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Pricing and penalty/compensation strategies of a taxi-hailing platform

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ABSTRACT

Smartphone-based taxi-hailing applications (apps) bring about significant changes to the taxi market in recent years. As platforms that connect customers and taxi drivers, taxi-hailing apps charge different rates for completed orders and penalize reservation-cancellation behaviors with different fines. In this paper, an equilibrium framework is proposed to depict the operations of a regulated taxi market on a general network with both street-hailing and e-hailing modes for taxi services, considering the reservation-cancellation behaviors of e-hailing customers. Based on the proposed equilibrium model, an optimal design problem of taxi-hailing platform's pricing and penalty/compensation strategies is formulated and solved by the penalty successive linear programming algorithm. To demonstrate the practicability of the proposed solution algorithms and the optimal pricing and penalty/compensation schemes, large-scale numerical examples are presented based on a realistic taxi network of Beijing.

1. Introduction

Along with the proliferation of smartphones, smartphone-based taxi-hailing applications (apps) are experiencing a fast growth in recent years. Through a taxi-hailing app, taxi customers can publish their instantaneous travel requests to nearby taxi drivers and taxi drivers can choose whether to take the taxi-hailing orders. For each responded travel request, the customer receives the information of the corresponding taxi driver, and the driver will be guided to the customer's location.[1] An e-hailing order is completed when the customer is sent by the reserved taxi to his/her destinations and pay the taxi fare as well as platform's information fee through the taxi-hailing app. Such convenient and instantaneous information exchange process effectively reduces the previous information barriers caused by spatial deviation between customers and taxi drivers. Taxi-hailing apps are widely believed by their proponents to be a powerful instrument for improving the taxi market efficiency.

However, in a taxi market with a fleet of taxis serving both street-hailing and e-hailing, the advanced communication technologies are not sufficient to guarantee the success of a taxi-hailing app - its pricing strategy is also essential. As a platform that connects customers and taxi drivers, a taxi-hailing app can charge/subsidize customers and taxi drivers respectively with different rates. The platform's charge on the taxi driver (/customer) side influences drivers (/customers)' mode split between e-hailing and street-hailing. And the number of customers and taxi drivers in e-hailing (street-hailing) mode determines the mode's customer waiting time and taxi searching time, which in turn affects customers' and taxi drivers' mode split. So due to the existence of cross-group externalities,

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[1] Compared to the radio-dispatch taxi service, taxi-hailing applications facilitate the direct communication between the taxi customers and taxi drivers, and further enable taxi drivers to choose between e-hailing and street-hailing orders.

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determining an appropriate pricing strategy for a taxi- hailing platform is an important but challenging task.

Besides the pricing strategy, one should also not ignore the importance of an appropriate penalty-compensation strategy to restrain reservation cancellation behaviors. As observed in reality, without a penalty for reservation cancellation behaviors, customers may cancel reservations frequently if they meet cruising taxis before their reserved taxis arrive, especially when the platform charges customers a high price for each completed e-hailing order. Such frequent reservation-cancellation behavior reduces customers' expected waiting cost, but leads to the waste of the supply of taxi service and increases the total vacant taxi hours. Therefore, determining a proper fine to penalize reservation-cancellation behaviors and a proper compensation to make up innocent victims is also important to the vitality of a taxi hailing platform.[2]

In this paper, we make the first attempt to depict the taxi market equilibrium under hybrid modes of e-hailing and street-hailing on a general network, with full consideration of customers' reservation cancellation behaviors under a given pricing and penalty/compensation strategy of the taxi-hailing platform. Based on the equilibrium model, we further investigate the optimal pricing and penalty/compensation strategy design problem. Specifically, we propose two strategies with regard to different managerial objectives. One strategy is for the platforms operated by public transportation agencies and aims at maximizing the social welfare while ensuring that no zone encounters an increase of average waiting times in both taxi driver and customer sides after implementing the pricing and penalty strategy. The other strategy attempts to maximize the revenue from pricing taxi-hailing platforms, which may become relevant if the platforms are owned and operated by private firms. For both strategies, a penalty successive linear programming algorithm is adopted to solve the problems. Finally, we provide numerical examples through using a realistic taxi network of Beijing to demonstrate the proposed modeling framework.

