Spatial Distribution of Access and the Role of Market Thickness: Theory and Evidence from Ride-Sharing

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Abstract

This paper studies the effects of economies of density in transportation markets, focusing on ridesharing. Our theoretical model predicts that (i) economies of density skew access to supply of drivers away from less dense regions, (ii) the skew will be more pronounced for smaller platforms (i.e., "thinner markets"), and (iii) rideshare platforms do not find this skew efficient and thus use prices and wages to mitigate (but not eliminate) it. We show that these insights are robust to whether the source of economies of density is the supply side or the demand side. We then calibrate our model using ride-level Uber data from New York City. We devise an identification strategy based on relative flows of rides among regions which allows us to infer unobsrevable potential demand in different boroughs. We use the model to simulate counterfactual scenarios providing insights on platform optimal pricing with and without spatial price discrimination, the role of market thickness, the impact of prices/wages on access to rides, and the effects of minimum-wage regulations on access equity across regions.

Keywords: Spatial Markets; Transportation; Economies of Density; Market Thickness; Ridesharing

1 Introduction

Ridesharing markets are increasingly forming an important and critical part of the transportation networks of major metropolitan areas (Fortune Business Insights (2021)). In these markets, ridesharing firms act as two-sided platforms, intermediating between consumer (passenger) demand, and driver supply. Ridesharing markets are *spatial*. Thus, inequality in access to rides across geographic areas is an important challenge, that has drawn attention from regulators, lawmakers as well as consumer and community advocates (Jin et al. (2019), Diao et al. (2021)). Such markets are prone to spatial agglomeration of drivers in high-density regions. While such agglomeration could improve matching locally, it comes at the expense of other, sparser, regions. Crucially, it is challenging to examine whether and to what extent the platform would find such agglomeration efficient: on the one hand, the platform benefits from better local matching in areas with agglomeration; but on the other hand, drivers that agglomerate in denser regions exacerbate the sparsity of the areas they abandon, an externality that the platform internalizes. Finally, it is challenging to empirically measure the extent to which some regions are under-served relative to others, given that unfulfilled demand is unobservable.

This paper studies this issue of inequality in access to ridesharing services across regions within large metropolitan areas. We use a combination of closely connected theoretical and empirical analysis. Our theoretical model examines drivers' and passengers' decision making among a set of $I \geq 2$ regions in a spatial market with a monopolist rideshare platform. Each region has an arrival rate of potential demand for rides that could end in the same region or a different one. Actual demand is a fraction of potential demand, depending on price (and wait time) in region i. A novel feature of our model is that it endows each region with a size rather than considering it a point. There is an infinite pool of potential drivers. Each driver chooses whether and in which region to enter the market. Each driver makes this choice to maximize her revenue given other drivers' choices. Revenue in each region is positively related to the wage per ride in that region and negatively related to the "total wait time" each driver has to wait in the region to give a ride to a passenger. Total wait time consists of (i) "idle time," the time it takes for the driver to be assigned to a passenger requesting a ride, and (ii) "pickup time," the time it takes to arrive at the pickup location after being assigned to a passenger. More drivers operating in each region i means a higher expected idle time in i. This forces the supply of drivers to geographically distribute itself proportionally to the distribution of demand. On the other hand, more drivers in region i means a lower expected pickup time in i, forcing drivers to agglomerate. This agglomeration can happen either because drivers directly prefer shorter pickup times (which we define as Supply-Side Economies of Density, or S-EOD) or because demand positively responds to short pickup times and supply follows (which we define as Demand-Side Economies of Density, or D-EOD). The interplay between the balancing force through idle times and the agglomerating force through pickup times has a key role in our results. The platform decides the price per ride p_i and driver wage per ride c_i in each region i. Any passenger who needs a ride gives rise one unit of "potential demand". This passenger actually decides to demand a ride if the price is below her willingness to pay (and, under D-EOD, if driver arrival time is sufficiently short). The percent-fulfillment of this realized demand in turn depends on the availability of driver supply. We define "access" to rides in any region i as the number of rides as a fraction of *potential* demand. We use this model to deliver a number of results on how the spatial distributions of access to rides is shaped in response to the incentives of the platform, drivers, and passengers.

