Do Households Value Lower Density: Theory, Evidence, and Implications for Cities

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Abstract

A substantial literature demonstrates that zoning restrictions on building height or density lower supply and increase housing prices. However, negative externalities due to household preferences for lower neighborhood density could justify restrictions on private developers. Thus building density in a laissez-faire city may be above the welfare maximizing level. The potential external costs of height and density are tested here and found to be substantial. Increased building separation appears to mitigate the external cost of height. This implies that some level of density or floor regulation (FAR) regulation is welfare-enhancing, and that the gap between price and marginal construction cost overstates the social cost of zoning because households value lower density.

JEL Codes: R0, R10, R14, R30
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1 Introduction

Do households value lower density? There are many studies showing that lower density is associated with higher neighborhood house price. McConnell and Walls (2005) provide a nice summary of studies finding that there is a positive price premium associated with access to parks and open space. Saphores and Li (2012) find that single family properities were valued higher with additional irrigated grass on the parcels and in the neighborhood. Chintantya and Maryono (2018) show that there is higher willingness to pay for proximity to urban green space. Lin, Jensen, and Wachter (2022) conclude that even small vacant unimproved lots raise adjacent property values in Philidephia. To the extent that open space is the opposite of development density, the positive open space premium is consistent with the hypothesis that households value low density and access to light and views.

There is growing evidence that residents are willing to pay more for space that is less obstructed by neighboring structures. First, Liu, Rosenthal, and Strange (2018) find that rents vary directly with floor level in commercial buildings in the United States, suggesting that consumers are willing to pay more for height-based amenities. Danton and Himbert (2018) report a similar pattern in residential buildings in Switzerland. Fleming et al. (2018) find that an extra hour of sunshine falling directly on a unit is associated with a higher asset price for housing in New Zealand. If households value height-based amenities such as views and sunlight, nearby building heights and density should have disamenity effects. Davidoff (2016) reports that topographic barriers have amenity effects that raise house prices. Borck and Schrauth (2021) show that local air quality, measured by the concentrations of NO_2 and O_3, decreases with local population density in Germany. Shoag and Veuger (2019) demonstrate that planning regulation is positively correlated with local restaurant quality; and Kuang (2017) shows that a higher quality of local restaurants increases local house price valuation. Together, these two papers suggest that planning regulation may increase households' willingness to pay for housing. Davidoff, Pavlov, and Somerville (2022) find that increased densification by "laneway homes" lowers nearby property values.

As noted in Quigley and Rosenthal (2005), urban planners implement many different types of regulations[1]. This reserach is concerned only with zoning controls that limit

[1] Among the planning regulations reviewed in Quigley and Rosenthal (2005), many have a problematical relation to economic efficiency. Local homeowners may vote for supply restrictions in order to raise house values. Alternatively, restricting access to smaller housing units or housing and building codes may be motivated by a desire to exclude lower income households for government fiscal reasons.

building density. Some regulations directly control building height. Others regulate density through requirements for open space and building setbacks. Regulations targeting floor area ratio(FAR) are most common. Planners argue that limiting density raises surrounding house prices but that indicates an increase in urban aesthetic value and makes neighborhoods more attractive.

Alternatively, a significant literature[2] argues that zoning raises the cost of housing production by requiring more land per unit of interior space. If this is true, then zoning reduces the supply of housing and increases housing costs without raising urban amenity, potentially distorting the location of labor and production[3].

Many empirical tests have found a positive relation between the stringency of zoning regulation and the price of housing. Generally, researchers attribute these price increases to density limits raising the cost of producing housing rather than raising the quality of the built environment. Examples of this literature include Segal and Srinivasan (1985), Malpezzi (1996), Green, Malpezzi, and Mayo (2005), Glaeser and Gyourko (2018), Saiz (2010), and Turner, Haughwout, and Klaauw (2014). These papers estimate the relation between the amount of land use regulation, measured by a citywide index, and housing price or rates of new housing construction. The general finding is that zoning is associated with higher prices per housing unit and lower amounts of new construction[4]. Rose (1989) and Saiz (2010) show that natural topographic restrictions on the supply of land for housing raise housing prices and lower the elasticity of supply of housing units. To the extent that topographic barriers emulate zoning restrictions by reducing the density of development, this suggests that planning restrictions raise prices. More recent research by Gyourko, Mayer, and Sinai (2013), Cun and Pesaran (2018), and Parkhomenko (2020) argues that the increase in zoning restrictions has contributed to increases in the dispersion of house prices across cities. Similarily, Song (2021) finds that increasing minimum lot size zoning increases sales prices. Büchler and Lutz (2021) among others report that up zoning in small areas, raises supply and lowers area prices.

The current state of the literature is quite curious. There is general agreement that lowering density below laissez faire raises house prices and lowers supply of interior space.

[2]See, for example, Glaeser, Gyourko, and Saks (2005), Glaeser and Ward (2009), and Glaeser and Gyourko (2018) among others.

[3]See Hsieh and Moretti (2018), Herkenhoff, Ohanian, and Prescott (2018), and Bunten (2017) among others

[4]Some research, including Green, Malpezzi, and Mayo (2005) and Saiz (2010), find that zoning also reduces the elasticity of housing supply measured as the relation between the percentage changes in housing units and the sale prices of housing units. Recently Liu (2018) noted that effects on housing space and housing units are not the same.

But those advocating regulation say this is an amenity effect while others attribute the rise in price to limitations on supply. The central difference is over the possibility that zoning increases the willingness to pay for housing[5]. In the context of building height regulations, the crucial question is whether that tall buildings have negative spillover effects on nearby properties because households prefer lower density.

A literature review indicates the lack of formal testing for and quantification of potential negative externalities of tall buildings on surrounding properties. This paper attempts to fill that gap. In addition, the paper models the potential effects of density externalities on the relation between a laissez-faire and an optimal city. Individual developers may perceive the demand for low density, but they do not bear the cost associated with the additional height of their structures and have an incentive to choose development density that is above welfare-maximizing levels. Comparing the planner's city with a laissez-faire city shows that the optimum city can be achieved by setting limits on building height, or by imposing a regulatory tax on housing development whose size reflects the external damage of the height externality. This means that the market price of additional structure height should exceed the marginal construction cost of adding height in the optimum city.

In contrast to other cases of urban externalities, the height or density externality modeled here is a local negative externality generated by laissez-faire development. Therefore, it is different from classical externalities such as traffic congestion and pollution externalities, or positive agglomeration economies, all of which are functions of total city population. Because height externalities, if they exist, are more severe in high-density areas, any downward adjustments of height are concentrated near the center city. Consequently, theory suggests that the optimal city has higher housing price, lower housing consumption and higher land rent. The city radii are identical provided that the externality is negligible at the low residential densities found near the edge of the city. These new results contrast with other externalities considered in the literature, such as unpriced traffic congestion, open space amenity at city boundary, or general pollution, all of which motivate the use of anti-sprawl policies such as urban growth boundaries.[6]

The height or density externality test implemented here is based on the difference in surrounding rents associated with the height of immediately adjacent buildings. Of course, height and density can have negative effects on users of the constructed environ-

[5]There have been a few research attempts to measure the net welfare benefit of zoning, such as Cheshire and Sheppard (2002), Glaeser, Gyourko, and Saks (2005), Turner, Haughwout, and Klaauw (2014), and Albouy and Ehrlich (2018), all of which find negligible benefit.

[6]See, for example, Brueckner (2001) for a discussion of these externalities, and Larson and Yezer (2015) for the effects of various zoning regulations.

ment other than the adjacent renters. For example, city streets are used by motorists, pedestrians, etc., and restrictions on light, air, and appearance are experienced by these individuals in addition to the occupants of surrounding structures. Accordingly, the externality estimate obtained here for rental units does not consider the possibility that additional amenity effects are produced by building height and density. A crucial aspect of the empirical research is that zoning must be exogenous. The existence of a height externality is tested here using data from Washington, DC, where height limits are based on a 1910 act of the US Congress rather than a locally elected government.

The empirical testing finds that building height generates substantial negative externalities for surrounding building rents. In addition, the negative effect of nearby building heights is found to be mitigated by distance to adjacent buildings. This suggests the externality depends on both height and building separation and that FAR regulation, which is currently the basis of many planning restrictions, could be welfare enhancing. The fact that the price effect is attenuiated by physical distance between buildings measured in meteres identifies it as related uniquely to development density.

This research develops a new method to quantify a height or density externalities, and provides a model that demonstrates how to set regulations to achieve a welfare optimum if such externalities are significant. The testing performed here and the urban modeling supporting welfare calcuations are new, however, the research does not imply that current regulation is optimal. In the specific case considered here, actual regulation lowers heights below the welfare optimum. This is not surprising because the FAR regulations were set by Congress in 1910. In some cities, planning regulations may be motivated by issues completely unrelated to externalities, including rent seeking by developers, fiscal or racial segregation, or limiting congestion of public facilities. Nothing in this research is designed to test if the criteria used by planners and politicians in setting regulations elsewhere are optimal. Instead, the effort here is to determine if, based on economic analysis, FAR regulation in dense urban environments can be welfare enhancing compared to laissez-faire, and to determine the effects of such regulation on the structure of optimal versus laissez-faire cities.

This paper is related to a large body of research that studies the effect of zoning on housing cost, particularly research that attempts to measure the stringency of land use regulations. One measurement technique, originating with Glaeser, Gyourko, and Saks (2005), focuses on the difference between the marginal benefit and the marginal cost of adding floors to existing housing in areas with height or FAR restrictions. The authors observe that the market prices of apartments in Manhattan are much higher than the marginal construction cost. They argue that if the housing market is efficient, building height should rise to the point where the housing value from an additional floor is equal to the marginal cost of adding that floor. Based on the same reasoning, Glaeser and Gyourko (2018) measured the ratios of medium price to minimum profitable construction cost for single-family homes across the US housing markets. They observed that cities with high price-to-cost ratios are also the cities with inelastic supply and restrictive planning regulations. There is an implicit assumption in this research that negative externality associated with density is negligible. This paper tests the possibility that the price-cost gap and/or ratio measure overstates the social cost of zoning.

Finally, this paper is also related to recent research by Asquith, Mast, and Reed (2021), Li (2021), and Pennington (2021) which finds that completion of high-rise apartment buildings reduce local neighborhood rents. Büchler and Lutz (2021) report that up zoning raises supply and lower rents. These studies argue that the negative effect of new construction on surrounding rents is due to a "supply effect" mechanism, or that the reduction in nearby rents is caused by an increased supply of housing. However, it is also possible for externalities associated with rising height and density to result in lower prices. A special falsification test is conducted here to distinguish between the neighborhood rent and the density externality hypotheses.

The plan of the paper is as follows: the next section discusses the general equilibrium effect of a building height externality; Section 3 then presents evidence of the existence of height or density externality in Washington, DC; and section 4 estimates prices and marginal costs and performs a welfare analysis of the current height restrictions.

2 Effects of height externalities on the city

2.1 Housing development in a Laissez-faire city

Households obtain utility from consumption of a composite good (c), housing space (q) in the unit that they occupy, and nearby building height or density (H). All households have an identical quasi-concave utility function: $U = v(c, q, H)$.[7] This is an open city model with costless migration of labor and capital producing iso-utility and iso-profit equilibria. A series of papers from Stull (1974) and Wheaton (1998) through Turner, Haughwout, and Klaauw (2014) and Larson and Yezer (2015) has established welfare

[7]The model developed here has some resemblence to Turner (2005) where household preferences are for open space as opposed to a general preference for lower density which is modeled here.

maximization in this model is achieved by maximizing aggregate land value. This is the object of the planning solution adopted here.

