

# The Tragedy of Your Upstairs Neighbors: Externalities of Home-Sharing

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## Abstract

A common critique of home-sharing platforms is that they enable hosts to impose costs on their neighbors, creating a market failure. To explore potential public policy responses, we develop a model of the markets for home-sharing and long-term rentals, and predict market equilibrium outcomes under different policy regimes. With respect to efficiency, we find that when the home-sharing decision is left to individuals, there is too much home-sharing, whereas if the decision is left to a city that maximizes resident surplus alone, there is too little home-sharing. However, when building owners decide on the home-sharing policy of their buildings, externalities are internalized, and the level of home-sharing activity is socially optimal. Our model predicts that, in equilibrium, building owners will be indifferent between allowing and banning home-sharing in their buildings. To assess this “no policy arbitrage” prediction empirically, we construct a dataset of NYC rental apartments listings, and find that, consistent with our prediction, costless policy choices analogous to home-sharing have no detectable effect on long-term rental rates.

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# 1 Introduction

The benefits of home-sharing platforms, such as Airbnb, HomeAway, VRBO, and CouchSurfing, are clear enough—underutilized resources are put to use, supply flexibility is increased, and consumer choice is expanded (Broda and Weinstein, 2004; Einav et al., 2016; Sundararajan, 2016; Horton and Zeckhauser, 2016; Farronato and Fradkin, 2018). However, a common criticism of the business model of home-sharing platforms is that it enables “hosts” (those renting out properties) to impose costs on their neighbors. These costs can be particularly large when long-term tenants are in close proximity, such as in urban apartment buildings.

If hosts bring in loud or disreputable guests but, critically, still collect payment, then the platform would seem to help create a classic case of un-internalized externalities that existing illegal hotel laws are intended to prevent: the host gets the money and the neighbors get the noise. This potential for “regulatory arbitrage” is a recurrent critique of “sharing economy” platforms more generally (Malhotra and Alstyne, 2014; Slee, 2016), and has been used in support of legislation restricting home-sharing activity, as well as in lawsuits against home-sharing platforms.<sup>1</sup>

The recent regulatory attention reflects the fact that home-sharing platforms have dramatically increased the scale of what had previously been a relatively limited phenomenon. This increase in scale has also lead to researcher interest in the effects of home-sharing, much of it focusing on price, such as long-term rental rates, home prices, and hotel prices (Farronato and Fradkin, 2018; Sheppard and Udell, 2018; Coles et al., 2017). Price changes in markets can have important practical and distributional consequences, but they have traditionally been viewed as neutral from an efficiency standpoint: every transaction has both a buyer and a seller, and hence price changes—so-called “pecuniary” externalities—are of little policy import. In contrast, the un-priced externalities that are the focus of this paper—so-called “technical” or “real” externalities—lack the symmetry of price changes and lead to a market failure.

Motivated by the public policy question raised by home-sharing platforms, we develop a model of the markets for home-sharing and long-term rentals, and examine the equilibrium predictions under different policy regimes. We examine the regimes in which hosting decision

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<sup>1</sup>The negative externality argument, along with the claim that home-sharing increases rents for long-term tenants, was recently cited in legislative action which dramatically increased fines for hosts found to be violating local housing regulations. Furthermore, building management company AIMCO has cited the negative externality argument as the main reason for a recent lawsuit against Airbnb. See <http://www.nytimes.com/2016/10/22/technology/new-york-passes-law-airbnb.html>, and <https://www.prnewswire.com/news-releases/aimco-files-court-appeal-to-stop-airbnb-from-illegally-renting-apartments-300588771.html>, accessed online on October 6, 2018.

rights are allocated to (1) individual tenants, (2) building owners, (3) cities, and (4) a national or supra-national regulatory body that acts as a utilitarian social planner. For each of the four policy regimes, we derive the market equilibrium and characterize the surplus of tenants (both hosting and non-hosting), building owners, and guests.

In our model, long-term tenants are key actors who must make two choices: (1) whether to be a home-sharing host, and (2) which building to live in. In deciding whether to host, long-term tenants consider only their financial pay-off from hosting: they host if they are allowed, and if the income they receive from home-sharing guests exceeds their individual hosting costs. Critically, would-be hosts do not consider the cost that their guests might impose on their fellow tenants. The income obtainable from home-sharing is endogenous, in that it depends on how many other tenants living in the same city choose to host. In choosing which building to live in, long-term tenants consider the rent they will face, whether they are allowed to home-share, and the negative externality costs borne by them from the home-sharing activity of other residents in the building.

We begin by examining the regime in which tenants are free to decide whether to become home-sharing hosts. This allocation of hosting decision rights mirrors the state of affairs in many major US cities such as New York, where tenants have the *de jure* (if not the *de facto*) right to sublet.<sup>2</sup> We then consider the regime in which building owners set a uniform policy for their building, taking into account only the effect their policy choice has on their rental income from long-term tenants. Next, we consider the regime in which cities set a policy: cities do not choose a blanket policy, but rather determine a quantity of hosting to be allowed. In practice, this quantity would be set through mechanisms such as taxation, rationed permits, and bureaucratic ordeals (Nichols and Zeckhauser, 1982). When setting a quantity, cities consider only the surplus of the tenants (i.e., the residents of the city). Finally, we consider the outcome of the regime where a social planner sets the city-level quantity of hosting, but unlike the city, takes into account both the tenants' and the guests' surpluses.

Our analysis shows that when individual tenants decide whether or not to host, there is too much hosting in equilibrium, in that the costs created by the marginal host exceed the benefits. Consequently, the equilibrium after the introduction of home-sharing might offer less surplus than an equilibrium before the introduction. Setting aside for a moment the case where building owners decide, we find that when the city sets the quantity, there is too little hosting. Essentially, the city behaves as a monopolist, reducing supply to raise prices,

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<sup>2</sup>Though NYC law requires subletting leases to be for a term of 30 days or longer, the option of subletting can not unreasonably be refused by the owner of the building. For review of the legal framework see <http://www.nycrgb.org/html/resources/faq/subletting.html>, accessed online on October 6, 2018.

thereby transferring surplus from guests to hosts. In practice, if cities are “already” picking the profit-maximizing quantity through their regulation and taxation of the hotel industry, the city might find it optimal to ban home-sharing altogether, as the increase in supply is unwanted.<sup>3</sup>

The efficient quantity of hosting is obtained when the home-sharing decision is left to building owners. The driver of this efficiency result is that in equilibrium, the marginal tenant is indifferent between buildings that allow and buildings that prohibit home-sharing, and hence building owners are also indifferent between allowing or prohibiting home-sharing. The reason building owners are indifferent is that rents in a competitive long-term rental market must be the same regardless of the home-sharing policy of the respective building: rents are equal because the building’s home-sharing policy imposes no direct cost on the building owner, and if a premium could be charged for one policy or the other, profit-maximizing building owners would choose whatever policy offered the premium. This building-owner self-interest equalizes long-term rental rates, and so the marginal long-term tenant—the one who is indifferent between buildings that allow home-sharing and those that do not—has a private benefit of hosting that is equal to the full costs of living in such a building. The full cost includes not only the tenants’ private cost of hosting, but also the costs imposed from home-sharing hosts in the same building. Note that in this analysis, we do not have to model the surplus of the guests explicitly, as the marginal guest surplus at the market-clearing home-sharing price is the same as the private benefit to the host.

Although the model is parsimonious, the core result—the attractive efficiency properties of allocating decision rights to building owners—is robust to various model extensions, including adding home-sharing supply that does not generate externalities, modeling externality costs as non-linear, allowing building owners to convert an entire property to home-sharing, giving tenants heterogeneous preferences over buildings, amenities, neighborhoods, and so on. At a high level, the reason for the invariance of our conclusions to these model extensions is that what matters for efficiency is the marginal tenant, and more complex model extensions mostly affect inframarginal market participants.

Despite the robustness of our results to several model extensions, an assumption that is critical to our results is that externalities are contained within a building. There are two strong justifications for this assumption. First, physical nuisances such as noise and smells dissipate with the cube of the distance from the source, making it hard for these kinds of costs to travel very far and remain large. Second, nuisances such as wear-and-tear, misuse

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<sup>3</sup> The high tax rates on the hospitality industry indicate that cities benefit from reducing hosting supply. For example, see <http://www.wsj.com/articles/SB10000872396390443749204578048421344521076>. For a list of state lodging taxes see <http://www.ncsl.org/research/fiscal-policy/state-lodging-taxes.aspx>, accessed online on October 6, 2018.

of common areas, and reduced physical security, are inherently within-building problems. Despite our view that real externalities are largely contained within buildings, we do show how our model can be adapted to other cost structures.

A key prediction of our model—and a necessary condition for our efficiency results—is that in a competitive equilibrium for long-term rentals, building owners cannot command increased long-term rental rates through their selection of a home-sharing policy. This is a difficult prediction to assess directly, as home-sharing is still a nascent phenomenon, and hence data from existing rental markets are unlikely to offer a compelling empirical test. However, there are other policies routinely chosen by building owners that are conceptually similar to the home-sharing policy. For example, the decision to allow subletting has slight administrative costs for the building owner, but a potentially large financial impact on would-be renters and current tenants alike. Subletting is an interesting case as it is qualitatively similar to home-sharing, albeit of longer duration. For this reason, we use the subletting decision of building owners—specifically, whether the building owner chooses to describe their building as being subletting-friendly in apartment listings—as a case study to assess our equilibrium “no policy arbitrage” prediction empirically.

Using a large dataset of rental listings in New York City, we find that there is no arbitrage opportunity in choosing a subletting policy. Although allowing subletting is strongly, positively correlated with rental rates, this relationship disappears when including controls. The effect of allowing subletting on rental rates is a precisely estimated near-zero when using machine learning approaches that model both selection and rental rates, i.e., the double-debiased machine learning (double-ML) approach (Chernozhukov et al., 2016). We also perform the same analysis for whether the building allows dogs—another largely costless policy—finding that the raw correlation is highly positive, but that it disappears with controls. To build confidence in our empirical approach, we also show that a premium can be charged for “policies” that are not costless to the building-owner but valued by tenants, such as the inclusion of an in-apartment washer and dryer.

In our model, the role of home-sharing platforms is critical—their emergence is the technological shock that makes home-sharing wide-spread—but also passive with regards to the negative externality problem. Although this passivity is a useful simplification for our analysis, platforms can take an active role in addressing problems created by home-sharing. We identify measures that home-sharing platforms are already taking, and which are in agreement to the predictions of our model, including Airbnb’s “friendly buildings” initiative.<sup>4</sup> We also suggest measures that platforms can take. For example, platforms managers create tools that allow building owners to centrally impose tenant-specific hosting caps—upper bounds

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<sup>4</sup><https://www.airbnb.com/help/article/1195/what-s-the-airbnb-friendly-buildings-program>

on individual home-sharing activity—which can be particularly important if externalities increase convexly in home-sharing activity (a possibility we discuss).

Our paper makes several contributions. Our key contributions are to conceptualize home-sharing as having the potential to create a market failure, develop a tractable model of the situation, illustrate various policy responses implied by the model, and test the model’s key prediction. Our paper contributes to the growing information systems literature examining the offline spillovers of online developments. However, our paper is distinctive in taking spillovers as a given, but then working through their prescriptive implications. Although our analysis focuses on various public policies related to home-sharing, our results also have implications for platform operators who must increasingly navigate the policy landscape while pursuing new business models.<sup>5</sup>

The rest of the paper is organized as follows. Section 2 reviews extant work on the real-world effects of online platforms, and explores what is distinctive about home-sharing. Section 3 develops the model, and presents the main results of the equilibrium and welfare analysis. Section 4 discusses and expands upon the policy prescriptions of the model. Section 5 presents results from an empirical analysis of the NYC rental market. Section 6 concludes with thoughts on directions for future research.

## 2 Background

Short-term rentals of personal spaces have long been possible (Jefferson-Jones, 2014), but a series of technological and entrepreneurial developments has massively increased the scale of home-sharing. Platform-mediated home-sharing is a continuation of the growth and maturation of online marketplaces, such as Amazon and eBay, which generate billions in revenue annually, and have garnered substantial attention from academics, practitioners, and policy makers (Bailey and Bakos, 1997; Brynjolfsson et al., 2003; Parker and Van Alstyne, 2005; Dellarocas and Wood, 2008; Brynjolfsson et al., 2011; Overby and Kannan, 2015).

More than two decades of managing online marketplaces has equipped designers with knowledge on how fundamental problems can be solved. For example, marketplaces typically employ search and recommendation algorithms to address the lack of market-thickening mechanisms (Resnick and Varian, 1997; Adomavicius and Tuzhilin, 2005; Dinerstein et al., 2018). To address adverse selection and moral hazard, they build and maintain reputation

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<sup>5</sup>Recent controversies around for-hire vehicle caps in NYC (arguably intended to reduce congestion), and electric scooter bans (arguably intended to reduce sidewalk blockages), suggest that our “negative externality of the online platform business” focus is far from a one-off issue for would-be platform managers and entrepreneurs. See <https://www.kxan.com/news/local/austin/woman-s-post-about-scooters-blocking-her-path-leads-to-new-program/1386887743>.

systems (Resnick et al., 2000; Cabral and Hortag su, 2010; Bolton et al., 2013; Moreno and Terwiesch, 2014; Fradkin et al., 2015; Filippas et al., 2018). Furthermore, entrepreneurs now have a deeper understanding of the various business models of two-sided markets (Rochet and Tirole, 2003; Parker and Van Alstyne, 2005; Eisenmann et al., 2006; Hagiu, 2014).

