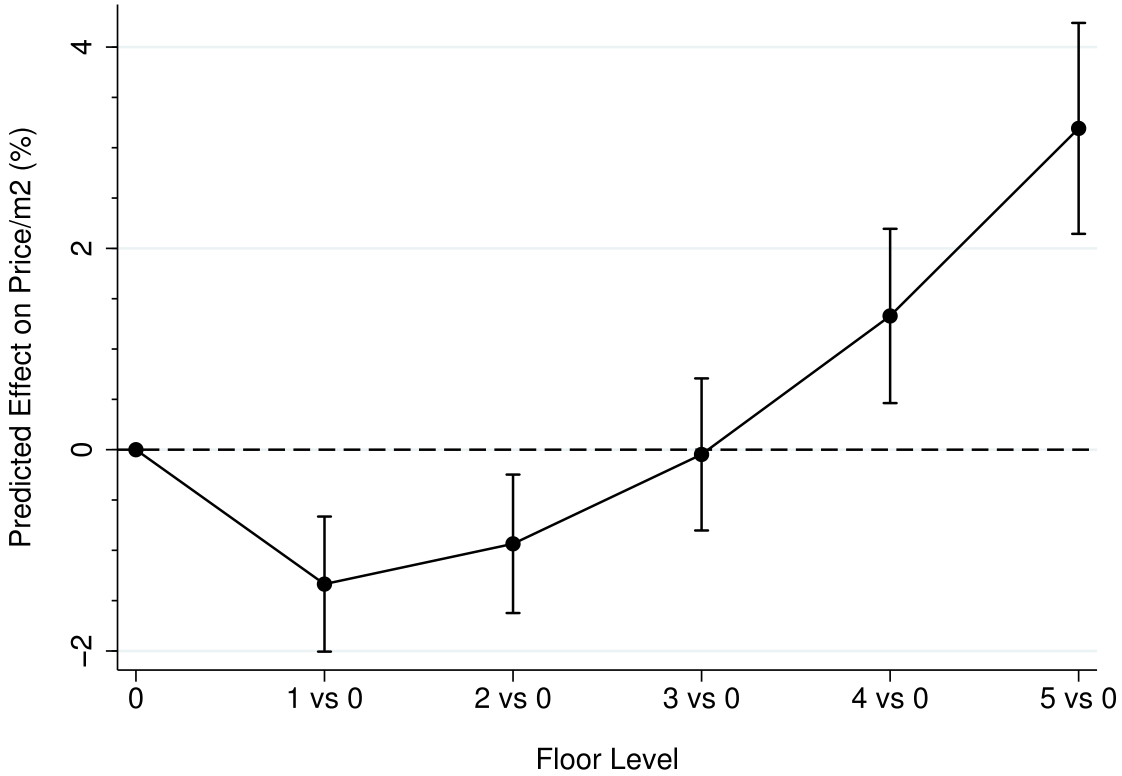


*Figure constructed as follows. We ran a log-linear polynomial regression of order two to capture the convex shape of the vertical rent gradient. We use the estimates reported in column (2) of Table B.1. More precisely, we use the coefficients on *Ground Floor*, *Floor Level* and *Floor Level Squared* (and their corresponding standard errors) to produce the stylized curve relative to the ground floor, with 95% confidence bands. The graph shows that first and second floors are, on average, cheaper per square meter than the ground floor.

for renovations, which we deal with by excluding buildings that were built during our sample period). For reasons discussed in section 4 the remainder of the paper presents results using the specification as described by equation (3). The results for the within building-year specification are reported in the appendix.

Figure 3 illustrates the findings regarding the non-monotonicity of the vertical rent gradient.[22] The figure shows that first and second floor apartments are, on average, between 1% and 1.5% cheaper per square meter than ground floor apartments. In addition, the amenity value of higher floors only negates the ground floor access premium from the third floor onwards.

[22]For the graphs we rely on a polynomial regression of second order as reported in the appendix in Table B.1. The second order polynomial is better suited to capture the convexity of the rent gradient on higher floor levels. The advantage of the log-log specification however, is that it captures the effect of the ground floor premium in a single coefficient, while the polynomial regression shifts parts of the ground floor premium into the negative first order floor coefficient.