Households prefer to live in neighborhoods with low building height ($v_H < 0$) as higher neighboring buildings block sunlight, air circulation, and views. The price of consumption goods is normalized to unity, p is the rental price of housing, household income is y, and distance to the city center is indexed by x. Households commute to work in the CBD and face a budget constraint that includes the composite good, housing, and transportation cost $t(x)$.

$$c + pq = y - t(x) \tag{1}$$

The first-order condition for utility maximization is:

$$\frac{v_q(y - t(x) - pq, q, H)}{v_c(y - t(x) - pq, q, H)} = p \tag{2}$$

Because households are identical, in equilibrium they must have the same level of utility. This is the household's no-arbitrage condition:

$$v(y - t(x) - pq, q, H) = u, \forall x \tag{3}$$

Eqs. 2 and 3 simultaneously determine each households' bid rent for space, $p(x, H)$, and housing demand, $q(x, H)$, for a given location x and nearby building height H, with income y and utility u parameters suppressed. Differentiating Eq. 3 by x and H, and making use of Eq. 2 yields an expression that has the familiar form of Muth's equation:

$$\frac{\partial p(x, H)}{\partial x} = \frac{-t'(x)}{q(x, H)} < 0 \tag{4}$$

which implies that, as a household moves further away from the CBD, the increases in commuting cost must be compensated by a sufficient reduction in housing cost. Moreover, a parametric increase in H will lower willingness to pay for housing, reflecting the disamenity from nearby height.

$$\frac{\partial p(x, H)}{\partial H} = \frac{v_H}{v_c q(x, H)} < 0 \tag{5}$$

Now consider the builder's problem, which differs from ordinary models in that height is an important characteristic. Housing output measured in square feet of floor space is the product of the number of stories (h) and land (l)[8]. Competitive housing builders maximize profit by choosing h and l. Construction cost is a function of building height $S(h)$. It is assumed that $S' > 0, S'' > 0$. r is the rent per unit of land paid to absentee landlords. Developers maximize profit per unit land in the laissez-faire city without considering the height externality:

$$\max_{h} p(x, H)h - S(h) - r \tag{6}$$

The first-order condition to maximize profit implies:

$$p(x, H) = S'(h), \forall x \tag{7}$$

Builders choose height where the marginal cost of adding an additional floor equals the market price of floor space. The second-order sufficient condition is satisfied given that construction cost is strictly convex in building height. The above equation implicitly defines the builder's best response, $h(x, H)$, as a function of adjacent builders' choices of H. Implicit differentiation yields: $\frac{\partial h}{\partial x} = \frac{p_x}{S''(h)} < 0$ and $\frac{\partial h}{\partial H} = \frac{p_H}{S''(h)} < 0$.

Competition among builders drives profit to zero, which yields a bid rent function for land in terms of x and H. Furthermore, nearby height depresses land rent.

$$r(x, H) = p(x, H)h(x, H) - S(h(x, H)), \quad r_x < 0, \quad r_H < 0 \tag{8}$$

So far, house price(p), housing demand(q), land rent(r) are solved in terms of x and h, but h ultimately depends on x. To solve for h, note that developers in the same neighborhood have a common distance from the CBD. Symmetry among builders implies that $h = H$ must hold in equilibrium. Eq. 7 can be rewritten as

$$p(x, h) = S'(h), \forall x \tag{9}$$

Because $p_H - S'' < 0$ and by the implicit function theorem, there is a unique h associated with every x. Solving the above equation yields the laissez-faire height $\hat{h}(x)$. Differentiating the above equation with respect to x produces a familiar result that building

[8] The formulation here follows Glaeser (2008), which is slightly different from the standard presentation where builders combine land and structure input, to produce housing square footage per unite land. There is no essential difference between these two formulations. Although as noted by Glaeser, the current formulation relates better to empirical cost estimates for creating space, such as those published by R.S. Means.

height falls with distance from CBD. Compared to the laissez-faire city without a height externality, the term $p_H < 0$ in the denominator indicates that the building height falls at a lower rate with distance x.

$$\hat{h}'(x) = \frac{-p_x}{p_H - S''} < 0 \tag{10}$$

Once $\hat{h}(x)$ is determined, the other key variables that describe the internal characteristics of a city can be rewritten in terms of location x: $\hat{p}(x) = p(x, \hat{h}(x)), \hat{q}(x) = q(x, \hat{h}(x)), \hat{r}(x) = r(x, \hat{h}(x))$. Differentiating the housing price equation yields Muth's Equation in a laissez-faire city with a height externality:

$$\hat{p}'(x) = -\frac{t'}{q}\left(\frac{-S''}{p_H - S''}\right) < 0 \tag{11}$$

The first term $-t'/q$ is Muth's original term. The second term $\frac{-S''}{p_H - S''}$ is positive but less than one, implying that the house price gradient depends on household preferences regarding neighborhood height. The larger the nearby height effect is, the flatter the price gradient. Intuitively, given that height is falling with distance, there is now a gain from moving out in the form of lower height which compensates, in part for the rise in transportation cost associated with moving out. If households do not care about neighboring height, the expression is reduced to Muth's original equation.

Similarly, the height externality also flattens the land rent gradient.

$$\hat{r}'(x) = r_x(x, h) + r_H(x, h)\hat{h}'(x) = r_x\left(\frac{-S''}{p_H - S''}\right) < 0 \tag{12}$$

Eqs. 10, 11, 12 show how the laissez-faire city responses to a height externality. These effects are summarized in the proposition below:

Proposition 1 *A height externality flattens the gradients of housing price, building height, and land rent. A stronger aversion to nearby height decreases these gradients.*

The height externality is a local externality and is larger in high-density areas. As building height falls with distance according to Eq. 10, the effect of the lower externality on house price is correspondingly reduced. The result is flatter house price and land rent gradients. Figure 1 illustrates this result by depicting a laissez-faire city under different levels of aversion to nearby height and shows that a higher level of aversion to nearby height results in lower and flatter gradients.

Thus, the added assumption that households are adversely affected by nearby height has not altered the central predictions of the standard urban model(SUM) regarding the internal structure of cities. In particular, the predictions that the price per square foot of housing, land rent per unit land, and building height or structures are all decreasing functions of distance to the CBD. The existence of a height externality flattens these gradients.

Finally, land rent at the edge of the city must equal agricultural land rent, which can be used to determine the city radius, $\bar{x}$:

$$\hat{r}(\bar{x}) = r_a \tag{13}$$

2.2 *Optimal city with height externalities*

After introducing a height externality to a laissez-faire city, new results regarding the divergence of the laisse-faire city from the optimal city follow logically. In an open city model, household utility levels are fixed. The objective of the planner is to maximize aggregate rent to the land owners[9]. Unlike builders, the planner reacts to the externality and perceives that $H = h$. Formally, the planner chooses $h(x)$ and $\bar{x}$, to solve the following problem:

$$\max_{h(x),\bar{x}} \int_0^{\bar{x}} 2\pi x\theta[p(x,h(x))h(x) - S(h(x))]dx + \int_{\bar{x}}^{\bar{m}} 2\pi x r_a dx \tag{14}$$

Where $\bar{m}$ is the geographic boundary of the city. The first part of Eq. 14 is residential land value, and the second part is agricultural land value. The planner's first-order necessary conditions are:

$$h(x) : p_H(x,h(x))h(x) + p(x,h(x)) = S'(h(x)), \forall x \tag{15}$$

$$\bar{x} : p(\bar{x},h(\bar{x}))h(\bar{x}) - S(h(\bar{x})) = r_a \tag{16}$$

Comparing Eq. 9 and Eq. 15, it is apparent that, while the laissez-faire builder builds up to the point where the house price equals marginal construction cost; the planner would choose a height where housing price exceeds marginal construction cost. The extra term, $p_H(x,h)h$, is the social cost of an additional floor. Once $h(x)$ is solved from Eq. 15, the spatial size of the city, $\bar{x}$, is determined by Eq. 16. The differences between the two cities are summarized below:

[9]This approach follows Stull (1974), Bento, Franco, and Kaffine (2006), and Helsley and Strange (2007), where the settings are open cities.

Proposition 2 *In an open city with a height externality, the laissez-faire equilibrium has a higher level of residential building height than the social optimum at all locations where the externality exists. Thus, the imposition of a regulatory tax on building height can be land rent maximizing.*

Proof: The laissez-faire solutions are denoted by hats and the first-best solutions denoted by stars. For part (a), suppose that $h^* \geq \hat{h}$. Then, given $S'' > 0, S'(h^*) \geq S'(\hat{h})$ holds, Eq. 9 and 5 imply that $p_H(h^*)h^* + p(h^*) = S'(h^*) \geq S'(\hat{h}) = p(\hat{h})$ must hold. But with $p_H < 0, p_H(h^*)h^* < 0$ and $p(h^*) < p(\hat{h})$ must hold. Therefore, $p_H(h^*)h^* + p(h^*) < p(\hat{h})$. This contradiction rules out the premise of $h^* \geq \hat{h}$, establishing $h^* < \hat{h}$.

Figure 2 illustrates the difference in building height profiles between the two cities. It shows that the gap between the two height profiles is especially large near the city's center. the externality is the product of $p_H(x, h)$ and h, and the tallest buildings are located at the center.

Proposition 3 *The laissez-faire equilibrium has a lower level of housing price, higher level of housing consumption, and a lower level of land rent than the social optimum at all locations where the height externality exists.*

Proof: Note that $h^*(x) < \hat{h}(x)$ is already established. For housing price, $\hat{p}(x) = p(x, \hat{h}(x))$, $p^*(x) = p(x, h^*(x))$, $p_H(x, H) < 0$ implies that $\hat{p}(x) < p^*(x)$. For housing consumption, $\hat{q}(x) = q(x, \hat{h}(x))$, $q^*(x) = q(x, h^*(x))$, and $q_H(x, H) < 0$ implies $\hat{q}(x) > q^*(x)$. For land rent, $\hat{r}(x) = r(x, \hat{h}(x))$, $r^*(x) = r(x, h^*(x))$, and $r_H(x, H) < 0$ implies that $\hat{r}(x) < r^*(x)$.

In the planned city, the lower building heights result in a higher housing price, as households are willing to pay more for the increased amenity. The higher housing price reduces housing consumption per household and raises land rent.

2.3 Sample solution with specific functions

To illustrate these general theorectical results, specific functional forms for household preferences and the housing construction cost function are imposed. This allows a solution for the population density function. Preferences are assumed to take a Cobb-Douglas form, and the housing construction cost function is exponential in building height. Formally, the functional form assumptions are:

$$v = c^{1-a}q^a H^{-\gamma}, \quad S(h) = kh^\delta \tag{17}$$

where the parameters are all positive and satisfy: $0 < \gamma < a < 1$, $k > 1$, $\delta > 1$. a is the share of expenditure on housing, and γ is the disutility from nearby height. Solving household's problem yields the following:

$$p(x, H) = (1-a)^{\frac{1-a}{a}} a(y - tx)^{\frac{1}{a}} u^{-\frac{1}{a}} H^{-\frac{\gamma}{a}} \tag{18}$$

$$q(x, H) = (1-a)^{\frac{a-1}{a}} (y - tx)^{\frac{a-1}{a}} u^{\frac{1}{a}} H^{\frac{\gamma}{a}} \tag{19}$$

Builders maximize profit per unit land by choosing building height: $\max_h p(x, H)h - kh^\delta - r$. The private developer's first order condition is: $p(x, H) = \delta kh^{\delta-1}$. Developers at the same distance, x, must choose the same height $H = h$. Therefore, the laissez-faire city height can be solved. Unlike private developers, the planner perceives $H = h$ when choosing building height. the planner maximizes aggregated land rent, and as analyzed previously, planner's first order condition is: $p_H(x, h)h + p(x, h) = S'(h)$. Solving this yields the optimum city's height. Let the laissez-faire solutions be denoted by hats while the first-best solutions have stars. A indicates the constant term $(1-a)^{\frac{1-a}{a}} \frac{1}{k\delta}^{\frac{a}{a(\delta-1)+\gamma}}$.