This accumulated experience has enabled the emergence of “sharing economy” platforms—online marketplaces relying on decentralized and heterogeneous crowds of individuals and small businesses who vary in their scale, expertise, and objectives, for their supply of capital and labor. Home-sharing is one example of “sharing economy” platforms, which today span a range of industries, providing services such as car- and ride-sharing, microloans, and startup funding (Horton and Zeckhauser, 2016; Sundararajan, 2016). The transactions on “sharing economy” platforms are of a more personal nature, and typically require internet- and GPS-enabled mobile devices, making these platforms harder to design and operate than other online marketplaces—this is the reason why we have only recently started seeing “sharing economy” markets emerge.

The scale of the sharing economy is growing. For example, ride-sharing platform Uber currently operates in more than 340 cities, in over 60 countries, with more than 400,000 driver-partners being active on the platform by the end of 2015 (Hall and Krueger, 2016; Hall et al., 2017). More than 3 million hosts and 200 million guests were active on Airbnb during 2017 (Coles et al., 2017). As the adoption of internet-enabled mobile devices increases, particularly in emerging markets, the economic significance of sharing economy marketplaces is expected to continue to grow.<sup>6</sup>

## 2.1 Offline effects of online platforms

The proliferation of online marketplaces has spawned a growing literature on the offline effects of online platforms. Much of the previous work has examined the effects of the entry of online platforms on offline competitors, including market share and prices (Seamans and Zhu, 2013; Kroft and Pope, 2014; Zervas et al., 2017). However, the waxing and waning of various industries are not market failures, and to the extent these effects are solely on prices, they create only pecuniary externalities: as every transaction has a buyer and a seller, changes in price have offsetting changes in utility for the demand and the supply sides of the market, and although these changes may be of distributional consequence, they can generally be thought of as not having efficiency implications (Greenwald and Stiglitz, 1986; Holcombe

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<sup>6</sup>See also <https://www.bcg.com/en-us/publications/2017/strategy-technology-digital-whats-next-for-sharing-economy.aspx>, accessed online on October 6, 2018.



and Sobel, 2001).<sup>7</sup>

Pecuniary externalities—the effects that changes have on prices (Scitovsky, 1954; Laffont, 1989, 2008)—are distinguished in the literature from “technological” or “real” externalities that are unpriced costs and benefits, and thus lead to market failure. This market failure is that the decentralized equilibrium may be characterized by inefficiently small quantities if externalities are positive, or inefficiently large quantities if they are negative. Although offline spillovers of online platforms frequently are both pecuniary and technological, it is the technological externalities that matter from a market efficiency standpoint.

There are numerous examples of online developments having offline effects outside of the direct effect on competitors, creating technological externalities instead. In the public health sphere, Chan and Ghose (2014) present evidence that by reducing the search costs for casual sex partners, the entry of Craigslist likely caused about a 16% increase in HIV cases—at enormous social cost. In related work, Greenwood and Agarwal (2016) examine the socioeconomic strata that are particularly vulnerable to HIV infections, and show that historically at-risk populations were adversely and disproportionately affected. As an example of a positive externality, Greenwood and Wattal (2017) exploit the natural experiment created by the introduction of Uber into cities in the state of California to investigate its effect on DUI arrests. They find that the effect was significant, resulting in about a 4% decrease in the rate of motor vehicle homicides. However, car-sharing can have a negative externality as well, such as exacerbating traffic congestion in urban centers (Clewlow and Mishra, 2017; Molnar and Mangrum, 2018). In a quasi-pecuniary externality, Burtch et al. (2018) examine the effect of the entry of sharing economy platforms on entrepreneurial activity as proxied by the volume of crowdfunding campaigns, and find that lower-quality campaigns were disproportionately negatively affected.

In the context of home-sharing, the technological externality describes the costs that hosts’ neighbors incur due to guests. The pecuniary externalities are the changes in price and value brought about by the entry of the home-sharing option in a city, such as to hotels, property values, and long-term rental rates (Cusumano, 2015; Guttentag, 2015; Zervas et al., 2017; Sheppard and Udell, 2018; Farronato and Fradkin, 2018).

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<sup>7</sup>Pecuniary externalities are often the result of positive change. For example, Sheppard and Udell (2018) provide evidence that increases in Airbnb availability are associated with increased house values—implying that home-sharing has pecuniary externalities—but also note that “Public policies that reduce house prices in pursuit of housing affordability by diminishing the efficiency with which an owner can make use of his or her property may fail to be welfare-improving, in the same way as a city that creates “affordable” housing by encouraging more crime hardly seems desirable.”



## 2.2 Regulatory responses to home-sharing

Although pecuniary externalities do not matter from an efficiency standpoint, their policy import is that they may have distributional consequences for different groups—owners versus renters, residents versus hosts, and so on. For example, a common criticism is that home-sharing platform entry increases house value and rents. As a result, the rise of home-sharing has sparked an ongoing policy debate between platforms and regulators; [Kaplan and Nadler \(2015\)](#) provide a timeline of the legal battle between the state of New York and Airbnb. We provide a summary of the different points of criticism and related work in [Table 1](#).

Table 1: Public policy issues of home-sharing

Issue	Previous work
Within-platform biases	<a href="#">Edelman and Luca (2014)</a> , <a href="#">Edelman et al. (2017)</a> .
Pecuniary externalities	<a href="#">Barron et al. (2017)</a> , <a href="#">Coles et al. (2017)</a> , <a href="#">Horn and Merante (2017)</a> , <a href="#">Zervas et al. (2017)</a> , <a href="#">Farronato and Fradkin (2018)</a> , <a href="#">Sheppard and Udell (2018)</a> .
Technological externalities	This paper

While some have argued that the presence of information on online platforms might reduce the need for regulation ([Cohen and Sundararajan, 2015](#)), other work has examined whether the sharing economy replacement of a traditional industry might have unwelcome effects. For example, [Edelman and Luca \(2014\)](#) employ a data set of Airbnb host pictures and rental prices, and find that non-African-American hosts command a price premium; [Edelman et al. \(2017\)](#) show that guests with distinctly African-American names are more likely to be rejected by hosts. [Zhang et al. \(2016\)](#) highlight the likely impact of informational asymmetry on sharing economy platforms by showing that high-quality pictures bring extra income to hosts, as they may ameliorate uncertainty and trust issues.

The literature on the price effects of home-sharing on rents and house-prices is fairly inconclusive. [Barron et al. \(2017\)](#) employ an IV framework and find that a 100% increase of Airbnb activity is associated with a 1.8% increase in rents and a 2.6% increase in house values. [Horn and Merante \(2017\)](#) obtain similar estimates, whereas [Sheppard and Udell \(2018\)](#) place the house value effect estimate between 6% and 11%. Given the rapid growth of home-sharing, these measures are hard to interpret, especially with regards to the stability of the trends—more recent studies report smaller estimates, hinting at home-sharing prices closing in on the market equilibrium price.

There is little non-anecdotal evidence that home-sharing significantly reduces long-term housing supply in the long-run. [Coles et al. \(2017\)](#) find that to match earnings from long-term rentals, the average NYC landlord would have to home-share for 216 days per year.

Instead, the same authors use internal Airbnb data to find that the median number of nights booked was 46. These results corroborate with findings from housing economics, identifying regulatory restrictions on housing development—and not home-sharing platforms—as the main driver of shortages in housing supply, and hence, higher rental rates (Gyourko and Molloy, 2015; Glaeser and Gyourko, 2017).

The real externalities of home-sharing are frequently cited by critics of home-sharing, but we are unaware of any attempt to measure them, or analyze their policy implications. To our knowledge, our paper is the first to consider the technological externalities of home-sharing. To the extent that these externalities exist, there are decentralized solutions that would work in theory, such as side payments and Coasian bargaining (Coase, 1960). However, it seems unlikely that bargaining would be effective, given the requirement for transfers between all affected parties after every transaction, the nebulous property rights in a large building, the difficulty in identifying offending parties, and the potential for opportunistic behavior arising from side payments.<sup>8</sup>

### 3 A model of home-sharing and long-term rentals

Consider a city with  $A$  apartment buildings. Each building has  $n+1$  tenants, and every tenant receives a net utility of  $u_0$  by occupying the apartment.<sup>9</sup> The market without home-sharing is the welfare baseline throughout our analysis; without the home-sharing option, each tenant obtains utility  $u_0$ , and the aggregate tenant surplus is  $U_0 = Nu_0$ , where  $N = (n + 1)A$ .

Let  $p$  be the home-sharing market price, which is also the benefit that a tenant who decides to host obtains. Each tenant  $i$  has an individual-specific hosting cost  $c_i$ , meaning that he is willing to participate in the home-sharing economy as a host if  $p \geq c_i$ .<sup>10</sup>

The home-sharing market supply is the number of tenants that would host at price  $p$ , denoted by  $S(p)$ . As higher prices result in more tenants willing to host,  $S'(p) > 0$ . Let  $\hat{c}(q)$  denote the hosting cost of the marginal host when  $q$  units are supplied, i.e.,  $\hat{c}(q)$  is the  $c_i$

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<sup>8</sup>“That’s a nice quiet apartment you have there—it would be a shame if someone started playing loud music late at night.”

<sup>9</sup>As will be clear later, we do not need to model rents explicitly.

<sup>10</sup>Heterogeneous hosting costs capture individual-specific factors such as the willingness of tenants to rent out their personal spaces, the opportunity cost of the time allotted to hosting, or the desire for social interaction. Hosting costs can also be negative, as exemplified by the popularity of the gratis home-sharing platform CouchSurfing (<http://www.couchsurfing.com>). Similarly, heterogeneity in home-sharing benefits can be reduced to heterogeneity in costs, justifying the assumption of a single market clearing price. Intuitively, a single market clearing price is conceptually similar to the assumption made in competitive labor markets about differences in observed wages, i.e., that they reflect the market rate for different worker attributes and/or compensating differentials about the job, rather than market power. In the context of home-sharing, idiosyncratic preferences for vertical neighborhood-, building-, and apartment-level attributes can be captured through a single market clearing price for the same reason.

of the marginal host. The demand by guests for home-sharing listings at price  $p$  is denoted by  $D(p)$  and is downward sloping, with  $D'(p) < 0$ . Similarly, let  $\hat{v}(q)$  denote the utility of the marginal guest when  $q$  units are supplied. Note that  $D(p)$  would also depend on hotel supply, and other accommodation offerings in the city that are substitutes for home-sharing listings.

Home-sharing generates costs to neighbors. Each listing generates a cost of  $c_E$  to every tenant other than the host living in the same building.<sup>11</sup> As a result, if host  $i$  switches from not hosting to hosting, then this would be socially efficient if

$$p \geq c_i + nc_E. \quad (1)$$

Equation 1 states an intuitive criterion for assessing the individual-level impact of the home-sharing option: if the negative externality that tenant  $i$ 's decision to host generates is outweighed by the private benefit from his home-sharing listing—market price minus the hosting cost—then the hosting activity of tenant  $i$  is socially efficient.

It is worth noting that although market quantities such as hosting costs and prices can vary substantially over shorter time periods, addressing week- or season-level considerations is orthogonal to the goal of our paper, which is to study the equilibria of the rental market. As such, the time scale for all relevant quantities of our model is a sufficiently large period of time, e.g., a year.<sup>12</sup> For the same reason, hosting intensity decisions need not be endogenous in our model, and we may instead think of tenants as hosting whenever they have the opportunity to do so, such as during vacations and weekends.<sup>13</sup>

### 3.1 The “tenants decide” (TD) regime

The first policy regime that we examine is the one where tenants are allowed to individually decide whether to host or not. In this case, tenant  $i$  will host if the going home-sharing price  $p$  is larger than his hosting cost  $c_i$ . Note that since apartments are homogeneous, tenants can not condition their home-sharing prices on apartment-observable characteristics. In the TD equilibrium, supply meets demand and long-term rents are equal across buildings. The

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<sup>11</sup>We consider alternative forms of externalities in Section A.1 and Section A.2, and find that the results derived in this section are invariant to these assumptions.

<sup>12</sup>For example, we can think of the home-sharing utility  $p - c_i$  as the total utility obtained throughout one year of home-sharing activity, i.e.,  $p - c_i = \int_{t=1}^{365} p(t) - c_i(t) dt$ . For a study that examines temporal variations associated with home-sharing, see [Farronato and Fradkin \(2018\)](#).

<sup>13</sup>In our time scale, hosts with high hosting intensity are captured through a lower hosting cost, and hence, larger benefits from home-sharing. Furthermore, the effect of hosting quantity decisions on price is factored in the supply function. For a model that examines intensity decisions in the sharing economy, see [Horton and Zeckhauser \(2016\)](#).

existence and uniqueness of the equilibrium are guaranteed because of the monotonicity and continuity of the supply and demand curves. Let  $q_T$  and  $p_T$  denote the equilibrium quantity and price respectively. The following proposition shows that there are hosts whose home-sharing listings generate higher negative externalities than the private benefits they obtain.

**Proposition 1.** *In the TD equilibrium, there exist tenants whose hosting activity is socially inefficient.*

*Proof.* Since every tenant who wants to be a host is allowed, tenant  $i$  hosts if the equilibrium price exceeds his hosting cost, i.e.,  $p_T \geq c_i$ . Let  $\hat{t}$  be the index of the marginal host in the equilibrium of the TD regime, i.e., the host that is indifferent between hosting and not hosting. We get  $p_T = c_{\hat{t}}$ , where  $c_{\hat{t}} = \hat{c}(q_T)$ . Since  $nc_E > 0$ , we get  $p_T < c_{\hat{t}} + nc_E$ , and hence Equation 1 does not hold for all tenants.  $\square$

Proposition 1 shows that there exist tenants whose listings' externalities outweigh the benefits they incur; those are exactly the tenants with hosting costs in the  $[p_T - nc_E, p_T]$  interval. Therefore, there is an inefficiently high quantity of home-sharing listings under the TD policy regime.

An important point is that home-sharing hosts occupy apartments in every building. As a result, under the TD regime those tenants who do not list their apartments are adversely affected, obtaining an average utility of  $u_0 - \frac{S(p_T)}{A}c_E$ , and hence externalities are not internalized.

