

Search Frictions and the Design of Online Marketplaces

Job Market Paper: Preliminary

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Search occurs in many markets but its importance for economic outcomes has been difficult to quantify because of a lack of data. I use data on browsing, communications, and transactions from Airbnb, a large and growing online marketplace for accommodations, to show that search frictions are important and that appropriate policies can reduce search frictions. Search on Airbnb occurs when potential guests browse the website and send inquiries to hosts about rooms to stay in. Only 15% of inquiries and 48% of searchers who send inquiries for a potential trip transact on Airbnb. I explain matching outcomes with an equilibrium model that includes directed search, limited consideration sets and incomplete information about which hosts are willing to transact. Search frictions in the model combine to reduce transaction probabilities by 21% and host revenue by \$62 per searcher compared to outcomes achievable by a fully informed social planner who maximizes consumer surplus. Policies that improve the set of options searchers consider increase matching rates and consumer surplus. The benefit of search policies depends on the tightness of the market and the share of utility that the marketplace can explain using observable data.

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1. Introduction

People search for jobs, houses, spouses and many other important goods and services. The purpose of search is to obtain information about the quality of a good and the seller's willingness to transact. The searcher is only able to obtain information about a limited set of options because search is costly. The uncoordinated searches of many individuals can, for a variety of theoretical reasons, result in suboptimal equilibrium outcomes (search frictions). There is little direct evidence on the presence and costs of search frictions because search behavior is typically unobserved. At the same time, the rise of the Internet has reshaped the process of search and presumably reduced frictions in most markets.

I demonstrate how to use data on online search, communications and transactions to study a matching model with rich heterogeneity and multiple frictions. I show that search frictions still exist online, that they are costly and that marketplace policies can reduce those frictions.

The setting of this paper is Airbnb, a large and rapidly growing online marketplace for accommodations. Search on Airbnb fails to result in a transaction for a variety of reasons, including rejection of offers by sellers, incomplete consideration sets and a lack of suitable options. The importance of these mechanisms for match rates, revenue and consumer surplus is determined in equilibrium and has implications for platform policy.

I build a model in which search failures arise in equilibrium out of decisions by guests (searchers) and hosts (sellers) in the marketplace. In the model, searchers face incomplete information about whether a host is willing to transact with them and about the characteristics of all listings in the marketplace. Sellers decide whom to allow to stay in their property. The model allows me to quantify the relative importance of the mechanisms by which search frictions arise. Imperfect knowledge by searchers about who is willing to transact results in 10% fewer bookings and \$33 less revenue. Incomplete consideration sets result in 12% fewer bookings and \$46 less revenue. Lastly, sellers in the market sometimes agree to transact too early, leading subsequent higher value guests with worse options and lowering overall consumer surplus.

Models of market equilibrium are useful for marketplaces because the parameter space of policies is too large to explore with experimentation, because the effect of policies depends on market conditions and because estimated treatment effects from searcher level experiments are biased. I use the model to simulate counterfactual alternative search rankings, search propensities and levels of market tightness. Policies designed to change what is displayed in search can reduce frictions but those policies’ efficacy depends on the tightness of the market and the degree to which observables explain searcher and seller behavior. Furthermore, experiments at a searcher level overstate the equilibrium effect of a policy by over 50% due to externalities that searchers impose on each other.

The data used for this paper comes from Airbnb’s internal databases which track website browsing, communications and transactions. Airbnb (“Air-bed and Breakfast”) provides a platform for individuals to temporarily rent out an unused room or property to travelers.¹ In 2012, Airbnb accommodated over 3 million guests and listed over 180 thousand new listings.

Search on Airbnb begins when potential guests submit their trip details, which consist of a city, dates of stay and number of guests into a search engine. The search engine returns a set of listings in that city. If a listed option is appealing, the searcher sends an inquiry to the host of that listing. An inquiry typically asks the host whether the place is available and additional details about the place.

The set of properties seen by a given searcher is generated according to a weighted sampling procedure similar to [Dinerstein et al. \(2013\)](#). Conditional on a consideration set, searchers choose which property to send an inquiry to according to a discrete choice model (fully described in [subsection 3.2](#)). The searcher’s utility for a particular listing is a function of characteristics such as location, size and price. As in [Hitsch, Hortacsu and Ariely \(2010\)](#), the demand of searchers also depends on the match between searcher and listing characteristics. For example, searchers for trips with more guests have a higher preference for bigger properties. Lastly, depending on their characteristics, searchers

¹Similar marketplaces to Airbnb exist in industries such as contract labor (Odesk, Freelancer and Taskrabbitt), dating (Okcupid, Match.com and Eharmony), craft goods (Etsy and Ebay) and private transportation (Uber and Lyft).

have varied propensities to send multiple inquiries both initially and after a first round of search.

The host can respond to an inquiry by stating that the place is available, unavailable or by asking a follow up question. The host’s response is indicative of a complex decision to let a stranger stay at his place which blends issues of trust, availability, hassle and waiting for a better offer.

A key advantage of my dataset is that I can classify the text of a host’s response as a rejection or a non-rejection. This type of information is rare in search markets² but is crucial in interpreting whether a transaction failed due to the searcher or the seller. Rejection by hosts happens in 48% of all inquiries. I decompose the causes of rejections into three distinct categories: congestion, screening and “stale” vacancies. Congestion occurs when a searcher sends an inquiry to a listing that is about to transact with another searcher. Screening occurs when a host rejects a searcher because of the searcher’s personal or trip characteristics. Stale vacancies occur when a listing which is not actually available for a given week is nonetheless visible in search and contacted. In my dataset, over 20% of communications are screened, over 21% are sent to stale vacancies and less than 6% are affected by congestion. This result is interesting because much of the theoretical literature on directed search such as [Kircher \(2009\)](#), [Albrecht, Gautier and Vroman \(2006\)](#) and [Burdett, Shi and Wright \(2001\)](#) has focused on congestion as the main cause of rejection in search markets.³

In [section 5](#), I combine the search and screening models into a simulation of how the market clears over time. Searchers enter Airbnb looking for a place in a given week and market and conduct search according to the directed search model. Inquiries sent by the searchers are either accepted or rejected by hosts for the reasons outlined above. If a guest chooses to book a property, the transaction takes some time to clear, which is calibrated to the data. Additional searchers enter the market sequentially and send inquiries. The actions of searchers and hosts then generate the aggregate matching and

²In the labor market, for example, analogous data would contain resume submissions, interview invitations and interview outcomes at a searcher-vacancy level.

³Stale vacancies are similar to congestion from the perspective of the searcher but are generated by a different seller behavior.

rejection probabilities. I do not calibrate the model to target booking rates, contact rates and the frequency of rejection. Nonetheless, the simulation outcomes come within several percentage points of these moments. Further, model outcomes closely match the empirical shares of rejections due to congestion, screening and stale vacancies.

In the model, search frictions arise because searchers and hosts do not have complete information and because search is costly. I solve for the ex-post consumer surplus maximizing allocation conditional on both host and guest preferences and find that there would be 21% more matches and \$62 greater host revenue per searcher than in the baseline scenario.

The policy space for marketplaces encompasses search ranking, information disclosure, new matching mechanisms and explicit rules that affect the behavior of agents. Furthermore, platforms have the ability to shape the number and types of agents that interact on the platform through marketing and other user acquisition efforts. Section 5.4 describes the results of counterfactual policy experiments aimed at reducing frictions.

The approach taken here differs from the aggregate matching function approach used in many papers on search markets ([Petrongolo and Pissarides \(2001\)](#)). In aggregate matching functions the number of potential matches given a set of searchers and vacancies is determined by a matching technology which is not, in general, based on micro-foundations. The lack of micro-foundations makes aggregate functions unsuitable for studying policies, technologies and changes in market structure which affect the matching process. For example, [Lagos \(2000\)](#) derives a micro-founded aggregate matching function for the taxi-cab market and shows that its shape will be sensitive to policy. Policies in my model affect the relative importance of searchers and sellers in the matching function and have varying effects that depend on the tightness of the market. Further, I find that aggregate matching on Airbnb has increasing returns to scale.

Lastly, I consider how a platform should design experiments to determine the effectiveness of policy changes. Most Internet companies evaluate policies such as design changes by randomly assigning some searchers to see the policy. However, in markets with scarcity, the behavior of some agents has externalities on other agents. Therefore,

the true effect of a policy on a market outcome is different from the estimated treatment effect using a searcher level randomization strategy. In [subsection 5.6](#), I implement an experiment in my model and show that inference from an evenly split experiment overstates the market level effect of a policy by over 50%. I then discuss how to combine experimental results with a model to obtain better inference about the equilibrium effects of policies.

2. Data and Setting

2.1. Airbnb Background

Airbnb describes itself as a trusted community marketplace for people to list, discover, and book unique accommodations around the world — online or from a mobile phone.⁴ It is a fast-growing startup that was founded in 2008 and that has more than doubled the number of guests accommodated in every year of its operation. In 2012, Airbnb accommodated over 3 million guests and listed over 180 thousand new listings. Airbnb operates in more than 34 thousand cities worldwide and is available in more than 30 languages.

Airbnb has created a market for a previously rare transaction: the rental of an apartment or part of an apartment in a city for a short term stay by a stranger.⁵ The reason why these transactions were not occurring previously was because there were large costs to securely exchanging money, communicating with strangers and evaluating a stranger's trustworthiness.

Airbnb's was one of the first platforms to provide a set of tools and services which strangers can use for arranging stays in a relatively risk-free manner. Airbnb's hosts are typically non-professionals, over 80% of whom list just a single room or property and use their Airbnb income to supplant other income sources.

In a typical Airbnb transaction, guests and hosts have the ability to inconvenience

⁴<https://www.Airbnb.com/home/press>

⁵Couchsurfing, a large travel based social network started in 2003 facilitates similar stays but without monetary exchange. Craigslist has listed sublets and short-term vacation rentals since the late 1990's. Vacation rentals by owners in tourist towns have also existed for a long time.

each other by being disruptive or by lying about the characteristics of a room or trip. Communication occurs on the platform both in order to preemptively prevent bad interactions and to cement the details of the trip such as the key exchange or check-in times. Importantly, hosts are allowed to deny potential guests for any reason. Guests and hosts have the opportunity to review each other after the trip. The stock of reviews on the site provides important information for subsequent users (Pallais (2013)). Airbnb also verifies photos, locations and contact information of listings. These services further reduce the potential of lemons to be successful in the marketplace (Lewis (2011)).

The payments mechanism on Airbnb is a big innovation compared to previous platforms for accommodations such as Craigslist, where payments were handled offline. Airbnb holds payments in escrow until the stay has happened in order to prevent fraud. The escrow service allows Airbnb to resolve disputes between guests and hosts and to enforce the payment of security deposits and cancellation penalties. Airbnb also offers a one million dollar insurance guarantee against major damage done to properties by guests for a subset of major markets. The marketplace provides users a way to verify their identity through both online social networks (Facebook, LinkedIn, and Twitter) and offline ID verification using a passport or driver's license.⁶ Airbnb generates revenue by taking a percentage fee of every transaction that takes place on the platform. Hosts typically have a 3% fee while guests have a variable fee that ranges between 6% and 12% depending on the details of the transaction.

The platform helps hosts manage pricing and availability calendars. Listings can be unavailable for two reasons: they can be booked or the host does not want any guests for a given set of dates. If a booking occurs on the site, a host's calendar is automatically blocked off and the host is no longer visible to searchers for those dates. However, if the host is unwilling to have guests, the burden is on the host to manually update the listing's calendar. Hosts might not update their calendars because they are uncertain about future availability, want to see potential guests or face updating costs. As a result, potential guests send inquiries to seemingly available listings which are actually off the

⁶For more details see: <http://blog.airbnb.com/introducing-airbnb-verified-id/>

market.

2.2. The Booking Process

There is a series of discrete steps in the process of booking a room.

1. Structured Search ([Figure 1](#)) - Searchers enter the travel dates, number of guests and location into a search engine and receive a list of results. The search can then be refined using filters, a map and sorting.

2. Investigation ([Figure 2](#) and [Figure 3](#)) - The searcher clicks on individual property and host pages to learn about property characteristics such as amenities, reviews, responsiveness and house rules.

3. Message ([Figure 4](#)) - The guest sends messages to hosts inquiring about room details and availability. A host can respond by saying that the room is unavailable, that the room is available or by asking a follow up question. The host might also not respond at all. A guest may send multiple inquiries both initially and after receiving some responses.

4. Booking - If a transaction is agreed upon in messaging, the guest can click the “Book It” button. If the host accepts, the money is charged and taken in escrow by the platform. Some transactions occur without a messaging step if the host allows the “Instant Book” or “Book It” features.

5. Stay - After a trip is booked, there is further communication needed to exchange keys and coordinate the details of the trip. Either side can cancel with a pre-specified penalty rate.

At each of the above steps, the potential transaction may fail. The probability of failure and the cost of search can vary with the type of stay that a guest is looking for. For example, longer stays require a lot more commitment by both sides of the transaction.

2.3. Data Description

My datasets are composed of the full set of inquiries and transactions that occurred in major US markets on Airbnb. For tractability, subsamples of the entire set of the data

are used in the various sections of the paper. In the descriptive evidence section I narrow my data set to comprise all contacts to US markets which occurred for trips starting in 2012 while in the model sections I focus on one market and a narrower set of dates. For each communication I observe the time a message was sent, who sent the message, who received the message and the content of the message. Each set of messages between a guest and a host is aggregated into a “thread” that contains information about trip dates, the number of guests and the room of inquiry.

I group each set of communications in my dataset by search spell (alternatively referred to as a trip attempt). A search spell is defined as a set of inquiries and transactions pertaining to a stay by a specific guest in a specific market and in a specific week of the start of the trip. I also observe a large set of characteristics about users and properties. For each property I observe the standard listed price, number of reviews, review score, location, number of pictures and other characteristics at any point in time. For each user, I observe the number of reviews, the number of pictures, demographics and other characteristics.

There are limitations to my dataset. I do not observe the date specific prices in the market. For example, hosts might change their pricing for specific weeks. In practice dynamic pricing behavior rarely occurs so that the listed price is a good measure of the actual price that searchers face.⁷ Furthermore, hosts might practice dynamic pricing by changing the price for a given week over time. I also do not have a perfect measure of property availability. I only observe the time of the last availability update. A property might be initially available for a given week, then become unavailable and then available again. I treat that property as always being available. Lastly, some of the observed characteristics such as age and gender are either missing or filled out inaccurately by users.

⁷I plan to discuss of pricing and bargaining in a future Appendix

2.4. Identifying Host Rejections

The meaning of textual data must be derived before the data is useful for empirical work in economics. There is no unambiguous classification of communications between searchers and sellers into an ontology because communication is ambiguous and serves many purposes. I identify the most important bit of information: whether a host's response to a guest indicates that the host is interested in the transaction. For example, the response "Sorry, the place is unavailable." should be classified as a rejection whereas the response "Yes it is available. Go ahead and book it" should be classified as a non-rejection.