$$\hat{h}(x) = A * a^{\frac{a}{a(\delta-1)+\gamma}} [(y - tx)u^{-1}]^{\frac{1}{a(\delta-1)+\gamma}} \tag{20}$$

$$h^*(x) = A * (a-\gamma)^{\frac{a}{a(\delta-1)+\gamma}} [(y - tx)u^{-1}]^{\frac{1}{a(\delta-1)+\gamma}} \tag{21}$$

Given that $a > \gamma$, the comparison between two solutions is consistent with proposition 2. Substituting Eq. 20 or Eq. 21 for H in the households' housing demand function, yields housing consumption in the two cities. The population density per unit land is the ratio of height to housing consumption. Let B denote the constant term $(1-a)^{\frac{(1-a)\delta}{a(\delta-1)+\gamma}} (\frac{1}{k\delta})^{\frac{a-\gamma}{a(\delta-1)+\gamma}}$

$$\hat{D}(x) = B * a^{\frac{a-\gamma}{a(\delta-1)+\gamma}} (y - tx)^{-1+\frac{\delta}{a(\delta-1)+\gamma}} u^{-\frac{\delta}{a(\delta-1)+\gamma}} \tag{22}$$

$$D^*(x) = B * (a-\gamma)^{\frac{a-\gamma}{a(\delta-1)+\gamma}} (y - tx)^{-1+\frac{\delta}{a(\delta-1)+\gamma}} u^{-\frac{\delta}{a(\delta-1)+\gamma}} \tag{23}$$

Comparing Eq. 22 and 23, it is clear that laissez-faire household density is higher than the planned city at all locations. Thus the planner is able to raise land value per unit land with lower population density and lower total population. Assuming that the building height externality is negligible at the low height and density near the city edge, the two cities have identical radii. Because the total population of a city is the integral of population density over all the distance from CBD, with identical city radius and because $D^*(x) < \hat{D}(x)$ at all locations, total laissez-faire population is larger than the optimal city population[10]. These new findings are summarized as follows.

Proposition 4 *The optimal city has a lower level of population density than the laissez-faire city at all locations where the height externality exists. Consequently, if the externality is negligible near the city edge, the optimal city has less population than the laissez-faire city, has the same radius, and higher aggregate land value.*

In sum, the model developed here has two new and perhaps surprising implications for the building height externality. First, there is a welfare argument for height or density restrictions or for a regulatory tax on building height. The size of the tax depends on building height and varies across locations.

Second, under standard preference and cost functions, the optimal city is less dense than the laissez-faire city. This implies that the planning solution manages to raise land rent with less population per unit of land. In fact, if there is no height externality at the low density near the edge of the city, the planned and laissez-faire cities have identical radii and land area. Thus the welfare gain from the planned city includes higher aggregate land value generated with a smaller population.

Finally, these results contrast with the literature on the effects of zoning on city spatial size. The empirical finding is that zoning raises housing prices and decreases city size. The results presented here agree with the empirical literature but suggest that the planners are raising welfare by increasing land value with a smaller aggregate population. Also, the empirical finding that local down zoning lowers house value ignores the general equilibrium result here that overall planning raises aggregate land value in the city. That is the partial equilibrium effect of density limits on land price of single properties ignores the possibility of a general equilibrium effect of planning on all land in the city.

[10] Laissez-faire city's population is $\hat{N} = \int_0^{\bar{x}} 2\pi\theta\hat{D}(x)dx$ and the optimal city's population is $N^* = \int_0^{\bar{x}} 2\pi\theta D^*(x)dx$. Clearly, $D^*(x) < \hat{D}(x)$ implies $\hat{N} > N^*$

3 Testing the existence and size of building height and density externalities

The analysis in Section 2 relies on the assumption that households care about nearby height or density. This section tests for the existence and size of a building height externality in a relatively dense urban area.

3.1 Rental data and building height measure

Housing rent data were collected from zillow.com. Rent is used instead of asset price because rental value does not involve expectations of future value. This is particularly important because the height and density of current surroundings may differ from future expectations. The rent for a unit in a building adjacent to low-rise structures would reflect the amenity associated with better views, more sunlight, and improved air circulation. In contrast, the asset price of the same unit would also incorporate the expected use of that adjacent space in the future.

The testing focuses on multi-story apartments rather than houses or townhouses because the building height externality is likely more substantial for areas with dense and tall buildings. The taller the average building height and the narrower the street width, the more consequential the restriction on amenities such as air circulation and sunlight is. The data sample includes apartment buildings located in two neighborhoods in Washington, DC: Navy Yard and Southwest Waterfront.

There are several reasons why the analysis here focuses on these two neighborhoods. First, zoning is exogenous–based on the passage of the Height of Building Acts of 1910. [11] Second, many buildings were recently constructed in these two neighborhoods after the area was selected as the location of the baseball stadium Nationals Park and federal employment was relocated to the area [12]. Some buildings were built before the rise in rent, and some were built after, which pushed construction to the 14 story height limit. Third, residential buildings in the areas are similar in terms of style and amenities. Fourth, differences in topography and construction cost are negligible. The area is essentially flat and uniform. Therefore, building heights equal building elevation above sea level.

[11]This federal law imposes maximum heights on buildings within Washington, DC based upon the width of the street, to a maximum height of 130 feet (commercial streets) and 90 feet (residential streets), and 160 feet for parts of Pennsylvania Avenue, NW.

[12]See Schuetz (2020), Navy Yard and Southwest Waterfronts are among the several neighborhoods with the largest amount of new housing.

If building elevations were different then building height would not reflect differences in the elevation of the top floors and height externality should be based on differences in elevation.

For each apartment unit, monthly rent and primary physical attributes such as floor area and the number of rooms were collected from Zillow. These data were collected in early Feburary 2021. Building characteristics such as distance to nearest public housing, rivers, etc., were calculated using GIS software. Table A.1 provides summary statistics of these attributes. The average monthly rent in the data is $2903 with a standard deviation of $899. The median unit has 719 squared feet floor space, with 1 bedroom and 1 bathroom and locates at 7 floor. Adjacent heights range from roughly 3 stories to 13 stories and the average is around 9 stories.

The height of each building and the adjacent buildings were collected. Height is measured in terms of the number of stories. For each apartment building, data on the length of each side, its adjacent height, and the distance to adjacent buildings were collected. The adjacent height measure, H_b, is the average of adjacent buildings' height weighted by the length of each side of the building.

$$H_b = \sum_{s=1}^{n} \frac{Height_s * Length_s}{Perimeter} \tag{24}$$

To construct this measure, it is necessary to define the maximum distance between two buildings considered to be adjacent. The definition of an adjacent building used here requires that the neighboring structure be within 200 feet. In cases where there was no building within 200 feet on one side of a building, that side is treated as facing open space, i.e. as not having an adjacent building. Using a similar method, distances between adjacent buildings were recorded for each side with an adjacent building, and calculated as the weighted average based on the side length.

3.2 Stochastic specification

To estimate the relation between rental cost and adjacent heights, the following hedonic model specification was adopted:

$$lnr_{ibn} = \mu + \lambda_n + \gamma H_b + \beta_1 h_b + \beta_2 Z_b + \beta_3 X_{ibn} + \varepsilon_{ibn} \tag{25}$$

where lnr_{ibn} is the logarithm of monthly rent for unit i in building b and neighborhood

n. γ is the coefficient of interest. If a height externality exists, then it is expected that $\gamma < 0$. H_b is the average height of adjacent buildings. h_b is the height of the building itself. While the theory developed above assumes that households care about nearby buildings rather than the height of their own building, the own building height is inserted to test whether that is really the case and forms part of the falsification test discussed below. X_i is a vector of unit characteristics that include standard hedonic controls such as the number of bathrooms, floor level, and the log of interior squared feet. Z_b is a vector of building characteristics, including building age, age squared, and its distance to the nearest grocery stores and nearest public housing complex. The λ_n are census block group dummies.

3.3 The role of building separatation

An implicit assumption associated with Eqs. 25 is that the effect of nearby building height on rent is additive independent and that $p_H(x, H)$ does not vary with distances between buildings. However, spaces between buildings should help to mitigate the negative height externality. Building designers generally favor wider separation to allow the admittance of sunlight, air circulation, and views. Planners often regulate floor area ratio(FAR) rather than building height. In Washington, D.C., the 1910 Height of Buildings Act set limits on height based on the width of the street on which a building is situated. In New York City, builders are allowed to build further upward, but successive setbacks are required. This pattern of regulation suggests planners believe that the relation between height and rent could depend on building separation or that D is an important parameter hidden inside $p_H(x, H)$. This suggests an alternative to Eq. 25 is[13]:

$$lnr_{ibn} = \mu + \lambda_n + \rho_1 H_b + \rho_2 H_b D_b + \rho_3 D_b + \beta_1 h_b + \beta_2 Z_b + \beta_3 X_{ibn} + \varepsilon_{ibn} \tag{26}$$

where D_b is the distance to adjacent buildings. If there is a density externality, the expectation is that $\rho_1 < 0$ and $\rho_2 > 0$

[13]The comparison between height and density is also similar to foreclosure externalities, where Liu and Yezer (2019) finds that it is the ratio of seriously delinquent or foreclosed units to total housing units, rather than the number of foreclosure units alone, that has negative effects on property value.

3.4 Identification

The hedonic specification used here is directly comparable to the approach used in previous studies of the effects of nearby neighborhood conditions on willingness to pay for housing. It is not uncommon to relate housing value to visibility of surrounding territory or to the amount of light received, as in Fleming et al. (2018). The specification here simply measures the externality created when buildings block light and views rather than measuring the positive amenity of light and view. Rather than measuring the positive light and view, the size of the obstruction is measured. There may be several reasons for this effect based on general amenity. Hedonic coefficient estimates are commonly used to measure the willingness to pay for proximity to urban amenities, such as open space, views, restaurants, better schools and lower crime. In sum, the hedonic approach to measuring externalities induced by neighborhood amenity is well established in the literature.

The identification challenge in estimates of Eq. 25 is that building rents could motivate the construction of taller buildings. This is certainly a possibility in areas where the regulatory ceiling is not currently met, but the positive effect of rent on surrounding building heights would bias estimates of the effect of height on rent in Eq. 25 upward and work against the finding of a negative height externality. For this reason, the estimates of the size of the externality should be regarded lower bounds. This is consistent with the fact that externalities experienced by non-renters are also not being measured to ensure that amenities associated with planning are not overstated.

Another possible identification problem raised by referees is based on a literature, including Asquith, Mast, and Reed (2021), Li (2021), and Pennington (2021), that finds new construction lowers nearby rents. This is interpreted as the result of a rise in local supply rather than a fall in a amenity due to the added density. Concern over this possible supply effect is addressed by constructing and adding another height measure. The new variable, "further block height," is the height of buildings that are adjacent to the buildings that are immediately adjacent to the object building. In effect the own building height, the adjacent building height and the further building height variables lie in a series of small concentric circles with own building at the center. If there is a local supply effect, it should be manifest in the estimated coefficients of the own and further building height variables and not just the adjacent building height. The density externality hypothesis tested here requires that the estimated coefficient of adjacent height be negative while those of own and further building height be non-significant or positive. A further falsification test based on Eq 26 specification requires that the estimated coefficient of adjacent building height be negative and of distance to adjacent structure be positive, while own and further building height effects are non significant or positive (higher rent generate taller buildings). In addition, local housing market differences are further represented by the inclusion of census block group dummies.

3.5 Empirical results

Table 1 reports estimates of Eq. 25 where H_b measures adjacent building height. In both specifications, standard errors are clustered at the building level to account for potential error correlation across units within the same building. Column 1 in Table 1 contains estimates of a limited version of Eq. 25 that does not include census block group dummies. Column 2 includes census block group dummies to control for unobserved local characteristics. Consistent with the literature on the value of light and air, the positive and statistically significant coefficient of floor level indicates that there is a positive premium associated with floor level or that residents are willing to pay more to live on a higher floor. Other standard hedonic variables such as the number of bathrooms, log of interior floor space, building age, building age squared, and log of building area yield coefficient estimates with expected signs. The estimated coefficient for own height is negative but is not statistically significant, The results also suggest that residents value proximity to local amenities such as the river and grocery stores. While buildings in the sample are market-rate housing, Navy Yard and Southwest waterfront also have a few affordable housing units. Rent appears to be higher for apartment buildings that are further away from complexes that include affordable housing.