5.2 Ground Floor Premium

The existence of a ground floor premium can be broadly motivated by two factors, access value versus amenity value. We extend our analysis in order to provide empirical evidence supporting the existence of these driving factors. On the one hand, the ground floor premium could reflect the value ground floor apartments generate from having direct access to the road, the same way retail-oriented firms in Liu et al. (2015) pay a premium for the direct access. On the other hand, ground floor apartments in residential buildings potentially host amenities such as gardens or terraces, which are typically not available to upper floor apartments. To determine which of these two channels (access vs. amenity) drives the ground floor premium, we employ the following modified version of our baseline specification:[23]

$$\begin{aligned}\ln P_{ibgmt} = &\beta_1 GF_i + \beta_2 GF_i \times BH_b + \beta_3 GF_i \times AM_b + \beta_4 GF_i \times AC_b \\ &+ \beta_5 GF_i \times AM_b \times AC_b + \gamma_1 \ln FL_i + \gamma_2 \ln FL_i \times BH_b \\ &+ \theta_1 TF_i + \theta_2 TF_i \times BH_b + \mu Z_i + \delta_b + \delta_{gt} + \delta_{mt} + u_{ibgmt}\,,\end{aligned} \tag{5}$$

where β_3 measures the effect of having a garden or a terrace and β_4 reports the effect of the availability of a lift on the ground floor premium. Furthermore, β_5 determines which of the two forces is dominant (i.e. buildings that have both a lift and a garden). Since the sign on β_3 is expected to be positive (i.e. a garden increases the ground floor premium) and the sign on β_4 is expected to be negative (as a lift decreases the premium on the ground floor), we interpret a positive sign on β_5 as evidence of a dominant amenity effect, while a negative sign on β_5 would be evidence of a dominant access effect that drives the ground floor premium.

There are a number of takeaways from the estimation results in Table 2. First, the ground floor premium ranges from 1.5-3%, which corresponds to move between 250-450 meters closer to the CBD.[24] Second, the amenity value of a garden or a terrace increases the ground floor premium by 0.5 percentage points (p.p.). Second, the value that the ground floor apartment generates from direct access to the road decreases by 1.4 p.p. in buildings with a lift. In other words, as access to upper floors is made easier, the premium enjoyed by ground floor apartments (without a garden or terrace) is almost entirely negated. Fourth, the triple interaction term between the ground floor, amenity and access binary variables is negative (-0.8 p.p.). The result indicates that the driving factor for the ground floor premium is indeed the value of direct accessibility. Fifth, once controlling for the presence of a lift, the ground floor premium is no longer decreasing in building height. This is due to the fact

[23] See Table B.2 for point estimate comparisons between competing specifications of column (3) from Table 2.

[24] See Table B.3 in the appendix for results on the horizontal rent gradient.

that taller buildings are more likely to have a lift, which in turn drives the ground floor premium down. Sixth, building age, internal density (number of apartments in the building) as well as the external neighborhood (with 100 meters) density do not appear to affect the ground floor premium.

Finally, column (6) relates the ground floor premium to the standard monocentric model and analyses its evolution depending on a building's location within a city. Here, we interact the ground floor premium with the commute distance from a building to the CBD. Controlling for the distance to the CBD reduces the ground floor premium to zero at the CBD center, but it gradually increases by 0.2 p.p. per kilometer as one moves away from the CBD center. We also construct two variables capturing the neighborhood density: we control for the number of buildings and the number of rental units within a 100 meter radius of a building. Results indicate that neither play a significant role. This is most likely due to the fact that ground floor apartments in the CBD are subject to more than residential density, but also general commercial and leisure activity (see standard monocentric model). Intuitively, ground floor locations may become less desirable as the number of surrounding commercial and leisure activities increase. In addition, ground floor apartments in central locations are likely to be less desirable due to the potentially heightened risk of burglary.

5.3 Vertical Rent Gradient

In this section, we focus on the determinants of the slope of the vertical rent gradient. To do so, we allow for the slope of the gradient to vary with different control variables. For simplicity, we assume a homogeneous ground floor premium across all buildings in this section, i.e. we estimate β_1 and β_2 without allowing for any other interactions. More precisely, we modify our baseline specification as follows:

$$\ln P_{ibgmt} = \beta_1 GF_i + \beta_2 GF_i \times BH_b + \gamma_1 \ln FL_i + \gamma \ln FL_i \times \mathbf{X}_b + \theta_1 TF_i + \theta_2 TF_i \times BH_b + \mu Z_i + \delta_b + \delta_{gt} + \delta_{mt} + u_{ibgmt}\,, \tag{6}$$

where $\mathbf{X}$ is a vector of variables expected to affect the slope of the vertical rent gradient, such as building age, density and height; neighbourhood density; and topographical features.

