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# Off-Street Parking for TNC Vehicles to Reduce Cruising Traffic

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Abstract—This paper considers off-street parking for the cruising vehicles of transportation network companies (TNCs) to reduce the traffic congestion. We propose a novel business that integrates the shared parking service into the TNC platform. In the proposed model, the platform (a) provides interfaces that connect passengers, drivers and garage operators (commercial or private garages); (b) determines the ride fare, driver payment, and parking rates; (c) matches passengers to TNC vehicles for ride-hailing services; and (d) matches vacant TNC vehicles to unoccupied parking garages to reduce the cruising cost. A queuing-theoretic model is proposed to capture the matching process of passengers, drivers, and parking garages. A market-equilibrium model is developed to capture the incentives of the passengers, drivers, and garage operators. An optimization-based model is formulated to capture the optimal pricing of the TNC platform. Through a realistic case study, we show that the proposed business model will offer a Pareto improvement that benefits all stakeholders, which leads to higher passenger surplus, higher drivers surplus, higher garage operator surplus, higher platform profit, and reduced traffic congestion.

### I. INTRODUCTION

The proliferation of smartphones has enabled transportation network companies (TNCs), such as Uber, Lyft and Didi, to offer real-time matching services for passengers and drivers, which significantly reduces the search frictions of the ride-hailing market. These emerging businesses have deeply transformed the landscape of urban transportation. Today, Uber has completed more than 10 billion trips with 3.9 million active drivers in over 65 countries [1]. It was estimated in [2] that Uber generated \$6.8B consumer surplus in the US in 2016.

Recently, the rapid growth of TNCs starts to exhibit externalities that negatively impact the transportation system. Among the various concerns, a major one is the "cruising congestion" caused by TNC vehicles. The TNC business model crucially relies on a very short passenger waiting time, which in turn depends on a large number of available but *idle* drivers. In New York City, TNC drivers spend more than 40% of their time empty and cruising for passengers [3]. This underutilization of vehicles not only leads to low driver incomes, but also created more cruising traffic that congested the city streets which are already saturated. In Manhattan, for-hire vehicles make up nearly 30% of all traffic [4].

One way to address the cruising congestion is by regulatory intervention [5], [6]. In 2019, the New York City Taxi and Limousine Commission (NYCTLC) required TNC platforms to cap their time cruising without passenger below 31% out of all driving time in Manhattan core at peak hours (currently 41% industry-wide) [4]. This regulation aims to motivate TNCs to better utilize their drivers' resources and reduce the cruising congestion. However, it was overturned by the Supreme Court of State of New York [7], claiming that the citys cruising cap was "arbitrary and capricious".

Another way to curb cruising congestion is by parking the vehicles when there is no passenger. Xu et al. [8] studied the allocation of road space to on-street parking for vacant TNC vehicles to reduce cruising congestion. The optimal parking provision strategy was proposed to address the trade-off between reduced cruising traffic and reduced road spaces. Ruch et al. [9] considered a mobilityon-demand system with a fleet of vehicles and a number of free parking spaces. A coordinated parking operating policy was proposed to meet the parking capacity constraint with minimum increase in vehicle distance traveled and minimum impact on the service level. Kondor et al. [10] investigated the minimum number of parking spaces needed for the mobility-on-demand services and analyzed the relationship between parking provision and traffic congestion. Lam et al [11] proposed a coordinated parking management strategy for electric autonomous vehicles to provide vehicle-to-grid services. Jian et al [12] considered an operator that integrates car-sharing and parking sharing platforms to provide bundled services (car and parking) to travelers.

In this paper, we propose a novel business model that integrates ride-hailing services and parking services into a single ride-sourcing platform (i.e., TNC). The platform (a) provides interfaces that connect passengers, drivers and garage operators (commercial or private garages); (b) determines the ride fare, driver payment, and parking rates; and (c) executes two matching processes for the market participants, where passengers are matched to TNC vehicles for ridehailing services, and vacant TNC vehicles are matched to unoccupied parking garages to reduce the cruising cost. Our key observation is as follows: regular parking demands are typically much longer than TNC parking demands (e.g., 1h vs 8min [4]). Based on the SF-Park data [13], there are inevitably gaps between two long-term parking customers subsequently taking the same parking space. The proposed business model enables the garage owners to fill these gaps using short-term TNC parking demands in real-time, which only takes the spaces that would have been unused if they are not provided for TNC parking. By unlocking the potential

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of these underutilzied parking garages, the proposed business model will benefit passengers, drivers, garage operators, and the TNC platform without affecting regular parking demand.