I use several approaches to determine whether a response is a rejection. If a contact led to a booking or was labeled as accepted by the host then it is classified as "not rejected". If a response was labeled by the host as a rejection or if there was no response within the week after the inquiry then the contact is classified as a rejection.

If the response does not fit into any of the above categories, a text classifier is applied to the first (or in some cases second) response by a host to a guest. I use a common technique in natural language processing called a regularized logistic regression to classify text (see [Appendix A](#) for details). I combine the text classification with cases when the response is discernible through other methods. If a response is classified as having a foreign language then that contact is not used in the analysis.

In total, 49% of all inquiries were rejected. Of all contacts classified as rejections, 37% were cases in which a host did not respond, 30% were host classified rejections after an inquiry and 32% used the classifier.

2.5. Descriptive Evidence about Rejections

Communication on Airbnb frequently fails to result in a transaction. For US Markets in 2012, just 15% of inquiries and 48% of search spells (a set of inquiries pertaining to a given trip) transact. In this section, I provide evidence that matching frictions are indeed large and prevalent across Airbnb and that there are likely to be unrealized matches because guests tend to leave after a rejection.

A searcher chooses how intensely to search in a given search spell. An inquiry is considered simultaneous if it is sent within the first two hours of the first inquiry being sent. Any search that does not occur soon after the first inquiry is considered sequential because the host's response or lack thereof provides additional information to the searcher. Of all search attempts, 70% begin with only one initial inquiry.

Figure 9 displays the set of potential outcomes for those search spells. Conditional on the initial inquiry not being rejected, a search spell results in a transaction 65% of the time. However, if the initial inquiry is rejected, searchers leave Airbnb without an additional inquiry 62% of the time. Even if the searcher partakes in sequential search by sending additional inquiries, she only books 41% of the time.

The above analysis does not control for guest, trip and market characteristics. Table 1 shows the results of a linear probability model where an indicator for whether an inquiry for successful booking is regressed on whether the first inquiry was rejected. Rejection is associated with a 50% decrease in the probability of eventually booking and stays similar in magnitude after adding controls for market, week and trip characteristics. My model explains how this effect emerges in equilibrium due to the timing of inquires and the preferences of guests and hosts.

3. Search Behavior

3.1. Consideration Set Formation

Potential guests on Airbnb search for a place to stay by entering a location, a set of dates and the number of guests. For each query, the search engine returns a set of 21 listings according to a search algorithm, which uses the distance of the listing from the query parameters and listing characteristics as features. The guest interacts with the search engine using a combination of additional search terms, filters, maps and sorting. Searcher don't see all listings because there are typically thousands of available listings for major US markets.. Some properties are more likely to be sampled due to the search algorithm

⁷Searches in October of 2013 for stays in New York, Seattle, San Diego, Austin, Los Angeles, Chicago, Miami and many other cities resulted in more than 1000 search results.

and the preferences of searchers. The probability with which a listing is sampled also depends on what other listings are still visible in the market. In this section, I describe a simple empirical model that captures these aspects of consideration set formation.

Searchers browse a random subset of all visible listings in the market which is drawn according to a set of sampling weights. The sampling weight of each listing, ω_h , is determined according to the following transformation ([Dinerstein et al. \(2013\)](#)):

$$\omega_h = e^{\gamma \frac{w_h - w_{min}}{sd(w_h)}} \quad (1)$$

where w_h represents the propensity of a listing, h , to be seen based on observed characteristics, w_{min} is the minimum of w_h over all listings and γ is a parameter that governs the degree to which the consideration sets of searchers are correlated with each other.

w_h is determined according to the following estimation equation.

$$h_{seen,g} = 1(X'_h\mu + \gamma_g + \epsilon_{gh} > 0) \quad (2)$$

where h denotes a listing, $seen$ indicates whether the listing was seen by searcher g , X_h are listing characteristics, γ_g is a guest specific fixed effect and ϵ_{gh} is a logit error term. Let w_h be the predicted logit index: $X'_h\hat{\mu}$ resulting from the above regression.

The estimating sample for [Equation 2](#) is a random set of searchers in a large U.S. city (referred to as City X from now on). Each listing which could have been seen by a searcher is matched to its characteristics at the time of the search. The procedure for computing sampling weights consists of two steps. In the first step, I estimate a conditional logistic regression that predicts which listings are seen by searchers out of all the listings that could have been seen using listing characteristics.

The total number of properties seen by a particular searcher is drawn according to an exponential distribution with mean equal to the mean number of listings seen in the demand estimation sample. For the purpose of the rest of the simulation, I assume that the sampling probabilities are independent of preferences. In practice, the consid-

⁷See [Appendix B](#) for estimates.

eration set might actually be correlated with preferences. I discuss how the assumption of consideration sets that are uncorrelated with preferences affect the model results in [section 5](#).

Even though I can see the code that generates the search algorithm I cannot exactly recreate the data generating process because the search ranking is determined according to a non-reproducible set of transformations of listing specific variables which are weighed against query specific parameters such as the exact location at which the map is centered. Furthermore, the consideration set is formed by a searcher interacting with the algorithm. Therefore, the exact search algorithm is not sufficient for modeling consideration set formation. This is a general problem for analyzing search data from the Internet.

3.2. Directed Search and Preferences

The guest's choice of which property to contact from a given consideration set is determined by a random utility discrete choice model. The property characteristics visible in search results are price, location, number of reviews, property type and any common social connections between the guest and host. Other features, which are visible upon further inspection, include additional pictures of the property, a free form textual description of the property, the text of listing reviews, a description of the host, average response time, average response rate, frequency of calendar update, security deposit, bedrooms, bathrooms and cancellation policies. The searcher weighs these characteristics and chooses one (or more) properties to contact.

Let a guest, g , enter the market at time, t . Each guest searches for a property to contact from a consideration set. The guest receives utility from property, h , according to a linear combination of property characteristics, a property random effect and a guest specific error term according to the equation below:

$$u_{ght} = \alpha_0 + (p_{ght} + f_{ght})(\alpha_1 + Z'_g\alpha_2) + X'_{ht}\beta_1 + f(X_{ht}, Z_g)'\beta_2 + \kappa_N + \gamma_h + \epsilon_{ght} \quad (3)$$

where X_{ht} is a vector of property characteristics including review quality, property type

and whether the host is a property manager. Z_g is a vector of trip and guest characteristics (Nights, Age, Guests), $f(X_{ht}, Z_g)$ is a set of interactions between guest and host characteristics, p_{ht} is the nightly price of the property for the trip, f_{ght} is the platform fee, κ_N is a neighborhood fixed effect and η_{ght} is an unobserved component of the utility which is distributed according to the type 1 Extreme Value (EV) distribution with variance 1. γ_h is a normally distributed listing level random effect. The random effect is included to account for unobserved heterogeneity at the listing level which is uncorrelated with the observed characteristics.

The searcher can also choose to take the outside option and leave. The searcher's value of the outside option is determined by the equation below.

$$u_{got} = T'_{gt}\mu + \kappa_t + \alpha \log(H_{gt}) + \epsilon_{got} \quad (4)$$

where T_g are guest and trip characteristics, H_{gt} is the number of listings in a guest's consideration set, κ_t are month of check-in fixed effects and ϵ_{got} is a type 1 EV error term.

The probability of making a choice between a particular property and the outside option is determined by the relative utilities of the two options, search costs, the continuation value of searching and the probability of booking a particular inquiry. Suppose that a searcher can only send an inquiry to one listing. The probability that a searcher sends an inquiry to property, h , as opposed to choosing the outside option is determined by the following equation

$$Pr(u_{go} < b_{gh}u_{gh} + (1 - b_{gh})u_{go} - c) = Pr(u_{go} + \frac{c}{b_{gh}} < u_{gh}) \quad (5)$$

where b_{gh} is the perceived probability that searcher, g , books property h and c is the search cost. In reality, there is a continuation value of sending an inquiry that is likely to be higher than the value of the outside option because some searchers do send more than one inquiry. Let b'_{gh} be the rate with which a searcher books any listing on Airbnb and suppose that any listing which the searcher books has equivalent value to the

first listing which the guest sent an inquiry to. The searcher's decision problem is then:

$$Pr(u_{go} < b'_{gh}u_{gh} + (1 - b'_{gh})u_{go} - c) = Pr(u_{go} + \frac{c}{b'_{gh}} < u_{gh}) \quad (6)$$

In either case, the consumer surplus in the above model depends on the value of the outside option and the magnitude of the effective search cost, $\frac{c}{b'_{gh}}$. The effective search cost is difficult to identify without making strong assumptions because it is not clear how consumer's expectations of booking probabilities are formed. Most searchers do not have enough experience with Airbnb to know what their probability of rejection and booking is for any given inquiry. I explore what the above two assumptions about b_{gh} imply for consumer surplus in the simulation.

The estimation procedure requires assumptions about the empirical analogue to the consideration set of each searcher. Consider the case when a searcher sees a set of listings in the first browsing session and immediately sends an inquiry. The consideration set for that scenario is composed of all the listings seen in the only search session. In other cases a guest sends an inquiry after many days of search for a particular trip. Some properties that the guest browsed could have been booked by someone else before the decision to send an inquiry was made. In other cases, guests send an inquiry to a host without seeing a property in the search results. This might occur if the guest navigated to the property through an outside link.

I include a property in the consideration set if the guest saw the property and sent an inquiry to any property up to 2 days afterward. If a guest did not send any inquiry then I include a property in the consideration set if it was seen on the last 2 days of search. Guests who sent an inquiry more than a day after the last search, who sent an inquiry to a property that was not observed in search or who viewed fewer than 10 total listings are excluded. I make the above assumptions so that the estimation data contains only decisions by searchers that mirror the underlying model of behavior.

No matter how many covariates are added to the model, there will still be important aspects of the property characteristics that are difficult to observe by the econometrician but not by the guest. For example, the property may have stylish furniture in the picture.

Such a listing is likely to charge a higher price than an otherwise similar property with worse furniture. I use a control function approach to address the endogeneity of price and omitted variable bias ([Smith and Blundell \(1986\)](#) and [Petrin and Train \(2010\)](#)).

I use the suggested price for the property by Airbnb as an instrument for price. Starting in late 2012, Airbnb began displaying a suggested price to some properties. The suggested price is calculated by taking a weighted average of the recent transaction prices of similar properties based on geography, reviews and several other characteristics. The similarity of listings is based on an arbitrary subset of characteristics chosen by a software engineer at Airbnb. If the true price is predicted using a full set of characteristics and a suggested price term, then the effect of the suggested price should only be due to the fact that it was seen by the host and served as an anchor. Therefore, conditional on controls, the suggested price should be exogenous. I combine the instrument with the estimation using a control function approach. In the first stage, I regress the listed price on the instrument and controls. The error term is then added into the utility specification in the second stage. I use a control function procedure because the non-linearity of the choice probabilities makes simpler procedures like two stage least squares unsuitable for this application.⁸

The first stage equation is:

$$lp_{ht} = X'_{ht}\beta + S_h\kappa_1 + IS_h\kappa_2 + \nu_{gpt} \quad (7)$$

where lp_{ht} is the listed price of a property at time t , X_{ht} are property characteristics, S_{ht} is the suggested price in March 2013, and IS_h is an indicator that takes the value of 1 when there is no suggested price. Not all properties have a suggested price because the suggested price algorithm requires there to be enough similar historical transactions to the property. The suggested price was updated over time but those updates were not recorded consistently. Therefore, I use the suggested price at the beginning of the estimation sample. If the algorithm does not change much over time and if the suggested

⁸The standard errors are currently computer without taking into account the estimation error in the first stage. I plan to recompute them using the bootstrap.

price influences price setting then the instrument should still be valid.

The residuals from equation (7) are added to the estimation procedure so that the utility specification is as written below.

$$u_{ght} = \alpha_0 + (p_{ght} + f_{ght})(\alpha_1 + Z'_g \alpha_2) + \hat{\nu}_{ht} \eta_1 + I S_h \eta_2 + X'_{ht} \beta_1 + f(X_{ht}, Z_g)' \beta_2 + \gamma_h + \epsilon_{gh} \quad (8)$$

The control function residual can be interpreted as an estimate of the omitted variables in the demand equation that are correlated to price. If $\hat{\nu}_{ht}$ is greater than 0, the listed price of a property is higher than the predicted price conditional on property characteristics and the suggested price. Therefore, omitted property characteristics allow the host to charge a higher price.

Another complication with the above specification is that random utility models is that they overstate the benefits to variety because the characteristic space expands with every product. In practice, additional products crowd each other out. I follow [Akerberg and Rysman \(2005\)](#) in adding a term for the log of the size of the consideration set to the value of the outside option in the estimation. This term corrects for the tendency of the utility from a random utility choice to diverge as the set of options grows. The correction suffers from bias if those individuals who view larger consideration sets conditional on observed characteristics also value the outside option differently than those who view smaller consideration sets.

3.2.1. Demand Estimation

The estimation sample consists of 6273 users with Airbnb accounts searching in City X between March 30, 2013 to June 25, 2013 for trips between April 2013 through July 2013. These users collectively viewed a total of 360 thousand listings in search. To be included in the sample, searchers had to have fewer than 9 guests, fewer than 15 nights of stay and must have searched before the day of the check-in. Searchers who only had 1 search were also excluded from the sample to reduce noise. Less than 1% of those searchers actually contact a host and these searchers are typically viewed as “non-serious” by analysts within the company. I also exclude those searchers who saw fewer than 10 or more than

500 properties because such observations are either incomplete or likely driven by bots. Lastly, I exclude views of “Shared” rooms which comprise $< 1\%$ of all inquiries. Of those searchers left, 54% chose the outside option.⁹

The estimates from the demand model without and with the correction for large consideration sets are displayed in [Table 2](#) and [Table 3](#). In both tables, Column 1 excludes the control function residual and Column 2 includes the control function residual. Each coefficient estimate and standard error is normalized by the coefficient on price in the estimation procedure.

Across specifications, guests value more reviews and higher rated reviews as expected. Further, trips with more guests are less price sensitive and value entire properties as opposed to private rooms. Older guests are less price sensitive, presumably because they are richer. The estimates with the control function residual tend to have lower coefficient estimates, suggesting that unobserved heterogeneity was indeed correlated with price. The specifications with the corrections for large choice sets further decrease the estimated value of listing characteristics.

The value of the outside option (inclusive of effective search costs) compared to the value of a listing is important for counterfactuals because policy changes change the listings that searcher see. The outside option is less valuable for trips with more than 1 night because the fixed cost of arranging a stay on Airbnb may only be worth incurring for longer trips. The outside option is also more valuable for searches occurring further in advance of the check-in.

