Management Science

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http://pubsonline.informs.org/journal/mnsc

MANAGEMENT SCIENCE
Articles in Advance, pp. 1–18
ISSN 0025-1909 (print), ISSN 1526-5501 (online)

A Balancing Act of Regulating On-Demand Ride Services

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Received: June 10, 2018
Revised: November 11, 2018; February 25, 2019
Accepted: March 13, 2019
Published Online in Articles in Advance: October 24, 2019

https://doi.org/10.1287/mnsc.2019.3351

Abstract. Regulating on-demand ride-hailing services (e.g., Uber and DiDi) requires a balance of multiple competing objectives: encouraging innovative business models (e.g., DiDi), sustaining traditional industries (e.g., taxi), creating new jobs, and reducing traffic congestion. This study is motivated by a regulatory policy implemented by the Chinese government in 2017 and a similar policy approved by the New York City Council in 2018 that regulate the "maximum" number of registered Uber/DiDi drivers. We examine the impact of these policies on the welfare of different stakeholders (i.e., consumers, taxi drivers, on-demand ride service company, and independent drivers). By analyzing a two-period dynamic game that involves these stakeholders, we find that, without government intervention, the on-demand ride service platform can drive the traditional taxi industry out of the market under certain conditions. Relative to no regulations and a complete ban policy, a carefully designed regulatory policy can strike a better balance of multiple competing objectives. Finally, if a government can reform the taxi industry by adjusting the taxi fare, then lowering the taxi fare instead of imposing a strict policy toward on-demand ride services can improve the total social welfare.

History: Accepted by Serguei Netessine, operations management.
Funding: This research was partially supported by the National Natural Science Foundation of China [Grant 91746210] (Shen).
Supplemental Material: The online appendices are available at https://doi.org/10.1287/mnsc.2019.3351.

Keywords: on-demand ride services • public policy • consumer welfare • social welfare

1. Introduction

On-demand ride-hailing services, such as Uber and DiDi, leverage information and mobile technologies to coordinate the connection between passengers and independent drivers anytime and anywhere. These on-demand ride services can scale up their operations in a time-efficient and cost-effective manner owing to the network effect and because they can operate without owning physical assets and regular drivers. In addition, many on-demand ride services disrupt the heavily regulated taxi industry because many governments are uncertain as to how to regulate these innovative businesses. Uber and DiDi are growing exponentially: Uber operates in 570 cities worldwide, and DiDi serves more than 450 million users in more than 400 cities across China as of 2017.

The benefits of on-demand ride service companies include convenient service that is more economical than taxi services for customers and flexible working hours for independent registered drivers. However, the rise of such companies leads to various social costs, ranging from taxi driver protests over unfair competition; public concerns over safety, privacy, and traffic congestion; and legal battles over labor law violations (e.g., Uber drivers should be classified as employees instead of independent contractors). As of August 2016, Uber was facing more than 70 lawsuits in federal courts (Kendall 2016). Noting that on-demand ride services incur social costs and benefits simultaneously, how should a government develop regulatory measures to strike a balance between encouraging innovative business models, such as Uber, and sustaining traditional industries, such as the taxi industry?[1]

To balance the social costs and benefits created by on-demand ride services, different governments have introduced different regulatory measures ranging from a *complete ban* in Denmark, Italy,[2] parts of Germany, Alaska, parts of Oregon, Vancouver, and Hong Kong to *regulatory measures* to control the "maximum number of registered drivers" for Uber in New York City (NYC) and for DiDi in various tier-1 cities, such as Beijing, Shanghai, and Hangzhou. Specifically, the New York City Council in 2018 approved control of the maximum number of registered drivers by "directly" capping the number of new Taxi and Limousine Commission (TLC) licenses. These TLC licenses are required for Uber or Lyft drivers to operate legally. In a similar vein, the Chinese government established rules in 2017 to control the maximum number of registered drivers "indirectly" by imposing eligibility criteria for drivers and cars to serve for ride service companies.[3] According to an official press release on the new regulatory control policy on July 28, 2016, the Chinese government expressed concern about consumer welfare, the sustainability of the taxi industry, and innovative on-demand ride-hailing services.

Motivated by the different measures (e.g., complete ban, direct cap on the number of new licenses, and eligibility criteria, etc.) adopted by different governments, we are interested in examining the impact of a class of regulatory policy that controls the maximum number of registered drivers on different stakeholders (on-demand ride service platform, consumers, drivers, and taxi drivers[4]), traffic conditions,[5] and the underlying competition between the on-demand ride service and taxis as well as consumer modes of transportation.

We present a unified modeling framework to examine the optimal government policy that aims to control the maximum number of registered drivers for an on-demand service company.[6] Our modeling framework captures (a) government control levers (e.g., policies for controlling the maximum number of registered DiDi drivers and a pricing strategy for taxi service[7]); (b) *vertical strategic interaction* between the government and DiDi; (c) *horizontal competition* among DiDi, taxis, and public transportation; and (d) DiDi's pricing and wage strategies to coordinate its supply and demand. Essentially, our intent is to answer the following questions.

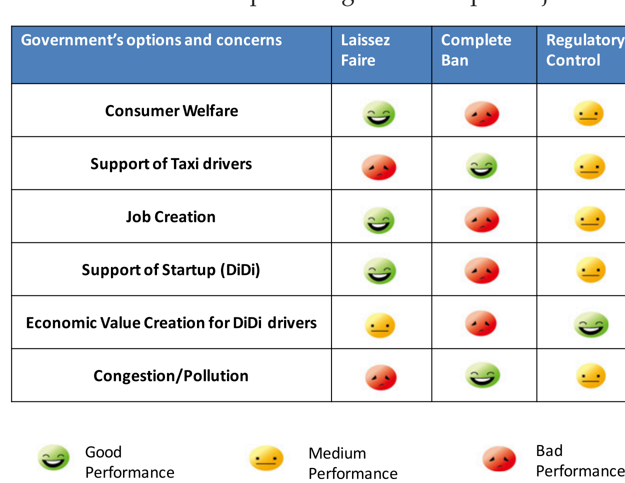
1. Can the taxi industry survive without government intervention?
2. Relative to no intervention (laissez-faire) or a complete ban policy, what is the impact of the regulatory measures that aim to control the maximum number of registered DiDi drivers?
3. If the government takes competing objectives associated with different stakeholders (consumers, taxi drivers, DiDi, and DiDi drivers) into consideration, which policy (laissez-faire, a complete ban, or some regulatory measures) strikes the best balance?
4. Besides directly regulating DiDi, should a government use taxi fares as an additional lever to control DiDi indirectly?

To answer these questions, we use a two-period model to capture the dynamics of government, consumers, taxi drivers, DiDi drivers, and DiDi. In period 1, the government uses eligibility criteria to control the maximum number of eligible drivers directly as in New York City or indirectly as in China. Then, each eligible driver decides whether to register as a DiDi driver. In period 2, DiDi decides its price and wage rate by taking both price-sensitive customers' travel options and earning-sensitive drivers' participating decisions into consideration. At the same time, each registered DiDi driver decides whether to participate. Our two-period dynamic game involves four strategic parties (government, DiDi, DiDi drivers, and consumers) along with the competitive objectives associated with these different stakeholders, and our analytical results can be summarized as follows.

1. Without government intervention, DiDi can drive the taxi industry out of the market if taxi fares are high and there are a large number of registered DiDi drivers.
2. Relative to laissez-faire and the complete ban approach, a carefully designed policy (i.e., eligibility criteria) can balance various competing objectives (Figure 1). Also, when taxi fares are higher than a certain threshold, the government should either regulate or ban DiDi completely to sustain the taxi industry.
3. To maximize total social welfare, the government's optimal regulatory policy depends on the taxi fares and the relative emphasis that the government places on different stakeholders.
4. Besides controlling the number of registered drivers indirectly through eligibility criteria in China (or directly through a specific cap in New York City), the government can use the taxi fares as a lever to control the number of DiDi cars on the road indirectly. Moreover, when the government assigns a comparatively small weight on taxi drivers' earnings, lowering taxi fares and taking a less strict policy toward DiDi can improve the total social welfare.

To the best of our knowledge, this paper is the first to develop a multistakeholder modeling framework for evaluating the impact of regulatory policies of on-demand ride services on competing objectives associated with different stakeholders. Although our model is motivated by the new measures implemented by

Figure 1. (Color online) Evaluation Graph for Government's Three Options Against Multiple Objectives



the Chinese government and in New York City, our results may offer policymakers a more formalized understanding of the implications of regulatory measures of on-demand ride services.

This paper is organized as follows. We provide a literature review in Section 2. In Section 3, we frame the general problem by providing some model preliminaries. In Section 4, we use backward induction to analyze the two-period model. In Section 5, we undertake a comprehensive evaluation of the Chinese government's policy. In Section 6, we examine the government's optimal policy to maximize total social welfare. In Section 7, we examine an alternative policy to relieve traffic congestion. Section 8 concludes this paper. For ease of exposition, all proofs are provided in Online Appendix C.

2. Literature Review

Our paper belongs to a research stream that deals with innovative business models in the sharing economy. Many researchers have been inspired by start-up companies that exploit advanced modern mobile technologies to facilitate peer-to-peer sharing of products (Fraiberger and Sundararajan 2015, Jiang and Tian 2018) and services (Hall et al. 2015, Azevedo and Weyl 2016, Einav et al. 2016). For example, Li et al. (2015) showed that professional hosts earned more than nonprofessional hosts and that Airbnb should charge nonprofessional hosts a lower commission rate. Fraiberger and Sundararajan (2015) studied peer-to-peer car rental markets using data from Getaround. Chen and Sheldon (2015) showed that, by adopting surge price, Uber could entice its drivers to drive more during peak time by providing higher wages. Several papers deal with the matching of customers and service providers (Allon et al. 2012, Hu and Zhou 2015, Chen and Hu 2016). Although these popular business models have been examined by economists (Rochet and Tirole 2003, 2006; Armstrong 2006) who focus on cross-network effects (Weyl 2010), our paper and some others that examine on-demand service platforms consider both within- and cross-network effects.

Our work is closely related to recent literature that examines pricing and various operational issues arising from various on-demand ride service platforms. Cachon et al. (2016) showed that surge pricing would benefit both providers and consumers when providers have a high opportunity cost. However, by using a queueing theoretical model, Banerjee et al. (2015) found that a static pricing strategy performs well. Both Bai et al. (2018) and Taylor (2018) incorporated customers' waiting time into their model framework to examine the optimal price and wage decision of an on-demand service platform. From the perspective of the supply side of an on-demand service platform, Gurvich et al. (2016) used a newsvendor framework to study a self-scheduling firm's optimal decision on staffing capacity control. More recently, Guda and Subramanian (2019) studied the impact of surge pricing on supply adjustment in different market zones. The authors showed that surge pricing can provide incentives for a better balance of workers in different market zones so that the platform can earn higher profit.

By studying the price and wage matching problem, Hu and Zhou (2017) found that a commission contract can be optimal when both demand and supply curves are affine functions with common price and wage sensitivity. Feng et al. (2017) compared customers' average waiting time under the on-demand matching mechanism with that under traditional street-hailing systems. The authors found that the on-demand matching mechanism may also result in lower efficiency and proposed adding response caps to the matching mechanism so as to overcome the problem. Regarding the matching system of a ride-sharing platform, Ozkan and Ward (2017) also proposed dynamic matching policies based on a continuous linear program. More recently, Benjaafar et al. (2018) examined the labor welfare of on-demand service platforms. They showed that both average labor welfare and agent workload are nonmonotonic in the labor pool size. Unlike this stream of work that focuses on a single on-demand service platform, our model framework incorporates competition among the on-demand ride service platform, taxis, and public transportation. In addition, unlike previous research that takes the perspective of a ride service company, we adopt the government's perspective, and we examine the impact of different regulatory policies on competing objectives associated with different stakeholders as well as traffic congestion.