The key contributions of the paper are summarized below:

- We proposed a novel business model that integrated parking services into the TNC platform. Based on the principle of sharing economy, the proposed solution will increase passenger surplus, driver surplus, garage profit, and TNC profit. In the meanwhile, it will reduce the cruising congestion without affecting the regular parking demand.
- We developed a market equilibrium model that captures the incentives of the passengers, drivers, garage operators, and the TNC platform. A queuing theoretic model is proposed to capture the dynamics of passengers, drivers, and the parking garages, and an optimization model is formulated for the TNC platform to jointly derive the optimal prices of the ride-hailing service and the parking service.
- We validated the proposed model through numerical simulations. The impacts of the proposed parking services on the ride-hailing market are assessed quantitively based on real San Francisco data.

## **II. THE BUSINESS MODEL**

We consider a transportation market with the TNC platform, a group of passengers and drivers, and a number of (private or commercial) parking garages distributed across the transportation network. Based on the principle of sharing economy, the TNC platform offers app-based interfaces that provide on-demand services to both passengers, drivers and the garage operators. Passengers can request on-demand ride services through the user app. Drivers can log on/off the app to provide ride services depending on their own work schedules. Garage operators can offer or withdraw any number of parking spots at any time depending on their operational strategies. Each ride is initiated by a service request from the passenger. The platform then matches the passenger with a nearby driver, who delivers the passenger to a pre-specified destination. After the passenger alights, instead of cruising on the street, the driver is dispatched to a nearby parking garage<sup>1</sup>, where he stays for a few minutes (e.g. 5-8 min [4]) until the next passenger arrives. Throughout this process, a few transactions take place: (a) each passenger pays a ride fare to the platform based on the trip distance and trip time; (b) each driver receives a payment from the platform based on the passenger fare and the commission rate; and (c) each garage operator receives a payment from the platform based on the accumulated TNC parking time at a per minute rate. We assume that all rates are determined by the platform, and all transactions are centrally processed through the cloud. In this case, there is no direct payment transfer among passengers, drivers and garage operators. The system diagram is shown in Figure 1. A few important remarks are in order:

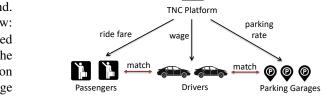


Fig. 1. The system diagram for the transportation market.

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- We argue that the parking service should be provided by the TNC platform rather than other third-party platforms. This is because the sharing-economy model for parking services requires the platform to (a) acquire the real-time location of TNC vehicles, and (b) accumulate a large number of users on both demand side (TNC vehicles) and supply side (parking garage) of the market. TNC is a natural candidate for running the proposed business model<sup>2</sup>.
- The proposed business model aims to unlock the potential of the *underutilized* parking garages, so that parking services complement the existing garage operation instead of substituting it. It is crucial to observe that each TNC vehicle only parks for 5-8 minutes before the next ride request. This enables the garage operator to fill the gap between regular long-term parking demands (e.g., 2 hours) using the short-term TNC parking demands (e.g., 5-8 min). The garage operator could offer more parking spaces to the TNC platform when it predicts that the regular long-term parking demand is low, and withdraw the parking services from the platform at any time when the regular demand is high. In this case, the parking spaces offered to the TNC platform would have been *unoccupied* if it is not reserved for TNC parking. Therefore, the proposed business model will not impact the regular parking demand<sup>3</sup>.
- Based on the above discussion, the marginal cost of the parking spaces offered to the TNC platform are minimum. This enables TNC vehicles to enjoy a heavy parking discount compared to other parking demands. The rates of the TNC parking services are determined by the platform, while the rates for other regular parking demands are determined by the garage operator. These two parking services are operated in parallel. The garage operator determines the allocation of the parking spaces in each service to maximize his profit.
- The proposed business model requires minimum hardware and software modification on the existing parking infrastructure. The TNC platform will develop an appbased interface for the garage operator. The garage operator will communicate with the TNC platform to enable smooth entry and exit of TNC vehicles. Parking data

<sup>&</sup>lt;sup>1</sup>We will show that on average, drivers benefit from following the platform dispatch. The spatial heterogeneity among drivers is left for further research.

<sup>&</sup>lt;sup>2</sup>We will show that TNC makes more profit by offering parking services. <sup>3</sup>Garage operators needs to reserve easy-access parking spaces for TNC vehicles to accommodate their short stay.

should be submitted periodically through the interface for financial settlements.

