

The Tragedy of your Upstairs Neighbors: When is the Home-Sharing Externality Internalized?

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Abstract

A common critique of home-sharing platforms is that they enable hosts to impose costs on their neighbors. We consider four potential public policy responses that differ in whether the decision right to host is allocated to: (1) individual tenants, (2) building owners, (3) cities, and (4) a social planner. We find that (2) and (4) are equivalent, with (3) leading to too little hosting, and (1) to too much hosting. The efficiency of (2) depends on building owners being indifferent between allowing and banning home-sharing in their buildings. To assess this “no policy arbitrage” prediction, we constructed a dataset of NYC rental apartments listings. Although we do not observe building home-sharing policies, there are several “policy” attributes captured in the data, such as whether buildings allow subletting. Consistent with our prediction, we find that policy choices have no detectable effect on rental prices. Despite the attractiveness of the equilibrium of policy (2), tenants must “sort” across buildings, potentially at substantial cost. We explore this sorting with an agent-based model, and show how individual preferences and moving costs affect the equilibrium.

1 Introduction

The benefits of home-sharing platforms such as Airbnb, HomeAway, VRBO and Couch-Surfing are clear enough—underutilized resources are put to use, and consumer choice is expanded (Broda and Weinstein, 2004; Einav et al., 2016; Sundararajan, 2016; Horton and Zeckhauser, 2016). However, a criticism of these platforms’ business model is that “hosts”

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(those renting out properties) impose costs on their neighbors, particularly when long-term tenants are in close proximity. 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 her neighbors get the noise. This potential for “regulatory arbitrage” is a recurrent criticism of “sharing economy” platforms more generally (Malhotra and Alstyne, 2014; Slee, 2016), and was used in support of New York State’s recent legislation that dramatically increased fines for hosts found to be violating local housing regulations.¹

Motivated by the public policy question raised by home-sharing, we develop a model of the market for both home-sharing and long-term rentals, and examine the outcomes under different policy regimes. We examine the regimes where hosting decision rights are allocated to (1) individual tenants, (2) building owners, (3) cities, or (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 of the short-term rental market, and characterize the surplus of tenants (both hosting and non-hosting), building owners, and guests.

In our model, tenants consider only their financial pay-off from hosting: they host if the income they receive from home-sharing guests exceeds their individual hosting cost and are allowed to host. The income obtainable from home-share hosting is endogenous in the model, in that it depends on how many other tenants choose to host. Critically, would-be hosts do not consider the cost that their guests might impose on their fellow tenants.

We begin with the case where tenants are free to decide whether to become home-sharing hosts. This allocation of hosting decision rights mimics the state of affairs in many major US cities such as New York, where tenants have the right to sublet.² We then focus on the case where building owners set a uniform policy for their building, with building owners only taking into account the effect their policy choice has on their rental income from long-term tenants. Next, we consider what happens when cities set a policy: cities do not choose a blanket policy, but rather determine the quantity of hosting to allow. In practice, this quantity would be set through mechanisms such as taxation, rationed permits, and bureaucratic ordeals (Nichols and Zeckhauser, 1982). When setting the quantity, cities consider only the

¹The negative externality argument, along with the claim that home-sharing increases rents for long-term tenants, was recently cited in lawsuits against Airbnb hosts. “Airbnb sues over new law regulating New York rentals.”, the New York Times, accessed online on April 4, 2017 (<http://www.nytimes.com/2016/10/22/technology/new-york-passes-law-airbnb.html>).

²Though 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 April 4, 2017.

surplus of the residents of the city. Finally, we consider a social planner that can also set the city-level quantity of hosting, but who takes into account the surplus of both residents (i.e., tenants) and guests.

Our analysis shows that when individual tenants decide, there is too much hosting in equilibrium, in that the costs created by the marginal host exceed the benefits. Consequently, the equilibrium following 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, 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.³

The efficient quantity of hosting is obtained when the decision is left to building owners. This occurs despite the fact that owners only consider rents from long-term tenants in their building. The reason 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 policy imposes no direct cost on the building owner; if a premium could be charged for one policy or the other, profit-maximizing building owners would choose whatever policy offered the premium. With long-term rental rates equalized, the marginal long-term tenant—the one who is indifferent between buildings that allow home-share hosting 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. The indifference of the marginal tenant combined with the indifference of all building owners are the drivers of the efficiency result. Note that in this analysis, we do not have to explicitly model the surplus of the guests, as the marginal guest at the market-clearing short-term rental rate is the same as the private benefit to the host.

The driver of the efficiency result is the prediction that, in equilibrium, building owners cannot increase profits by switching policies. Given that home-sharing is still a nascent phenomenon, data from an existing rental market are unlikely to offer a compelling test of this

³The high tax rates on the hospitality industry indicate that cities benefit by reducing hosting supply. For example, see “The best and worst cities for travel taxes.”, the Wall Street Journal, accessed online on January 11th, 2017 (<http://www.wsj.com/articles/SB10000872396390443749204578048421344521076>). For a list of state lodging taxes, also see <http://www.ncsl.org/research/fiscal-policy/state-lodging-taxes.aspx>, accessed online January 11th, 2017.

prediction. However, there are other policies set by building owners that are conceptually similar. For example, the decision to allow subletting has slight administrative cost implications for the building owner, but a potentially large financial impact on would-be renters and current tenants alike, who have to deal with sublessees of unknown quality and type. Subletting is an interesting case as it is qualitative similar to home-sharing, albeit of longer duration. We use the building owner subletting decision as a case study to empirically assess our equilibrium argument.

Using a large dataset of rental listings in NYC, we find no evidence that the building owners’ subletting policy choice is correlated with the posted rental rate, conditional upon other apartment attributes that affect the price, such as location and size. Our analysis provides evidence that there is no building policy arbitrage opportunity in the NYC rental market, consistent with the key prediction of our model.

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.” Second, moving to a new apartment is costly. Because of these costs, some tenants may not be able to move to a building with their preferred home-sharing policy. This includes tenants who are willing to host but find themselves in buildings that do not allow hosting, as well as those who do not want to participate in the home-sharing economy but have to endure the cost of their neighbors’ hosting activities.

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.

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 then presents the equilibrium and welfare analysis results for the four different policy regimes. Section 4 explores how different assumptions would affect the results, and expands on the policy prescriptions of the model. Section 5 presents results from an analysis of the NYC rental market. Section 6 presents the agent-based model. Section 7 concludes with thoughts on directions for future research.

2 Related work

There is a growing literature on the offline effects of online platforms. Previous work has mostly focused on a particular industry, such as estimating the effect of the entry of Craigslist on the newspaper industry (Seamans and Zhu, 2013; Kroft and Pope, 2014). While these effects can be sizable, the waxing and waning of various industries is not a market failure. In contrast, other entrepreneurial or technical developments can create new social costs and social benefits, which in turn have implications for public policy.