Importantly, in both specifications, there is a statistically significant negative effect of adjacent height on rent. In column 2, adjacent height has a statistically significant semi-elasticity of -1.50%, implying that adding an additional floor to existing adjacent buildings is associated with a 1.50% reduction in surrounding rent. At the sample mean of rent, this translates into approximately \$44 in rent per month. Overall, the results here indicate that $p_H(x, H) < 0$, implying that households prefer to live in buildings with lower adjacent heights.

Column 1 in Table 2 contains estimates of Eq. 26. In column 2, distance to adjacent buildings is inserted. By itself, distance is not statistically significant. In column 3, the interaction term between adjacent height and distance to adjacent buildings $H_b * D_b$ is inserted to test the effect of distance to adjacent buildings on negative nearby height effects. The estimated coefficient of the interaction term is positive and highly statistically significant, consistent with the expectation that distance between buildings mitigates the negative height effect. The coefficient of 0.061 implies that the height effect continues for an average of 114 feet based on the current heights of the buildings.

Column 4 presents an alternative specification that gives finer detail on the externality mechanism. First, an interaction between adjacent height and a dummy indicating whether adjacent height is taller than the building's own height is inserted. The coefficient of this height $\times$ higher height dummy interaction is negative and statistically significant at -0.086, implying that the negative effect of height is more pronounced if the adjacent buildings are on average taller than the own building height. Furthermore, distance $\times$ height $\times$ higher height dummy is also introduced, and the coefficient for this term is positive and statistically significant. This indicates that distance mitigates the externality, and the mitigating effect is especially large for buildings where the building height is lower than the height of adjacent buildings.

3.6 Identification test

This test requires forcing the further building height variable into the specification. These results are shown in Table 3. In all specifications, the coefficient estimates for adjacent height remain negative and statistically significant. The coefficients for both own and further block height are generally not statistically significant except in the most elaborated model shown in the last column, where both the coefficents of further block height and own height are positive and statistically signficant while adjacent height remain negative and statistically significant. The positive coefficents on further block height and own height are consistent with standard urban model's prediction that developers tend to build taller buildings where rents are higher. A further test forcing further block height into Eq 26 shown in the final two columns of Table 3, produces the same pattern of results with adjacent height effects mitigated by distance. Overall these results suggest that finding that additional housing supply lowers local housing markets may be confusing negative amenity whith housing supply effects on price changes.

4 Do current height limits maximize land value?

The previous results suggest that a negative height externality exists, and increased distances between adjacent buildings can mitigate it. These results support the assumption that households care about surrounding height ($v_H < 0$). However, these results tell us nothing about whether the current height limits in Washington, DC[14] are optimal. The existence of a height externality indicates that the laissez-faire height is above optimal, but current restrictions on height may not be an optimal response to the externality.

To answer this, recall that the planner's land rent maximizing solution Eq. 15 equates the cost of the externality to the margin between the rental price and marginal cost of building upward. Theory suggests that increased building density raises land value if and only if:

$$-p_H(x, h) * h < p - S'(h) \tag{27}$$

The term on the left-hand side of the inequality, $p_H(x, H) * H$, is the size of the external cost of building height, which equals the optimal regulatory tax. The size of the externality is the product of the height effect on rent and the number of floors influenced by the externality. The linear distance specification in table 2's column 3 suggests that $\frac{\partial lnp}{\partial H} = -0.070 + 0.061 * D$. Together, this implies:

$$\text{External Cost of Height} = p_H(x, H) * h = \frac{\partial lnp}{\partial H} * h * p \tag{28}$$

The term on the right-hand side of inequality 27, $p - S'(h)$, is the difference between the market price per square foot and the marginal construction cost of height. In a laissez-faire environment, private developers add height until this gap diminishes to zero. It is common to use this price-cost gap as a measure of the stringency of land use regulation.[15] In the absence of externalities, any price-cost gap caused by zoning generates a welfare loss.

To compute the two arguments of Eq. 27, an estimate for rental price per square foot and an estimate for the marginal construction cost of height is required. The median rent per square foot in the empirical analysis is \$3.78 per month, or \$45.36 annually. Consistent with studies of the vertical rent gradient Liu, Rosenthal, and Strange (2018) and Danton and Himbert (2018), the top rows of the Table 4 show that prices tend to rise with the floor level. The coefficient of floor level in Table 1 suggests that rent increases

[14]The federal law imposes maximum height limits on buildings within Washington, DC are based upon the width of the street, to a maximum height of 130 feet (commercial streets) and 90 feet (residential streets), and 160 feet for parts of Pennsylvania Avenue, NW. For much of the Navy Yard and SouthWest Waterfront neighborhood, the maximum height is 130 feet, which is approximately 13 to 14 floors

[15]See Glaeser, Gyourko, and Saks (2005) and Glaeser and Gyourko (2018)

by about 1% when moving one floor upward in the Navy Yard. The median unit in the sample is on the seventh floor with a rent of \$3.78 per square foot. An estimate of $45.36 * [1 + (h - 7) * 0.01]$ for annual rent is used here for the value of adding a new floor. At the maximum height of 14 floors in the sample, this price estimate is \$48.54 per square foot.[16]

The second step is to estimate an annualized flow value of marginal height construction cost, $S'(h)$. Estimates of construction cost per square foot for the Washington, DC area reported by Means[17] are shown in the table 5. Consistent with the architectural engineering literature[18], the table shows that the construction cost per square foot is increasing and convex in building height: average cost per square foot increases by about \$8.70 when adding a new floor between 3rd and 6th floors, but increases by \$9.30 per story between 6th to 15th floors. The increasing and convex relation is a result of the more expensive materials and construction techniques required for taller buildings. Fire safety codes in DC also mandate that buildings over six stories use heavy frames, while low-rise buildings with less than six floors use light frames or wooden material. The cost of installing elevators also increases with building height in a non-linear fashion, as the area allocated for elevators at each floor increases with building height.

At this point, it is useful to relate the different notions of cost back to the theory section. In the SUM, $S(h)$ is the total construction cost per square foot; the average cost per square foot is total cost divided by the number of floors, or $S(h)/h$. Because Means' estimates exclude land cost, they correspond to $S(h)/h$ nicely. The cost per square foot of adding an extra story is the marginal cost of height, or $S'(h)$. In the absence of height limits (and regardless of whether a height externality exists), buildings rise to the point where marginal cost equals price, or $p = S'(h)$. With a binding maximum height limit, $p > S'(h)$, the private benefit of adding an extra floor is simply the difference. Accordingly, the marginal cost of adding an additional story in Washington, DC is estimated by fitting an average cost function to the R.S. Means data and solving for the marginal cost

[16]It is important to note that, as building density rises, a small density effect on rents produces a large aggregate effect. For example, Büchler and Lutz (2021) report that, for housing in "raster" cells that are 100 meters square, raising density limits by 20% results in approximately 10% more housing space in the raster. The fall in own raster price compared to untreated rasters is only 0.5 to 1 percentage points and this effect is often not statistically significant. But consider that even a 0.5% fall in raster prices means that adding 10% to housing density produced a 0.5% externality on the original 90% of units. Thus adding 10% to the housing stock of a raster only increased willingness to pay for the entire stock by 10% - 90% (0.5%) = 5.5%, placing the size of the density externality approximately half the value of the space added to the stock. In dense areas, very small density effects on rents aggregate to large density externalities.

[17]RS Means Construction Cost dataset https://www.rsmeans.com/products/online

[18]See, for example, Picken and Ilozor (2003) and Blackman and Picken (2010)

function. Two alternative functional forms for $S(h)$ are considered here. The first case is a quadratic average cost function. This is often assumed in the architectural engineering literature. Fitting $S(h)/h = ah^2 + bh + c$ to the Means data yields the marginal cost function: $S_q'(h) = 0.1372h^2 + 16.6233h + 111.3533$. The second case is to assume an exponential total cost function: $S(h) = a + bh^c$, which is attractive for the analytical solution of the SUM. The fitted total cost is $S(h) = 117.9679 + 52.8395 * h^{1.5565}$ and the marginal cost is $S_e'(h) = 82.2426 * h^{0.5565}$.

Following Phillips (1988)'s approach for estimating capitalization rates, a pooled-tenured hedonic model is estimated. See Appendix A.4 for the discussion of the technique and results. The estimated coefficient of 2.8 for the tenure dummy variable implies a capitalization rate of 6.2%. Lastly, because the Means data is in 2012 dollars and the Zillow price estimates are in 2020 dollars, the estimated marginal construction cost is adjusted using the Consumer Price Index.

Figure 3 shows the optimal regulatory tax and the price-marginal cost gap. The figure is based on the median rent of $3.78 per square foot per month and the median distance to adjacent buildings of 91 feet. The horizontal axis is the hypothetical height of buildings in the Navy Yard area. The price-cost curves, $p - S'(h)$, are downward sloping. In the absence of height limits, private developers will build up to the point where this gap diminishes to zero. Laissez-faire heights can be found where $p - S'(h)$ touches the horizontal axis. The quadratic average cost function predicts that laissez-faire building heights should rise to 27 floors, while exponential cost predicts the laissez-faire height of 42 floors. Both estimates are well above the current height limit.

To identify the optimal height, the size of externality, $-p_h(x, h) * h$ is plotted. The curve is upward sloping as the size of the externality grows proportionally to building height. At the current zoning limit of 14 floors, the estimated price-cost difference is above the optimal regulatory tax, indicating that the current zoning is too restrictive. The intersection between the externality and the $p - S'(h)$ based on the quadratic average cost function implies that the optimal height is around 16 stories. The optimal height under the exponential cost function occurs at 18 stories. These predicted optimal heights are well below the laissez-faire heights. Still, they exceed the 14-floor maximum height in Washington, DC, implying that the current density is slightly below the efficient level. In addition, the figure also provides a means to measure welfare loss. The triangular area between the optimal height level and the vertical line of the 14-floor maximum indicates the potential welfare gain by adjusting the current limit to the optimal level.

The triangular areas between the optimal heights and the laissez-faire heights represent the welfare loss of departing from the optimal under laissez-faire.

To examine the sensitivity of these results to different price estimates, a lower $2.75 per square foot monthly rent and a rent estimate based on a 1% vertical price gradient are used while the distance to adjacent buildings is kept at the sample median. These results are shown in figures A.2. For the $2.75 square foot monthly rent, under the two cost functions, the efficient heights are around 16 to 18 floors. For the vertical rent estimates, the optimal heights are around 25 to 34 floors.

In the next table, different distances to adjacent buildings are considered. Increased distances flatten the externality curve. These results are shown in figure A.4. Reducing the median distance by 20% to 72 feet lowers the optimal heights to around 16 floors for both cost functions. Increasing building separation by 20% raises the optimal heights to 25 and 34 floors. These results highlight the trade-off between height and the extra space surrounding buildings. Both the height and proximity of structures are important determinants of the justification for planning restrictions on FAR. In the example from Washington, DC studied here, the height limits are more restrictive than the optimum computed using the estimates of the FAR externality.

5 Conclusion

Using data from a relatively dense area in Washington, DC, empirical testing shows that the relation between housing rent and adjacent building height and density is negative. Raising the average height of surrounding structures by one floor lowers rent in the preferred specification by about 1.5%. These estimates are both economically and statistically significant, confirming that households care about the nearby building height. In addition, the externality appears to be based on building density rather than building height alone, as a larger distance to adjacent buildings reduces the size of the externality. Identification tests that force further building heights into the equation show that the effecyt of adjacent height is not due to a local supply effect. While the substantial height externality suggests that some level of FAR regulation could enhance welfare, the optimal height appears to be slightly above the current height limit in Washington, DC.