Four broad results appear in Table 3. First, the ground floor premium is approximately 1.5%, which is in line with what we previously estimated. In addition, the top floor discount remains roughly around 2%. Second, the rental price per square meter elasticity with respect to the floor level stabilizes around 2%. Building height, availability of a view and neighborhood density (in number of rental units) appear to steepen the slope of the vertical rent gradient, a feature that is consistent with an amenity value accompanying verticality. Point estimates indicate that a view or the

Table 2: Determinants of the Ground Floor Premium

Dependent variable:	Log Rental Price Per Square Meter					
	(1)	(2)	(3)	(4)	(5)	(6)
Ground Floor	0.030***	0.023***	0.017***	0.018***	0.018***	-0.003
	(0.005)	(0.004)	(0.005)	(0.005)	(0.005)	(0.007)
Ground Floor × Building Height	-0.001	-0.003***	-0.000	-0.000	-0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Ground Floor × Amenity			0.005*	0.005*	0.005*	0.005*
			(0.003)	(0.003)	(0.003)	(0.003)
Ground Floor × Access			-0.014***	-0.014***	-0.015***	-0.013***
			(0.004)	(0.004)	(0.004)	(0.004)
Ground Floor × Amenity × Access			-0.008*	-0.008*	-0.008*	-0.008*
			(0.005)	(0.005)	(0.005)	(0.005)
Ground Floor × Building Age Period				-0.000	-0.000	0.001
				(0.001)	(0.001)	(0.001)
Ground Floor × Internal Building Density (# of Apartments)					0.000	0.000
					(0.000)	(0.000)
Ground Floor × Neighborhood Density (in 100 units)						0.000
						(0.002)
Ground Floor × Neighborhood Density (in 10 buildings)						0.001
						(0.002)
Ground Floor × Commute Distance from CBD (km)						0.002***
						(0.000)
Log Floor	0.022***	0.013***	0.012***	0.012***	0.012***	0.012***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Log Floor × Building Height	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Top Floor	-0.004	-0.021**	-0.022**	-0.022**	-0.022**	-0.022**
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Top Floor × Building Height	0.006**	0.009***	0.009***	0.009***	0.009***	0.009***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Buildings	37,382	37,382	37,382	37,382	37,382	37,382
Observations	265,089	265,089	265,089	265,089	265,089	265,089
Building FE	YES	YES	YES	YES	YES	YES
Grid-Year FE	YES	YES	YES	YES	YES	YES
Municipal-Year FE	YES	YES	YES	YES	YES	YES
Dwelling controls	NO	YES	YES	YES	YES	YES

Standard errors clustered at building level in parentheses. The variable Log Floor is the log of floor level + 1, which removes the missing values created by log of zero. Ground floor is a binary variable that equals one when the floor level is the ground floor, and zero otherwise. Top floor is a binary variable that equals one when the floor level is the top floor of the building and zero otherwise. *Building Age Period* corresponding the time period during which the building was constructed, e.g. between 2000-2005 (see Table A.1 for more details.). *Internal Building density* is measured by the number of individual apartments in the building. *Neighborhood Density* refers the number of buildings or individual apartments in a 100 meter radius around the given building. Dwelling characteristics include: the number of rooms and the existence of a balcony, view, parking spot or garage (see Table A.2 for more details.). *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

fact that the building is higher than the average building within a 100m radius increases the rental price per square meter elasticity with respect to floor level by 0.7 percentage points.

Third, the slope of the vertical rent gradient gets flatter the older the building as well as when the building is densely constructed, housing many individual apartments. The flatter gradient gradient due to building age reflects the fact that older buildings, while potentially desirable, may exhibit out-dated structural features. The urban resident in our setting will bid for higher vertical locations as long as those locations provide compensating amenity value. Densely constructed buildings are likely to be perceived as low cost, high density living quarters and no longer provide the required amenity value to compensate the lack of street access.

Finally, the vertical rent gradient flattens with every kilometer from the CBD center, i.e. steep rent gradients are predicted to be in the city center. Figure 4 illustrates