Several recent papers report on online developments spilling onto the offline world. For example, 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. Supporting this view, 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. On a more positive note, 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 is significant, resulting in about a 4% decrease in the rate of motor vehicle homicides. [Burtch et al. \(2016\)](#) examine the effect of the entry of sharing economy platforms on entrepreneurial activity proxied the volume of crowdfunding campaigns, and find that lower quality campaigns are disproportionately negatively affected. Their results indicate a shift from likely unsuccessful and hence socially inefficient projects, to employment on sharing economy platforms.

In the cases of the entry of Craigslist and of car-sharing, externalities were created by online platforms. The policy import of these externalities is that they potentially create a market failure, in the sense that decentralized equilibrium allocations may be characterized by inefficiently small quantities if externalities are positive, or inefficiently large quantities if they are negative.

The externalities discussed above are called “technological” in the literature to distinguish them from pecuniary externalities ([Scitovsky, 1954](#)). Focusing on the home-sharing case, the technological externality describes the costs that hosts’ neighbors incur due to guests. The pecuniary externality pertains to the price and value changes brought about by the entry of the home-sharing option in a city, such as to hotels, property values, long-term rental rates, and so on ([Farronato and Fradkin, 2015](#); [Sheppard and Udell, 2016](#)). Although changes in price may be consequential, they can generally be thought of as having no efficiency implications: every transaction has a buyer and a seller, and changes in price have offsetting changes in utility for the demand and the supply sides of the market ([Greenwald and Stiglitz, 1986](#); [Holcombe and Sobel, 2001](#)).⁴ It is the technological externality that matters from an market efficiency standpoint, and which is our focus.⁵

2.1 Regulating home-sharing

The popularity of the home-sharing platforms has sparked an ongoing policy debate between Airbnb and regulators, in which both the technological and pecuniary externality arguments

⁴Pecuniary externalities are often the result of positive change. For example, [Sheppard and Udell \(2016\)](#) provide evidence that increases in Airbnb availability are associated with increased house values implying that the platform brings about pecuniary externalities, but also note that “A service that increases house prices (such as improved police protection, making better local schools available to residents, or providing more and better public parks) need not diminish community well-being.”

⁵Side payments could, in theory, solve the externality problem ([Coase, 1960](#)). However, Coasian bargaining seems unlikely in the home-sharing context, as it is not used in other cases of externalities in apartment buildings.

have been made. [Kaplan and Nadler \(2015\)](#) provide a timeline of the legal battle between the state of New York and Airbnb. [Jefferson-Jones \(2014\)](#) details the historical context behind home-sharing, pointing out that up to one third of nineteenth century American households took in boarders. She further argues that imposing proposed restrictions on home-sharing would be, from a legal standpoint, an unconstitutional taking, and proceeds to identify a number of possible regulatory solutions.

Home-sharing platforms have also garnered significant research attention, much of it with potential policy relevance. 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 higher quality pictures bring extra income to hosts as they may ameliorate uncertainty and trust issues. A summary of the different points of criticism specific to the home-sharing domain is given in [Table 1](#).

On the more positive side, in addition to expanding the supply of accommodation and offering hosts additional income ([Quattrone et al., 2016](#)), home-sharing is likely to have other benefits. Home-sharing listings have traits that traditional short-term accommodation options lack, such as that they are more “home-like” ([Guttentag, 2015](#)). Further, hosts often provide advice and recommendations that enable guests to experience “the local life,” something that hotels have long strived to emulate ([MacCannell, 1973](#)). On the other hand, hotels can provide services that peer-to-peer solutions are unable to match, such as breakfast, conference rooms, and an overall higher level of standardization and reliability of service ([Cusumano, 2015](#)). Despite this differentiation, the two options clearly compete. [Zervas et al. \(2014\)](#) exploit the natural experiment created by the introduction of Airbnb in Texas and show that a 10% increase in Airbnb supply results in a 0.35% drop in monthly

Table 1: Public policy issues of home-sharing

Issue	Previous work
Within-platform biases	Edelman and Luca (2014) ; Edelman et al. (2017)
Pecuniary externalities	Farronato and Fradkin (2015) ; Sheppard and Udell (2016)
Technological externalities	This paper

hotel revenues, with lower-priced accommodation options bearing a larger percentage of this decrease. [Farronato and Fradkin \(2015\)](#) develop a model where accommodations can be provided by either dedicated suppliers (hotels) or flexible suppliers (peers). Using Airbnb data, they estimate that a 10% increase in the number of available listings decreases hotel prices by 0.38%. They also find that consumer surplus increases for two reasons: greater product variety, and higher accommodation capacity, especially in periods of peak demand.

3 The markets for short- and long-term rentals under different policy regimes

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 their apartment.⁶ Let $N = (n + 1)A$. A welfare baseline throughout our analysis is the market where the home-sharing option is not available, in which case every tenant obtains the same utility u_0 , and tenant surplus is $U_0 = Nu_0$.

Let p be the market price for a home-sharing stay, which is also the benefit that a tenant who chooses to host obtains. Each tenant i offers one unit of supply and has an individual-specific hosting cost $c_i \geq 0$, meaning that she is willing to list her apartment on a home-sharing platform if $p \geq c_i$.⁷ Note that the hosting intensity is not endogenous in our model; we may think of tenants as deciding whether to home-share or not whenever they have the opportunity to do so, such as during vacations and weekends.⁸

The home-sharing market supply is the number of tenants that would list their apartments 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. the c_i of the marginal host. The demand by guests for home-sharing listings at price p is denoted by

⁶As will be clear later, we do not need to explicitly model rents.

⁷The heterogeneity in hosting costs captures individual-specific factors such as the willingness of an individual to rent out their personal space, the opportunity cost of the time allotted to hosting, or the desire for social interaction. The aforementioned factors may even result in negative hosting costs for some individuals, as exemplified by the popularity of the gratis home-sharing platform CouchSurfing (<http://www.couchsurfing.com>). We show in Section 4.5 that the results of our model are invariant to the addition of other building types. Note that assuming homogeneous apartments and a single market clearing price is not a substantive assumption. The assumption 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.

⁸See [Horton and Zeckhauser \(2016\)](#) for a model of the sharing economy with endogenous supply on the intensive margin.

$D(p)$ 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 the hotel and other accommodation offerings in the city.

Each listing generates a cost of c_E to every tenant other than the host living in the same building (we consider non-linear costs in Section 4.4, and find that the results derived in this section are invariant to different assumptions). We implicitly assume that tenants are inelastic with respect to living in the city. Further, we assume that all hosts have the same capacity which is all used, i.e. the short-term rental market clears.

We say that the negative externalities from tenant i listing on a home-sharing site are internalized 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 in a rental market: the negative externality of tenant i 's decision to host is internalized if the private benefit from her home-sharing listing—market price, minus the hosting cost—outweighs the social cost that the same listing brings about, i.e., the costs that the neighbors bear. If Equation 1 holds for every tenant that hosts, then we say that *the negative externality of home-sharing is internalized*.

