Transportation Research Part C 92 (2018) 58–75

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Geometric matching and spatial pricing in ride-sourcing markets

Liteng Zha[a], Yafeng Yin[b,*], Zhengtian Xu[b]

[a] Department of Civil and Coastal Engineering, University of Florida, 365 Weil Hall, Gainesville, FL, United States
[b] Department of Civil and Environmental Engineering, University of Michigan, 2350 Hayward Street, Ann Arbor, MI, United States

ARTICLE INFO

Keywords:
Ride sourcing
Spatial pricing
Geometric matching
Spatial equilibrium and regulation

ABSTRACT

This paper develops a model to investigate the effects of spatial pricing on ride-sourcing markets. The model is built upon a discrete time geometric matching framework that matches customers with drivers nearby. We demonstrate that a customer may be matched to a distant vehicle when demand surges, yielding an inefficient supply state. We further investigate market equilibrium under spatial pricing assuming a revenue maximizing platform, and find that the platform may resort to relatively higher price to avoid the inefficient supply state if spatial price differentiation is not allowed. Although spatial pricing facilitates market clearing, the platform may still set price more than the efficient level, which compromises the public interest. We then propose a commission rate cap regulation that reaps the flexibility of spatial pricing and can achieve the second best under some homogeneity assumptions.

1. Introduction

Ride-sourcing companies such as Uber, Lyft and Didi Chuxing are transforming the way people travel in cities. These companies provide real-time, internet-based platforms that intelligently source ride requests to affiliated private drivers nearby.[1] Compared to the traditional dispatch taxi service, the online matching does not involve a human dispatcher and makes it possible for dispatch to be optimized at scale. The online matching also differs from street hailing in the sense that the "matching" distance between customers and drivers is now enlarged to a few miles, allowing a smaller "critical mass" of customers to sustain the market. Consequently, cities where street hailing was previously unstainable are experiencing a boom in ride-sourcing services.

Ride sourcing employs a similar trip fare structure as traditional taxi services, which includes a frag-drop fee, a time-based and a distance-based charge. For each completed trip, the platform charges a commission that is usually 20–25% of the fare paid by the rider. One of the most important features of the ride-sourcing market is its price differentiation, e.g., Uber's surge pricing and Lyft's prime time pricing. The differentiation is both temporal and spatial. It is advertised to be triggered when the vehicle supply is in shortage (or equivalently if demand surges) so as to attract more drivers to come online or serve the supply-shortage areas as well as limit the service to customers with the higher willingness to pay (Hall et al., 2015; Chen and Sheldon, 2016). Typically, surge pricing is implemented by multiplying a price multiplier to the base trip fare. The price multipliers are area-specific and updated periodically. Both customers and drivers are informed of the price multipliers before transactions occur (Chen et al., 2015). However, the industry practice of surge pricing has led to objection among its customers. Some are frustrated and even angered after being charged significantly higher fares (Curley, 2014; Didi Chuxing, 2017). Others expressed concern that platforms use surge pricing to collect

* Corresponding author.
E-mail address: yafeng@umich.edu (Y. Yin).

[1] The business models of these companies are becoming more comprehensive, and their service features include ridesharing and on-demand shuttles, etc.

https://doi.org/10.1016/j.trc.2018.04.015
Received 18 December 2017; Received in revised form 14 April 2018; Accepted 18 April 2018
0968-090X/

more revenue under the current percentage commission structure. The public outcry is further intensified when one single platform dominates the marketplace. To respond, Didi has self-imposed a dual cap control on price surge since March 2017[2] (Didi Chuxing, 2017).

In contrast to the fast growth of the ride-sourcing industry, the reaction from regulatory agencies has somewhat lagged. The current efforts still focus on ensuring its level of service such as vehicle inspection, insurance requirement and driver censoring. To our best knowledge, there is no formal regulation on the platform's price setting. This study contributes to the ongoing quest of developing regulatory policies for ride-sourcing services. We limit our scope to the spatial price differentiation practice and examine its impact on the imbalance between labor supply and customer demand across various regions. We attempt to demonstrate spatial pricing as an effective strategy for the platforms to mitigate the supply–demand imbalance and facilitate market clearing. To protect the public interest, we further explore a simple regulation policy for surge pricing without comprising too much its flexibility.