The existence of substantial structure density externalities has several implications. The theoretical analysis suggests that the laissez-faire city's structure densities are too high compared to the optimal city. Because the height externality is more severe in high-density areas, the optimum city has a much lower density in its center. In addition, assuming that the height externality goes to zero at the edge of the city, the optimal city has lower housing and population density, higher housing prices, higher aggregate land rent, and lower total population than the laissez-faire city. This result agrees with the finding common in the empirical literature that more intensive zoning raises housing prices, and lowers housing and population density. But the theoretical model regards these effects of regulation as potentially welfare-enhancing to the extent that they raise overall land rent with a smaller population and identical land area. The difference in interpretation is that, while limits on density raise nominal housing price, they also raise neighborhood quality. Furthermore, while the local effect of downzoning a given plot of land may be to lower land rent, the general equilibrium effect of efficient FAR limits is to raise surround rents and hence the aggregate land value in the city.

Because the implications of other externalities are quite different from those motivated by the density externality, optimal city structure would also depend on these other factors if they could be quantified. Nevertheless, the result shown here regarding the density externality, which is concentrated near the city center, should be addressed with a specific density or height tax to deal with the unique spatial pattern of the externality.

The results also imply that the gap between housing price and marginal cost(often referred to as "regulatory tax") is not a perfect indicator for measuring whether zoning is too restrictive. Because a proportion of this gap can be justified by building density externality, such difference overstates the social cost of zoning. The analysis here indicates that a substantial share of the price and marginal cost gap is justified by the height externality in Washington, DC. A better measure for the excessive cost of zoning should take account of the external cost of height and density. In addition, the effects on surrounding rents only capture the externality of height and density for renters. Other users of the same space, motorists, pedestrians, etc., also experience restrictions on light, air, and views associated with density. The value of these additional externalities is also external to the private development decision and could provide an additional element of external cost that justifies restrictions on FAR.

Finally, this study concerns the local neighborhood effects of structure density. There are many other features of the built environment that may influence neighborhood amenity. Some of these, such as building design and the character of open spaces, may be the object of planning but have not been considered here. The results here apply to structure height and spacing and not the design features of the buildings or the spaces between them.

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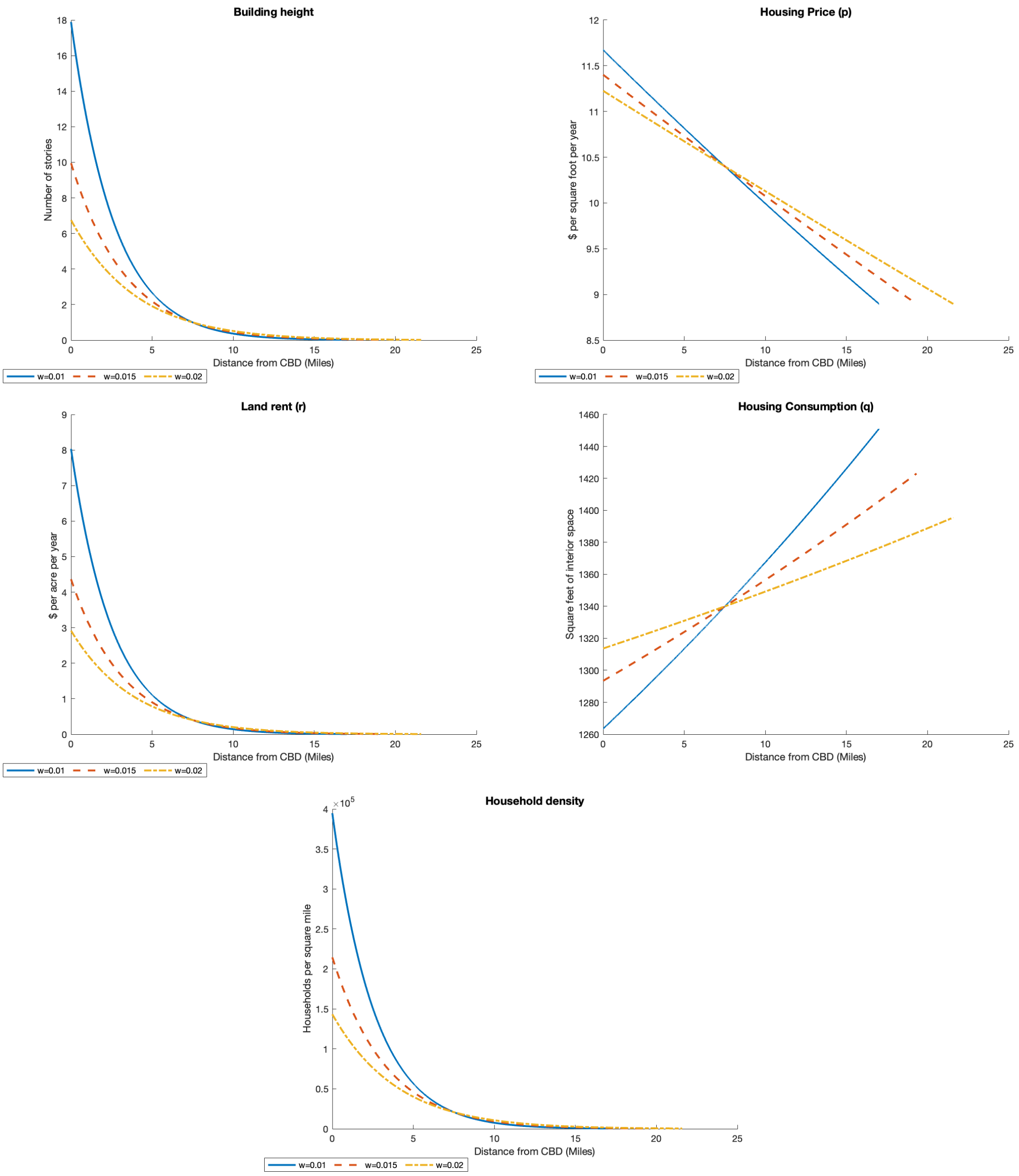
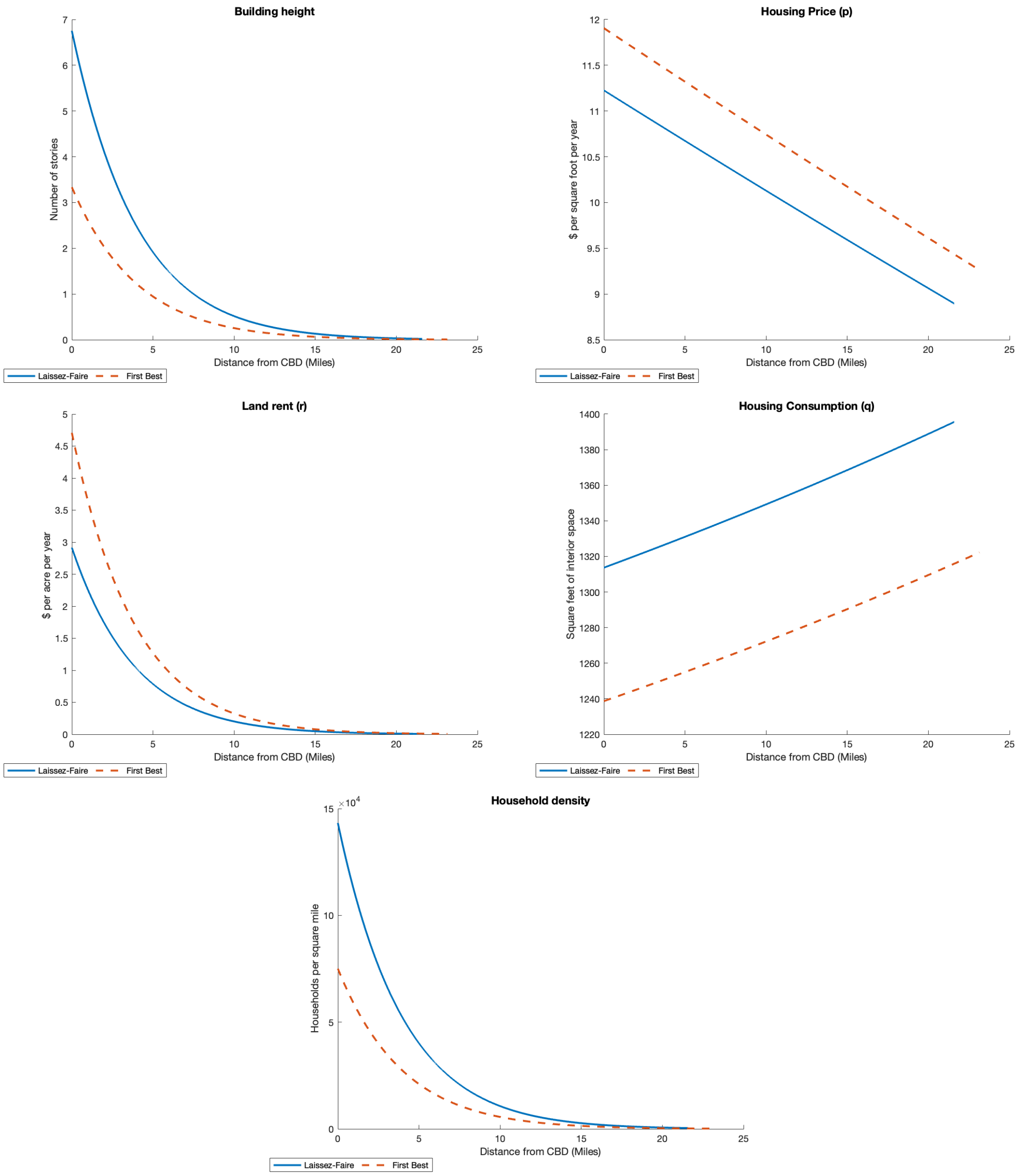
Figure

Figure 1: Laissez-Faire Cities with different levels of height externality



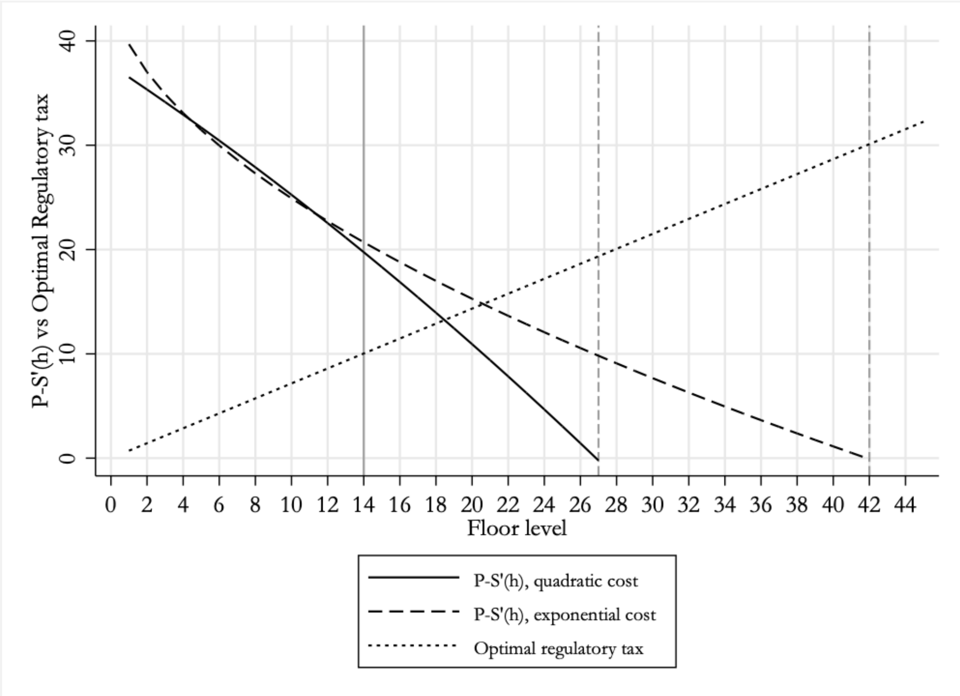
Note: This figure illustrates how a laissez-faire city responses to different level of height externality. It depicts the three laissez-faire cities with different strength of height externality(solid line being strongest, dashed line being medium, and the dotted lines represent the weakest). It illustrates that city with households that are more aversely affected by nearby height has flatter graidents of height, housing price, and land rent. The SUM here is simulated with a Cobb-Douglas utility function: $v = c^{0.76}q^{0.24}H^{-w}$. w is the aversion to nearby height, takes on the values of 0.01, 0.15, and 0.02. Larger w represents stronger height externality.