3.1 The “tenants decide” (TD) regime

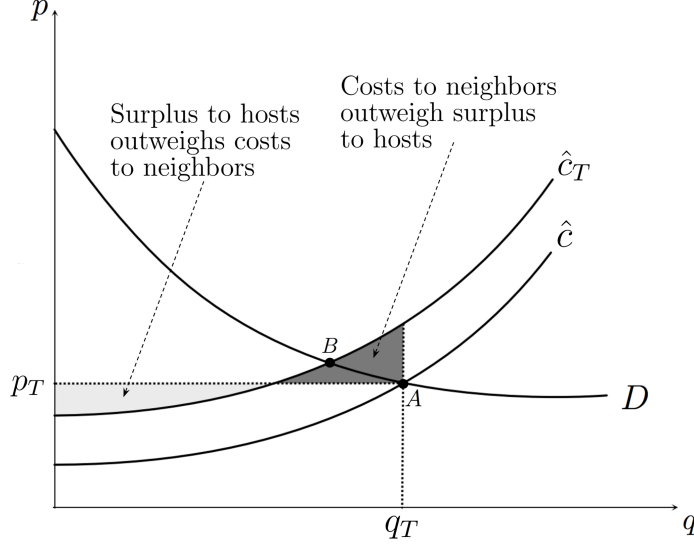
The first policy regime that we examine is the one where tenants are allowed to individually decide whether to host or not. In the TD equilibrium supply meets demand and long-term rents are equal across buildings. The equilibrium exists because of the monotonicity and continuity of the supply and demand 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 benefit they obtain.

Proposition 1. *The negative externality of home-sharing is not internalized in the equilibrium of the TD market.*

Proof. Since every tenant who wants to be a host is allowed, tenant i hosts if $p_T \geq c_i$. In equilibrium, let \hat{t} be the index of the marginal host, 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 $p_T < c_{\hat{t}} + nc_E$, hence Equation 1 does not hold for all tenants. \square

Proposition 1 shows that there exist tenants whose listings' externalities are not internalized;

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



those are exactly the tenants with hosting costs in the $[p_T - nc_E, p_T]$ interval, who host in equilibrium and violate the internalized externalities condition. 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 $u_0 - \frac{S(p_T)}{n+1}c_E$, which is less than the u_0 they would get in a market without the home-sharing option.

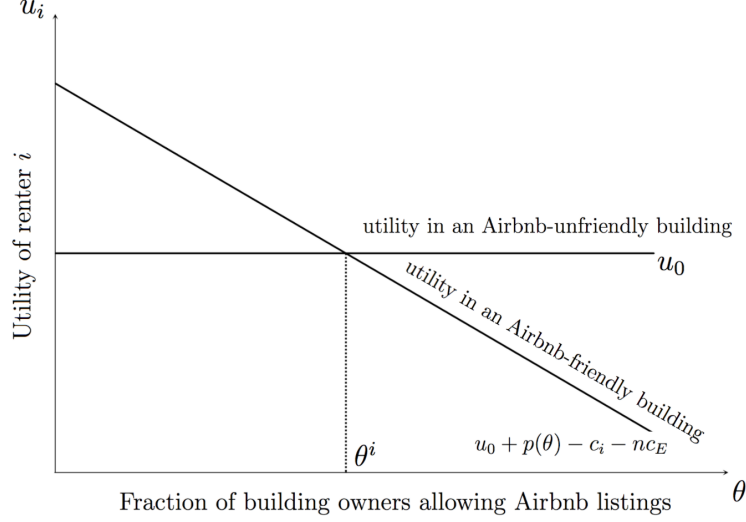
The TD equilibrium tenant surplus is given by

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

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 A indicates the TD equilibrium. The total cost curve of the marginal host is defined as $\hat{c}_T(q) = \hat{c}(q) + nc_E$ 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

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



that their profit from hosting outweighs their individual cost plus the negative externalities of their hosting. The 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. Note that even though the negative externalities of some home-sharing listings are not internalized 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.

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 offer their apartments up for home-sharing, or hosting is prohibited. We assume that building owners cannot make or take side-payments to and from tenants.⁹

Let θ denote the fraction of building owners that allow home-sharing, and θ_B be the building owner decides (BD) equilibrium fraction. We know that the fraction θ_B exists since $p'(\theta) < 0$ and the demand curve is downward sloping. To derive the BD equilibrium

⁹Coasian bargaining seems hard to implement in the home-sharing context (Coase, 1960). For a similar reason, we also assume that 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.

conditions we need to make two observations. First, in equilibrium tenants have moved into apartment buildings of the right “type,” and so hosts and non-hosts are sorted. Since everyone in a home-sharing-friendly building hosts, $q_B = \theta_B N$ is the equilibrium market supply of home-sharing units. Let $p_B = p(\theta_B)$ be the BD equilibrium price. Since building-specific policies can only restrict supply relative to the TD equilibrium, we immediately have $p_B \geq p_T$ and $q_B \leq q_T$. Second, the competitive equilibrium requires building owners to be indifferent between the two possible home-sharing policies, making long-term rents equal across buildings; if building owners could charge a premium for either allowing or prohibiting home-sharing in their building, then the market would not be in equilibrium.

It is worth examining here how the equilibrium quantity is obtained. The utility of tenants living in a building where home-sharing is prohibited is constant and 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 building (downward sloping curve). As the fraction of building owners that allow home-sharing increases, the price decreases and hence i ’s utility decreases. The tenant is indifferent between the two types of buildings when the fraction of home-sharing buildings is equal to θ^i such that $p(\theta^i) - c_i - nc_E = 0$.

Proposition 2. *In the BD equilibrium, the negative externality of home-sharing is internalized.*

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

The surplus of tenants in the BD equilibrium is

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

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. $U_B \geq U_0$

Proof. We have

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

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

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

Proposition 4. $U_B \geq U_T$

Proof. Subtracting the two quantities gives us

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

The first term is nonnegative as $p_B \geq p_T$. Since \hat{c} is increasing and $p_B = \hat{c}(q_B) + n_{cE}$ 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 is not internalized are exactly the tenants who 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 (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 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 consider a decision maker, such as a city-level regulatory body or the city mayor, who may designate the fraction of home-sharing-friendly buildings and wants to maximize tenant surplus. By adjusting the fraction of home-sharing buildings the decision maker effectively

controls the market supply. We refer to this case as the “city planner decides” (CD) policy regime.

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.*

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

Note that in the CD regime, there exist hosts whose value from hosting is greater than the corresponding marginal social cost but are prohibited from hosting. Our analysis still assumes that tenants have sorted to buildings with “appropriate” home-sharing policies.

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 $v_j - p$. The following proposition shows that the home-sharing quantity set by the social planner 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 $\hat{c}(q) + nc_E = \hat{v}(q)$. But this condition holds for $q = q_B$. Therefore, the BD equilibrium quantity maximizes social welfare, and our monotonicity assumptions imply that it is the unique optimal solution. \square

Proposition 6 illustrates the important advantage of building-specific policies; they not only lead to the negative externality of home-sharing being internalized, but are also optimal with respect to social welfare.