Although on-demand service platform start-ups are praised by consumers and venture capital firms, they disrupt traditional industries that the government may wish to protect to ensure social harmony. There is a new stream of research that examines the competition between the start-up companies and the incumbents they challenge. Seamans and Zhu (2013) conducted an empirical study to examine the competition between Craigslist and traditional newspapers. Zervas et al. (2017) investigated the impact of Airbnb on hotels in Texas and found that an increase in the market size of Airbnb would lead to a revenue decrease in the local hotel industry. Cramer and Krueger (2016) showed that UberX drivers enjoyed a higher capacity utilization rate than traditional taxi drivers by using data from Boston, Los Angeles, New York, San Francisco, and Seattle. Based on evidence from Shenzhen, Nie (2017) pointed out that the taxi industry has experienced significant losses and advocated government regulation of the on-demand ride service market. In contrast to this stream of empirical analysis, our work is motivated by Nie (2017) and the new regulatory measures implemented by the Chinese government in 2017. Furthermore, our analysis is based on a multistakeholder framework that takes competition and competing objectives into consideration.

Finally, our paper is related to the government policy literature that examines various regulatory issues arising from controversial industries, such as gambling (McBurney 2005, Hancock et al. 2008), drugs (Barry et al. 2014, Subritzky et al. 2016), and prostitution (Kilvington et al. 2001, Chuang 2010). Regardless of the popularity of the sharing economy, Malhotra and Van Alstyne (2014) revealed its "dark side": for example, the growth of Airbnb has contributed to a shortage of affordable long-term housing, and on-demand ride service companies are competing unfairly with the incumbent taxi industry by circumventing taxes and regulations. As a result, many legal experts are contemplating different methods to regulate the sharing economy (Koopman et al. 2015, Posen 2015, Ranchordás 2015, Rauch and Schleicher 2015), protect consumer rights, and support incumbent industries. Our paper is the first to present a unified, analytical, multistakeholder framework that captures the interactions among different parties and evaluates the impact of government policy on competing objectives associated with different stakeholders. Furthermore, in addition to direct regulatory policies, we also consider an indirect control policy using taxi fares as a lever to control on-demand ride services.

3. Model Preliminaries

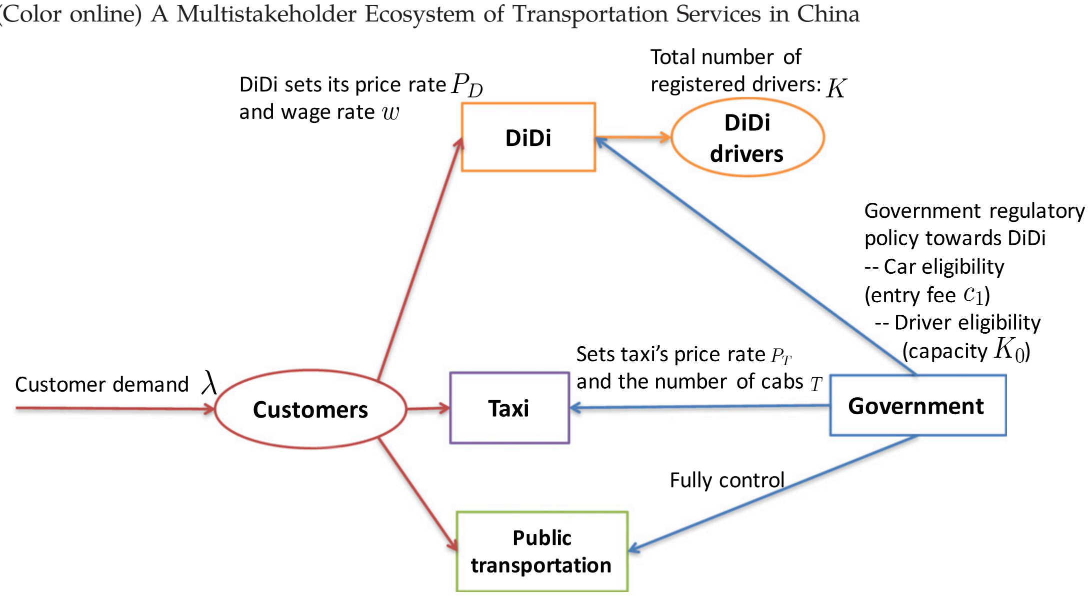
Consider the public transportation ecosystem depicted in Figure 2 that consists of the DiDi on-demand ride service, taxi service, and public transportation. In this ecosystem, DiDi uses price rate P_D and wage rate w to coordinate its customers and drivers. (For ease of reference, we use the subscripts T and D to denote quantities associated with taxi and DiDi services, respectively.) Public transportation services are fully controlled by the government in terms of price, capacity, and scheduling. In many countries, the government regulates the taxi industry by setting a price rate (P_T per kilometer) and the number of taxicabs (T) in a city. In our base model, we assume that P_T and T are "exogenously given."[8] (However, in Section 7, we relax this assumption and examine the implication when the government reforms the taxi industry by choosing P_T as a lever to control the on-demand service indirectly.)

3.1. Decisions

Let us describe the decisions to be made by each of the following four entities.

1. Government regulatory policy that intends to control the number of registered drivers. We focus on the case in which the government chooses to impose eligibility criteria to control the maximum number of registered DiDi drivers. For example, the Chinese government imposed the following rules. First, a car to be used for on-demand ride services cannot be more than eight years old (or driven for more than 600,000 km) (Spring 2016). We model these car eligibility criteria as an "entry fee" c_1 incurred by an eligible driver. Second, to be eligible as a DiDi driver, the driver must be a local resident (Li 2016) and have at least three years' driving experience (Russell 2016). Based on these driver eligibility criteria, we model the maximum number of eligible drivers as K_0.

Figure 2. (Color online) A Multistakeholder Ecosystem of Transportation Services in China



Note that the cap of new Taxi and Limousine Commission licenses approved by the New York City Council can also be modeled as the maximum number of eligible drivers K_0 without imposing any entry fee c_1.

2. DiDi's price and wage decisions that intend to coordinate customers and drivers. Given the government policy (K_0, c_1) and the presence of competing taxi and public transportation, DiDi will set its price rate P_D (i.e., price per kilometer) and wage rate w (i.e., payment to driver per kilometer).[9]

3. Consumers' travel mode decisions that intend to maximize consumer utility. To capture competition among multiple parties and to obtain tractable results, we assume that customers do not wait; therefore, we do not consider the waiting time issue examined by Bai et al. (2018). In addition, we focus more on the strategic interactions among different stakeholders than on detailed operational-level analysis because our goal is to examine the impact of different regulatory policies on competing objectives associated with different stakeholders. We defer the issue of waiting time for future research. To capture the heterogeneity among consumers' travel options, we adopt the willingness-to-pay model widely used in both transportation and operations management literature (McFadden 1998, Hidrue et al. 2011, Schwarzlose et al. 2014, Bai et al. 2018). Specifically, we assume that the consumer utility associated with transportation model i is given by

$$U_i(v_i) = v_i - P_i, \text{ where } i = \{\text{DiDi, Taxi, Public Transportation}\}, \quad (1)$$

where v_i is consumer valuation of different travel options, and P_i is the price rate of different travel services.[10] For ease of exposition, we scale the consumer valuation and the price of public transportation to zero because of its lower price and comfort level relative to taxi and DiDi services. Thus, the consumer utility associated with choosing public transportation is zero.

To capture the heterogeneity among consumers, we assume that the consumer valuation of taxi service $v_T \sim U[0,1]$ and the consumer valuation of DiDi service $v_D = \ell \cdot v_T$, where ℓ captures the extent to which consumers prefer DiDi to taxis. We also assume that $\ell > 1$ to capture the extent to which DiDi is preferred to taxis.[11] The assumption that $\ell > 1$ is reasonable because most customers prefer on-demand ride services, such as DiDi. For example, Lambert (2016) reported that most Australian consumers prefer Uber to taxis because Uber is more economical, safer, and more convenient. In the United States, most customers prefer Uber to taxis for similar reasons, and their preferences are reflected by the fact that, from 2013 to 2015, the number of Uber rides increased 10-fold, and taxi rides decreased by 2.1 million (*The Economist* 2015). In China, DiDi dominates the taxi service in terms of price, efficiency, service quality, and convenience.[12]

For tractability, we use the uniform valuation (i.e., $v_T \sim U[0,1]$) to show that the demand for each travel option is a linear function of the price rates associated with different modes.[13] The linear demand structure enables us to analyze the case in which consumers and the platform engage in vertical competition, and yet different travel options engage in horizontal competition. Faced with the three travel alternatives depicted in Figure 2, each consumer selects a particular service that maximizes the consumer's utility (more details are provided in Section 4.1).

4. DiDi driver's registration and participation decisions in relation to reservation value. In period 1, there are K_0 "potential" DiDi drivers who meet the driver eligibility criteria imposed by the government. For example, $K_0 = 0$ under a complete ban policy, $K_0 \to \infty$ if the government does not intervene, and $K_0 \in (0, \infty)$ under some form of regulatory policy (e.g., adequate driving experience, local residency, etc.) Each of these K_0 eligible drivers can decide endogenously whether to register with DiDi in period 1 by considering the entry fee c_1 and the anticipated net earnings in period 2. Among those K_0 eligible drivers, K is the "actual" number of drivers who register with DiDi in period 1. Hence, K is capped by K_0 (i.e., $K \le K_0$). In period 2, each of the K *registered drivers* decides whether to participate in providing a ride service by taking DiDi's price and wage decisions (P_D, w), total travel demand λ, and market conditions associated with taxis and public transportation into consideration. We show that there are k ($k \le K$) drivers providing ride service in period 2 (more details in Sections 4.2 and 4.4).

3.2. A Two-Period Model

By considering the decisions to be made by the aforementioned different entities over time, we can use Figure 3 to depict the sequence of events over two periods. Our two-period model is similar to that of Cachon et al. (2016) in the following manner. At the beginning of period 1, the government announces a regulatory policy (K_0, c_1) that intends to control the maximum number of eligible drivers K_0. Then, each of these K_0 eligible drivers decides whether to register as a DiDi driver in period 1 by considering the driver's long-term earnings and up-front investment costs c_1. We let K denote the actual number of registered drivers in period 1, in which $K \le K_0$.