For the remaining of this paper, Section 2 models the taxi service with the taxi-hailing platform under a given pricing/penalty strategy. Section 3 first provides the mathematical definition of stationary competitive equilibrium of taxi market with the taxi-hailing platform, then proves its existence and finally provides an efficient solution algorithm. The optimal design problem of taxi-hailing platform's pricing and penalty/compensation strategies is formulated, and the penalty successive linear programming algorithm is adopted to solve it in Section 4. Based on the realistic taxi network of Beijing, Section 5 presents numerical examples to demonstrate the equilibrium and pricing models. Lastly, Section 6 concludes the paper.

2. Literature review

The traditional taxi market with solely street-hailing mode has been extensively studied since 1970s. In those early studies, different aggregate models were proposed by economists to describe the demand–supply equilibrium, and the impacts of different regulatory regimes were discussed based on the models (e.g., Douglas, 1972; De vany, 1975; Häckner and Nyberg, 1995; Arnott, 1996; Cairns and Liston-Heyes, 1996; Flores-Guri, 2003; Fernandez et al., 2006; Moore and Balaker, 2006; Bai et al., 2014; Shi and Lian, 2016a, 2016b). In the late 1990s, Yang, Wong and their collaborators advanced this area by incorporating the spatial structure into the equilibrium model of taxi service. A series of studies were published to depict the vacant taxis circulation over the transportation network and thus can reflect the spatial characteristic of taxi-market equilibrium (Yang and Wong, 1998; Wong et al., 2001, 2008; Yang et al., 2002, 2005, 2010; Yang and Yang, 2011).

However, as taxi-hailing apps emerge in recent years, existing studies about the taxi market under hybrid modes of e-hailing and street-hailing are still rare. Enlightened by Yang and Wong (1998), He and Shen (2015) firstly proposed a spatial equilibrium model to systematically evaluate the impact of the taxi-hailing app's wide adoption on the taxi movement on a general network. The basic study framework of the taxi market equilibrium in this study is similar to that in He and Shen (2015). However, in He and Shen (2015), the platform's pricing strategy was not explicitly discussed, and users' reservation-cancellation behaviors were completely ignored. Wang et al. (2016) explicitly examined the impacts of platform's pricing strategies on the entire taxi market performance as well as platform's profitability. Through a partial-derivative-based sensitivity analysis, they show that at any stable equilibrium, if the platform manager increases the platform's charge on one side while keeping that on the other side unchanged, then the e-hailing demand must be decreased; and if the platform increases its charge rate on one side while reducing the charge rate on the other side by the same amount, then e-hailing demand can either increase or decrease depending on the satisfaction of the provided conditions. However, to enable an analytical discussion, Wang et al. (2016) adopted an aggregate model, without considering the spatial distribution of taxi demand, and users' reservation cancellation behaviors were also completely ignored.

Note that besides the fast growth of taxi-hailing apps, ride-sourcing services also experience great success and have aroused extensive research interest on their impacts and operations (e.g., Chen and Nie, 2017; Xu et al., 2017; Zha et al., 2016, 2017; Nie 2017; Ke et al., 2017; Chen et al., 2017). However, compared to the taxi-hailing apps, the affiliated drivers of the ride-sourcing services drive their own non-commercial vehicles and are not permitted to take street-hailing customers. In this paper, we do not investigate the ride-sourcing services, but focus on the taxi market under hybrid modes of e-hailing and street-hailing where vacant taxis can always circulate on streets to search for customers, or take e-hailing orders from the taxi-hailing platform.

3. Characterization of taxi markets with taxi-hailing platform

We consider a one unit period (one hour) for coupled metropolitan road network and taxi market. Let Ω represent the set of

[2] Many e-hailing applications will not continue to feed new service requests to taxi drivers if they already accepted orders. The appointment cancellation by the taxi drivers is not so common in practice, and we do not consider it in the proposed modeling framework.