4 Discussion of model results

In the previous section we derived the market equilibria of our model under different home-sharing policy regimes. A summary of our results is provided in Table 2.

Our analysis reveals that the TD regime has two fundamental problems. First, the amount of hosting is inefficient, in that there are home-sharing listings with higher externality cost than the associated benefit. Second, users not participating in the home-sharing economy are always worse off compared to a market without the home-sharing option. These two problems are fully alleviated by allowing owners to decide on a building-specific policy; in the BD equilibrium the negative externalities of hosting are internalized, and only hosts incur externality costs because of the sorting property.¹⁰

City planners have incentive to decrease home-sharing supply (see Proposition 5), but would also require hosts and non-hosts to sort. Building-specific policies imbue the market with a mechanism that allows hosts and non-hosts to be sorted across different buildings, hence those tenants who do not participate in the home-sharing economy do not see their

¹⁰One could posit heterogeneous utility functions, where visitors impose lower costs to those tenants with low hosting costs. Since tenants with lower hosting costs are the ones who host in the BD equilibrium, our result are unaffected in this case.

Table 2: Summary of the results of Section 3.

Policy	q_{market}	Internalized Ext/ty	Tenant Surplus	Guest Surplus	Social Welfare
TD	High	No	Low	High	Low
BD	Medium	Yes	Good	Good	Optimal
CD	Low	Yes	Optimal	Low	Good

surplus decrease. This result also offers an important policy prescription: a central decision-maker who wishes to impose restrictions on the market quantity, should choose a cap on the number of home-sharing buildings rather than apartments. In other words, licenses should be sold to building owners rather than individuals.

As tenant surplus increases as the home-share quantity decreases from q_B to q_C , factors not captured in our model, and which may decrease home-sharing supply, can—up to a point—be beneficial for tenants. These factors, such as moving costs and status-quo biased building owners, are discussed in more detail in Section 6.

4.1 Supply elasticity and tenant surplus

The surplus that the home-sharing option creates on the tenants' side is directly linked to 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.

The increase in tenant surplus in the case of the BD equilibrium is also rooted in the heterogeneous hosting costs. Consider again the extreme case where $c_i = c_H$ for all tenants i , we get that $p_B = c_H + nc_E$ 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 (equivalently, if demand is perfectly elastic), home-sharing under the BD regime does not decrease tenant surplus.

4.2 Social welfare

The socially optimal policy coincides with the outcome of the BD equilibrium; pushing the home-sharing supply below q_B has a distortionary effect.¹¹ As lower supply implies higher prices, guest surplus strictly decreases. The deadweight loss is initially exclusively due to

¹¹This result is in congruence with previous work on regulation that restricts housing supply. 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.

guest-side losses, as fewer guests are able to rent on home-sharing and those who can are able to do so at higher prices. On the tenant side, aggregate surplus increases as q approaches q_C from above, but fewer tenants are able to reap the benefits of renting. Therefore, for $q \in [q_C, q_B]$ part of the social welfare is transferred from the guest to the tenant side of the market. For $q \in [0, q_C)$ both sides incur losses, though the surplus of either side never becomes negative, hence the social welfare does not drop below that of a market without the home-sharing option.

One consideration relevant to policy decisions at the city level but not captured in our model 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. As a result, the tenant-optimal fraction of home-sharing friendly buildings should be higher than θ_C . Let us consider the special case where guests have an individual-specific budget (b_i) to be allocated between accommodation (p) and city activities ($b_i - p$). Following through with the analysis of Section 3.4, we can then show that the BD equilibrium is optimal for the local economy.¹²

In addition to the positive implications specific to home-sharing, the BD regime is also a market-based policy approach, in that it does not require a central regulatory body. Delegating decision power to market agents constitutes an “information-light” policy, as it does not depend on information that is unlikely to be available to the regulator (Tirole et al., 2015), such as the externality costs or the demand and supply elasticities.

Illustrating these points, a regulatory approach we did not discuss is 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 could be hard to estimate. Furthermore, although we model externality costs as being homogeneous, if they were building-specific, such as due to differences in construction or layout, any one tax level would be inefficient. In contrast, sorting-based solutions would still be efficient even with this building-specific heterogeneity. Furthermore, market-based policies are robust to temporal changes in market quantities. We may rely on the market to dynamically respond to shocks on any of these parameters by readjusting itself, rather than requiring a periodic re-evaluation of policy decisions.¹³

¹²This result is made more important in light of previous Airbnb internal studies that have shown that Airbnb guests on average stay two days longer and spend 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 April 4, 2017.

¹³The NYC taxicab medallion supply problem is a conceptually similar case in point, where supply failed to meet the growth in market demand due to regulatory restrictions (Tullock, 1975).

4.3 Moving as an equilibrating mechanism

When building owners decide on a building-specific policy, we find that the externality problem is “fixed” by tenants moving to buildings where home-sharing is allowed. 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. The sorting solution “works” because the negative externality is contained within the building, and because building owners maximize profits. If city residents worked collectively to set a policy, they would choose to restrict home-sharing at the expense of guests from outside the city (see Proposition 5).

4.4 Alternative functional forms of the externality costs

Our analysis in Section 3 assumes that the externality cost of an additional host to neighboring tenants is constant. In the general case however, externality costs need not be linear.

We first examine the case where the externality cost of the marginal host is diminishing. Let the externality costs be any increasing concave function. The analysis of Section 3 only depends on the marginal host, and the fact that externalities are increasing in the number of hosts. It is then straightforward to show that all of the results carry through unchanged.

An alternative view of the problem posits that externality costs could be convex in the number of hosts in a building. For example, having only a few visitors in a building may go unnoticed by tenants, but a horde 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 we can show that the home-sharing externality is internalized in the BD equilibrium allocation, and the social welfare is positive and optimal amongst those allocations that utilize building-specific policies. However, building-specific policies are no longer the socially optimal policy. To see why, having the tenants who wish to participate in the home-sharing economy live in the same buildings results in high externality costs due to the convexity assumption. This problem can be overcome by allowing building owners to instead set a maximum number of apartments that are allowed to home-share. The resulting symmetric equilibrium is then socially optimal. Note however that, unlike in the building-specific policies case, those tenants who do not participate in the home-sharing economy will now have to incur externality costs.