At the beginning of period 2, DiDi announces its pricing and wage decision (P_D, w) when the customer demand λ is realized. Given DiDi's decision P_D, each of the λ customers takes this information along with

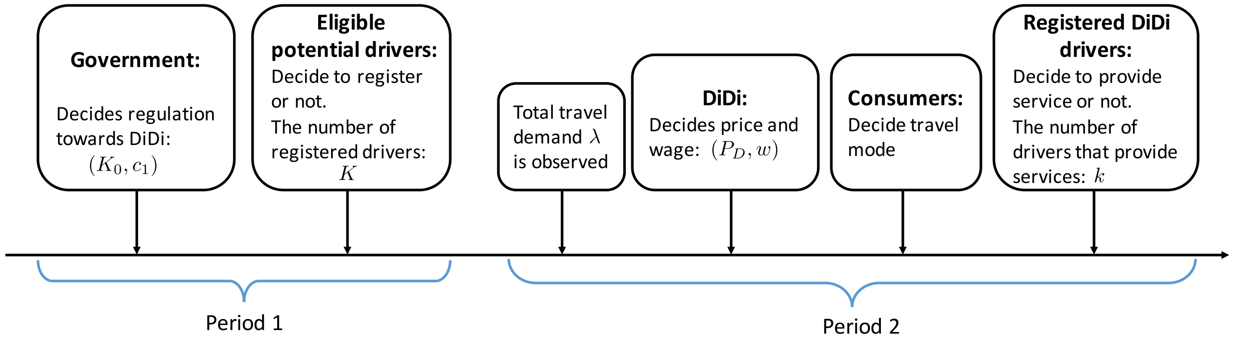


Figure 3. (Color online) Sequence of Events

the taxi price P_T (which is exogenously given in the base model) and public transportation price zero into consideration and selects the option that yields the highest utility. At the same time, the K registered drivers decide whether to participate in period 2 by anticipating the effective demand for the DiDi service λ_D along with the price and wage rate (P_D, w).

To capture the long-term earnings of each of the K registered drivers, period 2 is long (e.g., N subperiods) and represents the lifetime of a driver's car or the average time span for a driver to serve DiDi. For each of these N subperiods, each of the K registered drivers can use DiDi's policy (P_D, w) and the realized customer demand λ to determine whether to offer one's service. We let ξ_0 denote the expected earnings in each of the N subperiods within period 2. Then, by considering the discount rate δ for the subperiod, the total net present value of a driver's earnings over N subperiods is equal to $\frac{1-\delta^{N+1}}{1-\delta} \cdot \xi_0$, which converges to $\frac{1}{1-\delta} \cdot \xi_0$ as $N \to \infty$. Using the expected earnings and considering the up-front investment c_1, each of the K_0 potential eligible drivers registers as a DiDi driver in period 1 if the driver's expected surplus $(\frac{1}{1-\delta} \cdot \xi_0 - c_1)$ exceeds the driver's reservation value.

4. Analysis of Two-Period Model

We now analyze the two-period model described in Section 3 by using backward induction. In period 2, given the number of registered DiDi drivers K (determined in period 1), taxi price rate P_T, and the total customer demand λ, DiDi decides the optimal price and wage (P_D^*, w^*) to coordinate its supply and demand by taking the horizontal competition among DiDi, taxi, and public transportation into consideration. In period 1, we examine the number of registered DiDi drivers K in equilibrium by incorporating the strategic behavior of eligible potential drivers.

4.1. Demand for Each Travel Mode in Period 2

In preparation, we first determine the demand for each transportation mode in period 2 for any given price (P_T, P_D). In this case, a customer with valuation (v_D, v_T) chooses the DiDi service only if $U_D(v_D) \geq U_T(v_T)$ and $U_D(v_D) \geq 0$, chooses the taxi service only if $U_T(v_T) \geq U_D(v_D)$ and $U_T(v_T) \geq 0$, or chooses public transportation otherwise. Because $v_T \sim U[0,1]$ and $v_D = \ell v_T$, the potential consumer demand for each transportation mode is as follows.

Proposition 1. *Given the total customer travel demand λ, taxi price rate $P_T \in [0,1]$, and DiDi's price rate $P_D \in [0, \ell]$, the customer demand for DiDi service (λ_D), taxis (λ_T), and public transportation (λ_{pub}) satisfies the following:*

1. *when* $P_D > \ell \cdot P_T$, $\lambda_D = \lambda \cdot \left(1 - \frac{P_D - P_T}{\ell - 1}\right)$, $\lambda_T = \lambda \cdot \left(\frac{P_D - P_T}{\ell - 1} - P_T\right)$, *and* $\lambda_{pub} = \lambda \cdot P_T$;
2. *when* $P_D \leq \ell \cdot P_T$, $\lambda_D = \lambda \cdot \left(1 - \frac{P_D}{\ell}\right)$, $\lambda_T = 0$, *and* $\lambda_{pub} = \lambda \cdot (\frac{P_D}{\ell})$.

When there is competition, Proposition 1 reveals that, when $P_D > \ell \cdot P_T$, the demand for DiDi service λ_D decreases in P_D but increases in P_T, and the demand for taxis λ_T decreases in P_T but increases in P_D, which captures the underlying competition among different transportation modes. However, if DiDi charges a price P_D below $\ell \cdot P_T$, the demand for taxis is zero, which indicates that DiDi drives the taxi industry out of the market. As expected, for any given P_T and P_D, Proposition 1 implies that DiDi's demand λ_D increases in ℓ, whereas taxi's demand λ_T decreases in ℓ. Given the potential customer demand for each transportation mode as shown in Proposition 1, we next discuss whether DiDi can afford to charge an optimal price low enough (i.e., $P_D^* \leq \ell \cdot P_T$) so as to drive the taxi industry out of the market.

4.2. Number of Participating DiDi Drivers (k) in Period 2

Given the demand for each transportation mode for any given (P_T, P_D, w), we first determine the number of participating DiDi drivers k in period 2, in which $k \le K$ with K being the number of registered DiDi drivers in period 1.

To begin, recall that we assume customers do not wait. Hence, the total transaction quantity Q_D of DiDi in period 2 for any given number of participating DiDi drivers k is equal to $Q_D = \min\{\lambda_D, k\}$, where λ_D is the customer demand for DiDi as presented in Proposition 1.[14] In this case, the utilization of each of these k participating drivers is $\frac{Q_D}{k} = \frac{\min\{\lambda_D,k\}}{k} \le 1$. Combining this observation with the wage rate and the average service speed μ (i.e., average service units per unit of time), the expected earning rate of these participating drivers is $w \cdot \mu \cdot \frac{Q_D}{k}$. Now, suppose each of the registered DiDi drivers has a reservation rate R_2 per unit of time,[15] where R_2 follows a distribution $G_2(\cdot)$ with a density function $g_2(\cdot)$. In this case, a registered DiDi driver participates in period 2 if $w \cdot \mu \cdot \frac{Q_D}{k} \ge R_2$, which implies that the proportion $k/K = G_2(w \cdot \mu \cdot \frac{Q_D}{k})$. More formally, we have

$$k = K \cdot G_2\left(w \cdot \mu \cdot \frac{Q_D}{k}\right). \tag{2}$$

By noting that the total transaction quantity $Q_D = \min\{\lambda_D, k\}$, it is easy to verify from (2) that the number of DiDi drivers participating in period 2 increases in the wage rate w.

4.3. DiDi's Optimal Decisions (P_D^*, w^*) in Period 2

Given the total transaction quantity $Q_D = \min\{\lambda_D, k\}$, where k is as calculated in (2), we now determine DiDi's optimal pricing and wage decision (P_D^*, w^*) in period 2. By noting that DiDi's payoff equals $(P_D - w) \cdot Q_D$,[16] we can formulate DiDi's problem as

$$\begin{aligned} \max_{P_D, w} \quad & \Pi_D = (P_D - w) \cdot Q_D \\ \text{s.t.} \quad & Q_D = \min\{k, \lambda_D\} \\ & k = K \cdot G_2\left(w \cdot \mu \cdot \frac{Q_D}{k}\right) \\ & \lambda_D = \begin{cases} \lambda \cdot \left(1 - \frac{P_D - P_T}{\ell - 1}\right) & \text{if } P_D > \ell \cdot P_T \\ \lambda \cdot \left(1 - \frac{P_D}{\ell}\right) & \text{if } P_D \le \ell \cdot P_T \end{cases} \\ & 0 \le w \le P_D \le \ell. \end{aligned} \tag{3}$$

The first two constraints follow the definition of Q_D and k as explained earlier. The demand for DiDi λ_D is generated from Proposition 1, and DiDi's price rate P_D must be above the wage rate w and below the maximum consumer valuation ℓ. To develop the closed-form solution to this problem, we consider the case in which $R_2 \sim U[0,1]$ so that $G_2(x) = x$ and obtain Lemma 1.

Lemma 1. *There exists an optimal solution to problem (3) that balances DiDi's customer demand λ_D and DiDi's participating drivers k in period 2 so that $k = \lambda_D$.*

Lemma 1 implies that there exists an optimal solution to problem (3) that has $k = \lambda_D$; therefore, $Q_D = \lambda_D = k$ and $k = K \cdot G_2(w \cdot \mu \cdot \frac{Q_D}{k}) = Kw\mu$. Hence, $w = \frac{k}{K\mu} = \frac{\lambda_D}{K\mu}$. These observations enable us to simplify problem (3) as

$$\begin{aligned} \max_{P_D} \quad & \Pi_D = \left(P_D - \frac{\lambda_D}{K\mu}\right) \cdot \lambda_D \\ \text{s.t.} \quad & \lambda_D = \begin{cases} \lambda \cdot \left(1 - \frac{P_D - P_T}{\ell - 1}\right) & \text{if } P_D > \ell \cdot P_T \\ \lambda \cdot \left(1 - \frac{P_D}{\ell}\right) & \text{if } P_D \le \ell \cdot P_T \end{cases} \\ & \frac{\lambda_D}{K\mu} \le P_D \le \ell. \end{aligned} \tag{4}$$

Solving the simplified pricing problem given by (4) yields the following proposition. In preparation, let us define two thresholds: $\kappa_1 = \frac{2\lambda(1-P_T)}{\mu(2\ell P_T - (\ell - 1 + P_T))}$, and $\kappa_2 = \frac{2\lambda(1-P_T)}{\mu\ell(2P_T - 1)}$. By noting that $\kappa_1 < \kappa_2$, we obtain Proposition 2.

Proposition 2. *For any given taxi rate P_T, the platform's optimal price rate P_D^* satisfies the following:*

1. *When $P_T \le \frac{\ell-1}{2\ell-1}$, $P_D^* = \frac{(\ell-1+P_T)(2\lambda+K\mu(\ell-1))}{2(\lambda+K\mu(\ell-1))}$, and in this case, $P_D^* > \ell \cdot P_T$.*
2. *When $\frac{\ell-1}{2\ell-1} < P_T \le 0.5$, $P_D^* = \begin{cases} \frac{(\ell-1+P_T)(2\lambda+K\mu(\ell-1))}{2(\lambda+K\mu(\ell-1))} & \text{if } K < \kappa_1 \\ \ell \cdot P_T & \text{if } K \ge \kappa_1. \end{cases}$ Observe that $P_D^* > \ell \cdot P_T$ when the registered driver number $K < \kappa_1$.*
3. *When $P_T > 0.5$, $P_D^* = \begin{cases} \frac{(\ell-1+P_T)(2\lambda+K\mu(\ell-1))}{2(\lambda+K\mu(\ell-1))} & \text{if } K < \kappa_1 \\ \ell \cdot P_T & \text{if } \kappa_1 \le K \le \kappa_2 \\ \frac{\ell(2\lambda+K\mu\ell)}{2(\lambda+K\mu\ell)} & \text{if } K > \kappa_2. \end{cases}$ Observe that $P_D^* > \ell \cdot P_T$ when $K < \kappa_1$ and $P_D^* < \ell \cdot P_T$ when $K > \kappa_2$.*

Finally, the corresponding optimal wage

$$w^* = \begin{cases} \frac{\lambda(\ell-1+P_T)}{2(\lambda+K\mu(\ell-1))} & \text{if } P_D^* = \frac{(\ell-1+P_T)(2\lambda+K\mu(\ell-1))}{2(\lambda+K\mu(\ell-1))} \\ \frac{\lambda(1-P_T)}{K\mu} & \text{if } P_D^* = \ell \cdot P_T \\ \frac{\lambda\ell}{2(\lambda+K\mu\ell)} & \text{if } P_D^* = \frac{\ell(2\lambda+K\mu\ell)}{2(\lambda+K\mu\ell)}. \end{cases}$$

When the taxi price P_T is low, the first statement of Proposition 2 exerts that DiDi should set $P_D^* > \ell \cdot P_T$ to remain profitable. However, when the taxi rate P_T is high, the second and third statements reveal that DiDi can afford to charge a relatively low price $P_D^* \le \ell \cdot P_T$ when the number of registered drivers K is large enough. Combining this observation with the second statement of Proposition 1, we can conclude that, without government regulations, K can be large enough so that DiDi can afford to undercut taxi fares (i.e., $P_D^* \le \ell \cdot P_T$) and drive the taxi industry out of the market so that $\lambda_T = 0$. More importantly, this result demonstrates why the control of K is an important factor to ensure the survival of the taxi industry, particularly when P_T cannot be reduced in the short term. We state this implication more formally in the following corollary.