The standard deviation of listing random effects, which account for the listing level heterogeneity conditional on observables, ranges from 11\$ to 21\$ per night depending on the specification. Therefore, the variation of listing specific components of utility is about the same as the impact of having good reviews. The standard deviation of the error term ranges between \$40 and \$46 per night. The unexplained component of utility is important because it often takes on values that are much larger than the values of

⁹The actual conversion rate to sending an inquiry is lower because many searchers never create an account. I exclude non-registered searchers because I do not observe demographic information about them.

observable listing characteristics. The error term is driven by the fact that characteristics which are observable to searcher (photo quality, amenities, property size, etc...) are not included in the specification. Further, the error term can be inflated by unobserved preference heterogeneity and displayed listings on the website that are not viewed by the searcher.

3.3. Simultaneous and Sequential Search

Some searchers send multiple initial inquiries and continue search even if they are rejected. The propensity of searchers to engage in intensive search is a function of their characteristics. I estimate Poisson count of models of the number of inquiries sent initially and after rejection (shown in [Table 3](#)).¹⁰ For simultaneous search, the number of inquiries initially sent by a searcher minus 1 is regressed on trip and searcher characteristics. For sequential search, the number of subsequent inquiries is regressed on trip and searcher characteristics. The Poisson regressions are biased because the potential number of inquiries a searcher is willing to send is capped by the amount of listings in the market which are better than the outside option. In the simulation, I calibrate constants which inflate the number of potential inquiries that a searcher would like to send if there are enough good properties.

The search calibration accounts for the fact that some searchers are more likely to search intensively than others. For example, individuals who have successfully used the site before are more likely to continue search after an initial rejection.

4. Rejection and Screening

Hosts receiving inquiries from potential guests choose which of them to accept and reject. In the model, each host evaluates inquiries in sequence based on guest and trip characteristics.¹¹ If an inquiry is suitable, the host responds with a non-rejection and waits for the guest to eventually book. If the inquiry is not suitable, the host rejects and waits for

¹⁰The estimation sample consists of all non-foreign language inquiries sent by guests in City X between January 2012 and July 2013.

the next inquiry. If the guest is not rejected and agrees to book, then the host rejects subsequent inquiries until the initial guest books.

There are three reasons why hosts reject guests in my model: congestion, “stale” vacancies and screening.¹² Congestion occurs when a guest sends an inquiry to a host who is about to transact with someone else. This occurs because there is almost always some time between a communication and transaction on Airbnb. The gap between the communication and the transaction occurs because the guest has yet enter the credit card information or because there are still some final details being discussed. I classify any inquiries to hosts which are subsequently booked by a previously contacting guest for overlapping dates as congestion. Not all inquiries of this form receive an immediate rejection. Instead, the host may tell the guest to wait until there is a response from the previous inquiry. This type of rejection occurs for 5.6% of inquiries in the US for 2012.

A second type of rejection occurs because hosts are not available to anyone for a set of dates. Stale vacancies are more difficult to measure than congestion because listings that are unavailable and those that are very selective sometimes look similar in the data. There are two ways in which stale listings manifest themselves in the data. Firstly, hosts can update their calendars to state that they are unavailable for a set of dates. On average across market-weeks in the sample 56% of hosts eventually update their calendars to be unavailable and are not booked. However, for frictions to occur, those updates must occur at a point at which in which searchers are active in the market. In fact, many properties update their calendar more than 2 months ahead of the check-in date. In the data, 21% of all inquiries are sent to listings that are later updated to be unavailable for at least one of the dates of an inquiry and are not booked for any of the other dates of inquiry.

Some stale vacancies never update their calendar because updating the calendar is

¹¹In practice, there are some cases when a host receives inquiries in parallel. For example, a host might receive several inquiries at a time if he checks Airbnb infrequently. I abstract from this scenario because many hosts are notified by text or email of an inquiry and have an incentive to respond quickly. In other search markets, such as college admissions, a parallel model of decision making by the seller is more appropriate.

¹²[Appendix C](#) contains a static urn and ball model which demonstrates how rejections arise according to congestion, stale vacancies and screening.

costly, because the host wants to learn information about demand or because the host forgets. This behavior manifests itself in the data when a host rejects all inquiries for a particular set of dates. [Figure 7](#) shows the distribution of rejection rates (excluding congested inquiries) by host in a given week of check-in if a host received at least 5 inquiries for that week. There is a wide dispersion of rejection rates and a noticeable excess mass at 1, with over 10% of host-week combinations rejecting all inquiries. Nothing in the data distinguishes whether any particular host rejected all inquiries due to actual unavailability or due to high selectivity. If hosts reject each inquiry at a rate of 50% then there should be fewer than 3% of host-week combinations that reject all inquiries. At least some of the cases in which a host rejects everyone are probably due to stale vacancies. The upper bound for inquiries rejected due to unavailability includes all inquiries to hosts who reject all inquiries for a particular week. The lower bound is the set of all inquiries to hosts who eventually update their calendar to be unavailable. In total, the upper bound on inquiries rejected due to stale vacancies is 32% and the lower bound is 21%.

The last type of rejection occurs because hosts are screening amongst potential guests. Screening is determined by the characteristics of interacting searchers and hosts. Some hosts are more selective than others. [Figure 8](#) displays a histogram of the mean rejection rates (excluding congested inquiries) by property for all of 2012, conditional on a property receiving at least 10 inquiries. Many properties reject all or almost all inquiries while others accept almost everyone. The heterogeneity occurs because some properties are either more selective, more in demand or are just generally more unavailable than others. Indeed, many of the listings that rejected close to 100% of inquiries rarely responded and were eventually removed from the website. I exclude congested inquiries and inquiries to hosts who eventually updated their calendar to be unavailable. The remaining inquiries are rejected either due to screening or due to hosts who do not update their calendar. An upper bound on screening rejections includes those cases in which hosts rejected all inquiries in for a given week of trip while the lower bound does not. The upper bound on immediate rejections due to screening as a share of all inquiries is 31% while the lower bound is 20% in 2012.

Stale listings and screening account for most of the rejections that occur on Airbnb. These two frictions are approximately the same magnitude and their importance depends on assumptions. On the other hand, congestion, which has been a key focus in many theoretical models of directed search is a lot less important. In total, 57% of inquiries are affected by frictions either through screening rejection, congestion or a stale vacancy. If search costs are large, then these results already suggest that there are large welfare costs of search frictions.

There are some ambiguities in the classification. Listings that update their calendar to be unavailable might have been booked had a good enough offer come along early enough. Alternatively, they may have been booked off of the Airbnb platform.¹³ There is no good data on how often hosts multi-home in several accommodations marketplaces but this type of behavior may be important for the counterfactuals (i.e. [Athey, Calvano and Gans \(2013\)](#)). Another cause of error is that the text classification process is not fully accurate and could have mislabeled some responses. Lastly, some screening occurs later in the conversation and is not captured by my methodology.

4.1. Screening Model

Screening occurs on Airbnb because hosts have preferences over when and whom they host.¹⁴ For example, a host can find a guest untrustworthy because the guest is not reviewed, has a vague inquiry or doesn't have enough other profile information filled in. Hosts also reject guests because the check-in dates of the inquiry can break up a bigger, uninterrupted time of availability for the host, preventing future inquiries. Lastly, hosts may be waiting for a better guest/trip combination or might consider a particular inquiry

¹³In some cases, hosts indicate on their calendar that they were booked on another site. 1.81% of inquiries are sent to these hosts. There is no good evidence at Airbnb on how frequently transactions initiated on Airbnb are taken off of the platform. There are large incentives for guests and hosts to keep transactions online because of the insurance, reputation and secure monetary transfer that Airbnb offers.

¹⁴Bargaining plays a key role in other matching models with transferable utility between the two sides of the market. Bargaining infrequently results in transactions on Airbnb because there is often no Pareto efficient exchange possible. The potential cost to a host from a non-trustworthy guest, for example, is perceived to be much greater than the potential earnings from the stay. Furthermore, hosts might consider guest who immediately ask for a discount less trustworthy.

too much of a hassle.¹⁵

I model the probability that a seller rejects a searcher as a logistic function of guest characteristics, trip characteristics, seller characteristics and market demand. Consider the estimating below

$$Pr(R_{gh}) = Pr(\alpha_0 + X_g'\beta + Z_h'\delta + f(X_g, Z_h)'\lambda + \gamma_h + \eta_{gh} > 0) \quad (9)$$

where η_{gh} is the logit error term, R_{gh} is an indicator for whether the response is a rejection, X_g are the number of guests, guest reviews, guest gender, weekly demand, days in advance of the trip nights, guest age and month of check-in. Z_h are property type, property manager indicator, host age, the number of reviews and price. $f(X_g, Z_h)$ are interactions between guest and listing characteristics. $\gamma_h \sim N(0, \sigma_{sh}^2)$ represent listing specific random effects. The random effects account for heterogeneity in hosts' baseline propensity to reject. I account for the dynamic aspects of the host decision by controlling for the time in advance of the trip of inquiry and for the overall demand for each week of check-in. Nonetheless, the above model is incomplete because although it captures the decisions of hosts, it cannot be interpreted as a utility. In order to infer the utility of hosts, I would need to estimate a full structural model of host decision making with dynamic decisions driven by host expectations of future demand.

The potential dataset for estimation consists of all non-foreign language inquiries sent by guests in City X between January 2013 and July 2013. Each inquiry is then classified as a rejection according the procedure outlined in [subsection 2.4](#). I exclude inquiries in which congestion occurred and in which the host updated her calendar for the inquiry dates after the inquiry to indicate unavailability. The final dataset consists of 18145 observations of which 44% were rejected. I include cases in which the host rejected all inquiries, assuming for the case of the simulation that cases when the host rejected all inquiries for a week was due to screening.¹⁶

Table 4, panels a - c, displays the results of specifications with and without hosting

¹⁵The above reasons are evident in Airbnb surveys of hosts and common responses by hosts to guest inquiries. They are corroborated by the screening model estimates.

¹⁶I plan to experiment with alternative assumptions in an Appendix.

and guest specific random effects. Less “trustworthy” guests and inquiries which require more hassle such as last minute and short stays should be rejected more often. Panel (a) displays the coefficients on trip and guest characteristics of inquiries. Reviewed guests and females are less likely to be rejected presumably because hosts find them more trustworthy. Trips for 3 - 6 nights are less likely to be rejected than trips with less than 3 nights. Inquiries which are about a month ahead of the check-in date are less likely to be rejected than inquiries further or closer to the check-in date. The effect of a guest having prior reviews stands out as being an order of magnitude larger than all the other effects. Market conditions also matter for rejection behavior. The more overall demand there is in the market for the week of check-in, the more likely a host is to reject. In the specification with random effects, the standard deviation of the propensity of hosts to reject is large compared to the coefficients. This confirms previously discussed analysis which indicated that some hosts are a lot more selective than others.

Panel (b) displays the coefficients on host characteristics in the regression. More expensive properties, younger hosts and entire properties are more likely to reject guests. Property managers (hosts with more than 4 active listings) are less likely to reject because they care less about interacting with guests and operate more like hotels. The interaction between certain types of hosts and certain types of guests potentially generates a potential for mismatch in equilibrium. Panel (c) displays the logit coefficients on interactions between guest and host characteristics. As expected, property managers are less likely to reject last minute inquiries than non-property managers. Hosts renting out entire properties are comparatively less likely to reject trips with more guests and more nights compared to hosts renting out private rooms. The above results show that there are predictable conditions under which inquiries are likely to be good matches and other conditions under which that is not the case. Furthermore, there is significant heterogeneity in both the selectivity and preferences of hosts regarding the inquiries they reject.

5. Simulation of Equilibrium Outcomes

In this section I describe how to combine the search and screening models into a model of market equilibrium. I calibrate an equilibrium model and use it to study the mechanisms underlying search frictions. The goal of the model is to generate market level matching outcomes from micro-foundations. My model has few free parameters but fits the data well.

The simulation is similar to [Roth and Xing \(1997\)](#), which studies congestion in the clinical psychologist market. My model builds on that paper’s approach by estimating preferences from the data, by modeling multiple frictions and by comparing model outcomes to empirical moments. An alternative way to condition the model on the data would be to estimate rather than simulate all of the parameters. I chose to simulate because most of the calibrated parameters in the simulation have close empirical analogues in the data and because simulation is faster than estimation in terms of computational speed.

5.1. Simulation Setup

For a given check-in week in City X, I observe searchers and bookers on Airbnb. I also observe any listings that were visible for that week. Every searcher who enters the market looking to stay in City X for the week of the simulation draws a consideration set, receives a mean utility from every listing in the market and draws a random utility shock distributed according to the demand estimates from column (2) of [Table 3](#). Similarly, each listing receives a mean probability and a random error term conditional on searcher and listing characteristics from the logit model of rejection in column (1) of [Table 4](#). The same process is repeated for each subsequent searcher that enters the market.

I collapse the 7 days of the week being modeled into 1 time period to simplify the simulation. Each listing can only be booked once in each week. If a listing is booked for 3 days, I assume that the other 4 days are no longer going to be available. In the data, 22% of hosts who receive an at least one inquiry in a week book more than 1 trip in that

week. I avoid modeling this behavior because the model fits the data and accounting for multiple bookings adds complexity to the model. If a guest is looking for a stay of more than 7 days, then only the 7 days are used for the calculation of surplus and revenue in this section. Otherwise trips that cross into other weeks would affect outcomes for the simulation week.

The model relies on the calibration of several parameters related to market clearing and search intensity. All of the calibrated parameters are seen in [Table 4](#). The time to transact is determined according to an exponential distribution whose mean is the empirical mean of time to transact in the data. I assume that the time between browsing and sending an inquiry is negligible. Properties sometimes update their calendar to be unavailable for a set of dates. I calibrate the distribution of the time in advance of the check-in date for which availability is changed to an exponential distribution with an appropriate mean and the share of properties that set unavailability to the share in the data.

The model uses the Poisson regressions estimates for sequential and simultaneous search shown in [subsection 3.3](#). The simultaneous search Poisson model is combined with the simulation in the following manner. Each searcher draws a random Poisson variable, n_{sim} with mean equal to the product of the predicted mean from the Poisson regression times a calibrated constant, $\mu_{sim} > 1$. The searcher then sends inquiries to the minimum of either $n_{sim} + 1$ or the number of viewed listings with utility greater than the outside option. μ_{sim} is set to match the observed amount of simultaneous search in the data.

Sequential search is treated in the same manner. A searcher who is rejected draws a Poisson random variable, n_{seq} , according to the expected mean from the Poisson regression multiplied by a calibrated constant $\mu_{seq} > 1$. A draw of 0 implies that the searcher does not continue search. If the draw is greater than 0, then the searcher comes back to the market 1 day later and sees the entire choice set. The searcher then sends an inquiry to the minimum of n_{seq} and the number of properties remaining which are better than the outside option. μ_{seq} is set to match the observed amount of sequential search in the data.

Oftentimes a transaction does not occur even if there is no immediate rejection because the guest does want to book the place, the host ends up rejecting the guest later in the conversation or because the initial classification was wrong. I assume guests leave the market after an opportunity to book with a constant probability because in prior analysis I found that observed property characteristics are not predictive in determining whether a non-rejection results in a booking.