### **III. MATHEMATICAL FORMULATION**

Ride-hailing market is typically formulated as a two-sided market where the platform matches the supply side (driver) and the demand side (passenger) to make a profit. When parking service is integrated, the TNC platform faces a much more complicated market structure that involves two matching processes (i.e., matching passengers to drivers, matching drivers to parking garages) and three sides (i.e., passenger, drivers, and parking garages). In this case, the platform determines the ride fare, driver payment, and the parking rate to attract both passengers, drivers and the garage operators. These platform decisions will affect the decision making of passengers, drivers and the garage operators, which in turn determines the profit of the TNC platform. Below we present a mathematical model to capture the incentives of these market participants.

# A. The Matching Process

Consider a ride-hailing market that consists of N drivers, K parking slots, and a group of randomly arriving passengers. Upon arrival, each passengers immediately joins a queue and waits for he next available driver to be dispatched. After passenger alights, each driver is dispatched to a parking garage (if available) until the next ride request arrives (driver relocation is neglected in the aggregate model). This can be captured by a continuous-time queuing process where passengers are modeled as "jobs" and drivers are modeled as "servers". We assume that the arrival process of passengers is Poisson with rate  $\lambda > 0$ , and the service rate is exponential with rate  $\mu$ . This leads to an M/M/N queue, where the average number of idle TNC vehicles (vehicles without a passenger) is  $N_I = N - \lambda/\mu$ .

# **B.** Passenger Incentives

Passengers choose whether to take TNC based on the travel cost of the TNC ride. We define the total travel cost of the TNC ride as the weighted sum of the ride fare  $p_f$  and the waiting time  $t_w$ :

$$c = \alpha t_w + p_f. \tag{1}$$

where  $\alpha$  represents the trade off between time and money, the ride fare  $p_f$  is determined by the platform, and the passenger waiting time can be decomposed into two parts: (a) from the ride being requested to a vehicle being dispatched (denoted as  $t_1$ ), and (b) from the vehicle being dispatched to the passenger being picked up (denoted as  $t_2$ ). The former represents the waiting time in the M/M/N queue, and the latter represents the travel time between the passenger and the nearest idle TNC vehicle. We assume that the total waiting time  $t_w = t_1 + t_2$  depends on the density of idle TNC vehicles  $N_I$ . With slight abuse of notation, we denote  $t_w$  as a function  $t_w(N - \lambda/\mu)$ , then the arrival rate of passengers is captured by:

$$\lambda = F_p \bigg( \alpha t_w (N - \lambda/\mu) + p_f \bigg), \qquad (2)$$

We assume that  $F_p(\cdot)$  is a decreasing and continuously differentiable function, so that higher travel cost c indicates lower arrival rate of TNC passengers.

### C. Driver Incentives

Drivers decide whether to join TNC based on the net hourly wage offered by the platform. The net hourly wage of the TNC driver is defined as the gross wage  $w_q$  minus the vehicle expenses. The gross wag  $w_q$  is set by the platform [5], determined as the passenger ride fare minus the platform commission. The vehicle expenses consist of a one-time fixed cost (such as vehicle registration, maintenance, insurance) and the variable costs (such as gas expenses, work time, etc). Here we neglect the one-time fixed expenses since the fixed costs are discounted over the long term (e.g. 1 year) and does not affect the short-term driver supply in the TNC market (e.g., 1 hour).

After the passenger alights, drivers can either cruise at the cost of l (per hour) or park in the garage at the cost of  $p_a$ (per hour) subject to parking availability. Let r denote the average utilization rate of the K parking garages, then the net hourly wage of the drivers can be written as:

$$w_n = w_g + \frac{(l - p_g)Kr}{N} \tag{3}$$

To derive equation (3), we note that  $\frac{\lambda}{N\mu}$  is the occupancy rate of the TNC vehicles. If no parking service is provided, then the variable cost for all vehicles is l per hour. However, the TNC vehicle would save  $l - p_g$  (per hour parked) if the parking rate is lower than the cruising cost. Since the occupancy rate of the parking garages are r, the total saving for all TNC drivers are  $(l - p_g)Kr$ . Therefore each drivers receives a saving of  $\frac{(l - p_g)Kr}{N}$ . The total number of drivers N is a function on the net

hourly wage:

$$N = F_d \left( w_g + \frac{(l - p_g)Kr}{N} \right). \tag{4}$$

We assume that  $F_d(\cdot)$  is an increasing function, so that higher net wage indicates more supply of TNC drivers. Without loss of generality, the vehicle variable cost -l is neglected in (4) as it is a constant.