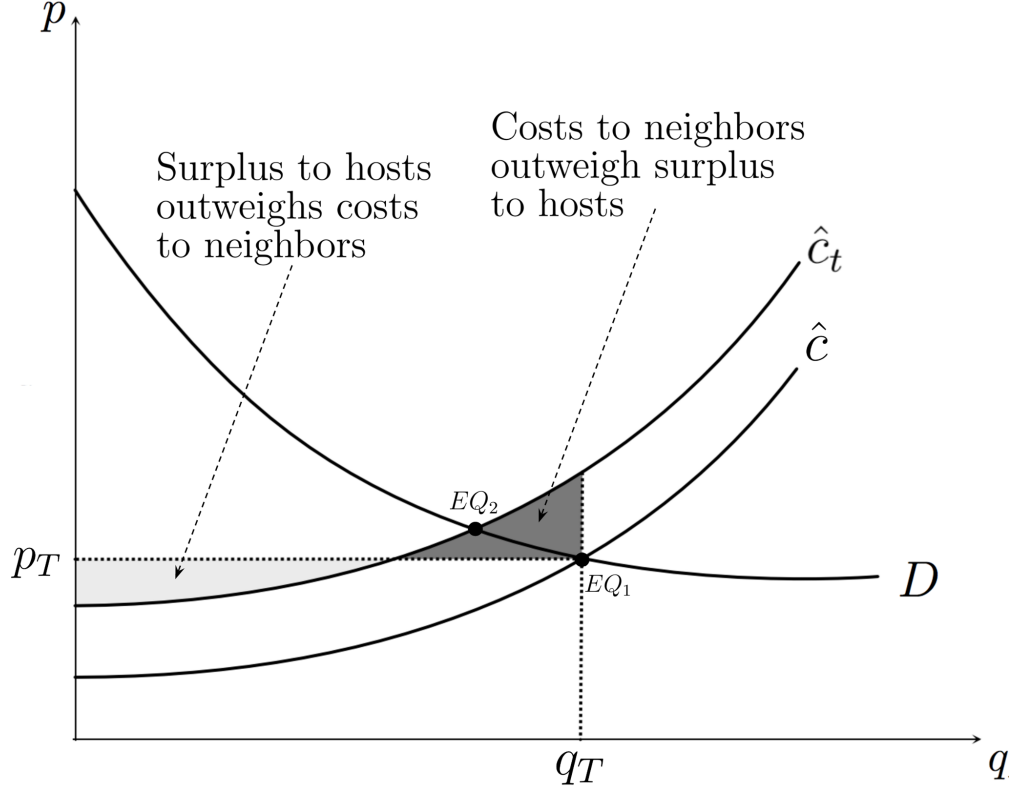
The tenant surplus in the equilibrium of the TD regime is given by

$$U_T = U_0 + \left( \int_0^{q_T} p_T - \hat{c}(q) dq \right) - q_T nc_E. \quad (2)$$

The first term of Equation 2 is the constant surplus due to tenants occupying apartments, the second term is the net surplus generated from hosting (market price minus hosting costs), and the last term is the sum of the home-sharing externalities. If the total externalities are higher than the sum of the hosts' benefits, the home-sharing option yields a decrease in tenant surplus.

Figure 1 illustrates this situation. Point  $EQ_1$  indicates the TD equilibrium. The total cost curve of the marginal host is  $\hat{c}_t(q) = \hat{c}(q) + nc_E$  and captures the social cost of home-sharing apartments. It is the difference between total cost and individual cost that potentially lowers tenant surplus. The light gray area depicts the positive contribution to the aggregate tenant surplus, which is due to those tenants with low enough hosting cost that their profit from hosting outweighs their individual cost plus the negative externalities of their hosting. The

Figure 1: Tenant surplus in the “tenant decides” market equilibrium.



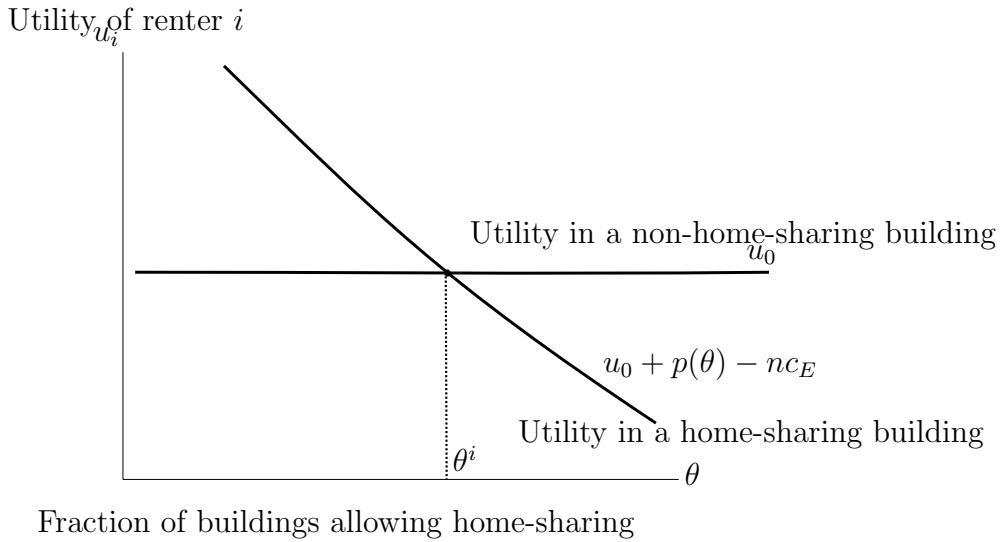
dark gray area depicts the negative contribution to the total tenant surplus, coming from those tenants with a low enough hosting cost to still want to host at the equilibrium price, but not low enough to outweigh the sum of their costs and the externality costs.

Although some home-sharing listings are potentially inefficient in the TD equilibrium, this does not imply that home-sharing decreases aggregate tenant surplus—this solely depends upon the relation of the quantities depicted by the two areas, with the main driver being the elasticity of the supply curve. Consider first the scenario where  $c_i = c_H$  for every tenant  $i$ , that is, the case of tenants with identical hosting costs. Equivalently, supply is perfectly elastic. Focusing on the TD regime, we get  $p_T = c_H$ , and consequently  $\int_0^{q_T} p_T - \hat{c}(q) dq = 0$ , and  $U_T < U_0$ . If we assume that hosting costs are drawn from some distribution, the same intuition holds when the variance of that distribution tends to zero. As the variance of the distribution of hosting costs increases,  $U_T$  increases as well, making it more likely that  $U_T > U_0$ . In other words, as the elasticity of supply decreases and holding externality costs fixed, it becomes more likely that the aggregate supply-side welfare will not decrease in the TD equilibrium.

### 3.2 The “building owner decides” (BD) regime

We now consider the regime where building owners set a common rule for their apartment building. The owners set a building-specific policy: either all tenants are allowed to home-share if they so wish, or hosting is prohibited. After building policies are set by owners, those tenants who reside in buildings that allow home-sharing decide whether to home-share or not, as in Section 3.1. We assume that building owners cannot make or take side payments to and from tenants.<sup>14</sup>

Figure 2: Comparing the utility of being a home-sharing host to not being a host



Let  $\theta$  denote the fraction of building owners that allow home-sharing, and  $\theta_B$  be the building owner decides (BD) equilibrium fraction. We know that the fraction  $\theta_B$  exists since  $p'(\theta) < 0$  and the demand curve is downward sloping. To characterize the market equilibrium under the BD policy regime, we derive two necessary conditions. First, the competitive equilibrium requires building owners to be indifferent between the two possible home-sharing policies, making long-term rents equal across buildings with different home-sharing policies; for if a building owner could charge a premium for either allowing or prohibiting home-sharing in their building, then the market would not be in equilibrium. Second, in equilibrium tenants have moved into apartment buildings of the right “type,” and so hosts and non-hosts are sorted. For if some tenant would be better off living in building of a different

<sup>14</sup>Coasian bargaining seems hard to implement in the home-sharing context because of high transaction costs, such as the cost of monitoring transactions, or of identifying and corralling the affected parties—Coase (1960) stressed the importance of such implementation problems in his seminal work. Similarly, building owners may not set hosting quantity caps, as this restriction would be, in most cases, hard to impose due to practical monitoring issues, e.g., a doorman can easily recognize non-tenants, but would have much greater difficulty tracking the number of stays by non-tenants.

“type,” he would also be willing to pay higher rent, violating the first competitive equilibrium condition.<sup>15</sup> Since every tenant in a home-sharing-friendly building hosts,  $q_B = \theta_B N$  is the equilibrium market supply of home-sharing units. For the same reason, it is only hosts that incur the externalities from home-sharing, and hence the home-sharing externalities are internalized under the BD regime. Note that this does not imply that apartments in home-sharing-friendly buildings are always occupied by guests, essentially amounting to hotels, but rather that tenants residing therein value the right to home-share whenever they have the opportunity to.

Letting  $p_B = p(\theta_B)$  be the equilibrium price, and observing that in the BD regime supply can only be lower than in the TD equilibrium, we immediately obtain  $p_B \geq p_T$  and  $q_B \leq q_T$ . To derive the competitive equilibrium, we need to examine the utility of tenants in different “types” of buildings. Tenants living in a building where home-sharing is prohibited obtain constant utility equal to  $u_0$ , as no other tenant hosts. The utility of tenants in buildings that allow home-sharing is a function of the number of hosts. Figure 2 depicts the utility of a host  $i$  with hosting cost  $c_i$  that lives in a home-sharing-friendly building (downward sloping curve). As the fraction of building owners that allow home-sharing increases, the price decreases and hence host  $i$ ’s utility decreases as well. A tenant is indifferent between the two types of buildings when the fraction of home-sharing buildings is equal to  $\theta^i$  such that  $p(\theta^i) - c_i - nc_E = 0$ .

**Proposition 2.** *In the BD equilibrium, there do not exist tenants whose hosting activity is socially inefficient.*

*Proof.* For a tenant  $i$  who lives in a home-sharing building to prefer to host,

$$u_0 + p_B - c_i - nc_E \geq u_0, \quad (3)$$

which implies that  $p_B \geq c_i + nc_E$ . For the marginal tenant  $\hat{b}$ , that is, the host with the highest hosting cost in the BD equilibrium, the above holds as an equality. Therefore  $p_B = c_{\hat{b}} + nc_E$ , where  $c_{\hat{b}} = \hat{c}(q_B)$ . This implies that Equation 1 holds for every host in the BD equilibrium.  $\square$

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<sup>15</sup>Although we have not modeled tenants as having idiosyncratic preferences for certain attributes, neighborhoods, school districts, and so on, the existence of such preferences does no matter to the model so long as the market is thick enough that tenants can find buildings that are more less equivalent (according to their preferences) but differ in home-sharing policy. Even if this is not the case—say because of strong building-specific preferences—a tenant who chooses not to change buildings values being in that particular building more than whatever cost or benefit is obtained by being in a building with a different home-sharing policy. As such, that tenant moving would lower overall surplus, as would the building owner changing the policy.



The surplus of tenants in the BD equilibrium is

$$U_B = U_0 + \left( \int_0^{q_B} p_B - \hat{c}(q) dq \right) - q_B n c_E. \quad (4)$$

In the next proposition, we derive a positive property of the BD equilibrium: tenant surplus never drops below that of a market without the home-sharing option.

**Proposition 3.** *In the BD equilibrium, tenant welfare increases compared to the market without home-sharing; that is,  $U_B \geq U_0$ .*

*Proof.* We have

$$U_B - U_0 = \left( \int_0^{q_B} p_B - \hat{c}(q) dq \right) - q_B n c_E = \int_0^{q_B} p_B - \hat{c}(q) - n c_E dq \geq \int_0^{q_B} p_B - \hat{c}(q_B) - n c_E dq,$$

where the inequality is due to  $\hat{c}$  being increasing in  $q$ . By definition,  $p_B = \hat{c}(q_B) + n c_E$  so the last expression is equal to zero, proving our result.  $\square$

As happens with the TD equilibrium, the increase in tenant surplus in the case of the BD equilibrium is also rooted in the heterogeneity in hosting costs. Consider again the extreme case where  $c_i = c_H$  for all tenants  $i$ , we get that  $p_B = c_H + n c_E$ , and as a result,  $U_B = U_0$ . This showcases the robustness inherent in the BD equilibrium: even if the worst-case distribution of hosting costs materializes, i.e., if demand is perfectly elastic, tenant surplus does not decrease in the BD regime.

A second positive result is that tenant surplus under building-specific policies always compares favorably to that of the TD policy regime.

**Proposition 4.** *In the BD equilibrium, tenant welfare increases compared to the TD equilibrium; that is,  $U_B \geq U_T$ .*

*Proof.* Subtracting the two quantities gives us

$$U_B - U_T = (p_B - p_T)q_B + \int_{q_B}^{q_T} \hat{c}(q) + n c_E - p_T dq \geq (p_B - p_T)q_B + \int_{q_B}^{q_T} \hat{c}(q) + n c_E - p_B dq.$$

The first term is nonnegative as  $p_B \geq p_T$ . Since  $\hat{c}$  is increasing and  $p_B = \hat{c}(q_B) + n c_E$  by definition, the integrand is nonnegative on the  $[q_B, q_T]$  interval. This proves the result.  $\square$

Tenant surplus in the BD equilibrium is always superior to that of the TD equilibrium. This is because the BD optimality condition guarantees that those tenants whose hosting externality outweighs the utility home-sharing generates are no longer willing to host.

To see why building-specific policies improve upon the supply-side surplus of the TD regime, we need to observe that there are two channels through which an additional home-sharing listing may decrease tenants’ surplus: (i) the listing imposes externalities greater than the corresponding benefits, and (ii) the corresponding benefits are less than the utility lost among all previous hosts due to the decrease in price that the higher supply results in. We showed that Equation 1 holds for all hosts in the BD equilibrium, hence no tenant surplus is lost due to excessive hosting externalities, and this condition is sufficient to guarantee that tenant surplus always increases compared to either the TD market or the market with no home-sharing option. However, this does not imply that tenant surplus is maximized.