The calibrated parameters above are sufficient to simulate the choices of agents in the market using the decision probabilities estimated in [subsection 3.2](#). However, because the demand for inquiries is not the same as the demand for stays in a room, the demand estimates cannot be directly used to make claims about consumer surplus. I bound consumer surplus in the simulation by making assumptions on search costs and searcher's expected booking probabilities.

I am assuming that sending an inquiry takes 5 minutes to compose. Assume that Airbnb users earn twice as much as the median annual income for males aged 25 - 44 in the United States.¹⁷ Then if searchers work 2000 hours a year then the shadow value of time will be \$3.24 per 5 minutes. I use this search cost for the rest of the simulation exercises.

I bound the consumer surplus in the simulation by using two assumptions about a searcher's expectation for the probability of booking. In specification 1, I assume that the searcher's expected booking probability of the listing is the probability of booking only that listing. Such a specification assumes that the continuation value of searching is equal to the value of the outside option. Alternatively, I set the searcher's expected booking probability equal to the observed probability of booking any listing. Under the above assumption, the utility of booking a listing that is not the first inquiry is equal to the value of booking the first contacted listing. In practice, the results with either adjustment do not make a large difference in the consumer surplus calculation because the search costs are low relative to the benefit of booking a room. I use the calculation

¹⁶Each page of search results on Airbnb displays at most 21 results. Therefore, the assumption is that searcher can see 2 pages of results and investigate several of those results within a 5 minute period.

¹⁷Source: U.S. Census Bureau, Current Population Survey, 2013 Annual Social and Economic Supplement.

in which the expected booking probability is the booking probability of only that listing for reporting the consumer surplus results.

For the week of April 10, 2013 and City X, I observe the set of all potential guests (with a linkable user id on Airbnb) who searched for days overlapping that week. I include only searchers who enter the market within 8 weeks and before the date of the check-in date. At the beginning of time, each visible property draws a demand and a screening random effect. Each searcher enters, draws a random browsing set, a number of potential simultaneous search and sends inquiry(s) according to the estimated demand model. This aspect of the simulation is an approximation because the utility of sending an inquiry should depend on the prior sent inquiries and policy by the platform which affects booking probability. The accuracy of the approximation depends on the assumption that the decision of a guest is primarily driven by the utility of booking a listing compared to the value of the outside option.

The host who receives the inquiry rejects the guest if that host is unavailable, has already been contacted by an eventual booking or draws a random term that leads her to reject. If the guest is not rejected, he draws a random term that determines if he actually books. If the guest is rejected, she draws a random variable that determines whether to continue search. If the searcher continues search, then she comes back 1 day later and sends the minimum of the randomly drawn inquiries and the number of listings in her consideration set whose utility is greater than the outside option. Afterwards, the next searcher enters the market.

5.2. Baseline Results

The final choice situation includes 1197 searchers and 914 visible listings (56 days in advance of the check-in dates). Table 5 column 1 displays the outcomes that occurred in the data for the choice situation. 50% of searchers sent an inquiry and 33% eventually booked a room. In comparison, column 2 displays the results of the simulation. The model outcomes match the data well considering that most of the moments in the table were not explicitly targeted by the calibration. The most significant differences between

the data and simulation is that simulation overstates the share of searchers sending an inquiry by 3% and understates the booking probability by 4%. The share of searchers that books is understated because some listings can actually be booked two or more times in a given week but that is excluded from my model. For example, there can be one two night stay and another three night stay for a given listing. I choose not to model the packing problem of hosts because only 22% of contacted listings have multiple bookings in a week and this feature would add additional complexity to the simulation.

5.3. Which Frictions Matter?

There are three mechanisms (excluding incurred search costs) by which actual market outcomes differ from the solution to the social planner’s problem: rejection, limited choice sets and dynamic mis-allocation. Table 6 displays moments for cases in which each mechanism is removed.¹⁸ First consider column (2), in which all listings that would reject each searcher are removed from that searcher’s choice set. Compared to the baseline simulation, removing rejecting hosts decreases inquiries by searchers because on average, worse quality listings are shown. However, the inquiries that are sent are much more effective. Without rejections, the share of searchers booking increases by 10%, the average revenue increases by \$34 per searcher and the average consumer surplus increases by \$8 per searcher. This is a large and surprising impact given the limited supply available on the platform. The improvement in matching indicates that there are suitable substitutes for rejecting properties on the platform, but that those properties are not being contacted at a high enough rate.

In Table 7, I display the equilibrium effect of each rejection cause separately. Of all rejection frictions, screening has the largest effect on booking and consumer surplus. The effect of screening in equilibrium is larger than it’s frequency in the data because screening properties are more likely to be included in searchers’ consideration sets and because there is a random component to screening. Listings that reject some guests can

¹⁸In the counterfactual exercises, the searcher’s expected probability of transacting given an inquiry should change. However, in the results below they do not. I will implement the correction in the future but doubt that such a correction would make much of a difference. Even if the expected booking probability per inquiry increases to 50%, the added benefit would be less than 10\$

be still be matched with other guests whereas congested and unavailable listings cannot. The importance of screening suggests that Airbnb should guide guests towards hosts that are willing to transact. Secondly, Airbnb should elicit host preferences about guests ahead of time, to improve Airbnb’s ability to guide the guest.

Column (3) of [Table 6](#) displays the simulated matching outcomes if searchers freely considered all listed properties rather than just a limited consideration set. The share of searchers who send an inquiry increases by 31%, the share that book increases by 12% and the revenue per searcher increases by 46\$. The effect on limited consideration sets is bigger than the cumulative effect of all rejection reasons because there are large product specific error terms. The demand estimates used in the simulation include an Akerberg-Rysman correction. However, that correction itself may be biased because those searchers who view a lot of listings may have a higher utility from using Airbnb. Alternatively, searchers may select onto consideration sets based on unobservable components of their utility. In that case, estimates of the standard deviation of the error term and utility from listings outside of the consideration may be overstated. [Appendix D](#) includes robustness checks which show that the effect of limited consideration sets is sensitive to the standard deviation of the error term. Column (4) displays the results of the simulation if the rejection friction and the partially observed choice sets were removed together. There is a \$72 surplus gain from having both frictions eliminated at once, which is approximately equal to the sum of the gains from removing rejections and partial consideration sets separately.

Lastly, I consider the solution to the social planner’s problem in this marketplace. The social planner dispatches each searcher to an appropriate outcome using information on random utility draws and the timing of entry and exit for every searcher and host. The consumer surplus maximizing allocation of the 1241 searchers to the 914 properties is a solution of the assignment problem with constraints. For each assignment of a searcher to a listing, the searcher must prefer the listing to the outside option and the listing must accept the searcher. Each listing can only be assigned to one searcher and each searcher can only be assigned to one listing. As in the simulation, there is a mass of unavailable

listings who are not matched and a share of searchers how don't book even if they are matched. Further, I assume that the viewed number of listings in the Akerberg-Rysman correction is equivalent to 195 listings, the average number of considered listings in the scenario with no rejections and full choice sets. Column (5) displays the results of that counterfactual. In the optimal scenario, the booking rate by guests increases by 21%, the consumer surplus per browser increases by \$87 and the total revenue by the hosts increase by 72% compared to the baseline. There are two reasons why the optimal allocation differs from the one in which searchers see all options except for those that would reject them. First, less search costs need to be incurred for matches to occur. Second, there is a dynamic mis-allocation of listings to guests. Searchers entering the market earlier sometimes book a listing that would have provided more utility to a later entrant. Mis-allocation is an important matching frictions in other empirical search models such as [Gavazza \(2012\)](#) for airplanes.

The overall booking rate in the surplus maximizing outcome is approximately the same as the outcome in which there are no rejections and full consideration sets. At most 48% of the searchers in this market can be successfully matched in equilibrium because supply constraints limit the ability of policy to improve outcomes in the marketplace.

5.4. Platform Policy

I have shown that search frictions significantly affect consumer surplus and revenue on Airbnb. Because even small changes in conversion rates can improve margins, the platform should actively be aiming to reduce frictions. Below, I analyze several types of policies the platform can undertake in practice to improve outcomes.

5.4.1. Search Algorithms

The order in which items are shown is a key policy for both online and offline marketplaces. For example, supermarkets strategically choose where to display various items and e-commerce sites refine their algorithms to display more relevant products. Furthermore, ranking algorithms are a major area of research within technology companies and in

computer science departments. Much of the research on search and recommendation engines focuses on search for content or non-capacity constrained goods (i.e. Amazon Books). However, when the supply of a given good is capped, one buyer of a good prevents other searchers from buying that good. The preferences of searchers entering the market over time determine whether the good is allocated in a surplus maximizing manner.

In this section I consider two possible and plausible search algorithms. Each search policy is intended to show more relevant listings to searchers in their consideration sets. I simulate better algorithms by deriving a new listing specific weight, w_h , and using the procedure in [subsection 3.1](#) to transform it into a sampling weight. In search policy 1, the weights are calculated by averaging the non-idiosyncratic component of utility from each property amongst all searchers. The second policy personalizes search results to each searcher based on searcher and listing characteristics. I compute the non-random component of utility for each searcher-listing pair and let that be the sampling weight in the model of consideration set formation. I also increase γ , the parameter which determines the correlation in browsing sets, to 1.5 because if searcher receive more relevant results they should be more likely to use the default algorithm rather than custom filters and browsing decisions. [Table 8](#) columns (2) and (3) show the results of these policies in order.

The non-personalized search algorithm increases contact rates by 6% and booking rates by over 2% compared to the baseline and the personalized search algorithm increases the share of searchers contacting by 7% and the booking rates by over 2%. Both algorithms increase consumer surplus but, as expected, the personalized algorithm results in a larger gain than the non-personalized algorithm. Even though personalization provides a boost to market efficiency and platform revenue, the gains to personalization are not large under these market conditions. Both ranking algorithms provide only small improvements compared to the full information benchmark because the random utility term matters for agent decisions but cannot be known by the algorithm creator and because search algorithms do not fully determine consideration set formation. Additionally,

the scarcity of listings in the market allows earlier market entrants to benefit more from search algorithms than later entrants who have fewer suitable listings to choose from compared to the baseline scenario.

The demand models I use to generate the search algorithms leave a lot of choice unexplained. In practice, market designers can choose how much employee time and resources to devote to generating features and better prediction algorithms. The increase in bookings in the counterfactual where searchers see the full choice set suggests that there are high returns to devoting resources to better demand models.

I have not explicitly modeled the effect of the order in which listings appear on a given page. There is a growing literature that examines the effect of the search order on advertising clicks, movie viewing decisions and other search behavior.¹⁹ I do not model the effect of the displayed order of a particular listing because the display order is poorly logged in the data and because searchers may see a listing many times in search at different rankings.

5.4.2. Encouraging Search

Airbnb encourages more simultaneous search by giving searchers the ability to reuse their old message.²⁰ Column 5 of [Table 8](#) displays the results of a policy that would double the simultaneous search propensity coefficient. Unsurprisingly, the amount of simultaneous search increases from 1.43 to 1.61 inquiries per searcher. The increase in the volume of simultaneous search is less than twofold because the consideration sets of searchers do not change. The resulting increase in the propensity to search leads to fewer than 1% more bookings. However, the increase in incurred search costs is large enough to offset the consumer surplus benefit. Therefore, policy that encourages more inquiries without encouraging more browsing will not be effective.

¹⁹For example, [Ghose and Yang \(2009\)](#) and [Jeziorski and Segal \(2009\)](#)

²⁰The platform clearly displays the following text underneath all inquiries: “Contacting several places considerably improves your odds of a booking.”

5.4.3. Policy to Reduce Rejections

Rejection frictions significantly decreases the matching rate and the surplus from Airbnb. The most direct way that Airbnb tries to reduce rejections is by encouraging searchers to verify their online and offline identities. Presumably, verified searchers are considered more trustworthy by hosts and are less likely to be rejected. Airbnb also has several mechanisms for detecting unresponsive hosts and removing the from search.

In this section I consider two additional policies aimed at reducing rejection frictions. The first policy removes listings that will reject a searcher with high probability (more than 60%) from a searcher's consideration set.²¹ Table 8 column (3) shows the effects of such a policy. Compared to the baseline, the contact rate decreases but the booking rate does not change. Although search costs are reduced, the average quality of matches decreases as well because selective listings tend to be more desirable to searchers. Therefore, removing those listings from the choice sets of many searchers reduces the surplus that individuals given a transaction.

An alternate policy which aimed at reducing congestion pauses hosts for 24 hours after being contacted. Such a policy might reduce congestion because transactions will have time to clear and fewer individuals will be able to send inquiries to unavailable and selective listings . Table 8 column (6) displays the results of this simulation and shows that there is a decrease in inquiries and a slight increase in booking due to this policy. Although the policy reduces rejections from congestion by 2% as intended there is a negligible effect on market outcomes.

5.5. Aggregate Matching Functions, Market Tightness and Policy

The setting of the prior simulations is one market and one week. However, market conditions vary on Airbnb both across markets and over time. In this section, I vary ratio of searchers to hosts and the overall amount of agents in the market to study how market conditions affect matching and policy. I randomly subsample or re-sample agents

²¹If this procedure leaves no viable options, then searchers are allowed to see listings whose probability of rejecting the searcher is less than .85%.

in the market to create alternate market conditions.²² Each market condition is simulated 10 times, with the amount of listings and guests varying between 50% and 150% of the amount seen in the data.

I use the simulated data to estimate a Cobb-Douglass matching function of the form:

$$\log(M_s) = \log(A) + \alpha \log(G_s) + \beta \log(H_s) + \epsilon_s \quad (10)$$

where M is the number of matches, G is the number of searchers and H is the number of listings in the market. [Table 9](#) displays the estimated results of this equation where the coefficients are allowed to vary by the search algorithm used.

The estimated matching function exhibits increasing returns to scale because $\alpha + \beta = 1.057$. A twosided t-test rejects the null hypothesis that $\alpha + \beta = 1$ at a 1% level. Returns to scale come from the fact that thicker markets allow for better matches between guests and hosts. Increasing returns to scale are important in the literature on marketplaces but are difficult to show empirically. Furthermore, increasing returns to scale may be one reason for why matching rates are higher in large markets on Airbnb, conditional on tightness.

Alternative Airbnb policies change the shape of the estimated matching function. For example, the interacted coefficients in [Table 9](#) show the matching function estimates when search rank is personalized according to the procedure described in [subsubsection 5.4.1](#). The search algorithm increases the share of matches due to the supply side in the market and decreases the share due to the demand side. This occurs because policy reduces search frictions and makes supply side constraints relatively more important in the market. Because the shape of the matching function changes with policy, the Cobb-Douglass matching function parameters cannot be interpreted as structural parameters.