Figure 2: laissez-faire City vs. First Best City



Note: This figure depicts the two different building height profiles in a laissez-faire city with a height externality and a optimal city. It illustrates that the optimal height is lower at every distance from the CBD and that the optimal city has a large city size. The SUM here is simulated with a Cobb-Douglas utility function: $v = c^{0.76}q^{0.24}H^{-0.02}$ and an exponential housing production function: $c(h) = c_0 h^{1.04}$.

Figure 3: Actual Price-Cost Difference vs Optimal Regulatory Tax



Note: Both rental price and cost estimates are based on the sample median of monthly rent ($3.78 per sqft) and distance to adjacent buildings (27.78 meters). Solid and long dashed lines plot the estimated difference between price and marginal construction cost of additional height, $p - S'(h)$. The dash line indicates the optimal regulatory tax, $p_h(x, h) * h$, which equals the size of the externality. At the current zoning limit of 14 floors, the actual price-cost difference is above the optimal regulatory tax, indicating that the current zoning restriction is too restrictive. The intersection points suggest the optimal height is around 18 to 21 floors. The intersection of $p - S'(h)$ curves with the horizontal axis indicates the laissez-faire height(27 and 42 floors).

Table

Table 1: Estimating the Building Height Externality

	Dependent Variable: Log(rent)	
	(1)	(2)
Adjacent Height	-0.014***	-0.015**
	(0.004)	(0.006)
Floor level	0.009***	0.009***
	(0.002)	(0.002)
Number of bathrooms	0.092***	0.094***
	(0.029)	(0.031)
Log of Interior Floor Space (sqft)	0.642***	0.649***
	(0.055)	(0.055)
Building age	-0.011	0.000
	(0.012)	(0.013)
Building age squared	0.001	-0.000
	(0.001)	(0.001)
Own Height (Story)	-0.008	-0.008
	(0.009)	(0.006)
Log of building footprint area	0.124***	0.110***
	(0.028)	(0.035)
Distance to public housing (mile)	0.296***	0.545***
	(0.071)	(0.146)
Distance to grocery store (mile)	-0.066	-0.173
	(0.081)	(0.115)
Constant	2.678***	2.702***
	(0.397)	(0.392)
CBG dummies	No	Yes
Observations	913	913
R squared	.857	.868

Note: Dependent variable is log of monthly rent. Adjacent height are measured in story, and is constructed as the average adjacent buildings' height weighted by the length of sides that face adjacent buildings.
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Buildings are weighted equally, standard error clustered at the building level are in parentheses.

Table 2: Does Distance to Adjacent Buildings Mitigate the Height Externality?

	Dependent Variable: Log(rent)			
	(1)	(2)	(3)	(4)
Adjacent Height	-0.015**	-0.016***	-0.070***	-0.161***
	(0.006)	(0.005)	(0.018)	(0.032)
Adjacent Height × Dist to Adjacent bldg(feet/100)			0.061**	0.169***
			(0.022)	(0.036)
Adjacent Height × Dummy(AH > OH)				-0.086***
				(0.020)
Adjacent Height × Dummy(AH > OH) × Dist to Adjacent bldg(feet/100)				0.110***
				(0.027)
Dist to Adjacent bldg(feet/100)		-0.066	-0.744***	-2.309***
		(0.067)	(0.249)	(0.508)
Floor level	0.009***	0.010***	0.009***	0.009***
	(0.002)	(0.002)	(0.002)	(0.002)
Number of bathrooms	0.094***	0.089***	0.091***	0.075***
	(0.031)	(0.030)	(0.029)	(0.026)
Log of Interior Floor Space (sqft)	0.649***	0.657***	0.655***	0.701***
	(0.055)	(0.053)	(0.050)	(0.042)
Building age	0.000	0.003	0.003	-0.054***
	(0.013)	(0.014)	(0.014)	(0.011)
Building age squared	-0.000	-0.000	-0.000	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
Own Height (Story)	-0.008	-0.011	-0.011*	0.021*
	(0.006)	(0.007)	(0.006)	(0.012)
Log of building footprint area	0.110***	0.118***	0.148***	0.220***
	(0.035)	(0.032)	(0.034)	(0.039)
Distance to public housing (mile)	0.545***	0.512***	0.477***	0.523***
	(0.146)	(0.147)	(0.133)	(0.126)
Distance to grocery store (mile)	-0.173	-0.158	-0.178	-0.594***
	(0.115)	(0.114)	(0.105)	(0.149)
Constant	2.702***	2.692***	3.221***	4.171***
	(0.392)	(0.367)	(0.420)	(0.476)
CBG dummies	Yes	Yes	Yes	Yes
Observations	913	913	913	913
R squared	.868	.869	.874	.887

Note: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. Buildings are weighted equally, standard error clustered at the building level are in parentheses.

Table 3: Falsification Test with further building height

	Dependent Variable: Log(rent)			
	(1)	(2)	(3)	(4)
Adjacent Height	-0.014**	-0.015**	-0.074**	-0.282***
	(0.006)	(0.006)	(0.027)	(0.027)
Adjacent Height × Dist to Adjacent bldg(feet/100)			0.064**	0.289***
			(0.029)	(0.027)
Adjacent Height × Dummy(AH > OH)				-0.112***
				(0.009)
Adjacent Height × Dummy(AH > OH) × Dist to Adjacent bldg(feet/100)				0.162***
				(0.013)
Dist to Adjacent bldg(feet/100)		-0.083	-0.776**	-3.672***
		(0.061)	(0.325)	(0.309)
Further block height	-0.003	-0.004	0.001	0.020***
	(0.005)	(0.005)	(0.005)	(0.005)
Floor level	0.009***	0.009***	0.009***	0.010***
	(0.002)	(0.002)	(0.002)	(0.002)
Number of bathrooms	0.096***	0.089***	0.091***	0.074***
	(0.031)	(0.030)	(0.029)	(0.025)
Log of Interior Floor Space (sqft)	0.650***	0.661***	0.654***	0.690***
	(0.056)	(0.053)	(0.051)	(0.041)
Building age	-0.001	0.001	0.004	-0.060***
	(0.013)	(0.014)	(0.015)	(0.006)
Building age squared	-0.000	-0.000	-0.000	0.003***
	(0.001)	(0.001)	(0.001)	(0.000)
Own Height (Story)	-0.005	-0.009	-0.012*	0.052***
	(0.008)	(0.008)	(0.007)	(0.009)
Log of building footprint area	0.111***	0.121***	0.149***	0.259***
	(0.037)	(0.036)	(0.034)	(0.015)
Distance to public housing (mile)	0.542***	0.499***	0.479***	0.704***
	(0.155)	(0.159)	(0.126)	(0.058)
Distance to grocery store (mile)	-0.191	-0.182	-0.172*	-0.845***
	(0.122)	(0.116)	(0.099)	(0.068)
Constant	2.680***	2.657***	3.262***	5.254***
	(0.401)	(0.377)	(0.476)	(0.419)
CBG dummies	Yes	Yes	Yes	Yes
Observations	913	913	913	913
R squared	.868	.869	.874	.892

Note: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. Buildings are weighted equally, standard error clustered at the building level are in parentheses.

Table 4: Rental Price Estimates

	Monthly rent per sqft	Price per sqft
Zillow's rental units in apartment buildings		
1-3 story	\$3.57	\$612
4-7 story	\$3.68	\$631
Above 7 story	\$3.90	\$668
All units	\$3.78	\$648
Zillow's median list price for condominium		
Zip code = 20003, Navy Yard		\$621
Zip code = 20024, Southwest waterfront		\$533
Washington		\$552
Washington-Arlington-Alexandria Metro		\$238

Source: Rents in the top panel are from listings on zillow.com. Bottom panel shows the listed sale price from the areas from zillow.

Table 5: Cost Estimates

Sqft cost	Type	Stories
\$136.70	Type V	Low-rise wood frame, 3 stories
\$162.87	Type II	Mid-rise, light-gauge steel & block, 6 stories
\$246.32	Type I	High-rise fireproof, 15 stories

Source: RS Means construction cost dataset.

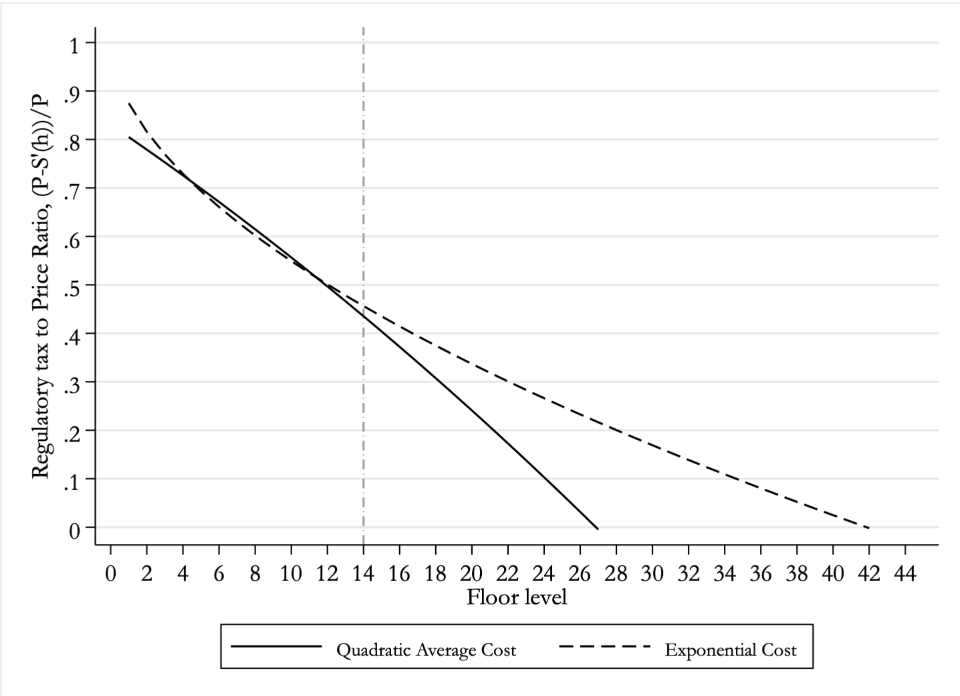
Appendix

Table A.1: Summary Statistics

Variable	Mean	SD	Min	P25	Median	P75	Max	Obs
Rental price								
Total monthly rent	2903.77	899.07	1750.00	2225.00	2700.00	3333.00	7471.00	913
ln(monthly rent)	7.93	0.27	7.47	7.71	7.90	8.11	8.92	913
Monthly rent per square foot	3.91	0.56	2.68	3.51	3.78	4.28	6.22	913
Adjacent Height	8.85	2.77	3.53	6.01	9.80	11.51	13.00	913
Distance to Adjacent building	25.90	5.58	18.96	18.96	27.78	28.84	39.46	913
Unit characteristic								
Floor level	6.78	2.83	1.00	4.00	7.00	9.00	14.00	913
Interior Square feet	755.65	237.74	337.00	577.00	719.00	917.00	1640.00	913
Number of bedrooms	1.16	0.69	0.00	1.00	1.00	2.00	3.00	913
Number of bathrooms	1.27	0.45	1.00	1.00	1.00	2.00	3.00	913
Building characteristic								
Own Height (Story)	11.43	1.05	9.00	11.00	11.00	12.00	14.00	913
Building Area	4422.29	1191.18	1738.02	3596.24	4731.44	5317.77	8042.58	913
Building age	1.52	2.20	0.00	0.00	1.00	2.00	12.00	913
Building age squared	7.17	22.67	0.00	0.00	1.00	4.00	144.00	913
=1 if adjacent to river	0.20	0.40	0.00	0.00	0.00	0.00	1.00	913
Distance to public housing (mile)	0.21	0.09	0.02	0.19	0.19	0.27	0.57	913
Distance to grocery store (mile)	0.28	0.11	0.02	0.19	0.35	0.35	0.53	913