Corollary 1. *When the taxi price $P_T > \frac{\ell-1}{2\ell-1}$ and the registered DiDi driver number $K \geq \kappa_1$, DiDi sets its optimal price $P_D^* \leq \ell \cdot P_T$ to drive the taxi industry out of the market so that demand for taxis $\lambda_T = 0$. However, when the taxi price $P_T \leq \frac{\ell-1}{2\ell-1}$, DiDi always sets $P_D^* > \ell \cdot P_T$ so that both the taxi service and DiDi remain in the market.*

According to Corollary 1, without government intervention, DiDi can drive the taxi industry out of the market when P_T is high and when the number of registered DiDi drivers K is large. This is because, when P_T is high, the taxi industry is not competitive. At the same time, when K provides an ample supply, competition among DiDi drivers is high, and DiDi can afford to set a comparatively low price (i.e., $P_D^* \leq \ell \cdot P_T$) and a lower wage rate to drive the taxi industry out of the market. Therefore, if the government wants to sustain the taxi industry under these conditions, the government can either (a) establish a regulatory policy (K_0, C_1) to control the number of registered drivers K in period 1 or (b) lower the taxi price P_T to make the taxi industry more competitive. This observation leads us to examine the impact of regulatory policy (K_0, c_1) on the number of registered drivers K and to examine the impact of P_T in Section 7.

Furthermore, from Proposition 2, we find that, for the case in which $P_D^* = \frac{(\ell-1+P_T)(2\lambda+K\mu(\ell-1))}{2(\lambda+K\mu(\ell-1))}$ or $P_D^* = \ell \cdot P_T$, DiDi's optimal price and wage are affected by the taxi price P_T. However, when $P_D^* = \frac{\ell(2\lambda+K\mu\ell)}{2(\lambda+K\mu\ell)}$ so that taxis no longer exist in the market, then DiDi can set its optimal price and wage freely without considering the taxi rate. Given the number of registered DiDi drivers K in period 1, we then compare the optimal P_D^* under different cases and obtain the following corollary.

Corollary 2. *Given the number of registered DiDi drivers K, DiDi sets its optimal price P_D^* lower in a market with competition from taxis than in a market without taxis.*

Corollary 2 implies that, when the taxi industry is competing with DiDi, DiDi sets a lower price and the government can then protect consumers from higher surge prices set by DiDi. Therefore, in addition to achieving social harmony, the Chinese government is committed to sustaining the taxi industry to create competition and keep DiDi's prices in check.

4.4. Number of Registered DiDi Drivers (K) in Period 1

We now utilize the results associated with period 2 to determine the actual number of registered DiDi drivers K in period 1. Recall from Section 3.1, that, for any given policy (K_0, c_1), each of the K_0 eligible drivers registers as a DiDi driver in period 1 if the driver's expected surplus $(\frac{1}{1-\delta} \cdot \xi_0 - c_1)$ exceeds the driver's reservation value R_1, where δ is the discount rate, ξ_0 is the driver's net earnings in each of the N subperiods in period 2 with $N \to \infty$, and c_1 is the up-front investment cost of meeting the car eligibility. To capture the heterogeneity among K_0 eligible drivers, we assume that they have a long-term reservation price R_1 (i.e., the opportunity cost of joining the platform), where R_1 follows a distribution $G_1(\cdot)$ with a density function $g_1(\cdot)$.

Before we compute K, let us first analyze each DiDi driver's net earnings ξ_0 in period 2. Recall from Section 4.2 that DiDi drivers with short-term reservation rates $R_2 \sim U[0,1]$ participate in providing ride service in period 2 when $w^* \cdot \mu \geq R_2$ and their net earnings are $w^* \cdot \mu - R_2$; otherwise, when $w^* \cdot \mu \leq R_2$, they do not provide a service and their earnings are zero. Therefore, an individual DiDi driver's expected net earnings in each subperiod in period 2 are

$$\xi_0 = \left[\int_0^{w^*\cdot\mu} (w^* \cdot \mu - R_2) \cdot g_2(R_2) dR_2 + \int_{w^*\cdot\mu}^1 0 \cdot g_2(R_2) dR_2\right] = \frac{\mu^2}{2} \cdot w^{*2}. \tag{5}$$

Given the regulatory policy (K_0, c_1) and the net present value of total earnings $\frac{1}{1-\delta} \cdot \xi_0$, the number of registered DiDi drivers K in period 1 corresponds to the proportion of those K_0 eligible drivers who decide to register with DiDi (i.e., drivers with positive surplus in which $(\frac{1}{1-\delta} \cdot \xi_0 - c_1) > R_1$). Because R_1 follows a probability distribution $G_1(\cdot)$, K satisfies

$$K = K_0 \cdot G_1\left(\frac{1}{1-\delta} \cdot \xi_0 - c_1\right) = K_0 \cdot G_1\left(\frac{1}{1-\delta} \cdot \frac{\mu^2}{2} \cdot w^{*2} - c_1\right), \tag{6}$$

where w^* is a function of K *in equilibrium* as shown in Proposition 2 and w^* always decreases in K. In addition, from (6), K can be expressed as an explicit function of (K_0, c_1) as in Corollary 3.

Corollary 3. *The number of registered DiDi drivers in period 1 (K) is increasing in the maximum number of eligible potential drivers (K_0) and decreasing in the entry fee (c_1).*

As shown in Corollary 1, when $P_T > \frac{\ell-1}{2\ell-1}$ and $K \geq \kappa_1$, DiDi can afford to set a low price $P_D^* \leq \ell \cdot P_T$ to drive the taxi industry out of the market (with $\lambda_T = 0$). This finding provides a plausible justification for Chinese regulatory policy (K_0, c_1) as a mechanism to help the taxi industry survive.

5. Evaluation of Regulatory Policy (K_0, c_1)

In this section, we use our analysis from Section 4 to evaluate the performance of a given government policy (K_0, c_1) with respect to competing objectives associated with different stakeholders (i.e., consumer welfare, DiDi drivers' earnings, taxi drivers' earnings, DiDi's profit, and the number of cars on the road, which can affect traffic congestion and air pollution). Then we compare the policy (K_0, c_1) against two benchmark policies (laissez-faire and complete ban); the laissez-faire policy corresponds to the case in which $K_0 \to \infty$ and $c_1 = 0$,[17] and the complete ban policy corresponds to the case in which $K_0 = 0$ and $c_1 \to \infty$. (We determine the optimal regulatory policy (K_0^*, c_1^*) in Section 6.)

Observe from (6) that the actual number of registered DiDi drivers in period 1 (i.e., K) is an explicit function of a policy (K_0, c_1). For example, through (6), it is easy to check that (1) the laissez-faire policy $(K_0 \to \infty, c_1 = 0)$ results in $K \to \infty$; (2) the complete ban policy $(K_0 = 0, c_1 \to \infty)$ results in $K = 0$; and (3) a regulatory policy $(K_0 \in (0,\infty), c_1 \in (0,\infty))$ results in $K \in (0,\infty)$. This observation implies that, instead of focusing on evaluating the performance of a given policy (K_0, c_1), it suffices first to focus on examining the corresponding performance of the corresponding value of K. Then, once we determine the optimal value K^*, we can apply (6) to identify the corresponding optimal regulatory policy (K_0^*, c_1^*). Note that when $K^* \in (0,\infty)$, (6) reveals that the corresponding regulatory policy is not unique. Therefore, the government has some flexibility to consider different driver eligibility criteria and car eligibility criteria to control K_0 and c_1 so long as (6) holds. If we were to consider the regulatory policy approved by the NYC Council that imposed a cap on K_0, then we can simply set $c_1 = 0$ for our evaluation.

Before we evaluate the performance associated with a given value of K (i.e., the actual number of registered DiDi drivers), let us first determine the total consumer welfare function. It suffices to focus on the total consumer welfare S for those who take rides by DiDi and taxis because we scale the consumer utility associated with public transportation to zero. First, when there are only taxis in the market, S equals the welfare of those who have valuation for taxis $v_T \in [P_T, 1]$ and take taxis; that is, $S = \lambda \cdot \int_{P_T}^{1} (v_T - P_T) dv_T$. Second, when both taxis and DiDi compete in the market, S consists of the welfare of those with valuation $v_T \in [P_T, \frac{P_D - P_T}{\ell - 1}]$ who choose taxis and the welfare of those with valuation $v_D = \ell v_T \in [\ell \cdot \frac{P_D - P_T}{\ell - 1}, \ell]$ who choose DiDi; therefore, $S = \lambda \cdot [\int_{\frac{P_D^* - P_T}{\ell - 1}}^{1} (\ell \cdot v_T - P_D^*) dv_T + \int_{P_T}^{\frac{P_D^* - P_T}{\ell - 1}} (v_T - P_T) dv_T]$. Third, when DiDi drives the taxi industry out of the market, S equals the welfare of those who have valuation for DiDi $v_D = \ell v_T \in [P_D^*, \ell]$ and who take DiDi; that is, $S = \lambda \cdot \int_{\frac{P_D^*}{\ell}}^{1} (\ell \cdot v_T - P_D^*) dv_T$. In summary, S satisfies

$$S = \begin{cases} \lambda \cdot \frac{(1-P_T)^2}{2} & \text{when } \lambda_D = 0, \lambda_T > 0 \\ \lambda \cdot \left(\frac{\ell - 2P_D^*}{2} + \frac{\ell \cdot P_T^2 + P_D^{*2} - 2P_D^* \cdot P_T}{2(\ell - 1)} \right) & \text{when } \lambda_D, \lambda_T > 0 \\ \lambda \cdot \frac{(\ell - P_D^*)^2}{2\ell} & \text{when } \lambda_D > 0, \lambda_T = 0. \end{cases} \tag{7}$$

5.1. Performance Evaluation of Regulatory Policy (K_0, c_1) via K

Using the optimal DiDi price P_D^* as stated in Proposition 2, we can obtain the corresponding total consumer welfare (i.e., S) as stated in (7); each DiDi driver's net earnings in each subperiod within period 2 (i.e., ξ_0) as stated in (5); the total earnings of all K DiDi drivers in period 2 (i.e., $\xi = K \cdot \xi_0$);[18] the total gross earnings of all taxi drivers (i.e., Π_T), where $\Pi_T = T \cdot (P_T \cdot \frac{\lambda_T}{T})$ with λ_T retrieved through Proposition 1; DiDi's profit (i.e., $\Pi_D = (P_D^* - w^*) \cdot \lambda_D$) with P_D^* and w^* retrieved from Proposition 2 and the corresponding λ_D retrieved from Proposition 1; and the total number of DiDi cars on the road (i.e., k) as stated in (2). By computing these equilibrium outcomes, we can examine the impact of K on these performance measures associated with different stakeholders under different conditions and obtain Corollary 4.