Further, the effectiveness of a better search algorithm depends on the extent to which the market is supply constrained. If there is a lack of options in the market then the search algorithm is not important. On the other, if there are many options

²²I break ties in the timing of entry of searchers by adding a random exponential noise component with a mean of an hour to each realized entry time.

then the consideration sets of searchers are more likely to include relevant listings with the personalized search algorithms. [Figure 10](#) shows how booking rates, revenue and consumer surplus vary as the amount of listings in the market change, holding the number of searchers constant. The difference in matches, revenue and surplus between the baseline and the policy simulation increases with the tightness in the market.

The results in this section support the view that two-sided marketplaces do grow more efficient over time, as the match rate given a specific tightness level increases the more agents there are in the market. Furthermore, because better policy impacts the returns to scale, marketplaces with better rules should grow quicker.

Several aspects of agent behavior can change with market tightness but are not in my model. Searchers might form bigger consideration sets if there are more listings to match with, which would result in even greater returns to scale if congestion remains a small issue. On the other side of the market, hosts may change pricing and rejection strategies with market conditions. The direction of these changes is not clear if the size of the market increases because there might be increased competition by hosts but also a greater surplus to share. Lastly, these estimates exclude the accumulation of reputation capital as agents interact over time as a reason for increasing returns to scale.

5.6. Experimentation

Internet companies typically run user level experiments to learn about the effects of policies. For example, a company may test a new feature by allowing 50% of users to see the new feature and comparing average outcomes between the treatment and control group. In many circumstances such tests yield the exact information the company desires. However, in the case of experiments where there are externalities, the treatment effect estimated from an experiment is misleading. The group receiving the treatment may impose negative (or positive) externalities on the control group.

Searchers who randomly see better search results have a higher probability of booking compared to the control. The control will then have a lower chance of booking because the treatment has occupied more of the good listings. I investigate whether such an effect

is quantitatively important by simulating an experiment in which 50% of searchers are assigned to the best overall ranking discussed in the previous sections while the other 50% receive the control. Column 1 of [Table 10](#) displays the treatment effect of the new ranking estimated from the A/B test while column 2 displays the market level effect if every searcher saw the new ranking. The experiment overstates the true effect of the new search ranking by 1.7%, the surplus per searcher by \$4.9 per searcher and the revenue per searcher by \$3.9. The discrepancy in effects arises because the treatment group in the experiment is taking away high value bookings from the control group. Furthermore, the effect of the experiment and the market level effect do not always have to go in the same direction. Mistaken inference about experiments is a potentially major cost for the marketplace because experimental results drive future policies and resource allocation by the company.

One way to obtain a market level treatment effect of a policy is to run a market by market experiment. However, market level experiments are not feasible when market definitions are ambiguous or when markets are not comparable. Another option for measuring the equilibrium treatment effect is to combine models like the one in this paper with experimental results. A model of market equilibrium should have parameters that are influenced by an experiment. For example, I used a particular set of sampling weights in the simulation of a better search algorithm. With experimental variation, I could estimate how exactly a new search algorithm changes consideration set formation. The alternate consideration set model can then be used to simulate market outcomes. Importantly, such an approach does not require a model of the search algorithm, which could be a very complicated machine learning model that is difficult to replicate. What matters for outcomes is how the algorithm influences consideration set formation or other relevant parameters. Other types of interventions can be modeled in the same way.

6. Conclusion

The rate at which heterogeneous agents successfully transact and the surplus generated by those transactions is a function of the information structure of a market. I use novel data on search and communication behavior to build a micro-founded model of matching. The underlying cause of the matching frictions in the model is that guests and hosts have heterogeneous preferences and must use communication and Airbnb’s site to obtain the necessary information to transact. Airbnb provides a review system, a communication platform and many other tools to reduce the cost of searching. Even with these tools, many potential transactions fail and search frictions combine to reduce transaction probabilities by 21%.

The costs of search frictions will vary across other search markets depending on the expectations of the searcher, the potential benefits of searching, the search algorithm and the details of consideration set formation. On Airbnb searchers almost always have the option of using another site to instantly book a hotel. In the labor and housing markets, the possibility of rejection is common to most options and likely causes searchers to incur search costs, to take longer to match and to match with less suitable partners.

In other search markets, such as college admissions, rejection rates are widely known by applicants and the rejection friction is less likely to be important. A similar methodology to the one described in this paper can be applied to other markets in order to quantify search frictions.

Airbnb loses profit because frictions reduce the volume and revenue of transactions. Airbnb’s policy makers can use data they observe about the history of both searcher and seller behavior to improve outcomes. In this paper, I simulate policies which use such data to improve the relevance of consideration sets and to reduce the chance that rejections occur. I find that search algorithms which show more relevant results to searchers improve transaction probabilities by 2%. Other simulated policies, which hide listings that reject with a high probability, don’t affect transaction probabilities and actually decrease surplus

²²However, even in the college admissions market, incomplete information about rejection matters. [Hoxby and Avery \(2012\)](#) show that some high school students do not use widely available information on rejection probabilities of colleges to make application decisions.

because hidden listings create more consumer surplus than non-hidden listings if booked.

I show that, in contrast to feasible policies, an all knowing social planner who directs search can generate large gains in volume, revenue and consumer surplus compared to the current state of the market. The gains to consumers are due to the social planner's knowledge of each agent's preferences. The ongoing reduction in the costs of storing and analyzing data, commonly referred to as the "Big Data" revolution, will likely have profound impacts for platforms like Airbnb because it brings the platform's information set closer to the full information benchmark. The degree to which an online platform can improve outcomes will in part be determined by the share of an agents' preferences that can be explained by observed characteristics and behavior.

I only model short-run responses of agents to policy changes. In the long-run, changes in policy will alter agent's market power and matching probabilities.²³ Changes in market power will cause hosts to adapt their pricing and rejection strategies accordingly. Guests will also change search and communication behavior depending on the search algorithm and the resulting probability that communication results in a booking. Furthermore, because policy has distributional effects, agents might have an incentive to conceal their type in order to receive more favorable matches or prices. It will be interesting to see how online marketplaces evolve to deal with long-run dynamics.

²³[Rochet and Tirole \(2003\)](#) and [Weyl \(2010\)](#) show how pricing and other policies affect the relative gains accrued by heterogeneous agents in a marketplace.

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7. Figures

Figure 1: Search View

Philadelphia, PA

01/02/2014 → 01/05/2014

2 Guests

SEARCH

LIST

PHOTO

MAP

☐ Redo search in map

Room type

☐ Entire home/apt 226

☐ Private room 289

☐ Shared room 16

Show More...

Price

\$10

\$1000+

Connections

☐ Social Connections 16

Learn More!

Neighborhood

☐ Center City 140

☐ South Philadelphia 84

☐ North Philadelphia 74

☐ Rittenhouse Square 64

Show More...

Amenities

☐ Wireless Internet 456

☐ TV 282

☐ Kitchen 410

Show More...

531 Rentals (Philadelphia) with 30 popular on Wish Lists

SHARE

1

Rittenhouse Sq 1BR Apt w/Grdn Patio
Entire home/apt — Philadelphia > Center City
99+ reviews
\$120
Per night

2

Convenient and Private Room in Home
Private room — Philadelphia > Mantua
49 reviews
\$30
Per night

3

ART MUSEUM GARDEN 2
Private room — Philadelphia > Fairmount
91 reviews 99+ other reviews
\$59
Per night

4

Amazing location 1bdr apartment
Entire home/apt — Philadelphia > Washington Square West
23 reviews
\$110
Per night

5

Serene, quiet basement @ 9th & Pine
Private room — Philadelphia > Washington Square West
90 reviews 1 other review
\$90
Per night

6

Loft Apt in Univ.City-USP,UPenn
Entire home/apt — Philadelphia > Kingsessing
67 reviews
\$103
Per night

7

Bright Room Near Italian Market
Private room — Philadelphia > Passyunk Square
56 reviews
\$62
Per night

Adam Zell reviewed this host

8

Bright Studio in heart of OLD CITY!
Entire home/apt — Philadelphia > Old City
9 reviews
\$110
Per night

Above are the results of a search in Philadelphia for January 2, 2014 to January 5, 2014. Selecting filters or moving the map changes the set of displayed results. The searcher can scroll the page to see 21 listings before she is prompted to go to the next page of results.

Figure 2: Listing View

Photos

Maps

Street View

Calendar

Sunny Room in Queens & Brooklyn

Description

Amenities

House Rules

10 minutes to Williamsburg, 20 minutes to manhattan!

A sunny private room with a Queen size futon and big closet in a new renovated apartment (this March), with a SHARED bathroom , has Wi-Fi, it's on the first floor, so no need to drag your heavy suitcase up down stairs. the street is quite and safe, the building has it's own washer and dryer, (though we still need to pay, but we don't have to walk far to do the laundry),. 3 minutes walk to M train Seneca Stop, 6 minutes walk to L & M train Myrtle-Wyckoff stop. the L & M both takes you to Manhattan in about 15 minutes ride, (than depends on where you are going to)

on the M train you can totally enjoy the sky ride, seeing Brooklyn views, takes you directly to the Central Park, MOMA, China Town, Queens, 5 Pointz (the amazing graffiti scene/blocks/gallery) etc.

the L train connects the most subway lines, hop on the L than very easy to switch to other places that you possibly wanna go to, also directly take you to Williamsburg, east village, Chelsea area, famous sky park - The High Line. and Rushwick (new area for underground

Room type:	Private room
Bed type:	Futon
Accommodates:	2
Bedrooms:	1
Bathrooms:	1
Country:	United States
City:	Queens
Neighborhood:	Ridgewood
Cancellation:	Strict

From

\$43

Per Night

Check in

mm/dd/yyyy

Check out

mm/dd/yyyy

Guests

1

BOOK IT!

SAVE TO WISH LIST

Saved 435 times

Yuchen

CONTACT ME

More about the host

93%

RESPONSE RATE

within a day

RESPONSE TIME

5 days ago

CALENDAR UPDATED

How does Airbnb promote safety?

- Educate yourself about safety
- Protected by the \$1,000,000 Airbnb Host Guarantee
- 24/7 phone support
- Rich user profiles and reviews

A searcher who clicks on a listing in the search results sees the following view. The ratings and text of reviews for the listing are visible lower on the page.

Figure 3: Listing Calendar

Sun	Mon	Tue	Wed	Thu	Fri	Sat
27 \$250	28 \$200	29 \$250	30	31	1	2
3 \$300	4	5	6	7	8	9
10	11 \$250	12 \$200	13 \$200	14 \$250	15	16
17	18 \$250	19 \$200	20 \$200	21 \$200	22	23
24	25	26 \$250	27	28	29	30 \$250

Available
Unavailable
Past

Above is the calendar tab of the listings page. Dates that have already been booked or that the host has marked unavailable are in red.

Figure 4: Inquiry Submission Form

Check in

09/13/2013

Check out

09/16/2013

Guests

2

Tell Alleyn what you like about their place, what matters most about your accommodation, or ask them a question.

Hi,

I'm an Airbnb employee that wants to check out Portland for a weekend with two friends. Is your place available?

☒ **Reuse this message next time I contact a host**

Contacting several places considerably improves your odds of a booking.

Can this host call you about your inquiry?

☒ Yes ☐ No

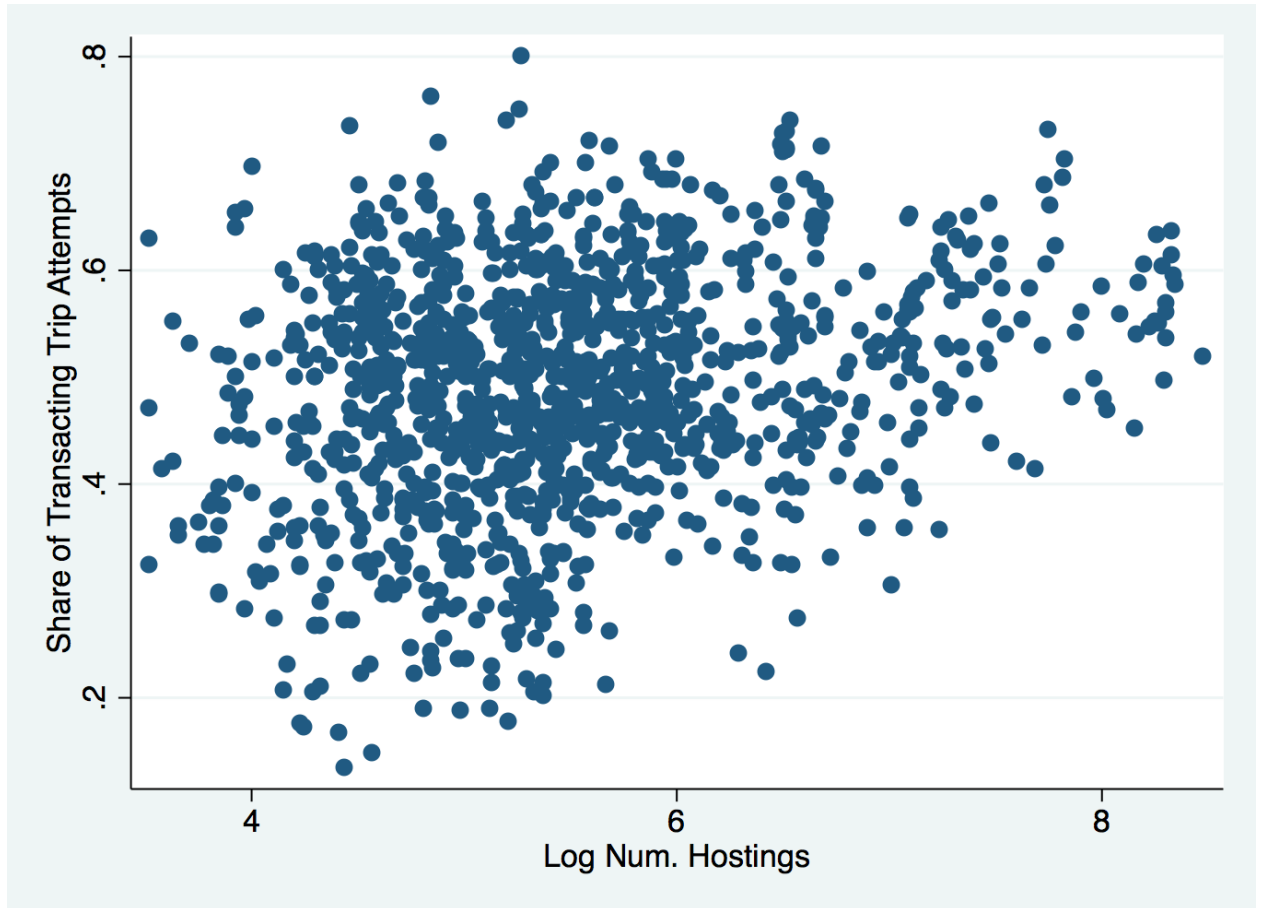
Your number won't be revealed. They can only call from 9am to 9pm in your time zone.