Our theoretical results based on the above model are qualitatively the same in case of either supply-EOD or demand-EOD. First, we find that access is skewed in equilibrium in favor of regions with higher potential-demand density. The primary reason for access skew is higher pickup times in sparser regions. Second, we find that platform size plays a significant role in access skew, with smaller platforms obtaining more unequal access. The intuition is that larger platforms have more demand, and correspondingly more driver entry, which leads to lower pickup times across the board. This reduces the importance of pickup times relative to idle times, and leading to more equal access across regions. Our third result finds that a profit-maximizing platform would optimally use prices and wages to mitigate but not fully eliminate the access skew. The platform implements this by offering higher wages to drivers in sparser regions but does only partially passing that extra wage on to passengers. It is helpful to understand why: The platform, like the drivers and passengers, benefits from the decreased pickup times due to EOD, hence the incentive to not fully eliminate the access skew. However, drivers do not internalize the negative externality they exert on sparser regions when they agglomerate in denser ones. The platform, however, does internalize this externality and would, hence, stand to gain from mitigating "over-agglomeration" of drivers.

We next take the theoretical model to data from Uber, the largest Rideshare platform in New York City (NYC), from March to June 2019. We leverage ride-level data on rides (including pickup and drop-off location), driver wages and prices across the regions (boroughs) of NYC. The dataset is publicly available from NYC's Taxi and Limousine Commission (TLC), and is rich in frequency of observations, with the complete rides across the regions of the city available collected in a standardised way. We use this data to calibrate our model.

A key part of our calibration is an identification strategy that we develop for inferring the ratio between access to rides in given regions i and i'. This is critical because access (i.e., rides divided by potential demand) is unbservable due to potential demand being uonbservable. Our strategy is based on an assumption that potential demand for rides from i to i' are equal to those from i' to i during any time period encompassing one or multiple days. This, in turn, is motivated by the assumption that for every trip there is a "trip back" by the same person shortly after (otherwise, the trip itself is the "trip back" for one that must have happened shortly before). Combined with other supplementary assumptions which we will detail later in the paper, this strategy allows us to prove a powerful result: access ratio between regions i and i' is equal to the ratio of rides from i to i' to those in the opposite direction. In summary, our identification strategy contributes to the literature by noting that in order to learn about unfulfilled demand in a region, one can leverage data not only on rides starting in that region, but also on rides *ending* there.[1] This approach allows us to avoid relying on supply-side moments for identification, which would require us to assume that the platform price and wage strategy are optimal.

We embed the above strategy within a formal estimation procedure with two steps. We first recover the number of rides for all origins and destinations as a function of model parameters and using the structure of our model. Next, we match those recovered rides to observed rides (specifically, we match relative flows of rides for all pairs of regions) to recover model parameters. We prove identification works under both S-EOD and D-EOD as long as there is sufficient independent variation between region densities and prices. Intuitively, this leverages our result that relative flows between regions recover access ratios. Access levels among regions can differ due to pricing or due to demand density. Thus, if there is sufficiently independent variation between the two, the role of each factor in shaping the access levels across regions is identified.

[1]In the main text of the paper, and then to a greater extent in the appendix, we provide further evidence as to why our identification strategy based on relative flows of rides is a useful one.

We then estimate the model not only for the extreme cases of S-EOD and D-EOD, but also for multiple in-between cases where a fixed "portion" of EOD comes from the supply side and the rest from the demand side. In all of these estimates, we consistently find that the potential-demand density is highest in Manhattan and lowest in the Bronx, with the rank ordering being the same irrespective of the source of EOD. We find that across a wide range of relative strengths of these two sources of EOD, the results are qualitatively the same. The price elasticities obtained by our model are reasonable and in the same range as findings in the literature for the same market.