### D. Garage Operator Incentives

The garage operator decides the number of parking spaces offered to the TNC platform based on the TNC parking rates and the statistics of the regular parking demand. In practice, the garage operator should predict the regular parking demand in the next a few minutes, evaluate how many parking spaces will be unoccupied, and offer these parking spaces to the TNC platform. To reduce the exposure, we assume that this underlying decision process is captured by a function that specifies the relation between the TNC parking rate  $p_g$  and the parking supply K:

$$K = F_g(rp_g) \tag{5}$$

where  $rp_g$  is the per hour earning of a parking space offered to the TNC platform. We assume that  $F_g$  is an increasing function so that higher earnings attract more parking supply.

It is important to note that the utilization rate of TNC parking space, r, depends on the passenger arrival rate  $\lambda$ , the number of drivers N, and the number of parking spaces K. With slight abuse of notation, denote r as  $r(\lambda, N, K)$ . We note that when there are i idle drivers in the system and  $i \ge K$ , all parking space will be occupied, and r = 1. However, when i < K, only i out of K parking spaces are occupied, and the average utilization rate satisfies r = i/K. In addition, we note that the passenger-driver matching process is an M/M/N queue. Therefore, the probability that there are i idle drivers, denoted as  $X_i$ , can be derived as:

$$X_{0} = \pi_{0} \frac{(N\rho)^{N}}{N!(1-\rho)}$$
  

$$X_{i} = \pi_{0} \frac{(N\rho)^{N-i}}{(N-i)!}, \quad \forall 1 \le i \le N-1$$
  

$$X_{N} = \pi_{0},$$
  
(6)

where  $\rho = \frac{\lambda}{N\mu}$  is the occupancy rate of TNC vehicles, and  $\pi_0$  is the probability of all drivers being idle in the ride-hailing market. The expected utilization rate of parking spaces on the TNC platform is

$$r(\lambda, N, K) = \sum_{i=1}^{N} X_i \min\left(1, \frac{i}{K}\right), \tag{7}$$

where  $\min(a, b)$  represents the min of a and b.

# E. Profit Maximization of the TNC Platform

Consider a TNC platform that charges commission to make a profit. In this paper, we assume that the platform charges a commission on the ride-hailing services, but does not charge a commission on the parking services. We argue that the TNC platform will refrain from taking commission from the parking services at least in the early stage of the proposed business model. In the next section, we will show that the TNC platform substantially benefits from the proposed business model even if no commission charge is directly collected from the parking sector.

In each hour, the platform receives  $\lambda p_f$  from passengers, pays  $w_g N$  to drivers, and keeps the difference to make a profit. The platform's profit maximization problem can be cast as:

$$\max_{p_f, w_g, p_g} \lambda p_f - w_g N \tag{8}$$

$$\begin{cases}
\lambda = F_p \left( \alpha t_w (N - \lambda/\mu) + p_f \right), \\
N = F_d \left( w_g + \frac{(l - p_g) K r(\lambda, N, K)}{N} \right) \\
K = F_g \left( p_g r(\lambda, N, K) \right).
\end{cases}$$

The overall problem (8) is non-convex due to the nonlinear constraints. However, since the dimension of the problem is small, we can solve the globally optimal solution to (8) via enumerations within sub-second.

### **IV. MAIN RESULTS**

This section discusses the feasibility of the proposed business model. We first demonstrate the benefits of the proposed model through an numerical example using real data from San Francisco, then we summarize the theoretical result in Theorem 1, which shows that integrating parking services to the TNC platform will offer a Pareto improvement, leading to higher passenger surplus, higher driver surplus, higher platform profit, and less traffic congestion.

## A. Numerical Example

Passengers choose their transport mode based on the total travel cost c. This can be captured by a logit model, which can be written as:

$$\lambda = \lambda_0 \frac{e^{-\epsilon c}}{e^{-\epsilon c} + e^{-\epsilon c_0}},\tag{10}$$

where  $\lambda_0$  is the number of potential passengers (all passengers regardless of their travel mode), and  $\epsilon$  and  $c_0$  are the model parameters. In our previous work [5], we proved that the passenger waiting time  $t_w$  is inversely proportional to the square root of the number of idle vehicles:

$$t_w = \frac{M}{\sqrt{N - \lambda/\mu}}.$$
(11)

The underlying intuition of this results is very simple: assume that all idle vehicles are uniformly distributed across the city. The passenger waiting time depends on the distance between the passenger and the closest idle vehicle, which is further proportional to the distance between any two nearby idle vehicles. Intuitively, the average distance between any two nearby idle vehicles is inversely proportional to the square root of the number of idle vehicles. Our result is consistent with the empirical data reported in [14].