Corollary 4. *Given the total travel demand λ and the taxi price P_T, the impact of the number of total registered DiDi drivers K on DiDi's optimal price P_D^*, consumer demand for the DiDi service λ_D, the earnings of each DiDi driver ξ_0, the total earnings of all DiDi drivers ξ, the DiDi platform's profit Π_D, the total earnings of all taxi drivers Π_T, total consumer welfare S, and the number of DiDi cars on the road k are listed in Table 1.*

Corollary 4 reveals that, in a competitive market in which both DiDi and taxis exist, DiDi lowers its optimal price P_D^* so that demand for DiDi λ_D increases when K increases. In addition, as K increases, competition among DiDi drivers increases. Consequently, DiDi can afford to lower its wage so that the earnings of each DiDi driver ξ_0 are reduced. However, as K increases, the total earnings of all DiDi drivers ξ first increase in K and then decrease in K when K becomes larger. Next, observe that DiDi's profit Π_D and consumer welfare S increase in K; however, the taxis lose part of their market share, and the total earnings of taxi drivers Π_T decrease in K. Finally, the number of DiDi cars on the road k increase in K.

In addition, when $P_T > \frac{\ell - 1}{2\ell - 1}$ and the government adopts no regulation of DiDi (so that $K \to \infty$), DiDi drives the taxi industry out of the market as stated

Table 1. Impact of K on Various Performance Measures

Market condition	Value of P_D^*	P_D^*	λ_D	ξ_0	ξ	Π_D	Π_T	S	k
Competitive market	$\frac{(\ell-1+P_T)(2\lambda+K\mu(\ell-1))}{2(\lambda+K\mu(\ell-1))}$	↓	↑	↓	↑↓	↑	↓	↑	↑
Only DiDi	$\ell \cdot P_T$	—	—	↓	↓	↑	X	—	—
	$\frac{\ell(2\lambda+K\mu\ell)}{2(\lambda+K\mu\ell)}$	↓	↑	↓	↑↓	↑	X	↑	↑
Only taxis	X	X	X	X	X	X	—	—	X

Note. ↑ (increasing); ↓ (decreasing); — (no change); X (does not apply).

in Corollary 1 so that taxi drivers earn nothing. However, when the government adopts a complete ban policy of DiDi (so that $K = 0$), then DiDi, together with its drivers, earns nothing.

Next, recall from earlier that (1) the laissez-faire policy ($K_0 \to \infty, c_1 = 0$) results in $K \to \infty$, (2) the complete ban policy ($K_0 = 0, c_1 \to \infty$) results in $K = 0$, and (3) the regulatory policy ($K_0 \in (0,\infty), c_1 \in (0,\infty)$) results in $K \in (0,\infty)$. We can compare the performance across these three regulatory policies via different values of K as listed in Table 2.

In the context of consumer welfare (S), the regulatory control (i.e., $K \in (0,\infty)$) corresponding to the case in which ($K_0 \in (0,\infty), c_1 \in (0,\infty)$) can achieve medium-level consumer welfare, which is higher than that of the complete ban approach. Next, we observe that, if one is only concerned about taxi drivers' earnings (Π_T), a complete ban approach would enable taxi drivers to achieve the highest level of earnings, the laissez-faire approach would disrupt the taxi industry (in particular, when P_T is high, taxis would have no market share), and a regulatory control approach would help the taxi industry to survive. Moreover, by reducing K_0 and increasing c_1 via various driver and car eligibility criteria, the government would take the safety of consumers into consideration.

In summary, we find that the regulatory control (i.e., $K \in (0,\infty)$) corresponding to the case in which ($K_0 \in (0,\infty), c_1 \in (0,\infty)$) can enable the government to strike a better balance of competing objectives. On one hand, relative to a complete ban, regulatory control supports the development of new businesses, which contributes to economic development, creates job opportunities, and provides convenience to consumers. On the other hand, relative to laissez-faire, regulatory control solves the social problems caused by the entry of new businesses (i.e., sustains the taxi industry and relieves traffic congestion from large numbers of DiDi cars on the road). Although these qualitative results in Table 2 may appear to be intuitive, our multistakeholder modeling framework and analyses can be used to examine the details of the impact of different policies on the competing measures of different stakeholders; these details cannot be determined without formal analyses. Therefore, our modeling framework and analyses can serve as building blocks for developing a more formal decision support system that can help policymakers to evaluate the implications of different policies for different stakeholders in the ecosystem. In Online Appendix B, we use real DiDi data collected from Hangzhou (capital of Zhejiang Province) to illustrate the analytical results presented in this section.

Table 2. Comparison of Three Government Policies

Government policy	S	Π_T	ξ_0	Π_D	k
Laissez faire: $K \to \infty$	H	X/L	L	H	H
Regulatory control: $K \in (0,\infty)$	M	M	H	L	L
Complete ban: $K = 0$	L	H	X	X	X

Note. H: high level; L: low level; M: medium level; X: none.

5.2. Impact of ℓ: Consumer Preference of DiDi to Taxi

As articulated in Section 3, we assume that consumers prefer DiDi to taxis so that consumer valuation $v_D = \ell \cdot v_T$ with $\ell > 1$. We now examine the impact of ℓ on the welfare of different parties because DiDi can increase ℓ by improving its service quality. Given K and λ, the impact of ℓ on the welfare of different parties can be described as follows.

Corollary 5. *Suppose DiDi and taxis coexist and compete in the same market. Then, when ℓ increases, we observe the following effects:*

1. *Consumer welfare S and DiDi platform's profit Π_D will also increase.*
2. *When $K \le \frac{\lambda}{\mu P_T}$, the total earnings of all DiDi drivers ξ are increasing in ℓ, and the total earnings of all taxi drivers Π_T are decreasing in ℓ.*
3. *When $K > \frac{\lambda}{\mu P_T}$, the total earnings of all DiDi drivers ξ are decreasing in ℓ, and the total earnings of all taxi drivers Π_T are increasing in ℓ.*

The first and second statements are intuitive: both consumers and the DiDi platform benefit from higher consumer valuation ℓ. The third statement appears to be counterintuitive because it suggests that the total earnings of all DiDi drivers decrease in ℓ and the total earnings of all taxi drivers increase in ℓ. This result is actually caused by DiDi's pricing and wage decisions as well as the underlying competition between DiDi and taxis.

To elaborate, recall from Corollary 1 that, for the taxi industry to always remain in the market, the taxi rate must be low so that $P_T \le \frac{\ell-1}{2\ell-1}$. When P_T is low, the condition $K > \frac{\lambda}{\mu P_T}$ occurs when K is large. When the taxi rate is low, the first statement of Proposition 2 states that it is optimal for DiDi to set its price rate $P_D^* = \frac{(\ell-1+P_T)(2\lambda+K\mu(\ell-1))}{2(\lambda+K\mu(\ell-1))}$ so that $P_D^* > \ell \cdot P_T$, and set the corresponding wage rate $w^* = \frac{\lambda(\ell-1+P_T)}{2(\lambda+K\mu(\ell-1))}$. First, observe that the optimal price rate P_D^* increases in ℓ, and the optimal wage rate w^* decreases in ℓ. Second, observe from the first statement of Proposition 1 that, when $P_D^* > \ell \cdot P_T$, the resulting DiDi demand $\lambda_D = \lambda \cdot \left(1 - \frac{P_D^* - P_T}{\ell-1}\right)$ and decreases in ℓ, and the resulting taxi demand $\lambda_T = \lambda \cdot \left(\frac{P_D^* - P_T}{\ell-1} - P_T\right)$ and increases in ℓ. These two observations imply that, when consumers have a stronger preference for DiDi (i.e., when ℓ increases), DiDi can increase its profit further by increasing its price rate P_D^* and decreasing its wage rate w^* even though the resulting λ_D is lower (i.e., improve profit by having a higher margin even though the demand is lower). As these K DiDi drivers experience a lower wage rate w^* and a lower demand λ_D, their total earnings decrease as ℓ increases. On the contrary, as the resulting taxi demand λ_T increases in ℓ, the total earnings of all taxi drivers increase in ℓ.

6. Optimal Government Regulatory Policy

In Section 5, we evaluate the impact of regulatory policies (K_0, c_1) on different performance measures by using parameter K. We now examine the optimal regulatory policy by weighing different performance measures.

6.1. Optimal Regulatory Policy

Recall from Corollary 2 that DiDi charges a higher price if the taxi industry exits the market. By assuming that most governments are committed to (1) achieving social harmony and (2) protecting consumers from paying higher prices, we focus on the case in which the government is committed to helping the taxi industry to remain in the market (i.e., $\lambda_T > 0$). In addition, recall from (6) that there is an explicit relationship between government regulatory policy (K_0, c_1) and the number of registered DiDi drivers K in period 1; therefore, it suffices to determine the optimal K^* and then use (6) to retrieve the corresponding optimal regulatory policy (K_0^*, c_1^*). By focusing on K, we can formulate a government's problem as

$$\max_K \quad \Pi_G(K) = \alpha_1 \cdot S(K) + \alpha_2 \cdot \xi(K) + \alpha_3 \cdot \Pi_T(K) + \alpha_4 \cdot \Pi_D(K)$$
$$\text{s.t.} \quad \lambda_T(K) > 0, \tag{8}$$

where $\alpha_i \in [0,1]$ (with $\sum_{i=1}^4 \alpha_i = 1$) is the weight assigned to different competing objectives. In addition, we define $\Pi_G(K)$ as the total social welfare. From Corollary 1, we know that, to ensure $\lambda_T > 0$, either $P_T \le \frac{\ell-1}{2\ell-1}$ or $K < \kappa_1 = \frac{2\lambda(1-P_T)}{\mu(2\ell P_T-(\ell-1+P_T))}$. Furthermore, from Proposition 2, we know that when taxis compete in the market, DiDi's optimal price $P_D^*(K) = \frac{(\ell-1+P_T)(2\lambda+K\mu(\ell-1))}{2(\lambda+K\mu(\ell-1))}$ and $w^*(K) = \frac{\lambda(\ell-1+P_T)}{2(\lambda+K\mu(\ell-1))}$. Therefore, we can further compute the consumer welfare $S(K) = \lambda \cdot \left(\frac{\ell-2P_D^*}{2} + \frac{\ell \cdot P_T^2 + {P_D^*}^2 - 2P_D^* \cdot P_T}{2(\ell-1)}\right)$, the total earnings of all DiDi drivers $\xi(K) = K \cdot \xi_0 = K \cdot \frac{\lambda^2\mu^2(\ell-1+P_T)^2}{8(\lambda+K\mu(\ell-1))^2}$, the total earnings of all taxi drivers $\Pi_T(K) = T \cdot P_T \cdot \frac{\lambda_T}{T} = P_T \cdot \lambda \cdot \frac{2\lambda(1-P_T)+K\mu(\ell-1+P_T-2\ell P_T)}{2(\lambda+K\mu(\ell-1))}$, and the DiDi platform's profit $\Pi_D(K) = (P_D^* - w^*) \cdot \lambda_D = \frac{\lambda K\mu(\ell-1+P_T)^2}{4(\lambda+K\mu(\ell-1))}$. By solving the government's problem (8), we obtain the following proposition.