We use our calibrated model to simulate five counterfactual scenarios. First, we examine how a profit maximizing platform would set prices and wages. We find that the profit maximizing price is 50% greater than the current price. These higher prices would lead to lower access across all regions, but there is also a distributional effect that decreases access skew across regions. Second, we evaluate the impact of platform size (i.e., market thickness) on the outcomes, by scaling up potential demand across all regions. As predicted by our theory, we observe that as the size increases, access levels increase in all regions while the skew in access is attenuated. To illustrate the magnitude, in one of our specifications, we find that access to rides in Manhattan under optimal pricing increases from 37.0% to 38.7% if Uber's potential demand grows from 80% of the size we estimate to 120% of the size we estimate. This 1.7pp growth in access translates to about 4.6% increase. The same numbers for Queens are 28.8% and 31.6% respectively, which translate to about a 9.7% increase in access. Our third counterfactual restricts the platform to using the same price and wage rates across regions (say, due a citywide regulation). We find that under such a counterfactual, geographical skew in access to rides gets exacerbated. More precisely, the ratio between access levels in the borough with the lowest access (Queens) and that with the highest access (Manhattan) drops from about 80% to about 60% if the platform does not use spatially differentiated pricing to mitigate the inequity. This result points to the idea that imposing equality in actions taken by a firm (platform) might exacerbate outcomes (access skew) that policy makers care about. The fourth counterfactual evaluates what level of region-specific wages will result in equalized access across regions. We find that the platform would need to pay significantly higher wages in low-demand regions (Queens) relative to high-demand regions (Manhattan). Also, as the platform size increases, the wages across the regions required to equalize access would converge. Finally, we examine the impact of minimum wage regulation that is common across regions. We find that such minimum wages might lead to lower access, because even though higher wages would result in more driver supply, the platform would raise prices beyond the level that was profit maximizing without the minimum wage constraint, which in turn would then harm access levels. Additionally, we find that access skew across regions would be lower in the presence of a minimum wage.

In summary, our paper contributes to the study of economies of density in rideshare in at least four important ways. First, our model endows each region with a non-trivial size which allows to capture the notion of pickup time in each area and how it varies with driver density. This, in turn, allows us to model economies of density both on the supply side and on the demand side. Second, our empirical strategy to recover access differences across regions based on relative flows of cross-region rides is powerful in that it helps infer unobservable access levels using only ride-level data. Third, we study (theoretically and empirically) not only driver behavior, but also that of the platform and the potential ways the incentives between the two entities might be (mis)aligned when it comes to economies of density. Finally, we extensively document (both theoretically and empirically) that the major implications of economies of density for rideshare markets–as summarized in our main results–are robust to what portion of economies of density arises from the supply side and what portion from the demand side.

There are a few aspects of our model that generalize beyond ride-sharing to spatial markets more broadly. First is the research examining platform incentives. The same mis-alignment between platform and driver incentives that we document in ride share could exist in other spatial markets (between micro-suppliers and a social-planner/market-maker) when it comes to economies of density. Second, in other passenger-transportation markets, leveraging the concept of relative outflows across regions could be applied to infer unfulfilled demand. Third, our results point to the fact that imposing constraints on firm actions (e.g. prices and wages) to make them more equal across regions may backfire by making other outcomes (e.g. access) more unequal across regions. Given that the same notion could apply in other markets, policymakers should adopt a more nuanced role in evaluating whether and how platforms share an incentive to achieve equity goals before imposing regulations.

2 Literature Review

Our paper relates to multiple strands of the literature: (i) the recent and growing literature on the empirical analysis of geographical distribution of supply, and its possible distortion from that of demand, in spatial markets; (ii) the literature on transportation markets (in particular ridesharing); and (iii) the literature that studies the effects of market thickness in two-sided markets.