Table 3: Determinants of the Vertical Gradient

Dependent variable:	Log Rental Price Per Square Meter					
	(1)	(2)	(3)	(4)	(5)	(6)
Ground Floor	0.023***	0.027***	0.017***	0.015***	0.015***	0.011**
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)
Ground Floor × Building Height	-0.003***	-0.003***	-0.002**	-0.002*	-0.001*	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Top Floor	-0.021**	-0.023**	-0.021**	-0.019*	-0.019*	-0.017*
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Top Floor × Building Height	0.009***	0.009***	0.008***	0.008***	0.008***	0.008***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Log Floor	0.013***	0.027***	0.045***	0.046***	0.044***	0.041***
	(0.003)	(0.004)	(0.005)	(0.005)	(0.006)	(0.006)
Log Floor × Building Height	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)
Log Floor × Building with View		0.006***	0.008***	0.009***	0.008***	0.008***
		(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Log Floor × Building Age Period		-0.002***	-0.004***	-0.004***	-0.004***	-0.004***
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Log Floor × Commute Distance from CBD (km)			-0.003***	-0.003***	-0.003***	-0.003***
			(0.000)	(0.000)	(0.000)	(0.000)
Log Floor × Neighborhood Density (in 10 buildings)				-0.003***	-0.002**	-0.003***
				(0.001)	(0.001)	(0.001)
Log Floor × Neighborhood Density (in 100 units)				0.003**	0.003***	0.004***
				(0.001)	(0.001)	(0.001)
Log Floor × Internal Building Density (# of Apartments)				-0.000**	-0.000**	-0.000**
				(0.000)	(0.000)	(0.000)
Log Floor × Altitude (in 100m)					-0.001	-0.001
					(0.001)	(0.001)
Log Floor × Slope of Terrain					0.002***	0.002***
					(0.000)	(0.000)
Log Floor × Building Higher than Average in Neighborhood						0.006***
						(0.002)
Buildings	37,382	37,382	37,382	37,382	37,382	37,382
Observations	265,089	265,089	265,089	265,089	265,089	265,089
Building FE	YES	YES	YES	YES	YES	YES
Grid-Year FE	YES	YES	YES	YES	YES	YES
Municipal-Year FE	YES	YES	YES	YES	YES	YES
Dwelling controls	YES	YES	YES	YES	YES	YES

Standard errors clustered at building level in parentheses. The variable Log Floor is the log of floor level + 1, which removes the missing values created by log of zero. Ground floor is a binary variable that equals one when the floor level is the ground floor, and zero otherwise. Top floor is a binary variable that equals one when the floor level is the top floor of the building and zero otherwise. *Building Age Period* corresponding the time period during which the building was constructed, e.g. between 2000-2005 (see Table A.1 for more details.). *Internal Building density* is measured by the number of individual apartments in the building. *Neighborhood Density* refers the number of buildings or individual apartments in a 100 meter radius around the given building. Dwelling characteristics include: the number of rooms and the existence of a balcony, view, parking spot or garage (see Table A.2 for more details.). *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

the result. The black curve represents the vertical rent gradient at the core of the CBD and the light gray dotted curve represents the vertical rent gradient at the CBD perimeter. As depicted in the figure, ground floor apartments are always cheaper than the upper floors when located at the core of the CBD. In contrast, ground floor apartments appear to enjoy a significant premium when located toward the CBD's perimeter. This is explained by the fact that the relative distance to the CBD captures density features of commercial and leisure activities such as noise, pollution and crime. Note that the upward sloping vertical rent gradient still persists in each of the curves, i.e. after a certain floor level, upper apartments command higher rental prices. For the remainder interactions with log floor level, a significantly negative(positive) coefficient on an interaction term indicates a flattening(steepening) of the gradient.