### 3.3 The “city planner decides” (CD) regime

We now turn our attention to decision makers such as city-level regulatory bodies or the city mayors, which we refer to as the “city planner decides” (CD) policy regime. The city planner may control home-sharing supply through various means, such as taxing and imposing other transaction costs to home-share, or issuing individual- or building-level licenses and permits. We assume that the incentives of the central planner are aligned with maximizing tenant surplus. The economic rationale behind this modeling choice is that city planners collect taxes from accommodation-related activities (see Footnote 3), and the political reason is that it is city residents—and not guests—that shape voting outcomes on the city level.

We first show that the city planner’s intervention lowers the home-sharing market supply relative to that of the BD regime.

**Proposition 5.** *Home-sharing supply is restricted in the CD regime relative to the BD regime.*

*Proof.* The quantity that maximizes tenant surplus can be found by solving the following optimization problem:

$$\max_{q \in [0, q_B]} \left( \int_0^q p(q) - \hat{c}(x) dx \right) - qnc_e. \quad (5)$$

Note we can impose the upper bound  $q_B$  on the feasible region without loss of generality, as tenant surplus strictly decreases for quantities greater than  $q_B$ . The optimal solution  $q_C$  satisfies the optimality condition

$$\frac{\partial p}{\partial q} q + p(q) = \hat{c}(q) + nc_E, \quad (6)$$

which states that the quantity  $q_C$  is that where the marginal revenue (left-hand side) equals

the marginal cost (right-hand side). Since  $\frac{\partial p}{\partial q} \leq 0$ , the city planner potentially restricts the number of home-sharing buildings, and we get  $q_C \leq q_B$  and  $p_C \geq p_B$ .  $\square$

In the CD regime, there exist hosts whose value from hosting is greater than the corresponding marginal social cost but are prohibited from hosting. As a result, while tenant surplus in the CD regime is maximized, this surplus is distributed to fewer tenants, i.e., those tenants with the lowest hosting costs. Lower supply implies higher home-sharing prices, and hence guest surplus strictly decreases. Therefore, restricting home-sharing supply creates a welfare transfer from the guest to the tenant side of the market. For  $q \in [0, q_C)$  both sides incur losses, though surplus never becomes negative for either side, and hence the social welfare does not drop below that of a market without the home-sharing option. Furthermore, while our analysis is invariant to the exact means that the city planner controls the market supply, we discuss the implications of the supply restriction mechanism choices in Section 4 (i.e., permits, taxes, and so on).

### 3.4 The “social planner decides” (SD) regime

We now consider a social planner who may set home-sharing supply, but optimizes for the surplus that hosting creates on both the supply and the demand sides of the market. We refer to this case as the “social planner decides” (SD) policy regime.

To incorporate demand-side considerations in our model, assume that each guest  $j$  who rents a home-sharing apartment at price  $p$  gets utility  $v_j - p$ , where  $v_j$  is the marginal utility  $\hat{v}(q)$  of the marginal tenant  $j$  when  $q$  units are supplied. The following proposition shows that the social planner’s choice coincides with the BD equilibrium quantity.

**Proposition 6.** *The optimal social welfare is obtained in the BD equilibrium.*

*Proof.* The social welfare maximization problem is

$$SW^* = \max_{q \in [0, q_B]} \int_0^q p(q) - \hat{c}(x) - nc_E dx + \int_0^q \hat{v}(x) - p(q) dx. \quad (7)$$

It is straightforward to show the maximizer of Equation 7 satisfies  $\hat{c}(q) + nc_E = \hat{v}(q)$ . This condition also holds for  $q = q_B$ , and hence the BD equilibrium quantity maximizes social welfare. The monotonicity of the supply and demand curves guarantee that this is also the unique optimal solution.  $\square$

Proposition 6 illustrates the important advantage of the BD policy regime: in equilibrium, not only are hosting externalities internalized, but also hosting quantity is optimal with respect to social welfare. Furthermore, from a social welfare perspective, home-sharing

quantity is allowed to be inefficiently high in the TD regime, and restricted to be inefficiently low in the CD regime.

### 3.5 Model extensions

As in any model, we make assumptions and leave out real-world complexities. In Appendix A, we consider a variety of model extensions and different assumptions, and reason about how they would change the model results. We show that our assumption of linear, homogeneous hosting costs are irrelevant to the optimality of the BD equilibrium, though assuming convex costs would lead to an equilibrium sub-optimal relative to that chosen by a social planner. However, we show that a slight modification—namely giving building owners the right to choose a policy and set a within-building hosting cap—restores optimality. Interestingly, Airbnb’s “friendly buildings” initiative gives building owners tools to track and cap individual hosting intensity within a building, making this kind of within-building cap policy feasible. We also consider allowing negative externalities to spillover onto other nearby buildings, although, as we emphasize, these spillovers are likely to be quite small relative to the within-building externalities.

In Appendix B, we further explore the tâtonnement process by which the equilibrium of the BD regime is obtained. To study this process, we develop an agent-based model of a market under the BD regime, and find that the market under the BD regime converges rapidly to the predicted equilibrium under several initial conditions and behavioral assumptions. Furthermore, our agent-based model allows us to examine additional real-life factors that may affect the BD equilibrium: we show how moving costs can decelerate this process and decrease the efficiency of the resulting equilibrium, and how within-building tenant “type” correlation—tenants with similar hosting costs living in the same buildings—has the opposite effect, accelerating convergence.

## 4 Home-sharing policy

In the previous section, we developed a model of a market for home-sharing and long-term rentals, derived the equilibria under policy regimes that differ only in which party the right to host is allocated to, and studied several extensions of the basic framework. The main results are summarized in Table 2.

Our analysis of the TD regime reveals that a market where all tenants are allowed to home-share suffers from two fundamental problems. First, the amount of hosting is inefficient, in that there will be tenants whose hosting activity generates higher externality costs

Table 2: Summary of the results of Section 3.

Policy	Inter'zed Externality	Tenant Surplus	Guest Surplus	Social Welfare
TD	No	Low	High	Low
BD	Yes	Good	Good	Optimal
CD	Depends	Optimal	Low	Good

than the associated benefits. Second, externalities are not internalized, and tenants not willing to participate in the home-sharing economy are always worse off compared to a market without the home-sharing option. These two problems vanish in the equilibrium of a market where owners decide on a building-specific policy; hosting quantity in the BD equilibrium is socially optimal, and the negative externalities of hosting are internalized because of the sorting property.

The BD regime is an “information-light” policy, in that it does not require a central regulatory body with complete information about externality and hosting costs. This is a considerable advantage in the case of home-sharing, where these costs are highly idiosyncratic and hard to quantify. Instead, the BD regime is a market-based policy, and these quantities are taken into consideration through the choices of the market participants who know them. Importantly, market-based policies are self-adjusting, in that they are robust to structural shifts in market quantities; any centralized policy would need to be subject to periodical reevaluation in order to remain efficient.<sup>16</sup>

The externality problem is “fixed” in the BD regime equilibrium by tenants moving to buildings that match their “type:” tenants who wish to host move to buildings that allow for home-sharing, and those who do not move to buildings that prohibit it. As such, our model shares some similarity with Tiebout (1956), but perhaps less similarity than might appear at first. Tiebout’s focus is on communities solving the problem of the elicitation and aggregation of preferences for public goods. In our setting, Tiebout’s sorting process would not solve the externality problem by individuals sorting over cities that allow or do not allow for home-sharing. Furthermore, long-term rental rates put in place a price mechanism that allows for the market to equilibrate, and which is absent from Tiebout’s framework.

Today, city and state regulators take a wide array of approaches to home-sharing policies, while home-sharing platforms are lobbying for or against some of them, and propose their own policies. In the rest of this section, we use our framework to study the externality and distributional consequences of these policies, and to examine how they align with the

<sup>16</sup>Tirole (2015) makes this case and provides historical and contemporary examples of this problem. In addition to home-sharing, the NYC taxicab medallion supply problem is a conceptually similar case in point, where a market inefficiency was created by supply failing to meet the growth in market demand due to regulatory restrictions (Tullock, 1975).

prescriptions of our model.

## 4.1 Centrally restricting supply

City planners, who we modeled as aiming to maximize tenant surplus, have incentives to decrease home-sharing supply (see Proposition 5).<sup>17</sup> As the socially optimal policy coincides with the outcome of the BD equilibrium, pushing the home-sharing supply below  $q_B$  has a distortionary effect.<sup>18</sup> The exact mechanism through which supply is restricted has important consequences.

One way to restrict supply would be by setting a cap in the number of apartments that are allowed to home-share in every building. In doing so, however, the sorting of hosts and non-hosts does not take place, and negative externalities are not internalized in equilibrium. Another commonly used supply-restricting mechanism is increasing the administrative costs of home-sharing, such as requiring permits or individual licenses, but clearly suffers from the same problem. Increasing costs shifts the supply curve  $\hat{c}(q)$  upwards, excluding some would-be hosts from home-sharing, and constitutes a direct transfer of surplus from tenants to the city planner.

The city may restrict supply while facilitating sorting by issuing a limited quantity of building-level licenses, but less than the socially optimal number,  $\theta_B N$ . The immediate effect of such an intervention is that rental rates would no longer be equal across different building “types” in the equilibrium of the BD regime. For if the rental rates were equal in equilibrium, the marginal host would have some positive utility from living in a home-sharing-friendly building, and building owners could increase their profit by increasing rental rates by exactly the amount that would again make the marginal host indifferent. As such, issuing building-level licenses to home-share essentially constitutes a transfer of surplus from tenants to building owners. Part of this surplus can subsequently be transferred to the city planner by appropriately pricing these licenses.

It is important to note that, as we discussed in the beginning of this section, optimally setting supply is hard regardless of the city planner’s objectives. First, the city planner would need to have perfect information of all relevant market quantities, such as hosting and externality costs, which are highly idiosyncratic and hard to measure. Second, after

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<sup>17</sup>The rationale behind the assumption that city planners aim to maximize tenant surplus is that city government profits by taxing the tenant side of the market. Furthermore, to the extent that the traditional accommodation industry substitutes for home-sharing, some of the excess demand will be covered from such options, which are in most cases subject to higher tax rates.

<sup>18</sup>This result is in congruence with previous work on centrally restricting housing supply through regulatory intervention. For example, Glaeser et al. (2005) examine the gap between building costs and market prices, and find that stricter zoning laws result in a 10-30% increase in housing prices.

setting an initial supply level, the city planner would have to engage in a potentially costly re-evaluation of these policy decisions in order to respond to structural shifts in these quantities. These difficulties carry through to regulatory approaches such as Pigouvian taxation, which would work in theory to internalize the home-sharing externality, but only if the regulator could set the appropriate tax based on  $nc_E$ , which is hard to estimate. Furthermore, although we model externality costs as being homogeneous, if they were building- and individual-specific, such as due to differences in construction, layout, and preferences, any one tax level would be inefficient. In contrast, market-based solutions based on sorting of “types” retain their positive properties under heterogeneity assumptions (Tirole, 2015).

## 4.2 Hosting caps

A common policy response to home-sharing is introducing hosting caps imposing restrictions on the home-sharing intensity of each apartment.<sup>19</sup> The economic rationale behind hosting caps is that by limiting the number of nights each apartment can be home-shared, hosts’ profits are reduced, and making properties exclusively available for home-sharing is likely rendered unprofitable.<sup>20</sup> There is little empirical evidence on how hosting caps should be determined; Coles et al. (2017) employ rental and Airbnb data, and estimate that in 2016 the break-even hosting caps—the caps that would make owners indifferent between these two options—exceed 180 nights across all New York City boroughs.

Hosting caps can be applied concurrently with the policy regimes we considered, and hence it is important to examine how their introduction affects the results of our analysis. If the break-even hosting cap can be set and enforced for each apartment, then some bad actors are presumably removed from the home-sharing market. As supply from existing hosts is reduced, the going price for home-sharing listings will increase, which in turn will incentivize new hosts to join the home-sharing market. These hosts will have higher hosting costs—otherwise they would have been already participating in home-sharing—and hence a market failure will be more likely to occur (see also the discussion in Section 3.1). It is also important to note that hosting caps are not enough by themselves for externalities to be internalized, as they restrict hosting intensity but do not provide the market with a sorting mechanism. The market under the BD regime recovers the positive properties of

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<sup>19</sup>For example, the city of Paris imposes hosting caps for short-term rentals in central Paris. See <https://www.independent.co.uk/travel/news-and-advice/airbnb-paris-rules-new-rental-limit-bookings-stay-nights-latest-a8054771.html>, accessed online October 6, 2018.

<sup>20</sup>The argument is that, if home-sharing brings in higher profits than long-term rentals do, then owners may take properties off the market for long-term rentals, and exclusively make them available on home-sharing platforms. This amounts to running an illegal hotel, and may reduce housing supply for city residents, which may in turn have direct distributional and welfare consequences (Sampson et al., 1997).



internalized externalities and efficient hosting. Furthermore, in the case of externality costs that are convexly increasing in individual hosting activity, hosting caps allow decentralized policy regimes to regain their efficiency (see also the discussion in Section A).

Often, however, hosting caps are set lower than their break-even values.<sup>21</sup> As we reasoned above, the implications for equilibrium quantities ultimately depend on the elasticities of the market demand and supply, i.e., the increase in prices due to decreased supply from previous hosts, and the reduction in prices due to supply from new hosts. Regardless, as the new equilibrium is characterized by tenants with higher hosting costs hosting in lieu of tenants with lower hosting costs, social surplus necessarily decreases.