Our model is built on a discrete-time geometric matching framework where a customer is matched to her closest available vehicle within a certain radius. We explicitly model the frictions in the matching and meeting process. Specifically, both customers and drivers will spend time on waiting to be matched. The matching time at each side increases with the number of agents on the same side due to the competition in receiving or providing services. In addition, the matched pair will wait for another en route time before a vehicle is physically occupied (Castillo et al., 2017; Xu et al., 2017). We analytically identify the tipping point between less efficient system states and more efficient ones (Castillo et al., 2017). The tipping point can be judged by examining the ratio between the intensity of unmatched or idle vehicles and that of the total unoccupied (idle plus en route) vehicles in a geographic area, providing a remarkably easy way of signaling the imbalance between supply and demand in practice.

We then proceed to investigate spatial pricing assuming a revenue-maximizing platform and considering both the short- and long-run labor supply. We analytically characterize the optimal price formula and numerically investigate the market states and agents' welfare under both spatial and flat pricing. We find that a platform using only flat pricing may prefer to set a higher price to avoid the supply shortage, especially when facing the uncertainties in marketplace. Spatial pricing is more flexible and in general benefits both the platform and drivers. When price is adjusted below its flat counterpart, customers are also better off. However, a revenue-maximizing platform may set the price above the efficient level. Indeed, we observe that customers are worse off under exceptionally high price surge even though the region is not in shortage of vehicle supply.

Considering the ambiguity of spatial pricing on the welfare of customers, we propose a commission rate regulation to protect the customers, which caps the amount of commission the platform can receive from each unit of service time (or distance). It aims to align the platform's objective of revenue maximization with that of maximizing occupied vehicle hours, which generally benefits customers. The additional revenue from the price surge completely goes to drivers. With a homogeneity assumption on agents' valuation, we show that such a simple regulation can achieve an idealized second best. We note that Didi's self-imposed control on surge pricing mirrors the proposed regulation, although theoretically we do not suggest a ceiling on price multipliers as Didi does (Didi Chuxing, 2017).

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature. Section 3 describes the specifications of demand, supply and geometric matching while the market equilibrium under spatial pricing is discussed in Section 4. Section 5 introduces our empirical study of spatial pricing using data from Didi Chuxing and Section 6 discusses its outcomes. Subsequently, Section 7 investigates the regulation policy. Lastly, we conclude this paper and point out future research needs in Section 8.

2. Literature review

Given an increasing number of studies on ride sourcing, below we present a review of literature relevant to pricing of the services.

A few studies conducted by Uber explore how labor supply responds to surge pricing (Hall and Krueger, 2015; Chen and Sheldon, 2016). They find that drivers will work longer given an unexpected price surge. Based on a large-scale dataset from Uber's API, Chen et al. (2015) demonstrate that the dominant effect of surge pricing is to suppress demand. There is no clear evidence that surge pricing induces drivers to highly surged zones at least in the short time interval during the surge. Their finding seems to be confirmed in an experimental study by Lyft (Nicholas, 2016).

Other studies aim to evaluate the performance of surge pricing and its welfare impacts on market agents. Banerjee et al. (2015) approach this problem using an M/M(k)/1 queuing model. They model surge pricing as a threshold-based dynamic pricing that depends exclusively on the number of idle vehicles. They show that surge pricing outperforms the optimal static pricing when the platform has limited information. Zha et al. (2017) investigate the time-of-day welfare effects of surge pricing. A multi-period time-extended model is introduced to capture drivers' work scheduling decisions. They find that surge pricing benefits the platform and drivers while the effect on customers is mixed. The potential harm to customers is also confirmed in a study by Guda and Subramanian (2017) where a two-zone, two-period model is developed to understand the temporal and spatial effects of surge pricing. They show that the platform may strategically increase price to stifle demand in locations of sufficient supply in order to induce drivers to move to areas where supply is in shortage. Then, price surge can even hurt the welfare of each market player. However, they highlight that surge pricing can send trustfully signal to drivers that there is a great need to move. Most recently, Galichon and Hsieh (2017) analyze surge pricing utilizing a centralized matching framework. They demonstrate the key fact that price is transferable among agents but not the waiting cost. Without price surge, customers and drivers may incur extended waiting

[2] Didi limits the price multiplier to 1.5 and the amount of surge from each trip to CNY 29 for Didi Express, and CNY 59 for Didi Premium. In addition, Didi has committed the additional commission from the surge to drivers. Therefore, the revenue Didi claims is independent of its surge pricing (Didi Chuxing, 2017).