Figure 4: The Vertical Gradient In The Monocentric Model*

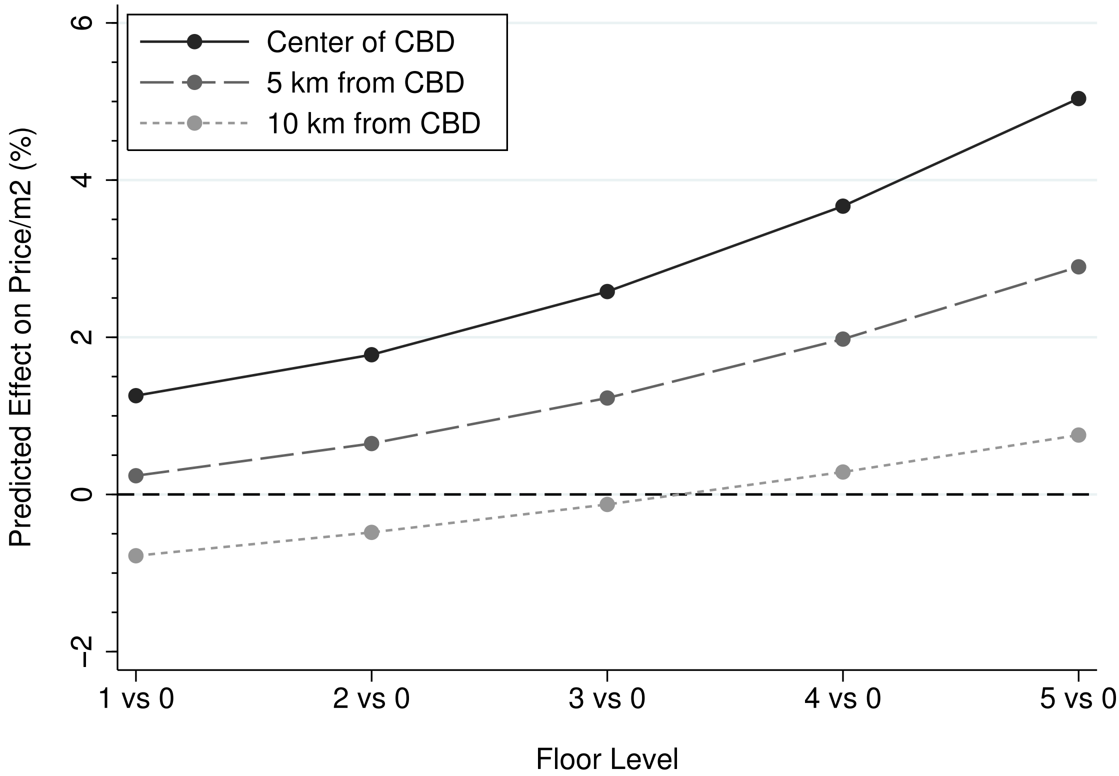


*Figure constructed as follows. Combining elements from the ground floor premium and vertical gradient analyses, we run a log-linear polynomial regression of order two with all the control variables at our disposal. We recover the coefficients on *Ground Floor*, *Ground Floor* × *Commute Distance from CBD*, *Floor* and *Floor Squared* (as well as their interactions with commute distance from CBD. We then selected three commute distances from the CBD: 0km, 5km and 10km to create the vertical rent gradient relative to the ground floor in each scenario. The graph shows that vertical rent gradient exists at various locations within a city, but may be less pronounced at further locations from the CBD.

5.4 Vertical Gradient Spillovers

In this section, we elaborate an empirical exercise that aims to highlight bidding behavior at different vertical locations in a building. Therefore, we extend our analysis to explore house price spillovers that manifest via gentrification of cheaper municipalities. Our analysis follows Guerrieri et al. (2013) closely in terms of the empirical specification, with the difference that we employ the vertical rental price gradient framework to focus on the potentially heterogeneous nature of rental price spillovers across different vertical locations within buildings.[25] More precisely, we build on their initial specification by focusing on the rental price growth rates associated with the upper and lower half of buildings as well as ground and top floor levels.

The gentrification mechanism proposed in Guerrieri et al. (2013) works as follows. Assuming full mobility of agents, rental prices are bid up as the outflow of poorer households from relatively cheaper areas is mitigated by an inflow of rich households

[25]We use equation (2) on page 50 of Guerrieri et al. (2013) to motivate our specification.

that prefer to locate in relatively cheaper areas that are close to existing rich areas. In other words, rental prices in relatively cheaper neighborhoods experience higher rental price growth rates the closer they are to initially relatively more expensive municipalities.

In order to analyse the potential spillover of house prices, we use the following specification, which we estimate separately for different vertical locations within buildings (i.e. ground floor, upper and lower half of buildings and top floor apartments):

$$\frac{\Delta P^{i,j}_{t,t+k}}{P^{i,j}_{t}} = \beta \ln\left(dist^{i,j}_{t}\right) + \theta \mathbf{X}^{i,j}_{t} + \gamma \mathbf{Z}^{i,j}_{t} + \delta_{jk} + \epsilon^{i,j}_{t,t+k} \tag{7}$$

where $\Delta P^{i,j}_{t,t+k}/P^{i,j}_{t}$ measures the percentage change in rental prices per square meter in municipality i within city j between time t and $t+k$. The variable of interest is $dist^{i,j}_{t}$, which measures the road distance (in kilometers) of municipality i to the closest initially expensive municipality within city j at time t.[26] Furthermore, we only keep rental price changes of the municipalities the in the bottom half of the rental price distribution in time t. The vector $\mathbf{X}^{i,j}_{t}$ is a set of municipality specific controls that account for initial cross-sectional differences at time t. These are the log of median taxable income, log of local personal income tax rate and log of local population. Similarly, the vector $\mathbf{Z}^{i,j}_{t}$ contains information on exogenous topographical features that influence rental prices, such as accessibility and the presence of a lake. Finally, δ_{jk} is a city-year fixed effect that controls for unobservables that change at the city-year level.[27]

For transparency, a discussion about the likely caveats in this extension is necessary. Firstly, we are unable to exploit our within building identification that was previously used to document the vertical rental gradient. In this extension, we aggregate up to the municipal level. Secondly, we are unable to explicitly identify residential sorting due to the lack of population data that would enable such an exercise at the floor level within a given building. However, the empirical model, given by equation (7) is able to provide empirical evidence that will highlight the existence of rental price patterns that are consistent with residential sorting via gentrification. More precisely, we are able isolate average rental price growth for different levels within buildings in a given municipality. Therefore, we use equation (7) to further disen-

[26]The initially expensive municipality is defined as the closest municipality that is in the top quartile of the rental price distribution in time t. We exclude city center municipalities when determining the set of initially expensive municipalities.