Proposition 3. *Suppose DiDi and taxis coexist and compete in the same market and $\alpha_1 \ge \alpha_2\mu$ (i.e., the government is concerned more about consumer welfare than about DiDi drivers' earnings).*[19] *Then, the optimal K^* that solves problem (8) is listed in Table 3.*

By noting from (6) that $K^* \to \infty$ corresponds to a laissez-faire policy $(K_0^* \to \infty, c_1^* = 0)$, that $K^* = 0$ corresponds to a complete ban policy $(K_0^* = 0,\ c_1^* \to \infty)$, and that $K^* \to \kappa_1$ corresponds to a regulatory policy[20] with $(K_0^* \in (0,\infty), c_1^* \in (0,\infty))$, Proposition 3 reveals that, when the government is concerned more about consumer welfare than about DiDi drivers' earnings (i.e., $\alpha_1 \ge \alpha_2\mu$), the optimal regulatory policy (K_0^*, c_1^*) (through K^*) depends on P_T and the weights assigned to different performance measures as follows.

First, when P_T is low (i.e., $P_T \le \frac{\ell-1}{2\ell-1}$), the first three rows in Table 3 reveal that the optimal policy is either the complete ban policy or the laissez-faire policy, depending on the government's relative emphasis on different performance measures. Second, when P_T is very high (i.e., $P_T > \frac{-(\ell-1)(2\alpha_1+2\alpha_4-\alpha_2\mu)}{2(\alpha_4-(\ell-1)\alpha_1-2\alpha_3)+(2\ell-1)\alpha_2\mu}$) and when the government wants to support the taxi industry (i.e., when α_3 is sufficiently high), the fourth row suggests that the complete ban policy is optimal. Finally, when P_T is high (i.e., $P_T > \frac{\ell-1}{2\ell-1}$), the fifth and sixth rows reveal that a regulatory policy with $(K_0^* \in (0,\infty), c_1^* \in (0,\infty))$ that yields $K^* \to \kappa_1$ (through (6)) is the optimal regulatory policy.

6.2. Numerical Analysis

We now numerically analyze the impacts of P_T and ℓ on the optimal regulatory policy (K_0^*, c_1^*) (through K^* as stated in (6)). We set $\mu = 1$ and consider three cases: (1) $\alpha_1 = 0.3, \alpha_2 = 0.2, \alpha_3 = 0.1, \alpha_4 = 0.4$; (2) $\alpha_1 = 0.3,\ \alpha_2 = 0.2, \alpha_3 = \alpha_4 = 0.25$; and (3) $\alpha_1 = 0.3, \alpha_2 = 0.2,$

Table 3. Optimal Government Policy Under Different Cases

	Conditions	K^*
$P_T \le \frac{\ell-1}{2\ell-1}$	$\alpha_1 - 4\alpha_3 + 2\alpha_4 < 0$ and $P_T > \frac{-(\ell-1)(\alpha_1+2\alpha_4)}{\alpha_1-4\alpha_3+2\alpha_4}$	$K^* = 0$
	$\alpha_1 - 4\alpha_3 + 2\alpha_4 < 0$ and $P_T \le \frac{-(\ell-1)(\alpha_1+2\alpha_4)}{\alpha_1-4\alpha_3+2\alpha_4}$	$K^* \to \infty$
	$\alpha_1 - 4\alpha_3 + 2\alpha_4 \ge 0$	$K^* \to \infty$
$P_T > \frac{\ell-1}{2\ell-1}$	$2(\alpha_4 - (\ell-1)\alpha_1 - 2\alpha_3) + (2\ell-1)\alpha_2\mu < 0$ and $P_T > \frac{-(\ell-1)(2\alpha_1+2\alpha_4-\alpha_2\mu)}{2(\alpha_4-(\ell-1)\alpha_1-2\alpha_3)+(2\ell-1)\alpha_2\mu}$	$K^* = 0$
	$2(\alpha_4 - (\ell-1)\alpha_1 - 2\alpha_3) + (2\ell-1)\alpha_2\mu < 0$ and $P_T \le \frac{-(\ell-1)(2\alpha_1+2\alpha_4-\alpha_2\mu)}{2(\alpha_4-(\ell-1)\alpha_1-2\alpha_3)+(2\ell-1)\alpha_2\mu}$	$K^* \to \kappa_1$
	$2(\alpha_4 - (\ell-1)\alpha_1 - 2\alpha_3) + (2\ell-1)\alpha_2\mu \ge 0$	$K^* \to \kappa_1$

$\alpha_3 = 0.4, \alpha_4 = 0.1$. Here, the government places more weight on taxi drivers (i.e., as α_3 increases) and less weight on DiDi (i.e., as α_4 decreases) as we progress from case 1 to 2 and from case 2 to 3. The optimal K^* associated with these three cases are provided in Figures 4–6, respectively.

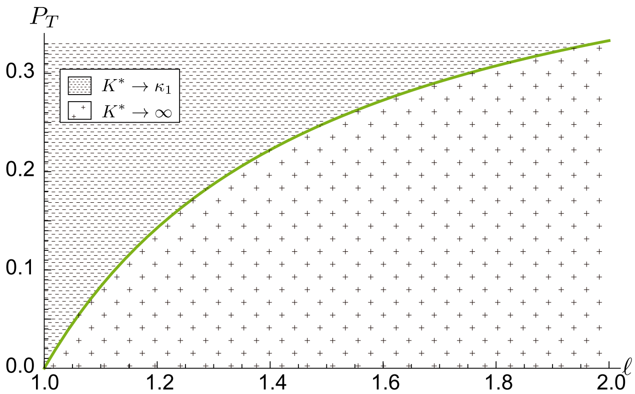
By comparing the optimal regulatory policy of the three cases depicted in Figures 4–6, we observe that, as the government is more concerned about the taxi industry (i.e., as α_3 increases), the government's optimal policy becomes harsher (i.e., the regions associated with the laissez-faire policy, $K^* \to \infty$, and the regions associated with the regulatory policy, $K^* \to \kappa_1$, become smaller). In addition, from Figures 4–6, it is easy to check that, as ℓ (i.e., consumer's preference of DiDi to taxis) increases, the government's policy is less harsh toward DiDi in all three cases (i.e., K^* increases as ℓ increases).

Finally, observe from Figures 4–6 that, as P_T increases, the trend of the optimal regulatory policy becomes harsher to ensure the survival of the taxi industry. Recognizing that P_T is regulated by the government, this observation motivates us to examine in the next section the implications of having the government use P_T as an indirect control lever to regulate DiDi.

7. Taxi Fare as an Indirect Control Policy

In this section, we examine the implications of the government using P_T as an indirect control lever to regulate DiDi. We first analyze the impact of P_T on DiDi's pricing decision and traffic congestion for a given regulatory policy via K (as explained in Section 5). Then we endogenize the P_T decision by studying numerically the case in which the government sets both the regulatory policy and taxi fares (i.e., (P_T, K)) to maximize the total social welfare Π_G.

Figure 4. (Color online) Case 1: Optimal Government Policy When $\boldsymbol{\alpha_1 = 0.3, \alpha_2 = 0.2, \alpha_3 = 0.1}$, and $\boldsymbol{\alpha_4 = 0.4}$



7.1. Analysis of the Strategic Role of Taxi Fare

For any given K, we now examine how the government can use P_T as an indirect control mechanism to regulate DiDi. To facilitate our analysis, we consider the following sequence of events that is consistent with our base model as described in Section 3.2 as follows:

1. The government decides on P_T.
2. DiDi decides on its (P_D, w).
3. Consumers decide on their travel mode (DiDi, taxi, or public transportation).
4. DiDi drivers decide whether to participate in providing a service.

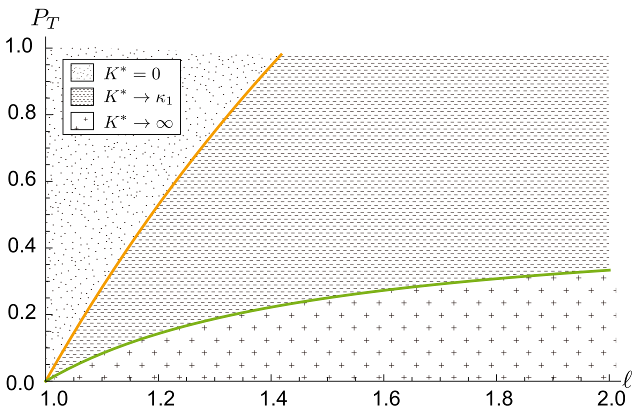
Note that DiDi drivers are independent contractors who can decide whether to participate in period 2. However, we assume that taxi drivers accept rides to recover their sunk costs. By recognizing these differences and by using the same approach as presented in Section 4, we can use backward induction to analyze DiDi's optimal price decisions as follows. (Details are omitted to avoid repetition.)

Proposition 4. *Given the number of registered DiDi drivers K and the demand rate λ, DiDi's optimal price P_D^* satisfies the following:*

1. *If $P_T < \frac{2\lambda+K\mu(\ell-1)}{2\lambda+K\mu(2\ell-1)}$, then $P_D^* = \frac{(\ell-1+P_T)(2\lambda+K\mu(\ell-1))}{2(\lambda+K\mu(\ell-1))}$. In this case, both DiDi and taxis coexist and compete in the same market.*
2. *If $\frac{2\lambda+K\mu(\ell-1)}{2\lambda+K\mu(2\ell-1)} \le P_T < \frac{2\lambda+\ell\mu K}{2\lambda+2\ell\mu K}$, then $P_D^* = \ell \cdot P_T$. In this case, DiDi can drive the taxi industry out of the market so that $\lambda_T = 0$.*
3. *If $P_T \ge \frac{2\lambda+\ell\mu K}{2\lambda+2\ell\mu K}$, then $P_D^* = \frac{\ell(2\lambda+K\mu\ell)}{2(\lambda+K\mu\ell)}$. In this case, DiDi can drive the taxi industry out of the market so that $\lambda_T = 0$.*

Note that Proposition 4 is akin to Proposition 2; however, Proposition 2 is based on a given P_T, and Proposition 4 is based on a given K. Furthermore,

Figure 5. (Color online) Case 2: Optimal Government Policy When $\alpha_1 = \mathbf{0.3}, \alpha_2 = \mathbf{0.2}$, and $\alpha_3 = \alpha_4 = \mathbf{0.25}$

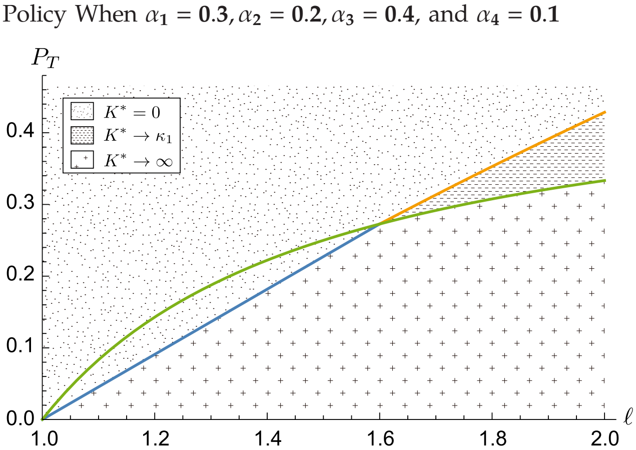


Proposition 4 has the same interpretation as Proposition 2: for the taxi industry to survive in a competitive market, the government needs to set a low taxi fare that has $P_T < \frac{2\lambda + K\mu(\ell-1)}{2\lambda + K\mu(2\ell-1)}$. Because $\frac{\ell-1}{2\ell-1} < \frac{2\lambda+K\mu(\ell-1)}{2\lambda+K\mu(2\ell-1)}$ for any $K > 0$, we obtain Corollary 6.