Your time zone: (GMT-08:00) Pacific Time (US & Canada)

SEND MESSAGE

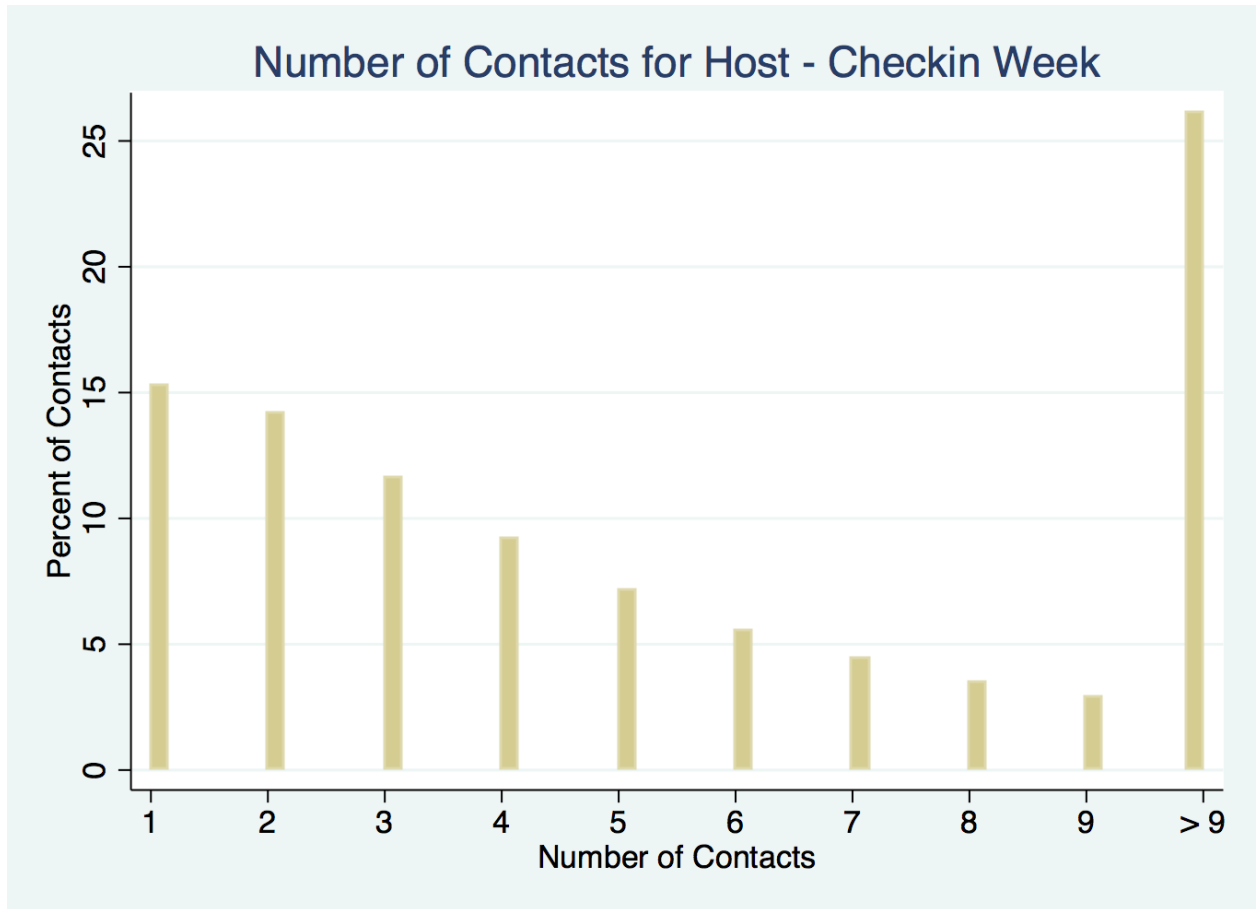
Above is the prompt that searchers see when they click the “Contact Me” button.

Figure 5: Transaction Probability by Size



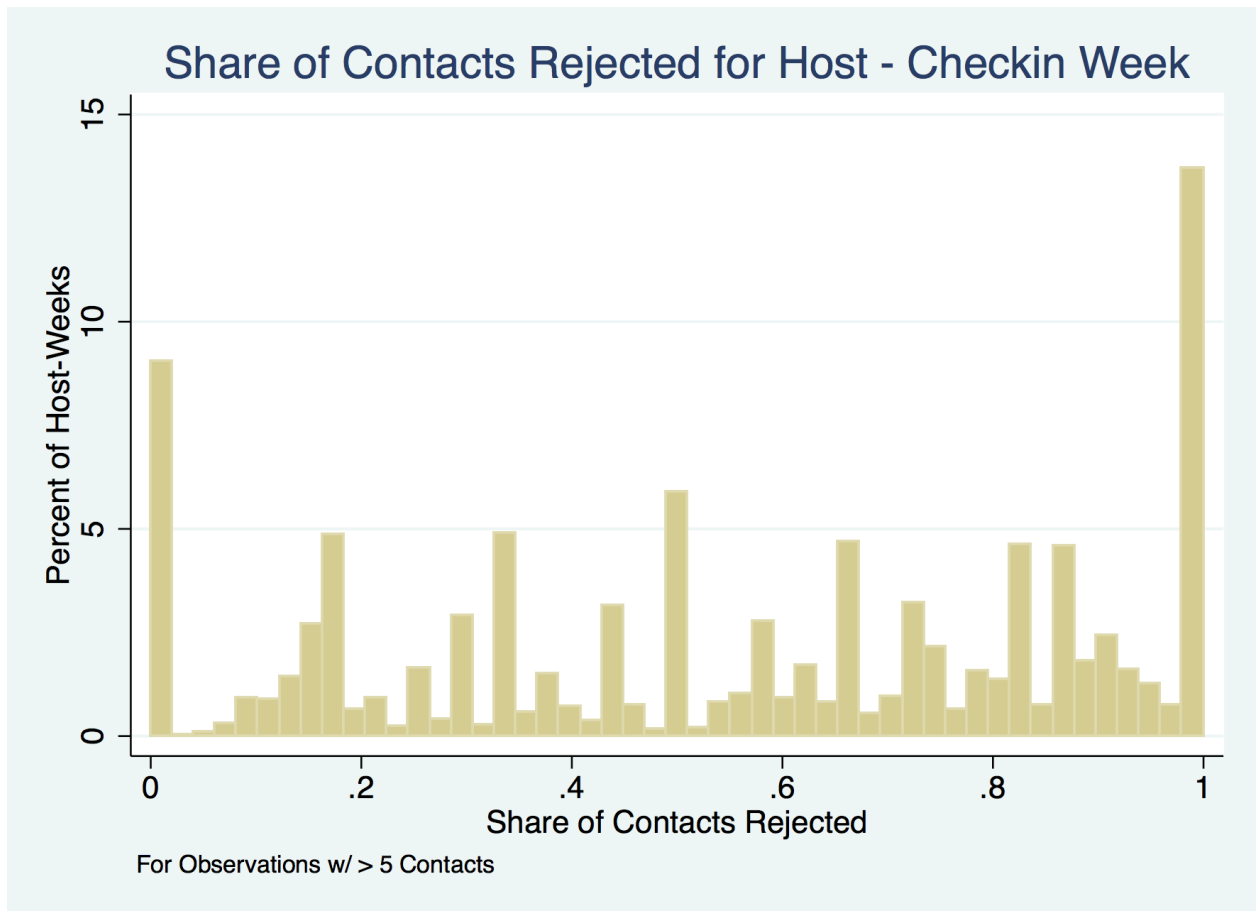
The above figure displays the share of individuals that sent at least one inquiry who transacted per market week. Each point represent a week and a market in 2012 for major US markets. The x-axis is a logarithm of the number of listings in the market for the week of inquiry.

Figure 6: Number of Contacts to a Host for an Overlapping Set of Trip Dates



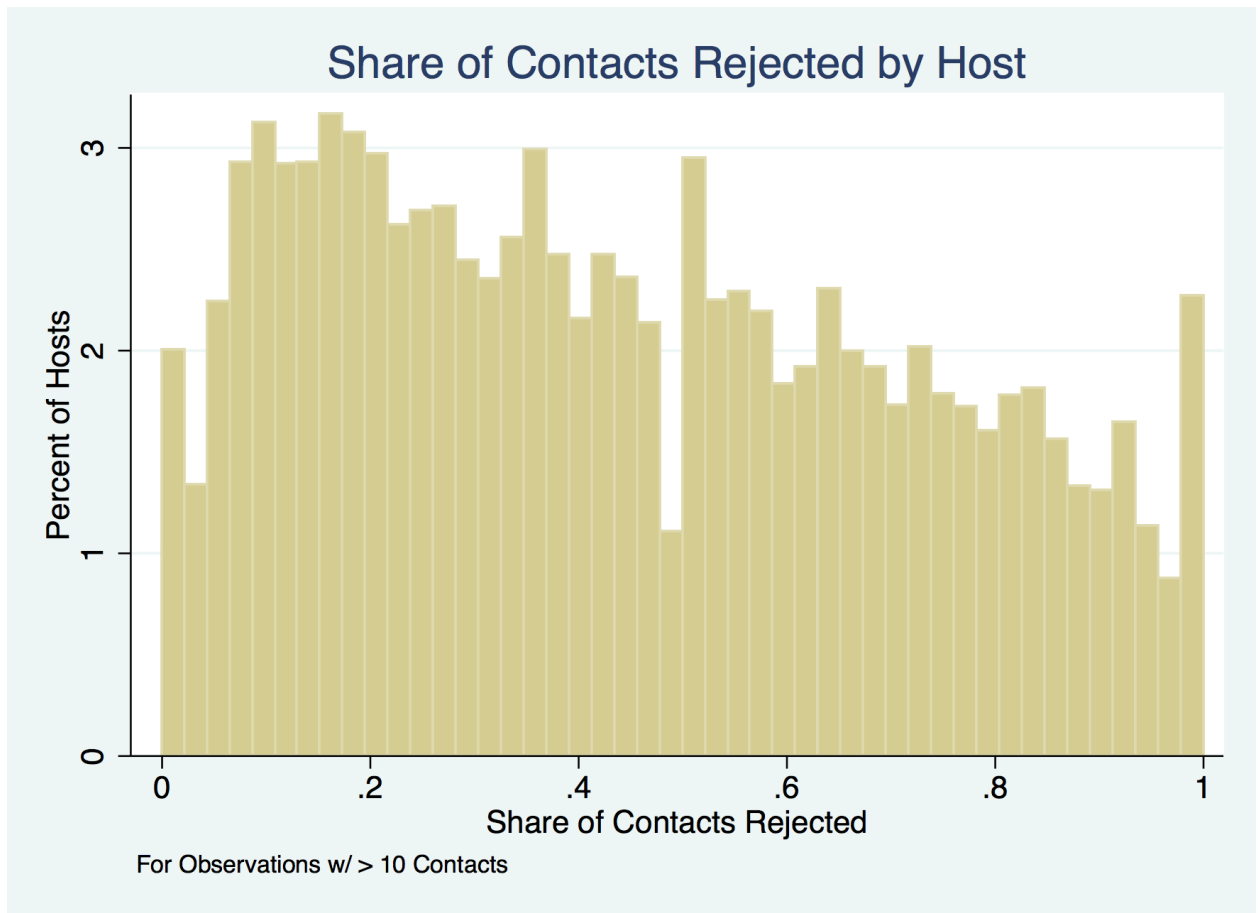
Each observation comprising the above histogram is an inquiry to a host for major markets in the US for 2012. Inquiries to hosts with a given number of total inquiries for a week of check-in are binned.

Figure 7: Average Rejection Rates by Host-Week



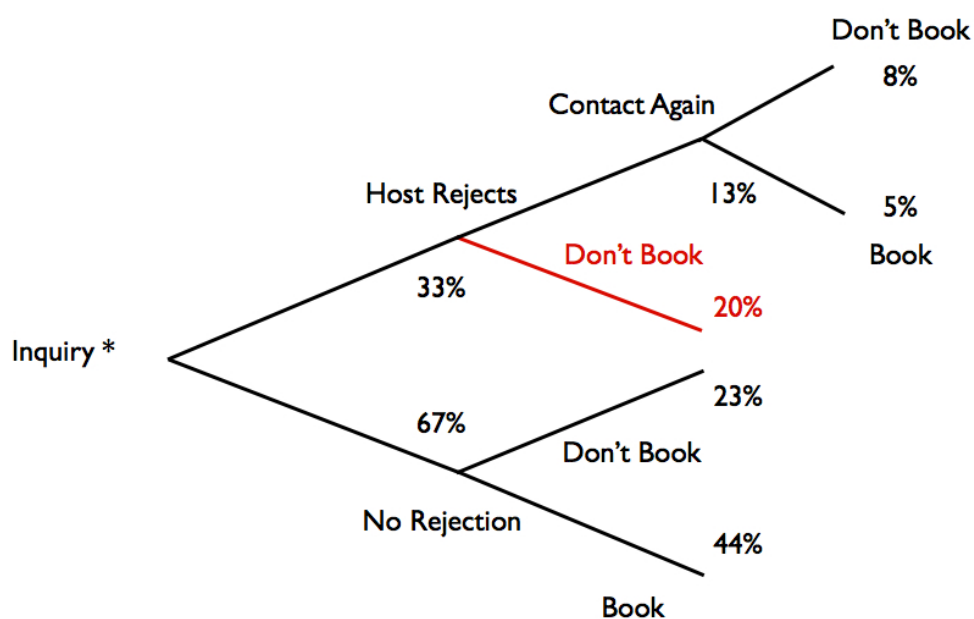
Each observation in the above histogram is a listing and a week of check-in in major US markets in 2012. Only observations with more than 5 inquiries for that week are included.

Figure 8: Average Rejection Rates by Host



Each observation in the above histogram is a listing in a major US market in 2012 with at least 10 inquiries.