4.5 Heterogeneity in supply

The model developed in Section 3 does not explicitly account for other types of residences such as individually-owned houses, condominiums, and co-ops, where decisions are made on the individual and board levels respectively. Since house owners do not require permission to home-share, introducing such types of buildings would potentially lead to a decrease in the equilibrium fraction θ_B of apartment buildings that allow home-sharing, but not to a decrease in the overall home-sharing supply. In the extreme case where all supply comes from such buildings, the market could be driven to a corner solution wherein no apartment building owner has incentive to allow home-sharing, as the price is not high enough for tenants to want to host. As externality costs are lower in individually-owned houses due to the absence of neighbors within the same building, social welfare would be higher. Co-ops and condominiums where the decision to allow home-sharing is made through majority, supermajority, or consensus votes are less likely to initially allow home-sharing, making them inframarginal. In equilibrium, they are however conceptually identical to apartment buildings, as condominium and co-op residents with strong incentives to home-share will move to buildings with appropriate policies. In both cases, the results of our model remain qualitatively unaffected.

5 Assessing the “no policy arbitrage” prediction

A key feature of our model is that building owners maximize their profits through their policy decisions, and hence they should, in equilibrium, be indifferent over policies that have no costs. In other words, building owners should not be able to increase their profits by choosing a different policy. The challenge in assessing this prediction is that we are not able to observe the counter-factual rental rate under a different policy for each building. Although the fundamental problem of causal inference is present in this context, it is not insurmountable, as finding a reasonable counter-factual in a thick rental market is possible.

The decision to allow or prohibit subletting offers a good test for our “no arbitrage” prediction, as it is conceptually similar to home-sharing. While subletting is of longer duration, setting a subletting policy has slight administrative cost implications for the building owner, but a potentially large financial impact on would-be renters and current tenants.

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. To the extent that the value of different amenities and dis-amenities is common in the market, and to the extent that there is more or less idiosyncratic variation in these attributes across different buildings, it should be possible account for these differences with a hedonic pricing model. Toward that end, 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 costless “policy” attributes, such as the building owner’s decision to allow for subletting.¹⁴

5.1 Data description

Our data set consists of 22,603 New York city apartment listings across 13,239 buildings collected in February 2017 from one of the leading online rental advertising platforms. Our web crawler pulls the information of every NYC rental listing on the web page, as well as all information contained in the listing’s respective building page. 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 97 attributes. Crucially, the attributes include information on whether the building allows for sublets, which we use to test our “no policy arbitrage” prediction.

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. Figure 3 provides 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.

5.2 Predictive model of rental rates

We construct a hedonic pricing model of what an apartment “should” rent, for given observable characteristics (excluding costless “policy” attributes). Toward that end we consider a

¹⁴Though NYC law mandates that subletting cannot be unreasonably refused, tenants must obtain approval from the property owner or landlord before subleasing their apartments. Allowing sublets can therefore be interpreted as the landlord signaling that she will not obstruct the process.

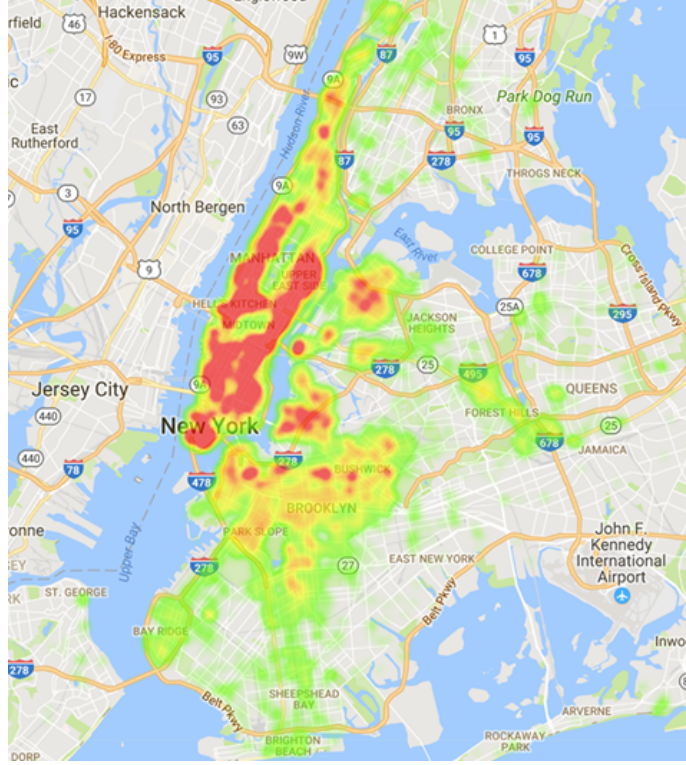


Figure 3: Heatmap of the spacial density of rentals

set of candidate machine learning techniques for our pricing model, including simple linear regression, linear 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.¹⁵

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

¹⁵We 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, accessed online on April 4, 2017.

Table 3: Definitions and summary statistics of key variables

Variable	Definition	Mean	SD.	Min	Max
price	Price of the rental	3,757.3	4,161.3	750	10,000
sqft	Square footage	1,023.9	542.6	100	12,173
bd	Number of bedrooms	1.63	1.04	0	7
age	Building age (years)	76.39	38.87	0	120
a_sublets	Building allows sublets	0.01	0.10	0	1

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.

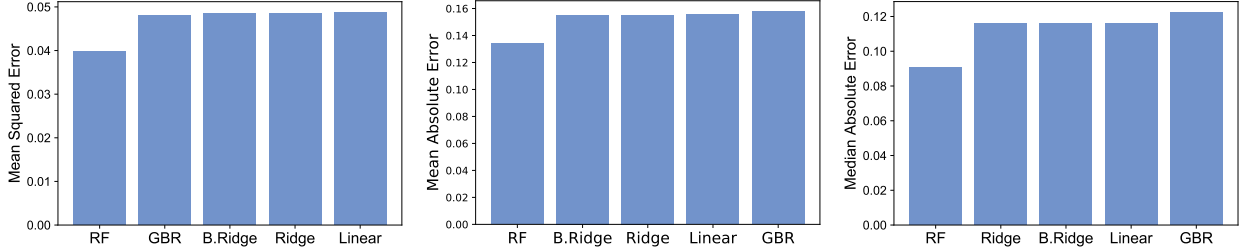


Figure 4: Out of sample predictive performance comparison.

The performance results are given in Figure 4. While all models achieve reasonably good performance, the random forest regressor consistently outperforms the other 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 utilize 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 by setting policy. We assess whether this prediction holds in our data set by regressing rental rates on policy decisions. We are assuming no market power and non-negotiable offers from owners, so that quoted rental rates are the actual market rates. Table 4 reports two regressions of the log price of a rental regressed on the subletting policy. In Column (1), no controls are included, while in Column (2), the predicted price for the apartment is included.

Table 4: Association between offered rental rate and building sublet policy for a selection of long term rentals in NYC.

	<i>Dependent variable:</i>	
	log(rental rate)	
	(1)	(2)
Building allows subletting	0.101*** (0.035)	−0.010 (0.015)
log(predicted monthly rent)		1.014*** (0.003)
Constant	8.038*** (0.004)	−0.147*** (0.027)
Observations	21,257	21,257
R ²	0.0004	0.813
Adjusted R ²	0.0004	0.813
Residual Std. Error	0.520 (df = 21255)	0.225 (df = 21254)
F Statistic	8.448*** (df = 1; 21255)	46,121.830*** (df = 2; 21254)

Notes: This table reports regressions where the outcome is the log monthly rental rate and the predictors are the building's subletting policy in column (1), and the subletting policy plus the predicted monthly rent in column (2). Significance indicators: $p \leq 0.10$: *, $p \leq 0.05$: **, and $p \leq .01$: ***.