Corollary 6. *Given the total number of registered DiDi drivers K and the demand rate λ, the taxi industry can survive only when the government sets* $P_T < \frac{2\lambda+K\mu(\ell-1)}{2\lambda+K\mu(2\ell-1)}$. *In addition, if the government adopts a laissez-faire policy so that* $K \to \infty$, *then the government should set an even lower taxi fare* $P_T \le \frac{\ell-1}{2\ell-1}$ *to ensure the survival of the taxi industry.*

Note that Corollary 6 is analogous to Corollary 1 and can be interpreted similarly. We omit the details. We assume the number of taxis on the road will not change because all taxi drivers will always serve in period 2. Therefore, to reduce traffic congestion, the government should focus on reducing k (i.e., the number of DiDi cars on the road in period 2). The following corollary establishes the relationship between k and P_T where taxis and DiDi coexist and compete in the same market.

Figure 6. (Color online) Case 3: Optimal Government Policy When $\alpha_1 = \mathbf{0.3}, \alpha_2 = \mathbf{0.2}, \alpha_3 = \mathbf{0.4}$, and $\alpha_4 = \mathbf{0.1}$



Corollary 7. *For any given number of registered DiDi drivers K, DiDi's optimal price is given as* $P_D^* = \frac{(\ell-1+P_T)(2\lambda+K\mu(\ell-1))}{2(\lambda+K\mu(\ell-1))}$, *and it is increasing in* P_T. *Also, the corresponding number of DiDi cars on the road is given by* $k^* = \frac{\lambda K\mu(\ell-1+P_T)}{2(\lambda+K\mu(\ell-1))}$, *where* k^* *is increasing in* P_T.

Owing to the underlying competition, Corollary 7 reveals the impact of P_T on P_D^* as well as k^*. This observation suggests that the government can use P_T as a lever to control DiDi's price rate and the number of DiDi cars on the road indirectly without imposing direct regulatory policy over DiDi. For instance, by lowering P_T, price competition forces DiDi to lower its price P_D^* and reduce the number of DiDi cars on the road k^*. We examine this issue next by examining the case in which the government sets its regulatory policy via K and the taxi rate P_T to maximize the weighted performance measure as stated in (8).

7.2. Maximizing Social Welfare via P_T and K

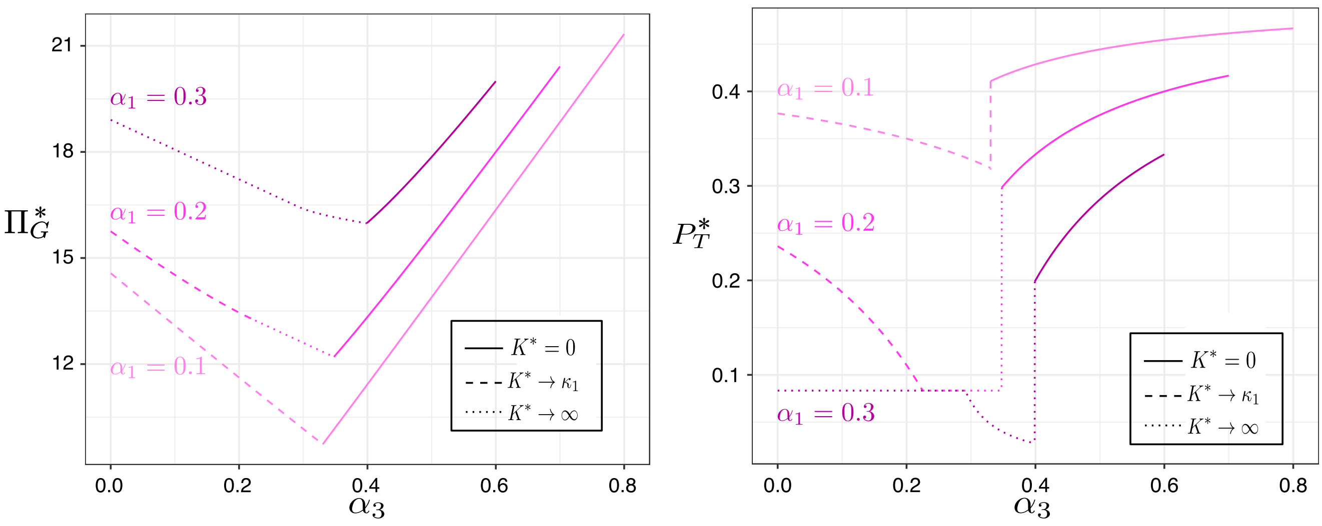
We now consider the case in which the government sets both regulatory policy (via K) and the taxi rate P_T. Specifically, the government decides the optimal pair (P_T^*, K^*) that maximizes the social welfare as defined in (8) while ensuring the survival of the taxi industry. Hence, the government's problem can be formulated as

$$\begin{aligned} \max_{P_T, K} \quad & \Pi_G(P_T, K) = \alpha_1 \cdot S(P_T, K) + \alpha_2 \cdot \xi(P_T, K) \\ & \qquad + \alpha_3 \cdot \Pi_T(P_T, K) + \alpha_4 \cdot \Pi_D(P_T, K) \\ \text{s.t.} \quad & \lambda_T(P_T, K) > 0, \end{aligned} \tag{9}$$

where $\alpha_i \in [0, 1]$ (with $\sum_{i=1}^4 \alpha_i = 1$) are the weights assigned to different competing objectives. Using the results (i.e., $K^*(P_T)$) as stated in Proposition 3, we can further optimize P_T for each case to obtain the optimal pair (P_T^*, K^*) that maximizes the government's objective function. To do so, we conduct two numerical experiments by setting $\lambda = 100$ and $\mu = 1$. In the first experiment, we fix $\ell = 1.1$, $\alpha_2 = 0.1$, vary α_3 from 0 to 0.8, and set α_1 at $0.1, 0.2$, or 0.3 so that $\alpha_4 = 1 - \alpha_1 - \alpha_2 - \alpha_3$. Then we plot the optimal policy (P_T^*, K^*) and the corresponding Π_G^* associated with the first experiment in Figure 7. Similarly, in the second experiment, we fix $\alpha_1 = \alpha_2 = 0.1$ and plot the corresponding results in Figure 8.

Observe from Figures 7 and 8 that the government should take a complete ban policy toward DiDi (i.e., by setting $K^* = 0$) when the government's emphasis on the taxi drivers' earnings (i.e., α_3) is sufficiently large but should take either a laissez-faire approach (i.e., setting $K^* \to \infty$) or a regulatory policy (i.e., setting $K^* \to \kappa_1$) toward DiDi when α_3 is small. In particular, when α_3 is small so that either $K^* \to \kappa_1$ or $K^* \to \infty$

Figure 7. (Color online) Π_G^* and (P_T^*, K^*) When (α_1, α_3) Varies

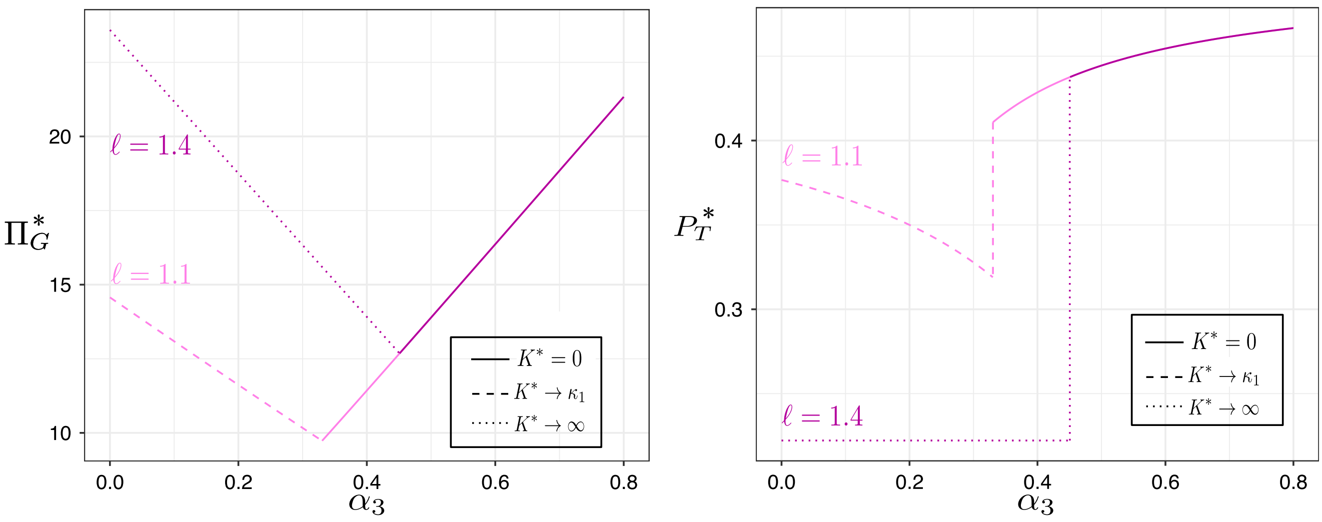


(depending on the value of α_1 as in Figure 7 or ℓ as in Figure 8), the optimal taxi rate P_T^* is nonincreasing in α_3 to stay competitive in the market; however, when α_3 is very large and the government issues a complete ban policy toward DiDi by setting $K^* = 0$, then the optimal taxi rate P_T^* is increasing in α_3. This result implies that, when the government does not place too much weight on taxi drivers' earnings (i.e., when α_3 is small), lowering P_T can improve the competitiveness of the taxi industry for survival. At the same time, lowering P_T is an optimal strategy that maximizes the social welfare $\Pi_G(P_T, K)$ by considering different competing objectives associated with different stakeholders.

Next, observe from Figure 7 that, when the government places more weight on consumer welfare (i.e., α_1 increases), it should lower P_T^*. In addition, as the government lowers P_T^*, the bound $\kappa_1 = \frac{2\lambda(1-P_T)}{\mu(2\ell P_T-(\ell-1+P_T))}$ becomes higher. Hence, when α_3 is comparatively small, the government should reduce P_T^* to ensure the taxi industry can survive and take a less strict policy toward DiDi (i.e., set a higher K^*) as α_1 increases so that consumers can enjoy a lower P_T^* and a higher availability of DiDi cars (via K^*). Similarly, when consumers have a stronger preference for DiDi (i.e., when ℓ is higher), Figure 8 reveals that the government should lower P_T^* and set a higher K^*.

From our numerical results, we can see that, if the government can both adjust taxi fares and regulate DiDi and not place too much weight on taxi drivers' earnings (i.e., α_3 is small), setting a lower P_T and a higher K^* can better balance the different objectives. In particular, when the government is concerned with consumer welfare and/or DiDi further differentiates its service quality from that of the taxi industry (i.e., α_1 is large and/or ℓ is high), it is optimal for the

Figure 8. (Color online) Π_G^* and (P_T^*, K^*) When (ℓ, α_3) Varies



government to simply set a more competitive P_T^* instead of tightening the control of DiDi or issuing a complete ban of DiDi.