[27]Guerrieri et al. (2013) run their regression in cross-section over two different time periods, using city level fixed effects. In our specification, we exploit the annual variation by allowing the change in rental prices per square meter to gradually increase with annual increments. See Table B.4 for a simple long first difference between 2014 and 2004.

Table 4: Vertical Gradient Spillovers

Dependent variable:	Growth in Average Municipal Log Rental Price				
Vertical Location (within buildings):	All	Ground Floor	Lower Half	Upper Half	Top Floor
	(1)	(2)	(3)	(4)	(5)
Distance to closest high price municipality (logs)	-0.014***	-0.001	-0.009**	-0.020*	-0.047*
	(0.004)	(0.006)	(0.004)	(0.011)	(0.024)
Distance to CBD (logs)	-0.016	-0.049***	-0.028**	-0.002	-0.009
	(0.016)	(0.017)	(0.013)	(0.027)	(0.052)
Clusters	55	55	55	55	55
Observations	2,632	710	1,454	1,178	481
City-Year FE	YES	YES	YES	YES	YES
Municipal controls	YES	YES	YES	YES	YES

Standard errors clustered at city-year level in parentheses. The specification of Guerrieri et al. (2013) clusters at the city level since their sample contains around 170 cities, whereas our sample only covers five. Municipal controls include: log of median taxable income, log of local personal income tax rate and log of local population. In addition, we include an index of accessibility and an indicator of the presence of a lake. Weighted by number of rental price postings in reference municipality in time t (see Table A.3 for more details.). *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

tangle whether rental price growth rates differ, on average, across locations within buildings.

Table (4) displays the results of the spillover exercise.[28] Column (1), reports the results when using the average municipal rental prices, while columns (2) to (5) present results for sub-sample analyses when limiting our sample to only ground floor apartments, only apartments located in the lower half of a building, only apartments in the upper half of the building or only top floor apartments. Three different results arise: Firstly, we are able to replicate (although smaller in magnitude) the general finding of a spillover from high priced municipalities to low priced municipalities, with the spillover being stronger the closer a cheaper municipality is to an initially relatively expensive municipality. Secondly, when splitting the average effect across different vertical locations, we find that the effect is driven by apartments located at higher vertical locations in buildings. As one moves up within a building, the spillover becomes increasingly more pronounced, with the majority of the spillovers taking place in top floor apartments. Relating this back to the vertical rent price gradient, this means that the gradient becomes steeper as prices in lower priced municipalities rise. Finally, we also find evidence for rental price spillovers from the CBD on apartments at lower vertical locations within buildings. In other words, the effect is strongest and most significant at the ground floor, while we find no significant spillover from the CBD on upper half or top floor apartments.

While our analysis is unable to clearly trace the mechanism that drives these rental price spillovers, it is in line with the predictions from a sorting framework. Moreover, the different spillovers from high priced municipalities other than the CBD and the CBD itself could potentially also be interpreted in a similar fashion compared to the trade-off of access versus amenities in a bidding framework. Both the bidding for

[28]Summary statistics are reported in Table A.3 in appendix.

lower floor apartments within a building as well as the bidding for central locations in the city are driven by a valuation of an increased ease of access. Taking that into account, it is not surprising that the spillovers of the CBD are highest on lower level apartments as urban residents could relinquish the access to the CBD if they are compensated with easier access to the road. Similarly, urban residents with higher incomes that could bid for the amenity value of living in a rich neighborhood might be willing to give this up if they are compensated with the amenity value derived from top floor apartments in poorer neighborhoods. However, all these results are rather suggestive and need further verification in future research. In the scope of this paper, however, the results show that explicitly focusing on the vertical dimension of housing might be able to uncover heterogeneity in bidding and sorting patterns within a city.

6 Conclusion

Our within building analysis documents the existence of a non-monotonic and convex vertical rent gradient in the residential context, adding to Liu et al. (2015). The ground floor premium is estimated to lie between 2-3% compared to the rental prices of all other apartments in a building, which is equivalent to moving between 250-450 meters closer to the CBD in the cities in our sample. Furthermore, we are able to disentangle different determinants of the ground floor premium and the vertical rent gradient, showing that the ground floor premium can indeed be explained as a valuation of ease of access and not as a valuation of ground floor specific amenities. In terms of the shape of the vertical rent gradient, not surprisingly, results indicate that the gradient is indeed convex, i.e. higher floors tend to command higher rental prices. Furthermore, the gradient tends to be steeper when the building is taller, has a view or is located closer to the CBD. Neighborhood density (number of rental units) around the building also tends to result in steeper rent gradients.