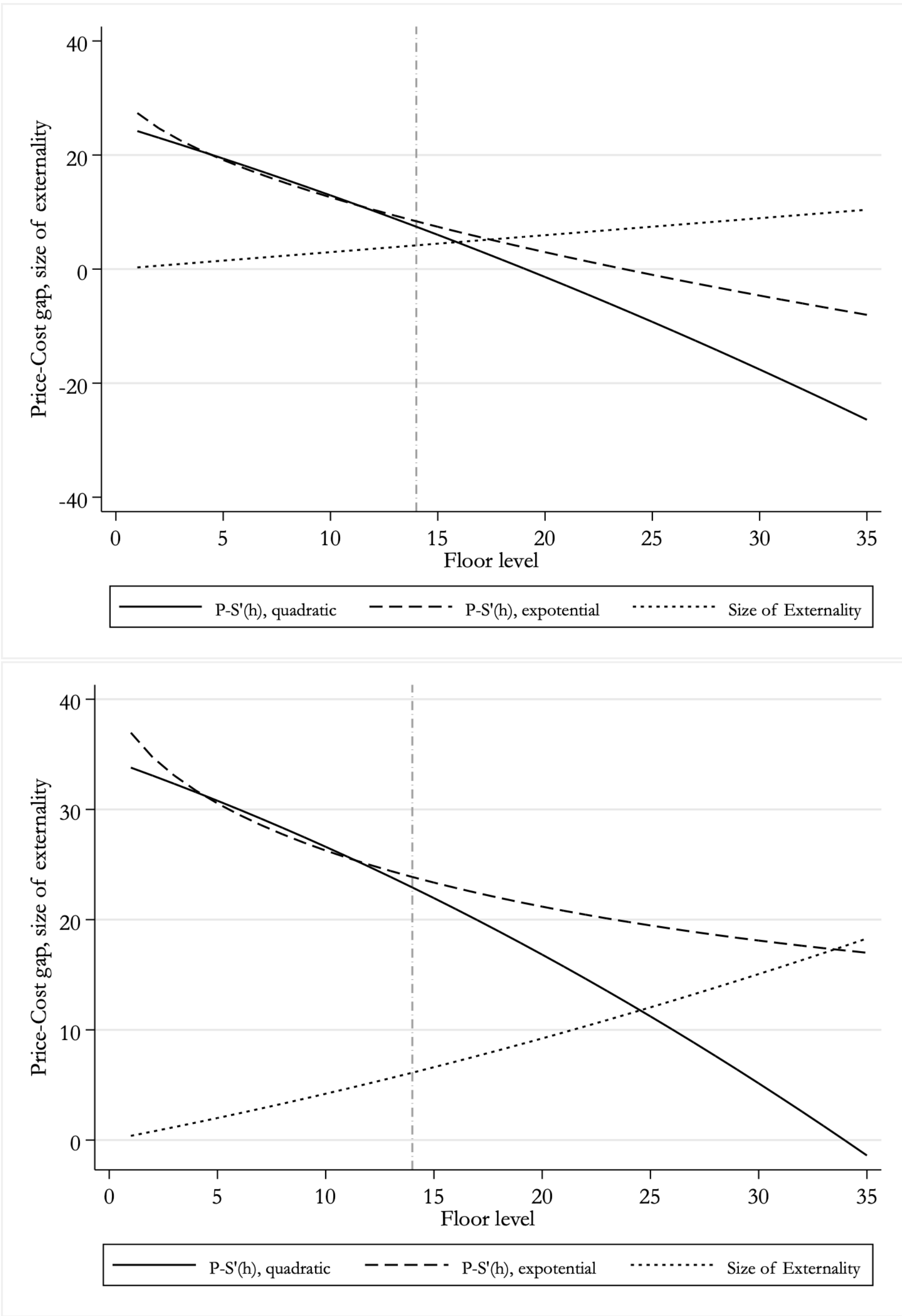
Note: Rental price, unit characteristics and building age are from zilllow.com. Adjacent building heights and distances are collected by author. Maps for building footprints and public housing are from DC open city data.

Figure A.1: Current "Regulatory Tax" to Price Ratio



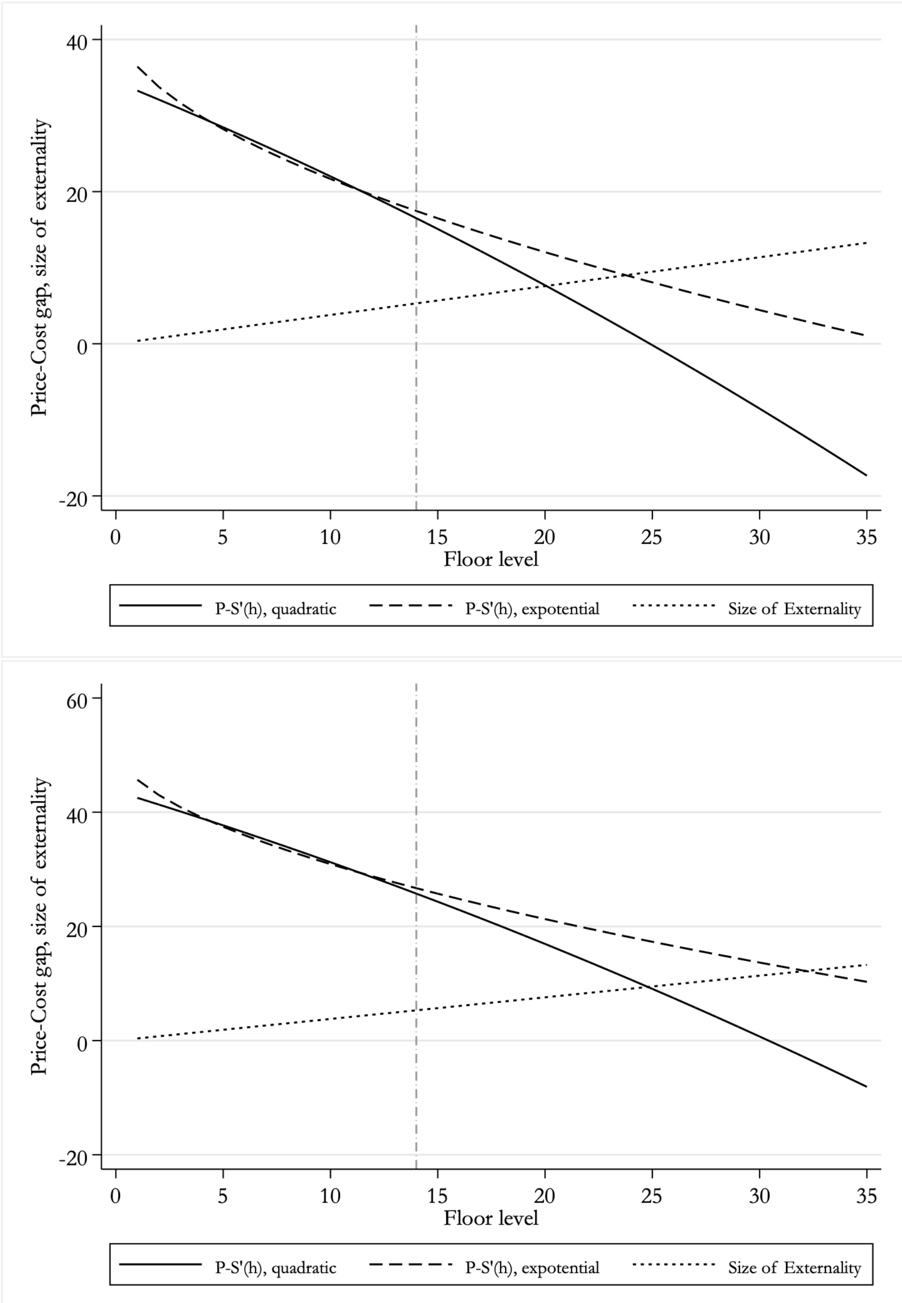
Source: Price estimate based on sample median rent per square foot from zillow.com. Construction costs are extracted from the R.S. Means Construction Cost dataset.
Note: The term "regulatory tax" here is defined as the difference between the estimated asset price and the marginal cost of building upward in the studied area. This figure shows that at the current maximum height of 14-story, the current "regulatory tax" is approximately 42% to 45% of the price.

Figure A.2: Optimal Height: Sensitivity to Price(1)



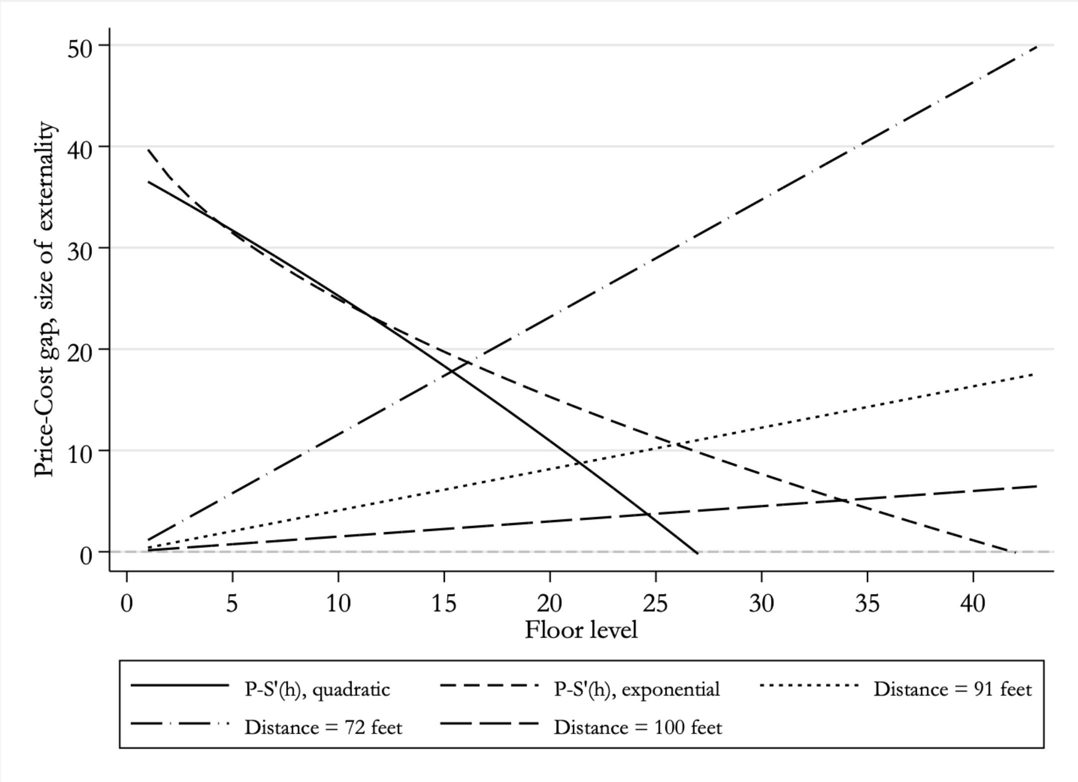
Note: the two figures here are plotted based on different rental price estimates. The top figure is based on the 533 assset price and a 6.2% CAP rent. The bottom figure is based on a vertical price $3.75 * [1 + (h - 7) * 0.01]$.