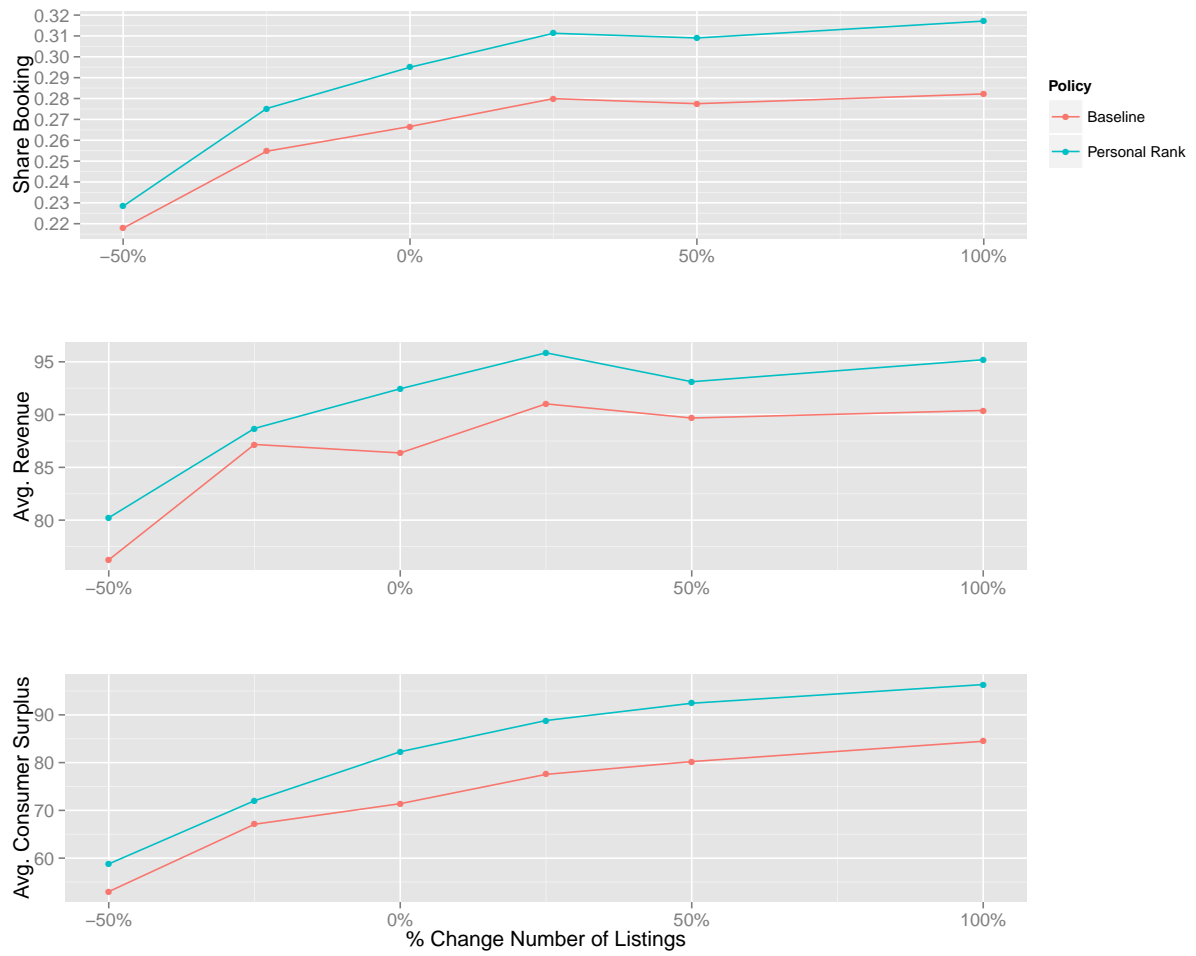
Figure 9: Sequential Search Outcomes



* For trip attempts with only 1 initial inquiry.
70% of all trip attempts in the US 2012.

The figure displays the outcomes of searchers who send an inquiry and don't send more in the following 2 hours. "No Rejection" refers to the case when the initial inquiry was not rejected, "Book" means the guest booked at least one stay for the week and market of the initial inquiry, "Contact Again" means that the guest sent another inquiry to a listing in the same market and week as the initial inquiry.

Figure 10: The Effect of Tightness on Matching Rates



The figure displays what happens to match rates, revenue and surplus per searcher when the amount listings in the market changes but the amount of searchers stays the same. Each point is an average of 10 simulations given a policy and a number of listings. “Baseline” refers to the simulation that keeps current policy while “Personal Rank” refers to a search algorithm that makes searchers more likely to observe high utility listings.

8. Tables

Table 1: Does Rejection Lead to Fewer Bookings?

	(1)	(2)
Rejected	-0.503*** (0.00127)	-0.505*** (0.00128)
Week FE	No	Yes
Market FE	No	Yes
Trip Characteristics	No	Yes
Observations	547680	547680

The above table displays the results of a linear probability model that predicts whether an individual will eventually book given that their initial inquiry was rejected. Specification 2 includes week, market and trip fixed effects.

Table 2: Demand Estimates (In Dollar Terms) With Random Effects

	Baseline	Control Function (Suggested Price)
Control Residual		0.148*** (0.037)
1 - 2 Rev. 4 Rat.	-17.820** (7.990)	-17.917** (6.987)
1 - 2 Rev. 4 + Rat.	12.024*** (3.660)	10.472*** (3.192)
3 - 9 Rev. 4.5 Rat.	7.865 (6.984)	5.487 (6.035)
3 - 9 Rev. 4.5 + Rat.	16.252*** (3.252)	12.856*** (2.817)
10 + Rev. 4 Rat.	0.332 (8.981)	-3.923 (7.768)
10 + Rev. 4.5 Rat.	12.841*** (4.272)	8.385** (3.707)
10 + Rev. 4.5 + Rat.	19.061*** (3.717)	14.117*** (3.240)
Unknown Rating	-2.865 (7.772)	-4.307 (6.723)
Prop. Mgr.	-27.875*** (3.594)	-22.935*** (3.069)
Prof. Pic.	0.956 (2.631)	1.765 (2.231)
Entire Property * 1 Guest	13.317* (7.332)	19.138*** (6.592)
Entire Property * 2 Guests	27.466*** (6.744)	31.889*** (6.091)
Entire Property * 3 Guests	14.334 (10.069)	20.391** (9.059)
Entire Property * 4 Guests	28.141*** (10.500)	32.733*** (9.466)
Entire Property * 5 - 9 Guests	66.364*** (14.942)	66.719*** (13.501)
Entire Property * 10 + Guests	0.085 (33.643)	-1.871 (30.919)
Entire Property * Price	0.149*** (0.058)	0.144*** (0.049)
Price * 2 Guests	0.061* (0.032)	0.054* (0.029)
Price * 3 Guests	0.279*** (0.048)	0.248*** (0.043)
Price * 4 Guests	0.276*** (0.049)	0.246*** (0.043)
Price * 5 - 9 Guests	0.274*** (0.060)	0.246*** (0.054)
Price * 10+ Guests	0.492*** (0.092)	0.465*** (0.088)
Price * Guest Rev.	-0.114*** (0.020)	-0.102*** (0.018)
Price * Age	0.004*** (0.001)	0.004*** (0.001)
Price * Age NA	0.178*** (0.056)	0.160*** (0.050)
Price * 3 - 6 Days Ahead	0.168*** (0.063)	0.149*** (0.056)
Price * 7 - 13 Days Ahead	0.136** (0.060)	0.121** (0.054)
Price * 14 - 20 Days Ahead	0.153** (0.062)	0.137** (0.055)
Price * 21 - 27 Days Ahead	0.159** (0.064)	0.142** (0.057)
Price * 28 - 56 Days Ahead	0.223*** (0.058)	0.200*** (0.051)
SD. Error	45.99	41.02
SD. Listing Random Effect	21.09	15.68
Num. Search Attempts	6,165	6,165

The above table displays the monetary value of characteristics (per night) associated with property listings in the demand model without random effects. The demand model is estimated on a sample of all searchers in City X from April to July of 2013. Standard errors are in parentheses. Neighborhood fixed effects are included in both specifications. “Control Residual” refers to the residual from the first stage regression of listed price on suggested price and other characteristics. “Price” refers to the per night price of the trip, “Days Ahead” refers to the number of days before the check-in at which the inquiry was sent. “Prop. Mgr.” is an indicator that takes on the value 1 if a host manages more than 4 listings. “Prof. Pic.” is an indicator for whether the picture was taken by a verified Airbnb photographer. “Entire Property” is an indicator variable that takes the value 1 when the entire property is being rented out.

Table 3: Demand Estimates (In Dollar Terms) With Random Effects:
Correction for Large Consideration Sets

	Baseline	Control Function (Suggested Price)
Control Residual		0.140*** (0.035)
1 - 2 Rev. 4 Rat.	-17.851** (7.706)	-17.931*** (6.774)
1 - 2 Rev. 4 + Rat.	11.812*** (3.526)	10.385*** (3.090)
3 - 9 Rev. 4.5 Rat.	5.814 (6.652)	3.775 (5.776)
3 - 9 Rev. 4.5 + Rat.	14.628*** (3.077)	11.602*** (2.676)
10 + Rev. 4 Rat.	-3.945 (8.467)	-7.519 (7.362)
10 + Rev. 4.5 Rat.	8.992** (4.003)	5.199 (3.486)
10 + Rev. 4.5 + Rat.	15.542*** (3.491)	11.247*** (3.057)
Unknown Rating	-2.855 (7.383)	-4.194 (6.415)
Prop. Mgr.	-28.447*** (3.327)	-23.730*** (2.856)
Prof. Pic.	0.903 (2.435)	1.673 (2.072)
Entire Property * 1 Guest	28.371*** (1.823)	25.428*** (1.635)
Entire Property * 2 Guests	9.609 (6.941)	15.490** (6.282)
Entire Property * 3 Guests	24.347*** (6.316)	28.847*** (5.746)
Entire Property * 4 Guests	8.841 (9.634)	15.130* (8.720)
Entire Property * 5 - 9 Guests	19.425* (10.042)	24.664*** (9.103)
Entire Property * 10 + Guests	47.008*** (14.366)	49.516*** (13.042)
Entire Property * Price	-9.664 (32.990)	-9.723 (30.463)
Price * 2 Guests	0.169*** (0.054)	0.162*** (0.046)
Price * 3 Guests	0.045 (0.031)	0.040 (0.028)
Price * 4 Guests	0.240*** (0.047)	0.215*** (0.042)
Price * 5 - 9 Guests	0.230*** (0.047)	0.206*** (0.042)
Price * 10+ Guests	0.221*** (0.059)	0.199*** (0.053)
Price * Guest Rev.	0.434*** (0.093)	0.411*** (0.089)
Price * Age	-0.101*** (0.019)	-0.090*** (0.017)
Price * Age NA	0.004*** (0.001)	0.004*** (0.001)
Price * 3 - 6 Days Ahead	0.185*** (0.055)	0.167*** (0.049)
Price * 7 - 13 Days Ahead	0.167*** (0.062)	0.150*** (0.055)
Price * 14 - 20 Days Ahead	0.139** (0.060)	0.125** (0.053)
Price * 21 - 27 Days Ahead	0.155** (0.061)	0.140** (0.055)
Price * 28 - 56 Days Ahead	0.166*** (0.063)	0.149*** (0.056)
Out. Opt. * Log(Viewed Listings)	0.234*** (0.057)	0.212*** (0.051)
SD. Error	45.43	40.79
SD. Listing Random Effect	16.65	11.66
Num. Search Attempts	6,165	6,165

The above table displays the monetary value of characteristics (per night) associated with property listings in the demand model without random effects. The demand model is estimated on a sample of all searchers in City X from April to July of 2013. Standard errors are in parentheses. Neighborhood fixed effects are included in both specifications. “Control Residual” refers to the residual from the first stage regression of listed price on suggested price and other characteristics. “Price” refers to the per night price of the trip, “Days Ahead” refers to the number of days before the check-in at which the inquiry was sent. “Prop. Mgr.” is an indicator that takes on the value 1 if a host manages more than 4 listings. “Prof. Pic.” is an indicator for whether the picture was taken by a verified Airbnb photographer. “Entire Property” is an indicator variable that takes the value 1 when the entire property is being rented out.

Table 4: The Determinants of Host Screening

	Baseline	Random Effects
Rev. Guest	-3.206*** (0.109)	-3.142*** (0.120)
Gender Filled Female	-0.004 (0.038)	0.012 (0.045)
Gender Filled Male	0.081** (0.040)	0.107** (0.047)
3 - 6 Days Ahead	-0.240*** (0.065)	-0.339*** (0.077)
7 - 13 Days Ahead	-0.419*** (0.062)	-0.498*** (0.073)
14 - 20 Days Ahead	-0.473*** (0.066)	-0.576*** (0.078)
21 - 27 Days Ahead	-0.553*** (0.069)	-0.652*** (0.082)
28 - 55 Days Ahead	-0.599*** (0.060)	-0.695*** (0.072)
56 + Days Ahead	-0.585*** (0.061)	-0.623*** (0.075)
Guest Age < 26	0.028 (0.047)	0.017 (0.056)
Guest Age 26 - 34	-0.036 (0.038)	-0.085* (0.045)
Guest Age 35 - 50	-0.054 (0.044)	-0.102* (0.052)
Guest Age 50 +	-0.020 (0.053)	-0.018 (0.063)
<i>N</i>	32,293	32,293
Log Likelihood	-19,894.900	-16,755.090
SD. Host RE		1.469
Trip Characteristics	YES	YES
Month FE	YES	YES

The above table displays the coefficients on host characteristics in a logistic regression that predicts rejections by hosts. Column 1 displays results from a model without listing specific random effects and column 2 includes random effects. "Guest Rev." is an indicator variable for whether the guest has been reviewed.

(a) Guest Characteristics

	Baseline	Random Effects
Price Listed	0.001*** (0.0002)	0.0004 (0.0003)
Host 1 - 4 Reviews	0.106*** (0.034)	0.119** (0.056)
Host 5 + Reviews	-0.247*** (0.031)	0.229*** (0.068)
Property Manager	-1.045*** (0.136)	-1.066*** (0.180)
Host Age < 26	0.040 (0.051)	0.123 (0.158)
Host Age 26 - 34	0.125*** (0.030)	0.018 (0.094)
Host Age 35 - 50	-0.386*** (0.036)	-0.348*** (0.106)
Age 50 +	-0.651*** (0.062)	-0.374** (0.159)
Entire Property	0.698*** (0.086)	0.644*** (0.128)
<i>N</i>	32,293	32,293
Log Likelihood	-19,894.900	-16,755.090
SD. Host RE		1.469
Trip Characteristics	YES	YES
Month FE	YES	YES

The above table displays the coefficients on host characteristics in a logistic regression that predicts rejections by hosts. Column 1 displays results from a model without listing specific random effects and column 2 includes random effects. “Rev.” refers to the number of reviews that the listing had at the time of the inquiry. “Prop. Mgr.” is an indicator that takes on the value 1 if a host manages more than 4 listings. “Age” refers to the host’s age. “Full Property” is an indicator variable that takes the value 1 when the entire property is being rented out.