In an extension to the vertical rent gradient empirical framework, we provide empirical evidence of rental price patterns that are consistent with residential sorting manifesting through gentrification (Guerrieri et al. (2013)). The results indicate that the closer cheaper municipalities are to initially relatively more expensive municipalities, the higher the growth in rental prices. In addition, we find that these spillovers effects are heterogeneous across floor levels. First, upper floors tend to experience greater rental price growth, on average, than the remainder of building. Second, lower floors are more likely to be affected by the distance to the CBD. Finally, the heterogeneous effects across floor levels remains consistent with an amenity versus access urban resident bidding function.

This paper provides clean identification of the vertical rent gradient and its determinants as well as an explorative exercise aimed at providing suggestive evidence of residential sorting via gentrification. Although we cannot provide an explicit description of the residential sorting mechanism, i.e. trace household movement and wealth at the floor level within buildings, our results are consistent with a sorting process supported by gentrification. Further research would attempt to trace households at this spatially disaggregated level in order to provide more explicit empirical evidence of residential sorting along the vertical dimension. In addition, we have shown empirically that verticality is an important dimension in residential location choice to consider in the standard monocentric model setting.

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Appendix

A Data

Table A.1: Building level summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Building height (in floors)	4.985	1.844	2	20	37382
Building construction period	8013.746	2.268	8011	8020	37382
Number of housing units within building	10.054	8.144	0	137	37382
Altitude (in meters)	661.752	167.613	338.436	1050.84	37382
Slope of terrain (degrees)	3.171	3.251	0	32.471	37382
Road distance to CBD (in km)	4.57	2.901	0.035	15.319	37382
Building disposing of a lift (dummy)	0.414	0.493	0	1	37382
Building disposing of a garden (dummy)	0.419	0.493	0	1	37382
Building disposing of a view at any floor level (dummy)	0.51	0.5	0	1	37382
Neighborhood density (buildings)	249.644	151.324	10	1070	37382
Neighborhood density (units)	20979.937	14818.188	100	116200	37382
Building higher than average in neighborhood (dummy)	0.534	0.499	0	1	37382

Building Construction Period is coded as follows: 8011 = < 1919, 8012 = [1919 , 1945], 8013 =[1946 , 1960], 8014 = [1961 , 1970], 8015 = [1971 , 1980], 8016 = [1981 , 1985], 8017 = [1986 , 1990], 8018 = [1991 , 1995], 8019 = [1996 , 2000], and 8020 = [2001 , 2005]. The variable, *Building Age Period*, used in the regressions is created by 8020 minus the building's construction period.

Table A.2: Apartment level summary statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Price per square meter (in CHF)	22.159	6.958	9	54	265089
Ground Floor (dummy)	0.18	0.384	0	1	265089
Top Floor (dummy)	0.018	0.133	0	1	265089
Floor Level	2.056	1.755	0	18	265089
Number of rooms	5.03	2.432	1	12	265089
Surface area (in sqm)	72.745	31.504	11	660	265089
View reported in posting (dummy)	0.213	0.409	0	1	265089
Balcony reported in posting (dummy)	0.102	0.303	0	1	265089
Access to outside parking (dummy)	0.18	0.384	0	1	265089
Access to parking in garage (dummy)	0.327	0.469	0	1	265089

Table A.3: Spillover Variable Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
Annual rental price growth rate (%)	7.95	15.533	-83.833	96.94	2632
Distance to closest high price municipality (logs)	1.696	0.58	0.195	2.866	2632
Initial mean housing price per square meter (logs)	2.886	0.163	2.398	3.611	2632
Distance to CBD (logs)	2.04	0.435	0.471	2.729	2632
Initial median taxable income (logs)	10.808	0.127	10.551	11.123	2632
Initial municipal personal income tax rate (logs)	2.56	0.168	2.18	2.804	2632
Initial population (logs)	8.720	1.058	6.12	12.018	2632
Index of accessibility	3.136	1.457	1	6	2632
Dummy for municipalities with access to a lake	0.049	0.217	0	1	2632

B Supplementary Tables

Table B.1: Baseline Estimations - Polynomial Specification

Dependent variable:	Log Rental Price Per Square Meter			
	(1)	(2)	(3)	(4)
Ground Floor	0.017***	0.012***	0.025***	0.020***
	(0.004)	(0.004)	(0.005)	(0.004)
Ground Floor × Building Height	-0.002***	-0.004***	-0.003***	-0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
Floor Level	-0.000	-0.003*	0.006***	0.004**
	(0.002)	(0.002)	(0.002)	(0.002)
Floor Level × Building Height	0.000	0.001***	-0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Floor Level Squared	0.002***	0.002***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Floor Level Squared × Building Height	-0.000***	-0.000***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Top Floor	0.012	-0.007	-0.005	-0.019
	(0.010)	(0.010)	(0.012)	(0.012)
Top Floor × Building Height	-0.000	0.003	0.003	0.005*
	(0.002)	(0.002)	(0.003)	(0.003)
Buildings	37,382	37,382	26,363	26,363
Observations	265,089	265,089	172,332	172,332
Building FE	YES	YES	NO	NO
Building-Year FE	NO	NO	YES	YES
Grid-Year FE	YES	YES	NO	NO
Municipal-Year FE	YES	YES	NO	NO
Dwelling controls	NO	YES	NO	YES