In Column (1), 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, in Column (2), we see that this “subletting premium” was likely entirely due to omitted variables bias: when we include the prediction as a control, the effect of subletting is a precisely estimated zero. Further, note that the R-squared statistic is high, which suggests that the observable non-policy attributes explain a large part of the variation in rental prices. This is some evidence that owners cannot, by a simple policy change, charge higher rents, consistent with our “no policy arbitrage” prediction.

6 Reaching equilibrium

The favorable properties of the BD regime might be less attractive if we consider the process of reaching the new market equilibrium. A first point of criticism is that our analysis does not consider the process through which the system reaches equilibrium. A long line of game-theoretic research shows that systems comprising individually rational decision makers are not guaranteed to self-stabilize: agents may get trapped in cycles of suboptimal states, and reaching equilibrium may require a prohibitively large amount of time ([Arthur, 1999](#); [Marcet and Nicolini, 2003](#); [Arthur, 2006](#); [Daskalakis et al., 2009](#); [Galla and Farmer, 2013](#)).

In our case, tenant “types”—those that want to list their apartment on a home-sharing platform at the current market price 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—raise questions about the applicability of the building-specific policy approach to real-life markets. To assess the importance of these considerations, we develop an agent-based model that simulates the tenants’ moving process. We first use our computational model to examine whether the individually rational behavior of tenants leads to the BD equilibrium, as well as the amount of time and sorting necessary for that to be achieved.

We then extend our model to account for moving costs and within-building correlations between hosting costs, and examine their effect on the market outcome.

6.1 An agent-based model of the BD regime

We begin our description of the agent-based model by focusing on tenants. Analogously to the model of Section 3, tenants list their apartment on a home-sharing platform if their building’s policy allows for hosting, and the market price exceeds their personal hosting cost. Tenants also bear the costs generated by other hosts that live in the same building. When a tenant finds herself in a situation where she would be better off incurring the cost to move to a building with different home-sharing policy, she enters the pool of individuals who want to move away from their apartment.

Tenants only consider their present benefits from living in a home-sharing friendly apartment against not being able to host. Furthermore, tenants do not form expectations about others’ behavior as it is assumed that they are “small” relative to the market. The reason for these assumptions 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, can expect to spend the rest of their time in whatever state they move to.

Market clearing is brought about through both rent and home-sharing policy adjustments. We model building owners as adjusting 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, while the latter are more likely to convert to a home-sharing-friendly policy. It is worth mentioning here that tâtonnement requires both rent and policy adjustments. Disallowing rent adjustments would impose an equal rents constraint for different policies, whereas we want to examine whether this property is satisfied “organically” in the outcomes of our simulations. Similarly, assuming that home-sharing policy adjustments do not take place would impose a constant supply constraint on the building owner side.

Each instance of our computational model is carried out for a pre-specified number of 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 policy 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 policy 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 her 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 an upper bound on the number of periods is exceeded. The computational equilibrium is defined as the state in which no tenant wants to switch buildings, and therefore no owner wants to change their 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.

6.2 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.

The ABM employed in our simulations consists of 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 short term rentals 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 due to the discrete nature of the ABM.

6.3 Convergence to the BD equilibrium

The collective behavior of individually rational agents is not guaranteed to result in convergence to equilibrium. To estimate whether the market operating under the BD regime robustly reaches the equilibrium state, we now run a large number of simulations starting

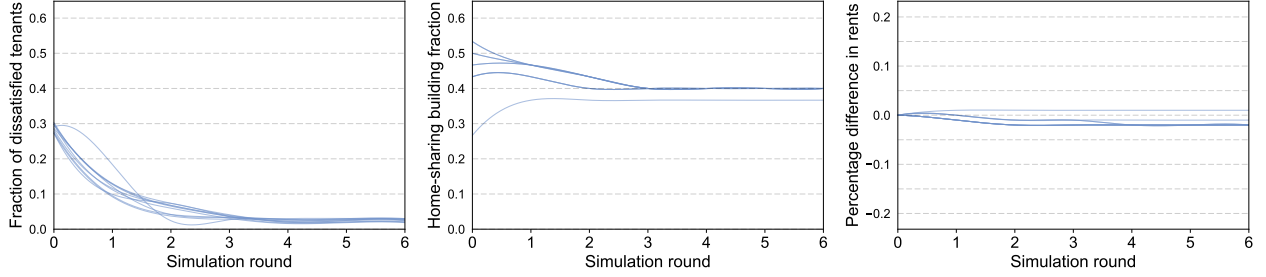


Figure 5: Fraction home-sharing-friendly buildings, fraction of tenants wanting to move, and percentage rent difference in each round for a set of example simulations.

from different initial conditions. We conduct 20,000 iterations with parameters chosen as described in Section 6.2. 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.

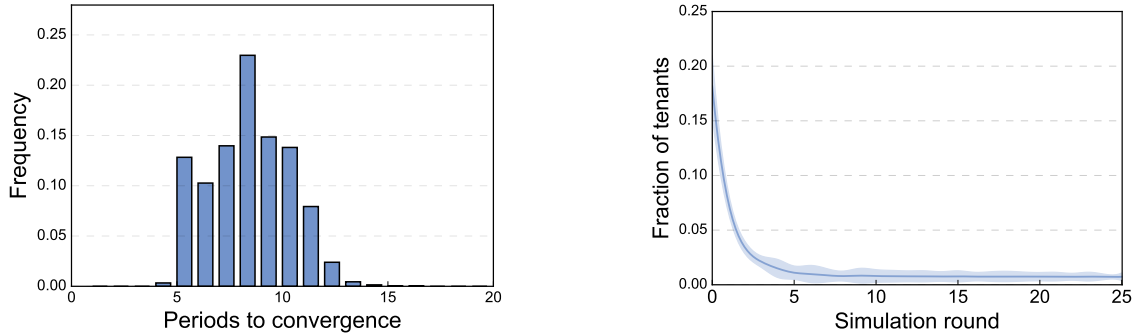


Figure 6: Distribution of equilibrium convergence times (left) and fraction of tenants who want to move as a function of time (right).

6.4 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; 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 different values that we tried not changing the results qualitatively. 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 can not change buildings.

To further examine the underlying effects, 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 almost barely affected, and 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. Amongst them, those tenants for whom the individual rationality condition is satisfied will list their apartment, 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.