(b) Host Characteristics

	Baseline	Random Effects
Prop. Mgr. * 3 - 6 Days Ahead	0.468*** (0.173)	0.545*** (0.198)
Prop. Mgr. * 7 - 13 Days Ahead	0.531*** (0.168)	0.552*** (0.192)
Prop. Mgr. * 14 - 20 Days Ahead	0.545*** (0.176)	0.666*** (0.203)
Prop. Mgr. * 21 - 27 Days Ahead	0.751*** (0.184)	0.800*** (0.215)
Prop. Mgr. * 28 - 55 Days Ahead	0.811*** (0.155)	0.855*** (0.181)
Prop. Mgr. * 56 + Days Ahead	0.780*** (0.149)	0.748*** (0.176)
2 Guests * Entire Prop.	0.019 (0.061)	-0.158** (0.074)
3 Guests * Entire Prop.	-0.200* (0.112)	-0.211 (0.139)
4 Guests * Entire Prop.	-0.220* (0.120)	-0.190 (0.155)
5 + Guests * Entire Prop.	-0.541*** (0.125)	-0.388** (0.170)
Entire Prop. * 2 Nights	-0.079 (0.095)	-0.092 (0.112)
Entire Prop. * 3- 4 Nights	-0.099 (0.090)	-0.115 (0.107)
Entire Prop. * 5 -6 Nights	-0.246** (0.106)	-0.280** (0.126)
Entire Prop. * 7 + Nights	-0.518*** (0.105)	-0.566*** (0.127)
<i>N</i>	32,293	32,293
Log Likelihood	-19,894.900	-16,755.090
SD. Host RE		1.469
Trip Characteristics	YES	YES
Month FE	YES	YES

The above table displays the coefficients on host characteristics in a logistic regression that predicts rejections by hosts. Column 1 displays results from a model without listing specific random effects and column 2 includes random effects. “Prop. Mgr.” is an indicator that takes on the value 1 if a host manages more than 4 listings. “Full Property” is an indicator variable that takes the value 1 when the entire property is being rented out. “Days Ahead” refers to the number of days before the check-in date at which the searcher entered the market.

(c) Host - Guest Characteristics

Table 3: RE Search Outcomes

	Num. Simultaneous Contacts - 1	Num Sequential Contacts
2 Initial Con.		0.226*** (0.027)
3 Initial Con.		0.336*** (0.040)
4 Initial Con.		0.566*** (0.057)
5 + Initial Con.		0.933*** (0.042)
Rev. Guest	-0.595*** (0.074)	0.621*** (0.086)
Exp. Guest	-0.464*** (0.067)	-0.079 (0.087)
3 - 6 Days Ahead	-0.047 (0.058)	0.279*** (0.062)
7 - 13 Days Ahead	-0.239*** (0.057)	0.551*** (0.058)
14 - 20 Days Ahead	-0.132** (0.059)	0.417*** (0.060)
21 - 27 Days Ahead	-0.210*** (0.064)	0.497*** (0.063)
28 - 55 Days Ahead	-0.225*** (0.054)	0.655*** (0.056)
56 + Days Ahead	-0.231*** (0.057)	0.722*** (0.057)
Gender Filled Female	0.144*** (0.041)	0.184*** (0.032)
Gender Filled Male	0.053 (0.043)	0.213*** (0.033)
<i>N</i>	15,190	10,354

Column 1 displays the results of a Poisson regression of number of inquiries after initial rejections on trip and guest characteristics. Column 2 displays the results of a regression of number of simultaneous inquiries on guest and trip characteristics. “Initial Con.” refers to the number of inquiries a searcher sent simultaneously at the start of search. “Rev.” and “Exp.” referred to whether the guest was reviewed or had a prior trip, respectively. “Days Ahead” refers to the number of days before the check-in date at which the searcher entered the market. “Filled Female” and “Filled Male” refer to cases when there was information on the gender of the searcher. The estimation sample consists of all non-foreign language inquiries sent by guests in City X between January 2012 and July 2013.

Table 4: Simulation Parameters

Calibrated Parameter	Value
Mean Hours To Book	35.08
Share of Listings Unavailable	0.22
Mean Time of Calendar Update (Days Before Checkin)	37
Mean Number of Listings Viewed	63
Probability of Leaving After Non-Rejection	0.265
Gamma (Determines Correlation of Browsed Listings)	0.5

The parameters above were calibrated to match the analogous moments in the data.

Table 5: Simulation Results

	Data	Baseline
Share Contacting	0.50	0.53
Share Booking	0.31	0.27
Mean Revenue	90.43	87.37
Mean Cons. Surp.		72.32
Sim. Inq. per Contacter	1.43	1.44
Seq. Inq. per Contacter	0.49	0.50
Share Screen Rej	0.29	0.31
Share Stale Vac. Rej	0.16	0.13
Share Cong. Rej	0.03	0.04

Column 1 displays the outcomes that actually occurred for City X and the week of April 10, 2013. Column 2 displays the analogous moments computed using the simulation. Share contacted is the share of searchers that sent at least one inquiry. Share booked is the share of searchers that booked a room. “Sim. Inq. per Contacter” is the average number of simultaneous inquiries sent. “Seq. Inq. per Contacter” is the average number of sequential inquiries sent. “Share Screen Rej”, “Share Stale Vac. Rej”, and “Share Cong. Rej” refer to share of inquiries due to screening, stale vacancies and congestion respectively.

Table 6: The Effect of Frictions in Equilibrium

	Baseline	No Rej.	Full Set	NR + FS	Max CS
Share Contacting	0.53	0.50	0.84	0.66	0.48
Share Booking	0.27	0.37	0.39	0.48	0.48
Mean Revenue	87.37	120.83	133.35	172.10	149.81
Mean Cons. Surp.	72.32	80.26	130.88	144.47	159.88

The above table displays the average outcome of 100 simulations for each counterfactual scenario. Column 2 shows results in which searchers cannot send inquiries to hosts who would reject them for any reason. Column 3 shows simulation results if searchers have all options in their consideration set. Column 4 shows results in which searchers have all options in their consideration set other than those that would reject them. Column 5 gives outcomes from the solution to the assignment problem which maximizes consumer surplus.

Table 7: The Effect of Rejections in Equilibrium

	Baseline	No Screen	No Cong.	No Stale	No Rej.
Share Contacting	0.53	0.52	0.53	0.53	0.50
Share Booking	0.27	0.34	0.27	0.29	0.37
Mean Revenue	87.37	111.92	88.80	94.49	120.83
Mean Cons. Surp.	72.32	81.78	72.59	74.55	80.26

The above table displays the average outcome of 100 simulations for each counterfactual scenario. Columns 2-4 shows results from simulations in which individuals cannot send inquiries to hosts who would have rejected those searchers due to screening, congestion and stale vacancies respectively. Column 5 shows results in which searchers cannot send inquiries to hosts who would reject them for any reason.

Table 8: Effects of Marketplace Policies

	Baseline	Best Rank	Personal Rank	Hide High Prob	More Search	Pause Overlap
Share Contacting	0.53	0.59	0.60	0.53	0.53	0.53
Share Booking	0.27	0.29	0.29	0.27	0.27	0.27
Mean Revenue	87.37	89.29	91.56	87.07	88.50	90.01
Mean Consumer Surplus	72.32	79.49	81.21	71.06	70.13	71.41
Simultaneous Inquiries per Contacter	1.44	1.46	1.47	1.42	1.60	1.43
Sequential Inquiries per Contacter	0.50	0.55	0.56	0.48	0.53	0.48
Share Screening Rejections	0.31	0.29	0.29	0.28	0.31	0.31
Share Stale Vacancy Rejections	0.13	0.16	0.17	0.13	0.13	0.13
Share Congestion Rejections	0.04	0.05	0.05	0.04	0.03	0.02
Mean Search Cost	3.36	5.96	6.09	5.01	5.67	5.02

The above table displays the average outcome of 50 simulations for each counterfactual scenario. Column 2 shows results from the simulation in which all searchers saw the highest average utility properties in search. Column 3 shows results from the simulation in which all searchers saw a personalized ranking. Column 4 shows results if the propensity of searchers to simultaneously search was doubled.

Table 9: Aggregate Matching Function

	Log(Bookings)
Constant	-1.689*** (0.116)
Personalized Algorithm	-0.035 (0.164)
Log(Listings)	0.226*** (0.012)
Log(Searchers)	0.831*** (0.012)
Personalized Algorithm * Log(Listings)	0.061*** (0.017)
Personalized Algorithm * Log(Searchers)	-0.042** (0.017)
Observations	500
R ²	0.954

The above table displays the average outcome of 10 simulations for each counterfactual scenario. Column 2 shows results from the simulation in which all searchers saw the highest average utility properties in search. Column 3 shows results from the simulation in which all searchers saw a personalized ranking. Column 4 shows results if the propensity of searchers to simultaneously search was doubled.

Table 10: Experimental vs Market Level Effects of Better Search Rankings

	AB	Market
Change in Share Contacting	0.086	0.060
Change in Share Booking	0.035	0.018
Change in Mean Revenue	5.802	1.920
Change in Mean Consumer Surplus	12.079	7.161

The above table displays the average outcome of 50 simulations for each counterfactual scenario. Column 1 shows the treatment effect of seeing the “Best Rank” search algorithm in a 50% experiment at a searcher level. Column 2 shows the actual effect of the “Best Rank” policy if all searchers were to see it.

A. Appendix: Rejection Classification

This Appendix describes how to use a regularized logistic regression to classify the text of communications between hosts and guests. I divide each message into individual words and combinations of words (n-grams).²⁴ I use n-grams as features in a regularized logistic regression (RLR) that predicts whether a message is a rejection or not.

The process of classification requires two steps: training and prediction. The procedure requires definitive cases when a message is either a rejection or not a rejection. A definitive case of a non-rejection occurs when a thread eventually leads to a transaction. A definitive case of a rejection occurs in a subset of messages for which hosts label that the room is “Not Available”. I choose the top 30 thousand n-grams in my sample in addition to features for question marks and the number of sentences for my classifier. Prior to classification, I correct the text for common misspellings and determine the language of the text (See Appendix for details).

The RLR is estimated using 500 thousand labeled messages. The purpose of using regularization is to reduce over-fitting that might occur when so many features are included. The RLR penalizes the model for having too many non-zero coefficients. The classifier places high weight on n-grams such as “Sorry”, “Unfortunately”, “Is Occupied” for rejections. I test the validity of the procedure using two methods. First, I use the estimated model to classify a hold-out sample of labeled data. The classifier achieves a type 1 error of 2.6% and a type 2 error of 2.0%. That is, 2.6% of non-rejections are labeled as rejections and 2.0% of rejections are mistakenly labeled as non-rejections. The second validation I use is a manual inspection of 500 previously unlabeled messages. The classifier has a type 1 error of 3.4% and a type 2 error 8.1% in that subsample.

I combine classifications from the NLP classifier with cases when the response is discernible through other methods. The final classification works as follows. If a contact led to a booking or if it was labeled as accepted by the host then it is classified as ‘not rejected’. If a response was labeled by the host as a rejection or if there was no response within the week after the inquiry then the contact is classified as a rejection. If a response is classified as having a foreign language then it is not used in the analysis.²⁵ Lastly, if the contact does not fit into any of the above categories, the NLP classifier is applied to the first (or in some cases second) response by a host to a guest. In total, 49% of all inquiries were rejected. Of all contacts classified as rejections, 37% were cases in which a host did not respond, 30% were host classified rejections after an inquiry and 32% used the NLP classifier.

²⁴For example, “car” is a 1-gram, “my car” is a 2-gram and “my fast car” is a 3-gram.

²⁵An inquiry with 3 or more words was tested for being in a foreign language if it had more than 30% of words that were not in the English dictionary and were not common misspellings. The message text was run through a language detection algorithm in Python called “guess-language” (<http://code.google.com/p/guess-language/>). If the algorithm guessed a valid non-English language then the inquiry was classified as being in a foreign language. A 50% cutoff was used for inquiries with 2 words.

B. Appendix: Derivation of Sample Weights

Table 11: Determinants of Sampling Weights

Private Room	−0.324*** (0.010)
1 - 4 Reviews	0.778*** (0.012)
5 - 9 Reviews	1.269*** (0.013)
10 - 19 Reviews	1.795*** (0.013)
20 - 39 Reviews	2.182*** (0.014)
40 - 80 Reviews	2.563*** (0.021)
80 + Reviews	3.479*** (0.036)
Price (50 - 74) USD	0.223*** (0.016)
Price (75 - 99) USD	0.292*** (0.017)
Price (100 - 149) USD	0.242*** (0.018)
Price (150 - 199) USD	0.526*** (0.019)
Price (200 - 299) USD	0.399*** (0.022)
Price (300 - 499) USD	0.349*** (0.026)
Price (500 +) USD	−0.096** (0.044)
Person Capacity	0.049*** (0.002)
Num. Pictures	0.015*** (0.0004)
Listing Tenure (Days)	−0.002*** (0.00002)
Neighborhood FE	YES
Num. Searchers	71,781

The above table displays the coefficients on listing characteristics which predict whether that listing is a part of a searcher's consideration set. The model is a conditional logistic regression.

C. Appendix: An Urn and Balls Model of Matching

To see how search frictions affect the matching rate consider the simple urn and ball model of matching described in [Petrongolo and Pissarides \(2001\)](#). Suppose there exists a mass, G , of identical guests sending 1 inquiry each to a mass, L , of identical listings who can only transact with one guest each. The resulting number of matches produced is $L(1 - e^{-G/L})$. If an all-knowing social planner was matching guests and listings then the total amount of matches would be $\min(G, L)$. To simplify further analysis, suppose that $L < G$. Therefore, the total inefficiency in the marketplace is a function of the failed matches, $Le^{-G/L}$. Inefficiency in this model comes from a coordination friction, where some listings reject guests because they are already booked. The welfare costs of the friction in this model are a function of the match utility of unmatched agents who could have been matched and the costs of wasted search.

Another friction that exists on Airbnb is that some listings are not actually available to anyone. Suppose that there is a mass of stale listings, U , which are not interested in transacting although they are visible to guests. The amount of matches in the marketplace

becomes $L(1 - e^{-\frac{G}{L+U}})$, with the amount of inefficient search equal to: $Le^{-\frac{G}{L+U}} > Le^{-G/L}$. Stale listings increase inefficiency due to additional mismatch and wasted search costs. Stale listings could be even more important in dynamic matching markets because the likelihood of a stale listing being contacted increases as non-stale listings are booked.

Lastly, there are some hosts who are selective about which guests and trips they are willing to host. Suppose that listings are only willing to transact with a random subset of searchers. Let there be a mass of K selective sellers who are willing to transact with a random guest at a rate c . The remaining $L - K$ non-selective sellers are willing to transact with anyone. The aggregate number of matches in the marketplace will be $(L - K)(1 - e^{-\frac{G}{L+U}}) + K(1 - e^{-\frac{cG}{L+U}})$ and the number of inefficient inquiries is, $Le^{-\frac{G}{L}} + K(e^{-\frac{cG}{L}} - e^{-\frac{G}{L}})$, where the first term represents coordination and stale vacancies and the second term represents screening frictions. In turn, the cost of screening frictions depends on the share of listings which are selective, $\frac{K}{L}$ and on the selectivity of the listings, c .

The frictions in an urn and balls model all operate through the rejection channel. When inquiries are rejected, search effort is wasted and potential transactions do not happen. A full model, such as the one of the paper, would account for the ability of searchers to conduct sequential and simultaneous search. Furthermore, such a model would allow for some searchers to leave after being being accepted for a variety of reasons. Nonetheless, most of the intuition from an Urn and Balls model will hold in more realistic models of matching. Rejections will occur, will be costly to searchers and will slow the rate of match formation. The quantitative impact of frictions must, however, be determined within a more realistic model that accounts for heterogeneity, simultaneous search and dynamics.

D. Appendix: Robustness of Results to Random Utility Assumptions

Forthcoming