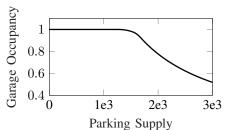
Drivers choose their work based on the net hourly wage. Under a logit model, the driver supply function can be written as:

$$N = N_0 \frac{e^{\eta w_n}}{e^{\eta w_n} + e^{\eta w_0}},$$
 (12)

where  $N_0$  is the number of potential drivers, and  $\eta$  and  $w_0$  are the model parameters. Garage operators decide whether to offer the parking space to the TNC platform based on the earnings offered by the platform. Assume that each parking space has a reservation earning, and the garage operator only offers the parking space if the platform earning *e* exceeds the reservation earning. Different parking spaces have distinct reservation earning is captured by a log-normal distribution. In this case, the parking supply function  $F_g$  can be written as:

$$F_g(p_g r) = K_0 \left(\frac{1}{2} + \frac{1}{2} \operatorname{erf}\left(\frac{\ln(p_g r) - u_0}{\sqrt{2}\sigma}\right)\right)$$
(13)

where  $K_0$  is all potential *idle* parking space calculated based on the arrival and departure pattern of long-term regular parking demand,  $erf(\cdot)$  denotes the error function, and  $u_0$ and  $\sigma$  are the model parameters.



1 Parking Ratio 0.8 0.60.40.20 1e3 2e3 3e3 0 Parking Supply

Fig. 3. Ratio of parked TNC vehicles out of all

idle TNC vehicles as a function of K.

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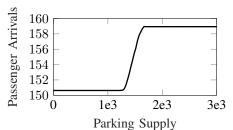
28.8

28.6

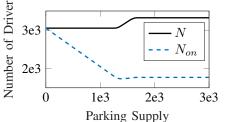
28.4

0

Passenger Cost



Average occupancy rate of the parking Fig. 2. garages as a function of K.



on-road drivers  $(N_{on})$  as a function of K.

Fig. 5.

Total number of drivers and number of money) as a function of K.

Fig. 4. Passenger arrival rate (per minute) as a function of K.

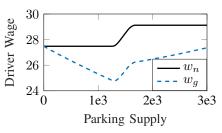
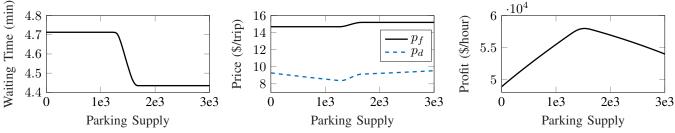


Fig. 7. Gross hourly wage  $(w_g)$  and net hourly wage of TNC drivers as a function of K.



Passenger waiting time (minute) as a Fig. 9. Per-trip passenger fare and driver payment Fig. 10. Fig. 8. function of K. as a function of K. function of K.

Hourly platform profit (\$/hour) as a

To setup the numerical study, we need to specify the values of the following parameters:

$$\Theta = \{\lambda_0, N_0, K_0, M, \alpha, \epsilon, c_0, \eta, w_0, \sigma, u_0, l\}.$$
 (14)

To this end, we consider the following profit maximization problem without parking services:

$$\max_{p_f, w_g} \lambda p_f - w_g N \tag{15}$$

$$\begin{cases} \lambda = F_p \Big( \alpha t_w (N - \lambda/\mu) + p_f \Big), \\ N = F_d \left( w_q \right) \end{aligned}$$
(16)

and we set the parameters values  $\Theta$  so that the optimal solution to (15) matches the San Francisco TNC market data. The values of these parameters are summarized below:

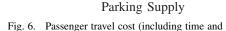
$$\begin{aligned} \lambda_0 &= 944/\min, N_0 = 10,000, K_0 = 10,000, M = 174.7, \\ \alpha &= 3, \epsilon = 0.155, c_0 = 15.48, \eta = 0.144, w_0 = 32.41, \\ \sigma &= 0.6, u_0 = 1.1, l = \$8/\text{hour} \end{aligned}$$

The detailed justification of these parameters values can be found in Appendix 1 of [6].

To understand impacts of parking on the TNC business model, we solve (8) in two steps: first we fix K and derive other endogenous variables as a function of K, which reflect how parking provision affects the surplus of passenger. drivers, garage operators, and the TNC platform; then we vary K to derive the optimal parking supply that maximizes the platform profit. Note that K is *endogenous* and the platform eventually chooses K that maximizes its profit.