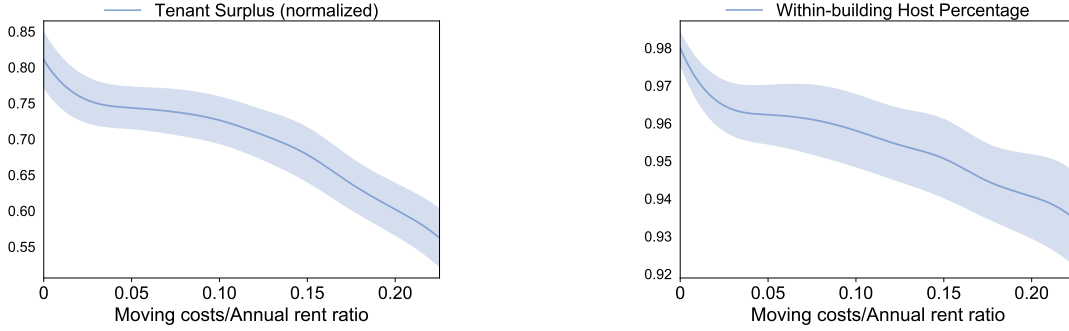


Figure 7: Tenant Surplus (left) and percentage of tenants living in home-sharing-friendly building that host (right) as a function of moving costs.

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

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

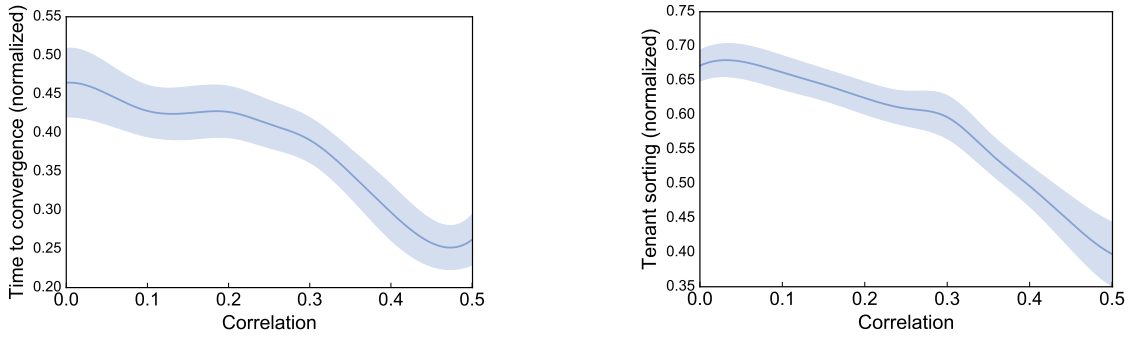
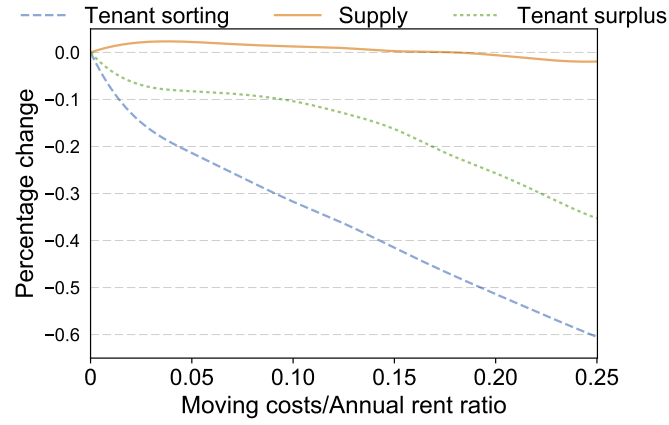
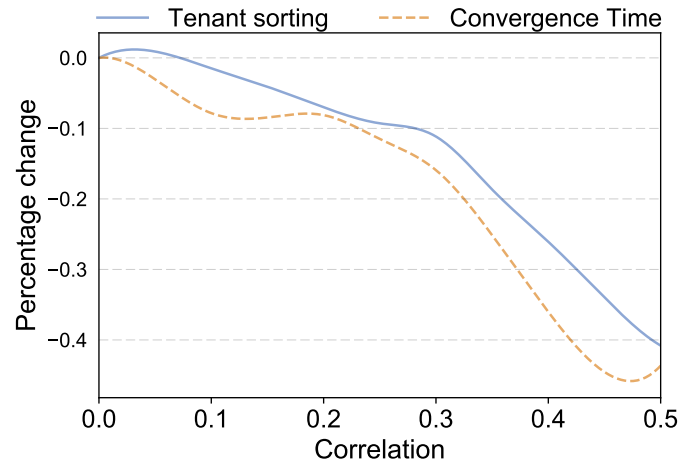


Figure 9: Time to convergence (left) and tenant sorting required to converge (right) as a function of within-building hosting cost correlation.

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



7 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 in a competitive long-term rental market terms are equalized between different types of buildings, and the marginal host’s individual benefit does not exceed the full cost of her 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 can not 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.

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 tenants 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.

References

- Arthur, W Brian**, “Complexity and the economy,” *Science*, 1999, *284* (5411), 107–109.
- , “Out-of-equilibrium economics and agent-based modeling,” *Handbook of Computational Economics*, 2006, *2*, 1551–1564.
- Bauer, Eric and Ron Kohavi**, “An empirical comparison of voting classification algorithms: Bagging, boosting, and variants,” *Machine Learning*, 1999, *36* (1-2), 105–139.
- Bonabeau, Eric**, “Agent-based modeling: Methods and techniques for simulating human systems,” *Proceedings of the National Academy of Sciences*, 2002, *99* (suppl 3), 7280–7287.
- Breiman, Leo**, “Random forests,” *Machine learning*, 2001, *45* (1), 5–32.
- Broda, Christian and David E Weinstein**, “Variety growth and world welfare,” *The American Economic Review*, 2004, *94* (2), 139–144.
- Burtch, Gordon, Seth Carnahan, and Brad Greenwood**, “Can you gig it? An empirical examination of the gig-economy and entrepreneurial activity,” *Working Paper*, 2016.
- Chan, Jason and Anindya Ghose**, “Internet’s dirty secret: Assessing the impact of online intermediaries on HIV transmission,” *MIS Quarterly*, 2014, *38* (4), 955–976.
- Chang, Ray M, Wonseok Oh, Alain Pinsonneault, and Dowan Kwon**, “A network perspective of digital competition in online advertising industries: A simulation-based approach,” *Information Systems Research*, 2010, *21* (3), 571–593.
- Coase, Ronald**, “The problem of social cost,” *Journal of Law & Economics*, 1960, *3*, 1–44.
- Cohen, Molly and Arun Sundararajan**, “Self-regulation and innovation in the peer-to-peer sharing economy,” *University of Chicago Law Review Dialogue*, 2015, *82*, 116.
- Cusumano, Michael A**, “How traditional firms must compete in the sharing economy,” *Communications of the ACM*, 2015, *58* (1), 32–34.
- Daskalakis, Constantinos, Paul W Goldberg, and Christos H Papadimitriou**, “The complexity of computing a Nash equilibrium,” *SIAM Journal on Computing*, 2009, *39* (1), 195–259.