### 4.3 The role of the platform

Online platforms reduce search and transaction costs, by aggregating supply and demand, maintaining reputation systems, offering transaction insurances, and standardizing and automating large parts of each transaction. In the context of home-sharing, this reduction in transaction costs can be thought of as a reduction in hosts' hosting costs, and was the main contributor of the proliferation of home-sharing (Horton and Zeckhauser, 2016).

In addition to decreasing hosting costs, it is also important to examine how platforms can help address issues related to the externalities of home-sharing. Platforms could increase the social surplus that home-sharing generates by reducing its negative externalities. In terms of our model's parameters, reducing negative externality costs implies pushing the total cost curve  $\hat{c}_t$  closer to the hosting cost curve  $\hat{c}$ , which results in higher equilibrium hosting quantities across *all* regimes we examined, and higher surplus for both sides of the market. As home-sharing platforms typically leverage a fixed percentage fee on transactions, they hence have strong incentives to reduce externality costs and maximize total surplus. As a consequence, home-sharing platforms already take several steps towards reducing externality costs. Part of the effort to reduce externalities centers on informing hosts and guests about the specifics of each building, neighborhood, and city, such as noise ordinance laws and expected behavior, and providing insurance to both hosts and building owners for misuse and damages. Furthermore, home-sharing platforms maintain reputation systems in order to enforce better behavior and remove bad actors from the market, although there is evidence that the effectiveness of such mechanisms may erode over time (Filippas et al., 2018). Along these lines, an interesting measure is Airbnb's provision of a platform for neighbors of hosts to

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<sup>21</sup>For example, the city of Amsterdam limits home-sharing intensity to thirty days per calendar year, which is substantially lower than the break-even value. See also <https://techcrunch.com/2018/01/10/amsterdam-to-halve-airbnb-style-tourist-rentals-to-30-nights-a-year-per-host/>, accessed online on October 6, 2018.

complain about cases where guests generated extensive negative externalities, such as noise issues or misuse of common spaces.<sup>22</sup> Furthermore, the enforcement of policy responses aimed at addressing externalities that are convex in home-sharing quantity, such as hosting caps, require that the platforms cooperate with city governments.

The second important dimension of problem is the whether the externality costs are internalized. Throughout the paper we have stressed that this property obtains *only* in the presence of building-wide policies, as the externalities of home-sharing are internalized only if hosts and non-hosts are sorted. As such, we expect home-sharing platforms to encourage a move towards this direction. Interestingly, Airbnb has initiated a “friendly buildings” program, coinciding with the prescription of our paper.<sup>23</sup>

Incumbents often employ lobbying in an attempt to pose regulatory barriers to the entry and growth of home-technology firms (Djankov et al., 2002; Cusumano, 2015). As a response, sharing economy platforms have recently intensified their lobbying efforts.<sup>24</sup> In the context of home-sharing, our model shows that these lobbying efforts should be directed towards state rather than city regulators, as city regulators have incentives to reduce supply, at the cost of restricting the growth of home-sharing platforms. Airbnb’s recent lobbying efforts have been in accordance to this finding.<sup>25</sup>

## 5 The “no policy arbitrage” prediction

A key feature of our model is that building owners make policy decisions that maximize their rental income from long-term tenants. As home-sharing policy imposes only slight costs, our equilibrium prediction is that building owners should not be able to increase their profits by their choice of a home-sharing policy. In short, the home-sharing policy of a building should have no effect on rental rates, all else equal. This prediction of “no policy arbitrage” is challenging to assess empirically for two reasons: the lack of data on home-sharing policies, and the fundamental problem of causal inference, that is, the impossibility of seeing rental rates for the same building under two different policies at the same time.

For the first problem—that home-sharing is still a nascent phenomenon and home-sharing policies are not observable in data from existing rental markets—we use proxy policies. These

<sup>22</sup>See also <https://www.airbnb.com/neighbors>, accessed online on October 6, 2018.

<sup>23</sup>See also <https://www.airbnb.com/help/article/1195/what-s-the-airbnb-friendly-buildings-program>, accessed online on October 6, 2018.

<sup>24</sup>For example, see <https://qz.com/630939/charted-which-tech-companies-spend-millions-in-lobbying-the-us-government/>.

<sup>25</sup>See <https://www.theinformation.com/articles/uber-airbnb-fight-cities-by-lobbying-states>, and <https://www.nytimes.com/2018/09/11/business/dealbook/fixer-regulatory-hacking-review.html>, accessed online on October 6, 2018.

proxy policies are also choices made by building owners and with only slight costs. Our primary proxy is the building owner’s decision to allow or prohibit subletting. Subletting policies are a good proxy for our “no policy arbitrage” prediction, as subletting is conceptually similar to home-sharing. Although of longer duration than home-sharing, setting a subletting policy has slight administrative cost implications for the building owner, a potentially large financial impact on would-be renters, and negative externalities for current tenants. We also use whether a building owner allows dogs as a second policy proxy variable (see Appendix C).

For the second problem—the need observe counter-factual rental rates under different policies—we construct a hedonic price model for apartment listings using apartment attributes *excluding* policy variables. This model predicts what an apartment “should” rent for based on fundamentals. The idea is simple: if we observe the rental price for an apartment in building  $A$  that allows subletting, the rental price in building  $B$  across the street that prohibits subletting might provide us with a good counter-factual. Of course, building  $B$  might not have a roof garden or the square footage might be smaller; any of these factors could affect the rental price, which would in turn undercut  $B$ ’s usefulness as a counter-factual. The hedonic model addresses this problem: to the extent that the value of different amenities and dis-amenities is common in the market, we can account for these differences.

To fix ideas, suppose we observe an apartment  $i$  renting for rental rate  $r_i$ . This can be decomposed as

$$\log r_i = \beta_1 \text{SUBLET} + \log \rho_i + \epsilon, \quad (8)$$

where SUBLET is an indicator that the apartment allows subletting,  $\rho_i$  is what the apartment would rent for based solely on the apartment’s fundamentals when subletting is not allowed, and  $\epsilon$  is an idiosyncratic error, with  $\mathbf{E}[\epsilon] = 0$ . The parameter  $\beta_1$  is a premium due to the home-sharing policy, with our “no policy arbitrage” prediction being that  $\beta_1 = 0$ .

If we regress  $\log r_i$  on SUBLET but do not include  $\log \rho$  on the right hand side, we would obtain a biased estimate for  $\beta_1$  if SUBLET was correlated with  $\rho$ . This is just omitted variable bias. One approach to reduce this bias is to approximate  $\rho$  using the apartment data. If we can approximate the rental rate using a trained model, such that  $\log \rho_i = \widehat{\log \rho_i} + \eta$ , with  $\mathbf{E}[\eta] = 0$ , then the residualized regression

$$\log r_i - \widehat{\log \rho_i} = \beta_1 \text{SUBLET} + \eta + \epsilon \quad (9)$$

would yield an unbiased estimate of  $\beta_1$ .

A key hurdle for this approach is how well  $\widehat{\log \rho_i}$  can approximate  $\rho$ . The prospects seem

good: this approach has been widely used in analyzing real estate markets, as real estate is highly vertically differentiated and the attributes consumers care most about—geographic location and size—are typically measured without error. Furthermore, both landlords and would-be tenants have strong incentives to share as much match-relevant information about apartments as possible, to reduce search costs (e.g., number of bedrooms, location, building amenities, and so on). Of course, not all attributes can be conveyed readily in data (e.g., what is conveyed by photos), but much of it is, and so long as the whatever error remains is captured by  $\eta$ , this approach “works.”

In addition to simply controlling for the predicted rent (or, equivalently, residualizing the outcome by the prediction) and assuming orthogonality with respect to SUBLET, we can also create a second model that predicts SUBLET, and implement the so-called “double machine learning” or double-ML approach (Chernozhukov et al., 2016).

## 5.1 Data description

To implement the approach described above, we collected New York City apartment listings from a website and then fitted a predictive model of the rental rate based on a host of geographic-, building-, and apartment-specific attributes. Critically, we do not include cost-less “policy” attributes, such as the building owner’s decision to allow for subletting.<sup>26</sup> We then used the approaches described above to estimate  $\beta_1$  and test our “no policy arbitrage” prediction.

Our data set consists of 21,262 New York city apartment listings across 13,243 buildings collected in February 2017 from StreetEasy, one of the leading online rental advertising platforms.<sup>27</sup> StreetEasy receives their listings data directly by large and small brokers and rentals brokerage firms, individual owners, co-ops, and homeowner associations. The website’s success depends on the accuracy of the listings information, and hence StreetEasy monitors for and removes fraudulent listings, verifies the identity of brokers and brokerage/management agencies, and keeps the listings information up to date by frequently contacting the agencies and the owners. Furthermore, as StreetEasy’s business model depends on providing renters with information, and hence StreetEasy has a strong incentive to include all attributes relevant to renters’ decision-making.

Our web crawler pulls the information of every NYC rental listing on the web page, as

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<sup>26</sup>Though NYC law mandates that subletting cannot be unreasonably refused, tenants must obtain approval from the property owner or landlord before subleasing their apartments. In practice, landlords have plenty of ways to make life more or less pleasant for tenants, including affecting the speed and alacrity with which a security deposit is returned, repair requests are answered, and so on. Allowing sublets can therefore be interpreted as the landlord signaling that he will not obstruct the process.

<sup>27</sup><http://www.streeteasy.com>

well as all information contained in the listing’s respective building page. Our data collection was completed successfully, in that the entire collection of rentals on the website at that time was parsed successfully, which we verified by cross-referencing a large number of samples of the data collected by our crawler with the available listings on the website at that time.

The attributes of each listing include characteristics of the listing (e.g. square footage, number of beds, dining room, a balcony, broker fee required, guarantors allowed), characteristics of the building (e.g. geographical information, age, doorman, laundry, rooftop, valet service), as well as characteristics pertaining to the webpage (e.g. the number of pictures uploaded for the listing) for a total of 87 attributes. Crucially, the attributes include information on whether the building allows for sublets, which we use to test our “no policy arbitrage” prediction.<sup>28</sup>

Figure 3 shows a heat map of our data set’s geographical information, where redder hues indicate a higher number of rentals in that area. Our data is concentrated in the Manhattan borough, which is also where most of the demand for home-sharing accommodation is found. Table 3 provides descriptions and statistics of key variables. We note that subletting-friendly policies are somewhat rare in our data set, with only around 1.1% of the listings explicitly allowing subletting.

Table 3: Definitions and summary statistics of key variables

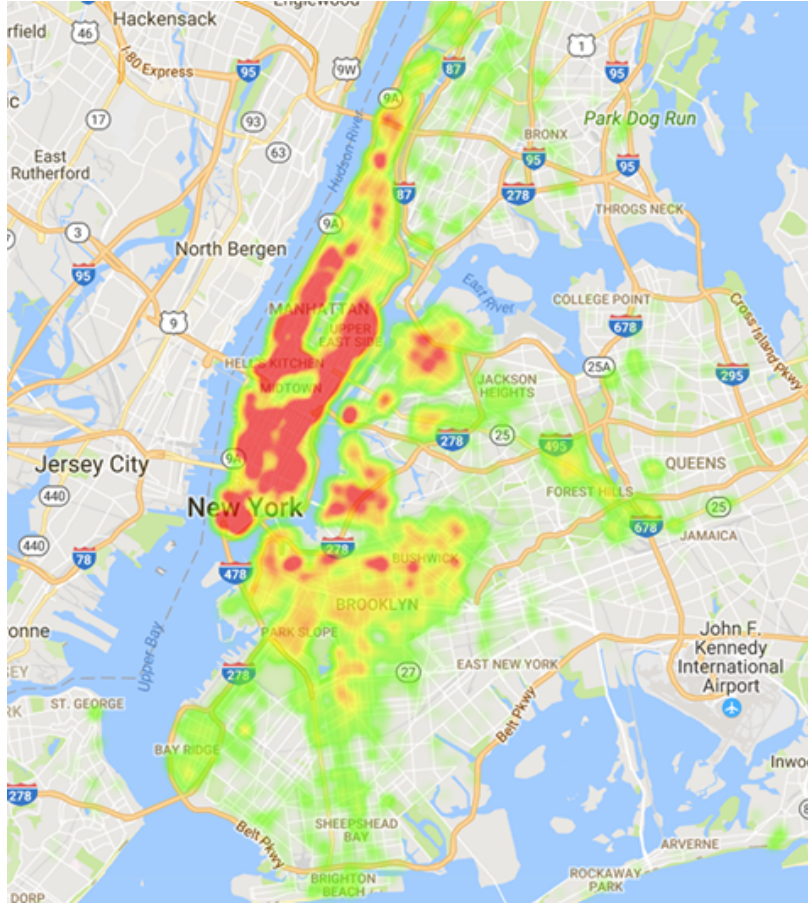
Variable	Definition	Mean	Median	Variance	Min	Max
price	Monthly rental price	3,760	2,800	4,161.3	750	10,000
sqft	Square footage	1,023.9	961	542.6	100	12,173
bd	Number of bedrooms	1.63	2	1.04	0	7
age	Building age (years)	76.39	72	38.87	0	120
a_sublets	Sublets allowed (1=Yes)	0.01	0	0.01	0	1
a_dogs	Dogs allowed (1=Yes)	0.18	0	0.14	0	1
a_washerdryer	Washer/Dryer in unit (1=Yes)	0.23	0	0.18	0	1

## 5.2 Predictive model of rental rates

To construct a counterfactual, we need a hedonic pricing model of what an apartment “should” rent, for given observable characteristics (excluding costless “policy” attributes). Rather than simply including many regression controls, we consider a set of candidate machine learning techniques for our pricing model, including simple linear regression, linear

<sup>28</sup>Though NYC law mandates that subletting cannot be unreasonably refused, tenants must obtain approval from the property owner or landlord before subleasing their apartments. Furthermore, landlords have in practice plenty of ways to make life more or less pleasant for tenants, including affecting the speed and alacrity with which a security deposit is returned, repair requests are answered, and so on. Allowing sublets can therefore be interpreted as the landlord signaling that he will not obstruct the process.