8. Conclusion

Owing to the social costs and benefits of ride-hailing services, such as DiDi and Uber, many governments are undecided regarding the regulation of these innovative services. As an initial attempt to explore the implications of a class of regulatory policies (K_0, c_1) adopted by the Chinese government and the New York City Council, we develop a unified two-period game-theoretic model to capture the strategic interactions among different stakeholders (government, DiDi, DiDi drivers, and consumers). We show that, without government regulation, the on-demand ride service can drive the taxi industry out of the market when taxi fares are high and when the number of DiDi drivers is high. Furthermore, we show that once taxis exit the market, DiDi increases its price. To protect consumers from paying high prices and to sustain the taxi industry, we examine the impact of different regulatory policies (complete ban, laissez-faire, and a regulatory policy that either caps the maximum number of DiDi drivers or imposes various driver eligibility criteria) on the competing objectives of different stakeholders.

Our key findings are as follows. First, compared with laissez-faire (i.e., no regulation), our analytical results suggest that a regulatory policy (i.e., $K_0 \in (0, \infty), c_1 \in (0, \infty)$) can help the taxi industry to survive in the market. Second, by imposing an entry fee c_1, the number of registered DiDi drivers decreases, and DiDi increases the wage rate so that each registered DiDi driver earns more under this regulatory policy. Second, compared with a complete ban policy, this regulatory policy strikes a balance among different competing performance measures: taxi industry survival, DiDi's profit, DiDi drivers' earnings, and consumer welfare.

We examine the government's optimal regulatory policy that maximizes the total social welfare based on the weighted sum of different objectives associated with different stakeholders (consumers, taxi drivers, DiDi company and DiDi drivers). We find that the government's optimal policy (K_0^*, c_1^*) depends on the taxi fare and the weights assigned to different objectives. Specifically, when the taxi fare is higher than a certain level (i.e., $P_T > \frac{\ell-1}{2\ell-1}$), we show that it is optimal for the government to intervene by imposing a regulatory policy or complete ban to ensure the survival of the taxi industry so as to (1) achieve social harmony and (2) protect consumers from higher price surges set by DiDi once taxis exit the market. By conducting a numerical study, we find that, as taxi fares increase, it is optimal for the government to set a harsher regulatory policy to reduce the number of registered DiDi drivers.

To reduce traffic congestion as well as balance the welfare of multiple stakeholders, we also examine an alternative way to control DiDi indirectly by reforming the taxi industry via adjusting the taxi fare P_T in period 2. We show that, by lowering the taxi fare, the government can force DiDi to lower its price and wage so that there are fewer DiDi cars on the road. Therefore, by allowing the government to set the taxi fare freely (as a decision in period 2), the government can control the number of DiDi cars on the road without imposing direct control. By conducting a numerical study, we also show that, when the government places a comparatively small weight on taxi drivers' earnings, it is optimal for the government to lower the taxi fare and take a less strict policy toward DiDi. In particular, when the government emphasizes consumer welfare and/or DiDi's service quality further improves, it can be optimal for the government to simply set a competitive taxi fare instead of a tightly regulated policy or a complete ban policy toward DiDi.

Our study represents an initial attempt to analyze the implications of government regulations regarding innovative business models (e.g., on-demand ride services). Our model and results can help governments develop better regulations with a better understanding of their implications. Despite the limitations of our model, new avenues for future research have opened up. First, it would be interesting to examine other direct or indirect regulatory approaches that can enable governments to support innovative start-ups without destroying traditional companies. For example, a government may adopt direct control of a start-up company's pricing format (e.g., the Chinese government could request DiDi to charge above certain levels), may require a company to differentiate its service from that of existing industries (e.g., the Chinese government could request DiDi to focus on SUV services only), or may provide subsidies to reform traditional industries (e.g., the Chinese government could provide subsidies to taxi companies to develop similar mobile apps to compete and to reduce taxi drivers' operational costs so as to reduce the taxi fare).

Our model focuses on strategic-level decisions without dealing with various operational aspects, such as waiting time, dynamic demand,[21] competition among taxi drivers, regulation of the taxi industry, and driver's career choice (i.e., to register as a DiDi driver or a taxi driver) so that the number of taxi drivers is determined endogenously. Therefore, it would be of interest to generalize our model by incorporating various operational issues in the future. In summary, we find that these innovative business models offer many research avenues for researchers to explore.

Endnotes

[1] FTC, 2016, The "Sharing" Economy Issues Facing Platforms, Participants and Regulators, FTC Staff Report, November 2016.

[2] In 2017, the European Union's top court decided that Uber should be regulated as a licensed transport firm (BBC 2017).

[3] For example, the following rule of Hangzhou was effective on March 1, 2017. First, to qualify as a ride service car, the vehicle must be locally registered, have been used for less than five years, have a wheelbase no shorter than 2,700 mm (2,600 mm for new energy-efficient cars), and an initial price of no less than RMB 120,000. Second, to qualify as a ride service driver, a driver must be a local resident or have had a local residence permit for more than six months in Hangzhou, have at least three years' driving experience, and pass certain driving tests associated with private ride services. Third, the new rules stipulate that the on-demand ride service is not allowed to set its price below the cost of operations.

[4] Recognizing that taxi drivers have been viewed as entrepreneurs after the economic reform in 1978, the Chinese government aims to strike a balance between encouraging innovative business services and sustaining the taxi industry to achieve social harmony—one of the important goals of the Chinese Communist Party.

[5] For example, Chinese government officials claimed that these new regulatory measures were intended to reduce traffic congestion (and air pollution) in major cities. The director of the Beijing Municipal Commission of Transportation stated that, as more than 100,000 private cars provide 600,000 to 700,000 trips each day for various on-demand ride services, the traffic congestion in Beijing has worsened (Yu 2016). Hence, these new measures can reduce the growth of on-demand ride services and reduce traffic congestion. Like the objectives of the Chinese government, those of the New York and London governments are to reduce the number of cars on the road so as to reduce traffic congestion (*The Economist* 2018).

[6] For convenience, we use DiDi to represent an on-demand service company throughout this paper.

[7] In many countries, such as China and Singapore, taxi fares are controlled by the government.

[8] This assumption is reasonable because these decisions are made rather infrequently. For example, the 2017 taxi rate in Beijing was set by the government in 2013. Before this rate reform in 2013, the previous rate change took place in 2006 (Jin 2013). Also, taxi drivers cannot switch to become DiDi drivers because they have signed long-term commitments: (a) most of them sign long-term (three-year) contracts with taxi companies and (b) most of them are in debt owing to high taxi licensing fees (RMB500,000 or US$75,320 in Shanghai).

[9] We restrict our focus on variable pricing so that (P_D, w) depends on the customer demand λ. In other words, we do not consider the true dynamic price setting; therefore, (P_D, w) depends on the demand rate at different geographical locations in every single time instant. The support of variable pricing has been documented in the literature. For example, as articulated in MacMillan (2015) and Taylor (2018), many customers resist real-time dynamic pricing, and most on-demand service platforms other than Uber and Lyft tend to adopt this form of time-based variable pricing. More importantly, our variable pricing assumption can be justified by the new DiDi's time-based variable pricing rule effective since April 2017 (*China Daily* 2017).

[10] Here we scale the customer travel distance to one because travel distance does not affect a customer's decision.

[11] In the event that some customers prefer DiDi and others prefer taxis, we can extend our model as follows: within the population, a proportion a of consumers prefer DiDi and, therefore, $\ell > 1$ although $1 - a$ of the consumers prefer taxis and, therefore, $\ell < 1$. For ease of exposition, we set $a = 1$ to capture the preferences of the majority. Nevertheless, we may use the same approach to examine the case in which $a < 1$, and we omit the details.

[12] Besides its own app, DiDi is also embedded in WeChat and Alipay (two dominant apps in China); therefore, it is very convenient for people to call the DiDi service and make a payment via these apps (Muoio 2016).

[13] In Online Appendix A, we examine the robustness of our results by (1) conducting a numerical study regarding the normally distributed consumer valuation and (2) analyzing another boundary case with independent consumer valuations. From these robust analyses, we find that our key results hold.

[14] When $\lambda_D > k$, we do not consider the case in which a DiDi driver provides services multiple times because customers do not wait and switch to other travel modes when no DiDi driver is available. Therefore, when $\lambda_D > k$, the excess demand is lost and the transaction quantity $Q_D = k$.

[15] R_2 incorporates the operational costs in certain time periods. First, R_2 varies among different DiDi drivers so that it captures the heterogeneity among them. Second, for each DiDi driver, R_2 may vary from time to time.

[16] Based on real DiDi data, we found that the average travel distance of a trip was rather stable across different hours. Therefore, we scale the expected travel distance of a trip to one throughout the paper.

[17] Before the Chinese government imposed regulations, any driver (both local residents or immigrants from other provinces with very little driving experience) could use any car (old or new, small or large) to register as a DiDi driver. First, as there were no eligibility criteria for DiDi drivers, anyone could register as a DiDi driver. Given the huge population in China, we simply assume $K_0 \to \infty$. Second, as there were no requirements for cars, drivers could use any car to provide services so that the entry fee was very low. For simplicity, we assume $c_1 = 0$.

[18] We can also consider the total net present value of all K DiDi drivers' earnings in period 2 (i.e., $K \cdot \frac{1}{1-\delta} \cdot \xi_0$), and by setting the discount factor $\delta = 0$, the net present value $\xi = K \cdot \xi_0$.

[19] Although we focus on the case in which $\alpha_1 \geq \alpha_2 \mu$, we can obtain the optimal government policy for the case in which $\alpha_1 < \alpha_2 \mu$ by using a similar method, and we show the result of that case in the proof.

[20] As implied from Propositions 1 and 2, we use $K^* \to \kappa_1$ to denote the case in which $K^* = \kappa_1 - \epsilon < \kappa_1$ (ϵ is arbitrarily small) to ensure that $\lambda_T > 0$ so that the taxi industry can remain in the market.

[21] We examine the case in which demand follows a two-point distribution and obtain the same structural results. We omit the details to avoid repetition and to simplify our exposition.

[22] In our data sets, we do not have DiDi's exact price and wage data of each trip for confidential reasons. However, we can learn DiDi's specific variable pricing rules from its mobile app. In Hangzhou, there are two parts to the charging rates: mileage fee (2.4 RMB per kilometer from 6:30 a.m. to 11 p.m. and 3 RMB per kilometer at night from 11 p.m. to 6:30 a.m. when the travel distance is smaller than 12 km; otherwise, the excess 12 km part is charged an extra 0.8 RMB per kilometer) and time fee (0.35 RMB per minute). The minimum charge is 8 RMB. In addition to the regular variable charging policy shown, DiDi claims that it also applies surge price during peak hours (e.g. 1.2 times the regular price).

[23] Bai et al. (2018) showed DiDi's average price rate in Hangzhou across different hours from 8 a.m. to 12 a.m. between September 7 and 13, 2015. Owing to data incompleteness and to make a parallel illustration, we show the average price rate from 8 a.m. to 23 p.m. before and after the new rules in Figure 15 in the online appendix.

[24] The taxi's pricing system of Hangzhou does not vary before and after the new rules so that we have only one bar to show taxi's price rate in Figure 15 in the online appendix. In Hangzhou, taxis

apply a tier pricing system: for the first 3 km, it charges a fixed amount of RMB 11; then, for the part between 3 and 10 km, it charges 2.5 RMB per kilometer; and for the part in excess of 10 km, it charges 3.75 RMB per kilometer. And we also apply the taxi's pricing system to the average travel distance and time of our data set to estimate the corresponding taxi's average price rate across different hours.

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