- Dietterich, Thomas G**, “Ensemble methods in machine learning,” in “International workshop on multiple classifier systems” Springer 2000, pp. 1–15.
- Edelman, Benjamin G and Michael Luca**, “Digital discrimination: The case of Airbnb.com,” *Working Paper*, 2014.
- , —, and **Dan Svirsky**, “Racial discrimination in the sharing economy: Evidence from a field experiment,” *American Economic Journal: Applied Economics*, 2017, 9 (2), 1–22.
- Einav, Liran, Chiara Farronato, and Jonathan Levin**, “Peer-to-peer markets,” *Annual Review of Economics*, 2016, 8, 615–635.
- Farronato, Chiara and Andrey Fradkin**, “Market structure with the entry of peer-to-peer platforms: The case of hotels and Airbnb,” *Working Paper*, 2015.
- Galla, Tobias and J Doyne Farmer**, “Complex dynamics in learning complicated games,” *Proceedings of the National Academy of Sciences*, 2013, 110 (4), 1232–1236.
- Genuer, Robin, Jean-Michel Poggi, and Christine Tuleau-Malot**, “Variable selection using random forests,” *Pattern Recognition Letters*, 2010, 31 (14), 2225–2236.
- Glaeser, Edward L, Joseph Gyourko, and Raven Saks**, “Why is Manhattan so expensive? Regulation and the rise in housing prices,” *The Journal of Law and Economics*, 2005, 48 (2), 331–369.
- Greenwald, Bruce C and Joseph E Stiglitz**, “Externalities in economies with imperfect information and incomplete markets,” *Quarterly Journal of Economics*, 1986, 101 (2), 229–264.
- Greenwood, Brad N and Ritu Agarwal**, “Matching platforms and HIV incidence: An empirical investigation of race, gender, and socioeconomic status,” *Management Science*, 2016, 62 (8), 2281–2303.
- and **Sunil Wattal**, “Show me the way to go home: An empirical investigation of ride-sharing and alcohol-related motor vehicle fatalities,” *MIS Quarterly*, 2017, 41 (1).
- Guttentag, Daniel**, “Airbnb: Disruptive innovation and the rise of an informal tourism accommodation sector,” *Current Issues in Tourism*, 2015, 18 (12), 1192–1217.

- Holcombe, Randall G and Russell S Sobel**, “Public policy toward pecuniary externalities,” *Public Finance Review*, 2001, 29 (4), 304–325.
- Horton, John J and Richard J Zeckhauser**, “Owning, using and renting: Some simple economics of the ‘Sharing Economy’,” *Working Paper*, 2016.
- Jackson, Joshua Conrad, David G Rand, Kevin Lewis, Michael I Norton, and Kurt Gray**, “Agent based modeling: A guide for social psychologists,” *Working Paper*, 2016.
- Jefferson-Jones, Jamila**, “Airbnb and the housing segment of the modern sharing economy: Are short-term rental restrictions an unconstitutional taking,” *Hastings Constitutional Law Quarterly*, 2014, 42, 557.
- Kaplan, Roberta A and Michael L Nadler**, “Airbnb: A case study in occupancy regulation and taxation,” *University of Chicago Law Review Dialogue*, 2015, 82, 103.
- Kroft, Kory and Devin G Pope**, “Does online search crowd out traditional search and improve matching efficiency? Evidence from Craigslist,” *Journal of Labor Economics*, 2014, 32 (2), 259–303.
- MacCannell, Dean**, “Staged authenticity: Arrangements of social space in tourist settings,” *American Journal of Sociology*, 1973, 79 (3), 589–603.
- Malhotra, Arvind and Marshall Van Alstyne**, “The dark side of the sharing economy ... and how to lighten it,” *Communications of the ACM*, 2014, 57 (11), 24–27.
- Marcet, Albert and Juan P Nicolini**, “Recurrent hyperinflations and learning,” *The American Economic Review*, 2003, 93 (5), 1476–1498.
- Nichols, Albert L and Richard J Zeckhauser**, “Targeting transfers through restrictions on recipients,” *The American Economic Review*, 1982, 72 (2), 372–377.
- Oh, Wonseok, Jae Yun Moon, Jungpul Hahn, and Kim Taekyung**, “Research Note: Leader influence on sustained participation in online collaborative work communities: A simulation-based approach,” *Information Systems Research*, 2016, 27 (2), 383–402.
- Quattrone, Giovanni, Davide Proserpio, Daniele Quercia, Licia Capra, and Mirco Musolesi**, “Who benefits from the sharing economy of Airbnb?,” in “Proceedings of the 25th International Conference on World Wide Web” 2016, pp. 1385–1394.

- Rahmandad, Hazhir and John Sterman**, “Heterogeneity and network structure in the dynamics of diffusion: Comparing agent-based and differential equation models,” *Management Science*, 2008, *54* (5), 998–1014.
- Schelling, Thomas C**, “Dynamic models of segregation,” *Journal of Mathematical Sociology*, 1971, *1* (2), 143–186.
- Scitovsky, Tibor**, “Two concepts of external economies,” *The Journal of Political Economy*, 1954, *62* (2), 143–151.
- Seamans, Robert and Feng Zhu**, “Responses to entry in multi-sided markets: The impact of Craigslist on local newspapers,” *Management Science*, 2013, *60* (2), 476–493.
- Sheppard, Stephen and Andrew Udell**, “Do Airbnb properties affect house prices?,” *Working Paper*, 2016.
- Slee, Tom**, *What’s yours is mine: Against the sharing economy*, OR Books, 2016.
- Sundararajan, Arun**, *The sharing economy: The end of employment and the rise of crowd-based capitalism*, MIT Press, 2016.
- Tebbens, Radboud J Duintjer and Kimberly M Thompson**, “Priority shifting and the dynamics of managing eradicable infectious diseases,” *Management Science*, 2009, *55* (4), 650–663.
- Tesfatsion, Leigh and Kenneth L Judd**, *Handbook of Computational Economics: Agent-based Computational Economics*, Vol. 2, Elsevier, 2006.
- Tiebout, Charles M**, “A pure theory of local expenditures,” *The Journal of Political Economy*, 1956, *64* (5).
- Tirole, Jean et al.**, “Market failures and public policy,” *The American Economic Review*, 2015, *105* (6), 1665–82.
- Tullock, Gordon**, “The transitional gains trap,” *The Bell Journal of Economics*, 1975, pp. 671–678.
- Zervas, Georgios, Davide Proserpio, and John W Byers**, “The rise of the sharing economy: Estimating the impact of Airbnb on the hotel industry,” *Journal of Marketing Research*, 2014.

Zhang, Shunyuan, Dokyun Lee, Param Vir Singh, and Kannan Srinivasan, “How much is an image worth? An empirical Analysis of property’s image aesthetic quality on demand at Airbnb,” in “International Conference on Information Systems (ICIS)” 2016.