Figure 3: Heatmap of the spacial density of rentals



regression with lasso (L1), ridge (L2), and both (elastic net) regularizations, bayesian ridge regression, and ensemble methods including gradient boosting regression and random forest regression.<sup>29</sup>

We followed a two-step process to identify the predictive model with the best performance. For each candidate model, we generate distinct configurations of their hyperparameter values by using a grid search that spans a large range of these values. Each candidate configuration is then evaluated in terms of their out-of-sample predicting performance by performing 5-fold cross validations on our data set, and averaging the results across the folds. The models are evaluated in terms of three measures of performance: the mean square error, the mean absolute error, and the median absolute error.

The performance results are given in Figure 4. All five predictive models achieve reasonably good performance. The random forest regressor consistently outperforms the other

<sup>29</sup>We use the Python scikit-learn package implementations for our predictive modeling analysis. The package's webpage provides a detailed description of the implementations of each of these models. See [http://www.scikit-learn.org/stable/user\\_guide.html](http://www.scikit-learn.org/stable/user_guide.html), accessed online on October 6, 2018.



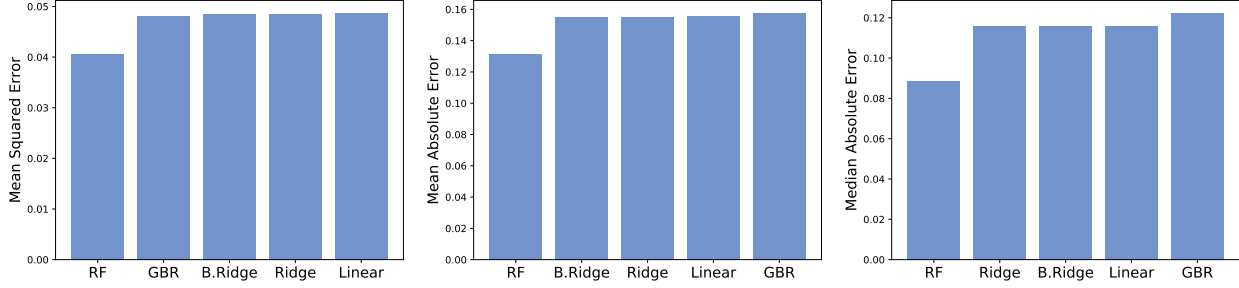


Figure 4: Out of sample predictive performance comparison.

models, across all three metrics. This is perhaps not surprising, given that ensemble methods have consistently been shown to be superior in terms of predictive performance (Bauer and Kohavi, 1999; Dietterich, 2000). It is worth noting two additional points about our approach. First, the fact that we use cross-validation for our evaluation means that the performance results that we are getting are not the result of overfitting. This is also the case in our counterfactual analysis: for every observation, the predicted price is always the output of an out-of-sample prediction, as the fold to which that observation belongs is left out of the training set on which the predictive model is trained. Second, the random forest method has a built-in, robust metric of variable importance that we may use as a robustness check of our results (Breiman, 2001; Genuer et al., 2010).

### 5.3 Effects of policy choices

Our model’s “no policy arbitrage” prediction is that building owners cannot command higher rent through setting costless policies. We are assuming no market power and non-negotiable offers from owners, so that quoted rental rates are the actual market rates.

In Column (1) of Table 4, we report the results of a regression of the log rental price on an indicator for whether that apartment building “allows” subletting. From this regression, we can see buildings allowing subletting have, on average, about 10% higher rental rates. A naive interpretation would be that building owners could increase profits by 10% simply by allowing subletting (assuming there are no real additional costs to this policy). However, as we discussed when presenting Equation 8, to the extent the subletting variable is correlated with building attributes that affect rents, this estimate is likely to be (severely) biased.

In Column (2), when we residualize the rental rate by the hedonic model prediction, we see that the “subletting premium” from Column (1) is likely entirely due to omitted variables bias: the effect of offering subletting is a precisely estimated zero.

In Column (3) of Table 4, we report the double-ML estimate of the effects of subletting. We again obtain an essentially precisely estimated zero. For the double ML estimates, we use



Table 4: Double ML estimate of effects of sublet policy on long term rentals in NYC.

	<i>Dependent variable:</i>		
	$\log Rent$	$\Delta \log Rent$	$\Delta \log Rent$
	(1)	(2)	(3)
Building allows subletting (1/0)	0.101*** (0.035)	-0.009 (0.015)	
$\Delta$ Building allows subletting			0.005 (0.043)
Constant	8.038*** (0.004)	-0.038*** (0.002)	-0.038*** (0.002)
Observations	21,257	21,257	21,257
R <sup>2</sup>	0.0004	0.00002	0.00000
Adjusted R <sup>2</sup>	0.0004	-0.00003	-0.00005
Residual Std. Error (df = 21255)	0.520	0.225	0.225

*Notes:* This table reports the relationship between posted log monthly rental rates and subletting policies. In Column (1), the outcome is the rental rate and the regressor is the subletting policy. In Column (2), the outcome is the residualized log rental rate and the regressor is the subletting policy. In Column (3), the outcome is still the residualized log rental rate and the regressor is the residualized policy variable. The subletting policy variable is residualized with respect to the predictions from an extreme gradient boosting (Chen et al., 2015) using an extensive collection of controls, implementing the “double ML” estimate (Chernozhukov et al., 2016). Significance indicators:  $p \leq 0.10$  : \*,  $p \leq 0.05$  : \*\*, and  $p \leq .01$  : \*\*\*.

extreme gradient boosting (Chen et al., 2015) to create semi-parametric estimates predictions for the policy variable SUBLET (referred to as  $D$  in the double ML literature) and residualize it, and use the same rental rate prediction from Column (2).

The Column (2) and Column (3) results support our contention that owners cannot, by a simple policy change, charge higher rents, consistent with our “no policy arbitrage” prediction. Note that for “policies” that are not costless—say adding some amenity to a building—our approach should predict a premium is possible. As a robustness test, we apply the same hedonic regression approach in Appendix C for a “policy” that is costly for owners and clearly valued by renters, namely whether the apartment has an in-apartment washer and dryer. We find that, as expected, a substantial rental premium can be charged for providing this service—though the raw OLS regression overstates the premium.

As an additional robustness test, we examine in Appendix C the effect of the building owner’s decision to allow or ban dogs. This decision is conceptually similar to home-sharing, as it has slight administrative costs for building owners, but dogs have the potential to impose substantial costs on neighbors. We again find no detectable effect on rental prices after controlling for fundamentals.

## 6 Conclusion

Our model suggests that allowing individual building owners discretion in setting home-sharing policies is likely to be socially efficient. The social welfare obtained in the case where individual owners set building-wide policies coincides with that obtained in a market regulated by a social planner. The reason is that terms between different types of buildings are equalized in a competitive long-term rental market, and the marginal host’s individual benefit does not exceed the full cost of him living in such a building. The two alternatives we examined—allocating decision rights to the individual tenant or to the city—are likely to lead to too much, and too little, hosting, respectively.

Our empirical analysis of the NYC rental market strongly suggests that, as predicted by our model, building owners cannot extract premia through costless decisions about policies that potentially imply negative externalities for other tenants. Employing an agent-based modeling approach, we exhibit that a market under the building-specific policies regime always converges to equilibrium. Higher moving costs reduce tenant surplus, while within-building tenant type correlation decreases the amount of moving necessary for the equilibrium to be reached.

As technological innovations continue to bring forth applications which were previously not possible, and to blur the boundaries between the personal and the professional, policy-

makers will debate about policy that addresses externality issues, and managers will strive to aid this effort proactively, or face significant regulatory hurdles. Our paper adds rigor to the policy debate about home-sharing, introduces a theoretical framework that can generally be applied to externalities caused by online platforms, and offers clear prescriptions for platform managers.

A natural direction for future work would be an empirical investigation of some of the aspects of the model. For example, it might be illuminating to interview building owners making decisions and how they are dealing with existing and/or prospective tenants. Another direction is to test whether cities with particularly inelastic travel demand—and hence the ability to extract substantial rents—are also the cities most interested in restricting home-sharing.

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## A Extensions

### A.1 Heterogeneous within-building externalities

The analysis of Section 3 assumes that the externality cost of an additional host to neighboring tenants is fixed, and that all tenants incur the same externality costs. This is a simplification that makes no difference to the results of our model. Assuming heterogeneous externality costs to tenants simply creates surplus or costs to inframarginal tenants without affecting anything on the margin—and what matters is the cost of the marginal tenant. As such, all results carry through for any concave cost function. It is worth noting that the most realistic extension for this type of heterogeneity is to assume that tenants with low hosting costs are also the ones who incur the least amount of externalities from home-sharing; these are exactly the tenants who participate in the home-sharing economy in the BD equilibrium.

As an assumption, linear costs might fail to capture the possibility that having only a few visitors in a building may go unnoticed by tenants, but a horde of guests may create substantial problems. In this case, externality costs can be modeled as a convex increasing function of the number of hosts. Carrying out the analysis of Section 3, one can show that the home-sharing still externality is internalized in the BD equilibrium allocation, and the social welfare is positive and optimal among those allocations that use building-specific policies, for the same “marginal tenant is what matters” reasoning. However, the BD equilibrium is no longer characterized by socially optimal home-sharing activity if the building owner still has to set a blanket policy.

The reason BD is no longer socially optimal is that, as one might intuit, convex costs create a social planner incentive to minimize the number of hosts in a same building, which can be done by spreading a relatively small amount of hosting across all building—something a blanket building policy makes impossible. This problem can be easily overcome by giving building owners the power to set within-building hosting caps, i.e., imposing an upper bound on hosting intensity per tenant, which we further discuss in Section 4.2. The model prediction would be that more buildings would then allow home-sharing, but cap it at smaller amounts per apartment within each building.

### A.2 Outside-building externalities

One consideration potentially relevant to policy decisions at the city level, and that is not captured in our framework, is the impact of guests on the local economy. The positive impact from every additional guest is not only generated through lodging payments, but also through activities such as dining, shopping, and sightseeing. Incorporating this additional benefit to

our model would push the tenant-optimal fraction of home-sharing supply to be higher than  $\theta_C$ . However, it is important to note that these effects are pecuniary externalities, meaning there is unlikely to be a market failure rationale for considering these effects.

The optimal home-sharing quantity under the presence of these positive, system-wide externalities directly depends on additional assumptions on guest behavior. We consider the special case where each guest has an individual-specific budget  $b_i$  for their trip, spends an amount  $p$  for accommodation, and the remaining budget,  $b_i - p$ , on city activities.<sup>30</sup> Following through with the analysis of Section 3.4, we can then show that the BD equilibrium is optimal for the local economy. Furthermore, as listings on home-sharing platforms are more geographically dispersed than hotels, these benefits are also likely to be more geographically spread out (Coles et al., 2017). However, it is worth noting that this increase in consumption is possibly offset by a decrease in consumption of other activities.

Outside-building externalities of guests may also be negative. For example, extraordinarily noisy guests may impose negative externalities to tenants residing in neighboring buildings. However, our view is that between-building externalities are likely to be small in magnitude. First, physical nuisances such as noise and smells dissipate with the cube of the distance from the source, making it hard for these kinds of costs to travel very far, and certainly not to neighboring buildings. Second, nuisances such as wear-and-tear, misuse of common areas, and reduced physical security, are inherently within-building externalities.

If we do assume that between-building externalities exist and they are negative, the optimal amount of home-sharing would change. Consider a configuration where all buildings exist in a line and that spillovers occur to the buildings left and right of the focal building. In the simplest case, we may assume that the marginal guest in building  $i$  does not only impose a negative externality  $c_E$  on every tenant of building  $i$ , but also a fraction  $\alpha < 1$  of this externality on each tenant of buildings  $i - 1$  and  $i + 1$ . An immediate implication of such externalities is that the gap between the cost curve  $\hat{c}$  and the total cost curve  $\hat{c}_t$  grows by a factor of  $2\alpha$  (see Figure 1). As a result, the socially optimal home-sharing quantity would decrease. At the same time, the TD equilibrium  $q_T$  would remain unaffected, as individual decision-makers only care about their own profit, and market failure would be more likely to occur.

In the BD regime, the presence of negative outside-building externalities implies that,

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<sup>30</sup>Internal Airbnb studies have shown that the average Airbnb guest stays two days longer and spends an additional \$200 on local businesses, compared to tourists staying in hotels. <http://www.airbnb.com/press/news/new-study-airbnb-generated-632-million-in-economic-activity-in-new-york>, accessed on October 6, 2018. Furthermore, Alyakoob and Rahman (2018) show that increased home-sharing activities has a positive and salient impact on restaurant employment in New York City.

in all non-trivial cases, there will be some tenants who do not participate in the sharing economy but who incur externalities. Equilibrium rents are now not equalized, but rather depend on the number of buildings that allow for home-sharing. In the example of linearly ordered buildings, there now are three equilibrium rents, reflecting the three potential states a building can be in relative to its “neighbor” buildings: a building can be one, two, or zero adjacent buildings that allow for home-sharing, with average rents declining in the number of adjacent home-sharing buildings.

While the exact characterization of the new equilibria hinges upon additional assumptions, an interesting case is that of would-be hosts who experience lower externalities, i.e.,  $c_i$  is correlated with  $c_{E,i}$ . We can show that there now exists a unique equilibrium where buildings that allow home-sharing cluster: non-hosts incur higher between-building externalities than would-be hosts, and are willing to pay more to live away from home-sharing-friendly buildings. Therefore, the equilibrium of the BD regime remains socially efficient. Furthermore, this result straightforwardly extends to general topologies, such as grids.

### A.3 Supply heterogeneity

The model of Section 3 assumes uniform apartment buildings, where apartments are rented out to tenants. We examine how ownership and heterogeneity in building types would affect the main results.