The empirical literature on the spatial match between supply and demand is new and small. To our knowledge, Buchholz (2018); Brancaccio et al. (2019c) are the only papers directly examining this issue, and papers such as Frechette et al. (2019); Brancaccio et al. (2019a,b) look at related problems. They extend the empirical techniques in the matching literature (see Petrongolo and Pissarides (2001) for a survey) in order to structurally infer the size of unobserved demand (e.g., passengers searching for rides) in different locations of a decentralized-matching market when only the size of supply (e.g., available drivers) and the number of demand-supply matches (e.g., realized rides) are observed. They accomplish this by inverting a matching function that gives the number of rides as a function of searches and vacancies. Our relative-outflows method is complementary. On the one hand, it requires the extra assumption that potential demand for rides from region i to region i' is the same as that for rides in the opposite direction. We justify this in our application by noting that almost all passengers have a home base that they need to return to, if the time period considered spans at least a day. But this assumption would clearly not hold if what is transported is goods rather than passengers. On the other hand, our method (i) requires data only on the number of rides rather than rides *and* vacant supply, search time, etc.; (ii) it applies generally to all passenger-transportation markets regardless of whether the matching system is centralized (e.g., rideshare) or decentralized (e.g., taxicabs);[2] and, finally, (iii) our approach detects skew of supply away from a given region i even if in response to short supply, passengers in i have learned to forego searching (which would make it look like demand is low).

The second strand of the literature to which our paper relates is the set of papers on the functioning of transportation (in particular rideshare) markets. This strand itself can be roughly divided into (at least) two categories. One category is the group of papers focusing on this market as it relates to labor economics.[3] The second category, to which our paper belongs, consists of papers focusing on evaluating the performance of these markets and on market design aspects. Some of those papers, although related to our work in many ways, focus on questions that are inherently not spatial (examples are Cohen et al. (2016); Nikzad (2018); Lian and van Ryzin (2019); Cachon et al. (2017); Guda and Subramanian (2019); Asadpour et al. (2019)). Others study questions that are related to the spatial nature of the market (such as Castillo et al. (2017); Frechette et al. (2019)), but they do not examine the spatial distribution of supply and potential mismatches with demand. Many of the papers that do study geographical supply-demand (im)balance in transportation (such as Banerjee et al. (2018); Afèche et al. (2018); Besbes et al. (2018)) focus on the short-run, intra-day, aspects. Some other papers (such as Buchholz (2018); Lagos (2000, 2003); Bimpikis et al. (2019); Shapiro (2018); Lam and Liu (2017); Garg and Nazerzadeh (2019); Ata et al. (2019); He et al. (2020)), however, examine such spatial markets from a long-term perspective. Our paper is complementary to this literature in that it provides a detailed theoretical and empirical investigation of economies of density (arising from both supply and demand sides) and market thickness, while abstracting away from some of the phenomena considered in these papers.

It is worth noting that a large part of this literature has focused on the ways in which rideshare platforms improve upon the traditional taxi system, in particular due to their flexible pricing and superior matching algorithms (Cramer and Krueger (2016); Buchholz (2018); Frechette et al. (2019); Cohen et al. (2016); Shapiro (2018); Castillo et al. (2017); Besbes et al. (2018); Lam and Liu (2017) among others). We add to this literature by arguing that even within the world of rideshare which utilizes central matching, the quality of supply-demand match may be influenced by platform size.

Also close in spirit to our paper in this strand of the literature is Rosaia (2023), which studies

[2] Another subset of the literature on spatial markets that this paper builds on is the study of location decisions, resulting in agglomeration. Papers such as Ellison and Glaeser (1997); Ahlfeldt et al. (2015); Datta and Sudhir (2011); Holmes (2011); Miyauchi (2018) examine agglomeration of firms or residents. We add to this literature by arguing, empirically and theoretically, that agglomeration is also present in transportation markets. In addition, our comparative static theory results, which characterize how the extent of agglomeration is impacted by different factors, may be applied beyond transportation systems.

[3] For instance, Chen et al. (2017) examine how much workers benefit from the schedule flexibility offered by ridesharing. Cramer and Krueger (2016) study the extent to which ridesharing, compared to the traditional taxicab system, reduces the portion of time drivers are working but not driving a passenger. Chen and Sheldon (2016) examine the reaction of labor supply to the introduction of ridesharing. Buchholz et al. (2018) estimate an optimal stopping point model to study the labor supply in the taxi-cab industry.