Standard errors clustered at building level in parentheses. Ground floor is a binary variable that equals one when the floor level is the ground floor, and zero otherwise. Top floor is a binary variable that equals one when the floor level is the top floor of the building and zero otherwise. Dwelling characteristics include: the number of rooms and the existence of a balcony, view, parking spot or garage. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table B.2: Determinants of the Ground Floor Premium - Alternative Specifications

Dependent variable:	Log Rental Price Per Square Meter		
	(1)	(2)	(3)
Ground Floor	0.023***	0.007*	0.017***
	(0.004)	(0.004)	(0.005)
Ground Floor × Building Height	-0.003***	-0.002***	-0.000
	(0.001)	(0.001)	(0.001)
Ground Floor × Amenity	0.005*	0.005*	0.005*
	(0.003)	(0.003)	(0.003)
Ground Floor × Access	-0.014***	-0.014***	-0.014***
	(0.004)	(0.004)	(0.004)
Ground Floor × Amenity × Access	-0.008*	-0.008*	-0.008*
	(0.005)	(0.005)	(0.005)
Floor Level	0.010***	-0.004**	
	(0.001)	(0.002)	
Floor Level × Building Height	-0.000***	0.001***	
	(0.000)	(0.000)	
Floor Level Squared		0.002***	
		(0.000)	
Floor Level Squared × Building Height		-0.000***	
		(0.000)	
Top Floor	-0.022**	-0.007	-0.022**
	(0.010)	(0.010)	(0.010)
Top Floor × Building Height	0.007***	0.003	0.009***
	(0.002)	(0.002)	(0.002)
Log Floor			0.012***
			(0.003)
Log Floor × Building Height			0.002***
			(0.000)
Buildings	37,382	37,382	37,382
Observations	265,089	265,089	265,089
Building FE	YES	YES	YES
Grid-Year FE	YES	YES	YES
Municipal-Year FE	YES	YES	YES
Dwelling controls	YES	YES	YES

Standard errors clustered at building level in parentheses. The variable Log Floor is the log of floor level + 1, which removes the missing values created by log of zero. Ground floor is a binary variable that equals one when the floor level is the ground floor, and zero otherwise. Top floor is a binary variable that equals one when the floor level is the top floor of the building and zero otherwise. Dwelling characteristics include: the number of rooms and the existence of a balcony, view, parking spot or garage. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table B.3: Horizontal Gradient

Dependent variable:	Log Rental Price Per Square Meter	
	(1)	(2)
Road Distance from CBD	-0.052***	-0.071***
	(0.010)	(0.013)
Road Distance from CBD Squared		0.002***
		(0.001)
Observations	285,450	285,450
Municipality FE	YES	YES
City-year FE	YES	YES
Dwelling controls	YES	YES
Geographic controls	YES	YES

Standard errors clustered at municipality level in parentheses. Dwelling characteristics include: the number of rooms and the existence of a balcony, view, parking spot or garage. Geographic controls are altitude and slope of terrain. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table B.4: Vertical Gradient Spillovers

Dependent variable:	Growth in Average Municipal Log Rental Price				
Vertical Location (within buildings):	All	Ground Floor	Lower Half	Upper Half	Top Floor
	(1)	(2)	(3)	(4)	(5)
Distance to closest high price municipality (logs)	-0.029*	0.013	-0.002	-0.059*	-0.145**
	(0.017)	(0.016)	(0.010)	(0.034)	(0.060)
Distance to CBD (logs)	0.005	-0.027	-0.027	0.022	0.064
	(0.024)	(0.027)	(0.025)	(0.037)	(0.091)
Observations	255	69	139	116	50
City FE	YES	YES	YES	YES	YES
Municipal controls	YES	YES	YES	YES	YES

Standard errors clustered at city-year level in parentheses. The specification of Guerrieri et al. (2013) clusters at the city level since their sample contains around 170 cities, whereas our sample only covers five. Municipal controls include: log of median taxable income, log of local personal income tax rate and log of local population. In addition, we include an index of accessibility and an indicator of the presence of a lake. This table reports the long difference between 2014 and 2004. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$