A common type of residential ownership structure is co-op and homeowners associations, where home-sharing policy decisions are typically made by majority voting, or on the board level. These ownership structures are conceptually identical to apartment buildings, with voting outcomes depending on the hosting costs of the marginal tenant in each building. Insofar that there exists an open market for buying and selling apartments, residents with strong incentives to home-share will move to co-ops and homeowner associations that allow home-sharing, and tenants with strong disincentives will move to those that prohibit it. Today, home-sharing is typically prohibited in these buildings as tenants who reside therein such buildings likely have high hosting costs, and hence they are inframarginal.<sup>31</sup> To the extent that there is a sufficiently large number of such buildings, some will likely switch to a home-sharing-friendly policy, depending on the hosting cost distribution of the owners’ population and the going home-sharing price.

Another type of ownership is individually owned houses. Owners typically do not require permission to participate in home-sharing, introducing individual ownership to our model would lead to a decrease in the equilibrium fraction  $\theta_B$  of apartment buildings that allow

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<sup>31</sup>See for example <https://cooperator.com/article/non-owner-residents/full>, accessed on October 6, 2018.

home-sharing under the BD regime. Keeping all else equal, the equilibrium quantity of home-sharing supply would not change; the only difference is that part of the home-sharing supply now comes from individually owned houses instead from apartment buildings. As externality costs therein are lower due to the absence of neighbors within the same building, an immediate benefit of introducing individually owned houses to our framework would then be that social welfare likely increases. In the corner case where enough supply comes from individually owned houses, no apartment building owner has incentive to allow home-sharing, as the benefits are not high enough for any tenant to be willing to host. It is easy to see that the internalized externalities property still obtains in the BD equilibrium.

## B Reaching equilibrium

In the main part of the paper, we show that the market under the BD policy regime is characterized by efficient hosting quantities and internalized externalities. Importantly, we discuss in Section 4 that the BD regime is a market-based policy. As a result, relevant market quantities do not have to be estimated by a central planner, and the market can readjust itself to structural shifts in these quantities.

Even though the regime wherein owners decide on their building’s home-sharing policy is efficient and plausible, convergence to the market equilibrium requires tenants to “sort” into buildings of the appropriate policy, thereby creating two potential problems. First, individually rational behavior is not guaranteed to converge to a steady market state, or may require a prohibitively large amount of time to do so. The resulting fluctuations in prices as well as changes in other market quantities could require substantial tenant sorting to “fix.” A long line of game-theoretic research shows that systems comprising individually rational decision makers are not guaranteed to self-stabilize. For example, agents, often modeled as best-responding to the current system state, may get trapped in cycles of suboptimal states, and the market may either fail to reach equilibrium or require a prohibitively large amount of time (Arthur, 1999; Marcet and Nicolini, 2003; Arthur, 2006; Daskalakis et al., 2009; Galla and Farmer, 2013). Furthermore, in the case of home-sharing tenant “types”—those that want to host and those that do not—are initially mixed across buildings. Any policy imposed by a landlord will leave some of them happy and others unhappy. Tenants who are dissatisfied will subsequently look to move to a building with their preferred home-sharing policy. However, to do so they would have to incur costs such as time spent in searching and evaluating, realtor fees, moving expenses, and so on. The sorting mechanism is costly, and these costs could dissipate the surplus of home-sharing. As a consequence, some tenants may get “locked into” their current building, and the market may fail to reach the state that

the BD equilibrium predicts.

These two issues—(1) can the equilibrium be reached and (2) what are the implications of adjustment costs—may raise questions about the applicability of the building-specific policy approach to real-life markets. To explore the tâtonnement process by which an equilibrium is obtained, we construct an agent-based model of the home-sharing rentals market. Agent-based models (ABMs) are computational simulations in which entities are programmed to interact and respond to their environment over time (Jackson et al., 2016). ABMs are commonly used to study emergent and transitory macro-level phenomena created by micro-level behavior, which would otherwise be theoretically intractable (Schelling, 1971; Bonabeau, 2002; Tesfatsion and Judd, 2006; Rahmandad and Sterman, 2008; Tebbens and Thompson, 2009; Chang et al., 2010; Oh et al., 2016).

We first show that the market operating under the building-specific policy regime converges to the competitive equilibrium under a variety of initial conditions. We then incorporate moving costs to the model and find that a 1% increase in moving costs results in roughly a 1% decrease in the tenant surplus generated through home-sharing, compared to the case where moving costs are zero. While the home-sharing equilibrium supply only marginally decreases with higher moving costs, some tenants are “locked into” buildings with undesirable (for them) home-sharing policies. As a result, tenants with higher hosting costs end up becoming home-share hosts, and tenants with lower hosting costs are excluded from home-sharing, creating an inefficiency. Nevertheless, the net effect of home-sharing on tenant surplus is always positive. It is also worth noting that the moving expense is likely a one-time cost, as we find that in almost all cases tenants will select into buildings of the right “type.” Finally, we show that including within-building correlation in tenant types—captured through correlated hosting costs for tenants residing in the same building—leads to faster convergence, as well as to a decrease in the number of tenant moves necessary for the market equilibrium to be reached.

## B.1 An agent-based model of the BD regime

We build our ABM analogously to the model of Section 3. We begin our description by focusing on tenants. At time  $t$ , tenant  $i \in I$  lives in a building  $b_i(t) = j \in J$ , and can home-share only if the policy of the building allows for hosting. If he is allowed, tenant  $i$  hosts if the market price for home-sharing,  $p(t)$ , exceeds his personal hosting cost,  $c_i$ . If  $k_j(t)$  other hosts live in the same building, then tenant  $i$  incurs total externality costs  $k_j(t)c_E$ . Buildings that allow for home-sharing charge rent  $r_1(t)$ , and buildings that prohibit home-sharing charge rent  $r_0(t)$ .



When tenants would be better off living in another building, they enter a pool of tenants who want to move from their apartments. To move, tenants incur a cost  $c_{i,m}$ . There are two cases in which tenants move. First, tenants want to move if they are currently not allowed to host and hosting would increase their utility. In the language of our model, tenant  $i$  wants to move if there exists some building  $j'$  such that

$$u_0 - r_0(t) \leq u_0 - c_{i,m} - r_1(t) + p(t) - c_i - k_{j'}(t)c_E.$$

Second, tenants want to move if they are currently allowed to host, but would be better off in a building that prohibits home-sharing as they would not have to incur the externalities from other tenants' hosting activity. Formally, tenant  $i$  wants to move if there exists some building  $j'$  such that

$$u_0 - r_0(t) - c_{i,m} \geq u_0 - r_1(t) - k_j(t)c_E + \max\{0, p(t) - c_i\}.$$

We assume that tenants only consider their present utility from living in a home-sharing friendly apartment against not being able to host, i.e., they do not form expectations about others' behavior, they are “small” relative to the market. The reason for this assumption is that the agents' decision process is in practice stationary: in our simulations we find that tenants (almost) never move buildings twice, and owners (almost) never change their building's policy more than once: agents, both owners and tenants, spend the rest of their time in the state they move to.

Market clearing is brought about through both rent and home-sharing policy adjustments. Building owners adjust rents and home-sharing policies in response to the relative demand for moving to home-sharing friendly and unfriendly buildings. For example, if there are more tenants looking to move to buildings that allow for home-sharing than to those which prohibit it, then rents in the former buildings increase in the next period, while the latter may convert to a home-sharing-friendly policy. It is worth mentioning here that tâtonnement requires both rent and policy adjustments. While the theoretical model we developed predicts “no policy arbitrage” in equilibrium, i.e., that rents are equalized across building “types,” we do not disallow rent adjustments in the ABM, as we want to examine whether this property is an “organic” market outcome in our simulations. Similarly, assuming that home-sharing policy adjustments do not take place would impose a constant supply constraint on the building owner side.

As moving decisions usually take place in a yearly basis, each period in our ABM can be thought of as a year in a real-life rental market. Each instance of our computational model is carried out for 50 periods, or until the market reaches a steady state. Initial building policies

are randomly selected with equal probability; other methods of initialization that we tried do not qualitatively change our results.

We describe the order in which events take place in every period below.

1. **Pool of movers is identified.** Tenants who are dissatisfied with their building’s current home-sharing policy and who would be better off incurring the cost of moving to another building enter the pool of potential movers to and away from home-sharing-friendly apartments, creating market demand for the corresponding building “type.”
2. **Building-specific policies are adjusted.** Building policies respond to the market demand. For example, if more tenants want to move to home-sharing-friendly buildings, then the home-sharing-unfriendly buildings probabilistically change their policies to cover, in expectation, a percentage of the excess demand. The exact percentage is a parameter of the ABM, and our results are qualitatively insensitive to whether too few or too many buildings change their policies to cover the excess demand. If there is no net difference in demand, policies remain unaffected.
3. **Rents are adjusted.** Rents also respond to the aggregate demand. Buildings with policies for which there is higher demand increase their rental prices by a constant amount, while rents in the other category remain unchanged. Similarly to policies, if the two type of demands are equal, there is no change in rents.
4. **Tenants move.** After rents and building policies are adjusted, tenants determine whether they want to change buildings. A tenant attempts to move if the difference in utility obtained by changing apartments is higher than his moving cost. If the sets of tenants that want to move to buildings with different policies are both non-empty, we randomly select pairs of tenants and switch the building in which they reside. In the case where the demand to move to one type of building exceeds the other, some tenants will not be able to move.
5. **Market quantities are updated.** The tenants update their hosting decisions. The price of home-sharing rentals, modeled as a decreasing linear function of supply, responds to the new market state.

These five steps constitute a period in our model, and are repeated until the system converges to the computational equilibrium, or until fifty periods have passed. The computational equilibrium is defined as the state in which no tenant wants to switch buildings, and therefore no owner wants to change the building’s home-sharing policy or increase rents. If the upper bound on the number periods is exceeded, then we say that the market fails to reach an equilibrium.

## B.2 Example simulations

To illustrate how our computational model works, we provide the results of a set of example simulations. Figure 5 depicts the time series of the fraction of home-sharing-friendly buildings, the fraction of tenants that are dissatisfied and want to move, and the percentage difference in rents of the two types of buildings until convergence is achieved. Each simulation is represented by a separate line.

For the purposes of our simulation, we consider an ABM with 3,000 tenants (agents) living in 30 buildings of capacity 100 each. The hosting cost of each tenant is determined through identical and independent draws from a uniform distribution with positive range. As a result, the supply curve is approximately linear and upward sloping. To start, tenants do not incur a moving cost to move apartments. Initial building home-sharing policies are randomly determined. These two factors add stochasticity in our model and hence result in different paths for each simulation. The demand curve for home-sharing is linear and downward sloping. Note that other configurations that we tested did not change the significance or the direction of the results. We use the same simulation parameters in the rest of this section unless otherwise noted.

As expected, the entry of the home-sharing option and the subsequent owners' decisions on building-specific home-sharing policies initially leave some tenants unhappy. Most of the tenant sorting occurs early on in the process, and the number of dissatisfied tenants rapidly drops, with less than 5% being dissatisfied after the second period. The process converges to a state where there is a negligible amount of tenants that are dissatisfied (less than 3%). Note that the number of unhappy tenants is not driven to zero since our computational model is discrete, and the optimal solution need not have an integer number of buildings allowing for home-sharing. Similarly, the number of home-sharing-friendly buildings initially varies but soon converges to one of two values, again due to the discrete nature of our model. Finally, the rent equalization property of the BD policy regime is also satisfied in the example simulations, with equilibrium rents being approximately equal—disparities are again small, and due to the discrete nature of the ABM.

## B.3 Convergence to the BD equilibrium

Our first question pertains to the time of convergence to equilibrium for a market operating under the BD regime. As we discussed in the beginning of Appendix B, collective behavior of individually rational agents is not guaranteed to result in convergence to equilibrium. In the case of home-sharing, this failure to converge is consequential, as the market may not obtain the positive properties of the BD regime, or it may require a prohibitively long time

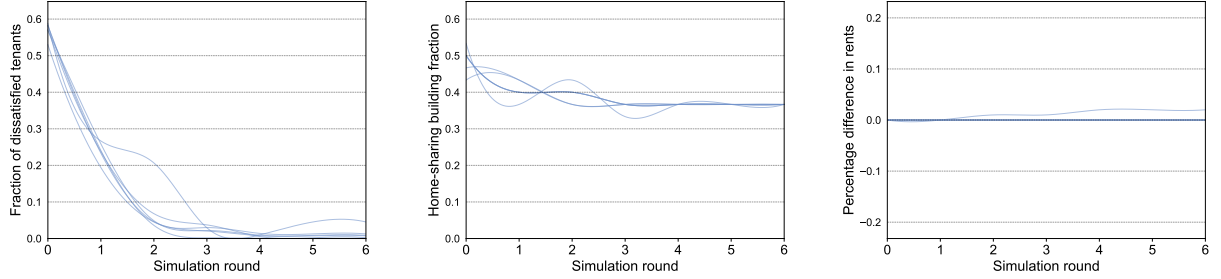


Figure 5: This figure plots the results for a set of example simulations of our agent-based model. Each line indicates a different instance of the ABM. For every round of the simulation, the leftmost panel plots the fraction of tenants that want to move to a building of different type, the middle panel plots the fraction of buildings that allow for home-sharing, and the rightmost panel plots the percentage different of long-term rental rates between buildings of the two types.

to obtain them.

To estimate whether the market operating under the BD regime robustly reaches the equilibrium state, our approach is to run a large number of instances of the ABM model starting from different initial conditions. We conduct 20,000 iterations with parameters chosen as described in Section B.2. The upper bound for convergence is set to  $T = 100$  periods; if the market does not reach equilibrium until time  $T$ , then we assume that it has failed to converge.