Figure A.3: Optimal Height: Sensitivity to Price(2)



Note: the two figures here are plotted based on different rental price estimates. The top figure is based on 25th percentile rent, and bottom figure is based on 75th percentile rent. Each figure plots the cases of quadratic, exponential respectively.

Figure A.4: Distance to Buildings and Optimal Height



Note: The figure plots the cases of quadratic and exponential cost respectively. The downward sloping curves plots the price-marginal cost curves, $p - S'(h)$. The upward sloping curves plot the size of externality with three different distances. Increased distance to buildings flatten the externality curves and raises the optimal height.

A.1 Naïve regression

We start with a simple naïve regression of *ln(unit rent)* on nearby height and a constant. The resulting adjacent height coefficient is highly statistically significant at -.0195 (p<0.01). Because taller buildings tend to be built in more attractive locations, adding location fixed effects reduces the upward bias, as shown in column 2 below. However, these simple specifications suffer from omitted variables bias. To address this concern, comprehensive building and unit characteristics are added in the main regression in table 1.

Table A.2: Relation Between Rent and Adjacent Height

	Dependent Variable: Log(rent)	
	(1)	(2)
Adjacent Height	-0.020***	-0.027***
	(0.006)	(0.008)
Constant	8.083***	7.987***
	(0.059)	(0.034)
CBG dummies	No	Yes
Observations	913	913
R squared	.0535	.0778

Note: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Buildings are weighted equally, standard error clustered at the building level are in parentheses.

A.2 Additional controls

As a robustness check, a set of additional controls are added. This includes the distances to the nearest metro and the baseball stadium Nationals Park, and a dummy indicates if the building has mixed land use on the ground floor. As we can see in the following tables, the estimates are qualitatively similar.

Table A.3: Additional controls

	Dependent Variable: Log(rent)			
	(1)	(2)	(3)	(4)
Adjacent Height	-0.022**	-0.027***	-0.077***	-0.165***
	(0.008)	(0.007)	(0.022)	(0.011)
Adjacent Height × Dist to Adjacent bldg(feet/100)			0.064*	0.210***
			(0.032)	(0.013)
Adjacent Height × Dummy(AH > OH)				-0.101***
				(0.010)
Adjacent Height × Dummy(AH > OH) × Dist to Adjacent bldg(feet/100)				0.112***
				(0.012)
Dist to Adjacent bldg(feet/100)		0.234**	-0.742	-3.222***
		(0.105)	(0.460)	(0.197)
Floor level	0.010***	0.010***	0.009***	0.010***
	(0.002)	(0.002)	(0.002)	(0.002)
Number of bathrooms	0.090***	0.094***	0.096***	0.071**
	(0.027)	(0.027)	(0.027)	(0.026)
Log of Interior Floor Space (sqft)	0.650***	0.645***	0.640***	0.696***
	(0.050)	(0.050)	(0.048)	(0.042)
Building age	0.005	0.011	-0.000	-0.114***
	(0.020)	(0.017)	(0.017)	(0.007)
Building age squared	-0.001	-0.002	-0.000	0.009***
	(0.001)	(0.001)	(0.001)	(0.001)
Own Height (Story)	-0.010	-0.019**	-0.002	0.024***
	(0.009)	(0.008)	(0.012)	(0.004)
Log of building footprint area	0.084**	0.035	0.128***	0.302***
	(0.032)	(0.038)	(0.044)	(0.015)
Distance to public housing (mile)	0.538	0.546	0.567	-0.192**
	(0.424)	(0.408)	(0.348)	(0.073)
Distance to grocery store (mile)	0.003	0.212*	-0.122	-0.789***
	(0.119)	(0.112)	(0.144)	(0.059)
Distance to nearest metro(mile)	-0.028	-0.544**	0.211	1.470***
	(0.223)	(0.219)	(0.479)	(0.066)
Distance to baseball stadium Nationals Park (mile)	0.157	0.573	-0.047	-0.486***
	(0.308)	(0.355)	(0.260)	(0.016)
Own Mixed land use dummy	-0.077**	-0.122***	-0.065**	0.053***
	(0.034)	(0.032)	(0.027)	(0.008)
Constant	2.854***	3.068***	3.326***	4.473***
	(0.461)	(0.444)	(0.498)	(0.147)
CBG dummies	Yes	Yes	Yes	Yes
Observations	913	913	913	913
R squared	.876	.878	.88	.894

Note: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. Buildings are weighted equally, standard error clustered at the building level are in parentheses.

A.3 Alternative Height Measure

An alternative height measure is considered here. Specifically, if one side of the building has no adjacent building, then the height of that side is treated as 0. Results in table A.4 find a qualitatively similar result. Column 3 suggests that a rise in height on all sides of a building reduces rent by 1.79%. At the sample mean, this is approximately a $48 monthly rental payment. The estimated effect here is more pronounced than that in the main table. Here, height is added on all sides of the building, while the measure in the main text only raises height for existing adjacent buildings. In addition, column 4 also finds a positive and statistically significant interaction coefficient for height and distance, indicating that distance plays a role in mitigating the height externality.

Table A.4: Alternative Nearby Height Measure

	Dependent Variable: Log(rent)			
	(1)	(2)	(3)	(4)
Nearby height	-0.0124	-0.0610	-0.0179	-0.1112
	(0.0038)***	(0.0127)***	(0.0048)***	(0.0229)***
Nearby height × Distance to Adjacent buildings		0.0018		0.0034
		(0.0005)***		(0.0009)***
Distance to Adjacent buildings	-0.0072	-0.0189	-0.0080	-0.0370
	(0.0017)***	(0.0034)***	(0.0032)**	(0.0075)***
Floor level	0.0093	0.0083	0.0098	0.0090
	(0.0018)***	(0.0019)***	(0.0021)***	(0.0021)***
Number of bathrooms	0.0978	0.1014	0.0944	0.0930
	(0.0236)***	(0.0245)***	(0.0286)***	(0.0272)***
Log of Interior Floor Space	0.6351	0.6407	0.6445	0.6595
	(0.0479)***	(0.0470)***	(0.0491)***	(0.0440)***
Building age	-0.0024	-0.0032	0.0021	-0.0151
	(0.0129)	(0.0111)	(0.0142)	(0.0076)*
Building age squared	0.0004	0.0008	-0.0003	0.0020
	(0.0010)	(0.0008)	(0.0010)	(0.0006)***
Own Height (Story)	-0.0120	-0.0128	-0.0137	-0.0233
	(0.0080)	(0.0059)**	(0.0075)*	(0.0056)***
Log of building footprint area	0.0886	0.1205	0.0622	0.1199
	(0.0283)***	(0.0292)***	(0.0314)*	(0.0359)***
=1 if adjacent to river	0.0543	0.0367	0.0274	0.0711
	(0.0346)	(0.0340)	(0.0360)	(0.0244)***
Distance to public housing (mile)	0.1463	0.0726	0.5577	0.1285
	(0.0875)	(0.0813)	(0.1713)***	(0.2031)
Distance to grocery store (mile)	-0.1521	-0.1016	-0.2426	-0.0963
	(0.0891)	(0.0818)	(0.0815)***	(0.0524)*
Constant	3.2359	3.2846	3.4797	3.9700
	(0.3740)***	(0.3260)***	(0.4414)***	(0.4202)***
CBG dummies	No	No	Yes	Yes
Observations	913	913	913	913
R squared	.863	.869	.874	.882

Note: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$. Buildings are weighted equally, standard error clustered at the building level are in parentheses.

A.4 Estimating the cap rate following Phillips' approach

To estimate the capitalization rate, the following equation is estimated following Phillips (1988):

$$ln(price)_i = \beta X + \gamma TENURE + e_i \tag{A.1}$$

where $ln(price)_i$ equals the log of listing price for "For Sale" units and the log of annual rent for "For Rent" units in the Navy Yard and Southwest Waterfront neighborhood. X are hedonic variables number of bedroom and log of floor space. $TENURE$ equals one if unit is listed as "For Sale", and zero if it is listed as "For Rent".

Note for if a unit is for sale, then

$$ln(VALUE)_i = \beta X + \gamma + e_i \tag{A.2}$$

And if a unit for rent:

$$ln(RENT)_i = \beta X + e_i \tag{A.3}$$

Take the difference of the two equations and then take the antilog yields the housing capitalization rate.

$$\frac{RENT}{VALUE} = \exp(-\gamma) \tag{A.4}$$

The parameter γ estimates the average percentage difference in *price* between owner and rental properties. The housing capitalization rate is then calculated as the antilog of the estimated tenure coefficient. Table A.6 shows an estimated coefficient of 2.8 for $TENURE$ which suggests a housing capitalization rate of 6.2%. Columns 5 and 6 estimate the capitalization rate for Navy Yard and Southwest waterfront separately, and the results indicate cap rates of 5.39% and 6.7% respectivelyfor the two neighborhoods.

Table A.5: Housing Capitalization Rate Estimate

	Dependent Variable: Log(price) or Log(rent)					
	Full sample		Restricted			
	(1)	(2)	(3)	(4)	(5)	(6)
Tenure	2.786***	2.740***	2.780***	2.794***		
	(0.043)	(0.059)	(0.079)	(0.049)		
Tenure (zip = 20003)					2.903***	2.929***
					(0.081)	(0.078)
Tenure (zip = 20024)					2.656***	2.710***
					(0.081)	(0.059)
Bathroom	0.128***	0.152***	0.165	-0.049	0.158*	-0.006
	(0.034)	(0.053)	(0.099)	(0.078)	(0.086)	(0.071)
log(floor space)	0.692***	0.803***	0.777***	0.819***	0.855***	0.867***
	(0.062)	(0.103)	(0.171)	(0.106)	(0.151)	(0.096)
Constant	5.525***	4.795***	4.923***	4.714***	4.422***	4.223***
	(0.383)	(0.635)	(1.046)	(0.646)	(0.924)	(0.615)
Building Dummies	No	Yes	No	Yes	No	Yes
Observations	250	250	27	27	27	27
R squared	.967	.999	.987	.998	.99	.999

Note: $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. Listing rent and sale data were scrapped from zillow.com in 2021. Columns 1 and 2 include the full sample of buildings. Columns 3 and 4 restricted to only buildings which have units for rent and for sale.

Table A.6: Housing Capitalization Rate Estimate

	Dependent Variable: Log(price) or Log(rent)			
	(1)	(2)	(3)	(4)
Tenure	2.776***	2.793***		
	(0.019)	(0.013)		
Tenure * Month = April			2.784***	
			(0.049)	
Tenure * Month = May			2.762***	
			(0.035)	
Tenure * Month = June			2.772***	
			(0.028)	
Tenure * Month = July			2.794***	
			(0.028)	
Tenure * Month = Aug			2.825***	
			(0.024)	
Tenure (Navy Yard)				2.780***
				(0.019)
Tenure (Southwest waterfront)				2.808***
				(0.019)
Bathroom	0.191***	0.107***	0.111***	0.104***
	(0.037)	(0.029)	(0.029)	(0.029)
Bedroom	0.151***	0.133***	0.119***	0.135***
	(0.036)	(0.032)	(0.033)	(0.032)
=1 if Studio	0.027	0.073**	0.059	0.073**
	(0.044)	(0.035)	(0.036)	(0.035)
FL	0.004	0.010***	0.010***	0.010***
	(0.003)	(0.003)	(0.003)	(0.003)
log(sqft floor space)	0.279***	0.428***	0.442***	0.426***
	(0.068)	(0.062)	(0.063)	(0.063)
Constant	8.007***	6.971***	6.901***	6.997***
	(0.402)	(0.382)	(0.388)	(0.382)
Building Dummies	No	Yes	Yes	Yes
Date Dummies	Yes	Yes	Yes	Yes
Observations	198	198	198	198
R squared	.992	.996	.997	.997

Note: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Listing rent and sale data were scrapped from zillow.com between April to August of 2020. Dependent variable is log(price) for sale units, and log(annual rent) for rental units. Buildings in the sample contains both sale and rental unit.