Our results are reported in Figure 6. Convergence times appear to be following a truncated normal distribution. Importantly, we do not find any case where the market does not reach equilibrium. The error bar of the number of tenants who want to move as a function of time is presented as a ribbon on the mean, and shows that the number of dissatisfied tenants quickly drops to near-zero values. Furthermore, the equilibrium number of tenants home-sharing is on average within 0.1% of the BD equilibrium quantity (standard deviation=0.005). Accounting for the discrete nature of our computational model, the results of our experiment indicate that the market both reaches equilibrium within a reasonable time limit, and that this equilibrium always coincides with the theoretical prediction for the BD regime.

## B.4 Moving costs

An important factor that is not captured by our theoretical analysis are the costs associated with moving: tenants who are dissatisfied with their building’s home-sharing policy have to incur substantial costs to move to a building of the appropriate “type.” As a result, some tenants may elect to stay in their current building even if they would be better off elsewhere;

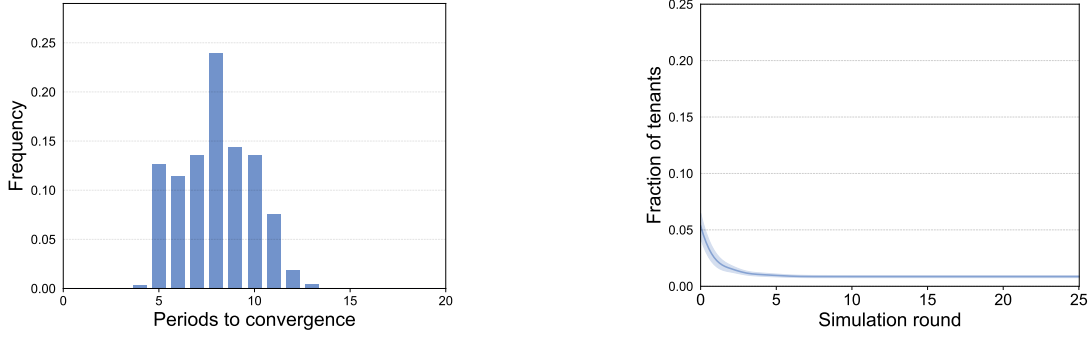


Figure 6: Distribution of equilibrium convergence times (left) and fraction of tenants who want to move as a function of time (right).

the market is then pushed to a sub-optimal state with a number of home-sharing rentals different than what is predicted by the BD equilibrium without moving costs.

To assess the impact of the costs of moving on the market operating under the BD regime, we employ our computational model and carry out simulations while varying moving costs. Moving costs are set equal to 10% of the annual rent, with the results remaining qualitatively similar for different values that we tried. Figure 7 reports error bars depicting the (normalized) mean tenant surplus and the average fraction of tenants that host in home-sharing-friendly buildings as a function of moving costs, reported as the ratio with respect to the annual rent. We notice a considerable decrease in tenant surplus. However, we also observe that almost every tenant in the home-sharing-friendly buildings hosts for even large values of moving costs, but the percentage starts decreasing as moving costs become very large; this indicates that some tenants are dissatisfied but cannot change buildings.

To examine the underlying effects further, we report in Figure 8 the percentage change effect of costs on the amount of sorting required, the home-sharing market supply and the tenant surplus. Home-sharing market supply is barely affected, and is equal to the BD equilibrium value for a wide range of tenant costs. However, both the tenant surplus and the sorting required for convergence to equilibrium decrease as moving costs increase. This implies that, while the home-sharing supply remains efficient, tenants with high hosting costs are “locked into” home-sharing-friendly buildings; these tenants see their utility decrease but cannot move. Among them, those tenants for whom the individual rationality condition is satisfied will list their apartments, although the internalization condition (Equation 1) does not hold. As a result, market price decreases, and tenants with lower hosting costs are no longer willing to incur the cost to move to home-sharing-friendly buildings. This effect is welfare-reducing, with a 10% increase in moving costs resulting in an average of 10% decrease in tenant surplus on a yearly basis.

It is important to note that the discount rate of tenants and the amount of “organic”

moving that occurs can matter in the interpretation of the results. If tenants have a low discount rate, moving costs would become less important relative to the long-term benefits of being in the “right” building. Similarly, if tenants move frequently anyway, the cost of being in the “wrong” building can be fairly small, especially with a high discount rate. We view the simulation of market adjustment with moving costs as an illustration of the mechanisms by which welfare-relevant outcomes arise.

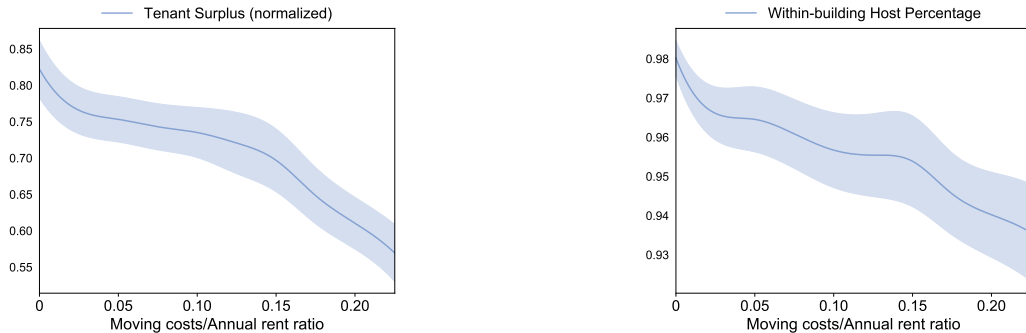


Figure 7: Tenant Surplus (left) and percentage of tenants living in home-sharing-friendly building that host (right) as a function of moving costs.

## B.5 Correlation in tenant types

An additional concern with the BD equilibrium is the amount of sorting that needs to take place before the equilibrium is reached. However, the amount of moving required for that to happen can in fact be less than one might initially think: rather than full mixing, it seems likely that in practice similar tenants live in the same building, hence tenant “types” are correlated within buildings. In our model, this intuition translates into tenants with high hosting costs (e.g. high opportunity cost, wealthier individuals) to be more likely to reside in some buildings at the time of the introduction of home-sharing in the market, while tenants with lower hosting costs in others. Since tenants are already “sorted,” we would expect that the sorting necessary for the process to reach equilibrium may be less than if tenants were fully mixed.

We incorporate the above intuition in our computation model by adding within-building hosting cost correlations. The hosting costs of tenants within a building can be independently drawn ( $\text{corr}=0$ ) or completely correlated ( $\text{corr}=1$ ). The results of our experiments are shown in Figure 9, and the percentage change effects are reported in Figure 10. Initially, correlation has a small but negative effect on both tenant sorting and time to convergence. As the value of correlation further increases, we observe a large reduction in both quantities, with a 10%

Figure 8: Percentage changes with respect to the zero moving cost case.

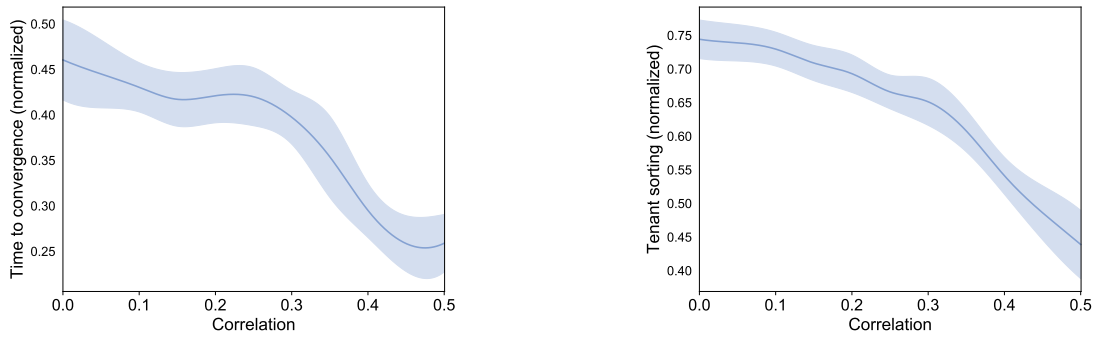
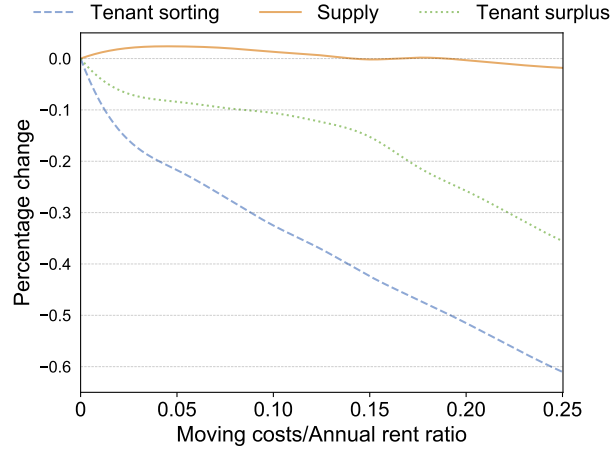
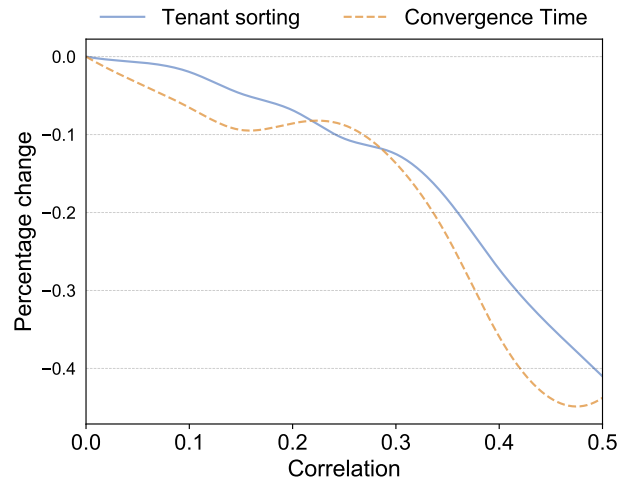


Figure 9: Time to convergence (left) and tenant sorting required to converge (right) as a function of within-building hosting cost correlation.

Figure 10: Percentage changes with respect to the zero correlation case.



increase in correlation resulting in an average of 14% decrease in tenant sorting and a 10% decrease in convergence time.

## C Hedonic approach to other building attributes

Table 5 mirrors the hedonic pricing approach used in Section 5.3, but for whether the listing offers an in-apartment washer and dryer. This option is valued by consumers but is also costly to building owners. Note that for this regression, for the predicted rental rate we do not use our original prediction, as this included the washer/dryer indicator in the model. For this rental prediction, we use the same extreme gradient boosting we use for the policy variable.

Table 5: Effects of having in-apartment washer/dryer on long term rental price in NYC.

	<i>Dependent variable:</i>		
	<i>log Rent</i>	$\Delta \log Rent$	$\Delta \log Rent$
	(1)	(2)	(3)
In-apartment washer/dryer (1/0)	0.509*** (0.008)	0.008** (0.004)	
$\Delta$ In-apartment washer/dryer			0.134*** (0.001)
Constant	7.919*** (0.004)	−0.040*** (0.002)	0.00001 (0.0003)
Observations	21,257	21,257	21,257
R <sup>2</sup>	0.174	0.0003	0.402
Adjusted R <sup>2</sup>	0.173	0.0002	0.402
Residual Std. Error (df = 21255)	0.473	0.225	0.039

*Notes:* This table reports the relationship between posted log monthly rental rates and whether the building has an in-apartment washer and dryer. In Column (1), the outcome is the rental rate the regressor is an indicator for an in-apartment washer/dryer. In Column (2), the outcome is the residualized log rental rate and the regressor for an in-apartment washer/dryer. In Column (3), the outcome is still the residualized log rental rate and the regressor is the residualized policy variable. The policy variable and the outcome is residualized with respect to the predictions from a extreme gradient boosting (Chen et al., 2015) using an extensive collection of controls, implementing the “double ML” estimate (Chernozhukov et al., 2016). Significance indicators:  $p \leq 0.10$  : \*,  $p \leq 0.05$  : \*\*, and  $p \leq .01$  : \*\*\*.

Table 6 also follows the hedonic pricing approach used in Section 5.3, but focuses on whether the listing allows for dogs. The decision of the building owner to allow or ban dogs is conceptually similar to home-sharing: allowing dogs has slight administrative costs for owners, but some consumers value this option, while dogs may impose substantial negative externalities to neighbors, in the form of barking, biting, allergens, and smells. Note that for this regression, for the predicted rental rate we do not use our original prediction, as this included the dogs indicator in the model. For this rental prediction, we use the same



extreme gradient boosting we use for the policy variable. As predicted by our model, we find a precisely estimated zero effect of allowing dogs on rental rates.

Table 6: Double ML estimate of effects of dog policy on long term rentals in NYC.

	<i>Dependent variable:</i>		
	$\log Rent$	$\Delta \log Rent$	$\Delta \log Rent$
	(1)	(2)	(3)
Building allows dogs (1/0)	0.287*** (0.009)	0.006 (0.004)	
$\Delta$ Building allows dogs			0.001 (0.001)
Constant	7.987*** (0.004)	-0.039*** (0.002)	0.00002 (0.0002)
Observations	21,257	21,257	21,257
R <sup>2</sup>	0.046	0.0001	0.00005
Adjusted R <sup>2</sup>	0.046	0.0001	0.00000
Residual Std. Error (df = 21255)	0.508	0.225	0.031

*Notes:* This table reports the relationship between posted log monthly rental rates and dogs policies. In Column (1), the outcome is the rental rate and the regressor is the dogs policy. In Column (2), the outcome is the residualized log rental rate and the regressor is the dogs policy. In Column (3), the outcome is still the residualized log rental rate and the regressor is the residualized dogs variable. The dogs policy variable is residualized with respect to the predictions from an extreme gradient boosting (Chen et al., 2015) using an extensive collection of controls, implementing the “double ML” estimate (Chernozhukov et al., 2016). Significance indicators:  $p \leq 0.10$  : \*,  $p \leq 0.05$  : \*\*, and  $p \leq .01$  : \*\*\*.