As the number of parking spaces K increases, the average occupancy of each garage decreases. Therefore, it is easier for each idle TNC vehicle to find a parking space. This indicates that the occupancy of parking garages is a decreasing function of K, and the ratio of parked TNC vehicles out of all *idle* TNC vehicles is an increasing function of K. The average occupancy of the TNC parking spaces is shown in Figure 2. The ratio of parked TNC vehicles is shown in Figure 3. The number of passengers and drivers as are shown in Figure 4 and Figure 5, respectively. The passenger travel cost is shown in Figure 6. The driver gross wage and net wage are shown in Figure 7, and passenger waiting time is shown in Figure 8. The passenger ride fare, per-trip driver payment, and per hour parking rate is shown in Figure 9. The platform profit is shown in Figure 10. All variables are represented as functions of K.

Based on Figure 2-10, the optimal solution as a function



1e3

3e3

2e3

of K clearly has three distinct regimes:

- When  $K \leq 1272$ , all parking spaces are fully occupied. Passengers and drivers are unaffected. Driver savings from parking the TNC vehicle are reaped by the TNC platform, who pays a reduced gross wage and enjoys an increased platform profit. The number of TNC vehicles on road is reduced, and therefore traffic congestion is reduced.
- When  $1272 \le K \le 1607$ , both passengers and drivers benefit from the parking services. The passenger total travel cost reduces, the driver net wage increases, more passenger are delivered, and more drivers are hired. The number of TNC vehicle on the road network slightly increases, but is significantly smaller than at K = 0. The platform profit is maximized at K = 1515.
- When K ≥ 1607, all idle TNC vehicles are parked. Passenger and drivers are unaffected. The cost due to over-provision of parking spaces are covered the TNC platform, who pays an increased gross wage and earns a reduced profit. Traffic congestion is unaffected.

By comparing the proposed business model with (15), our numerical study clearly indicates that at the optimal solution, the proposed business model benefits both passengers, drivers, garage operators, the TNC platform. In the meanwhile, it reduced the number of TNC vehicles on the road network, which helps to alleviate the traffic congestion.

### B. Analysis

We emphasize that many of the aforementioned insights hold for a large range of model parameters. For notation convenience, let  $\lambda^*(K)$ ,  $N^*(K)$ ,  $c^*(K)$ ,  $w_n^*(K)$  and Profit(K) denote the optimal to (8) as a function of K, where  $\lambda^*(K)$  denotes the passenger arrival rate,  $N^*(K)$  denotes the number of drivers,  $c^*(K)$  denotes the passenger travel cost,  $w_n^*(K)$  denotes the driver net wage, and Profit(K) represents the platform profit. Let  $K^*$  denote the profit-maximizing parking provision. We introduce the following proposition:

Proposition 1: Assume that the profit maximization problem (8) with exogenous K has a unique solution, then there exists  $K_1 < K_2 < K_0$  such that

 $\begin{array}{l} ({\rm i}) \ \lambda^*(K) = \lambda^{\bar{*}}(0), \ N^*(K) = N^*(0), \ \forall 0 \leq K \leq K_1, \\ ({\rm ii}) \ \lambda^*(K) = \lambda^*(K_2), \ N^*(K) = N^*(K_2) \ , \ \forall K_2 \leq K \leq \bar{K}, \\ ({\rm iii}) \ \lambda^*(K^*) > \lambda^*(0) \ \text{and} \ c^*(K^*) < c^*(0) \\ ({\rm iv}) \ N^*(K^*) > N^*(0) \ \text{and} \ w^*_n(K^*) > w^*_n(0), \\ ({\rm v}) \ \operatorname{Profit}^*(K^*) > \operatorname{Profit}(0). \end{array}$ 

The proof of Proposition 1 is deferred to the journal version due to space limit. The assumption of solution uniqueness is numerically validated and holds for all parameters within regime of practical interest. In Proposition 1, (i) and (ii) represents the insight for regime 1 and regime 3, and (iii)-(v) shows that at the optimal solution  $K^*$ , parking services benefit passengers, drivers and the TNC platform.

In the case study, the optimal number of parking space is  $K^* = 1515$ . This only accounts for less than 1% of the 166,500 parking spots in the parking garages and commercial lots of San Francisco (note that  $K_0$  denotes the idle parking spots out of all spots). At this optimal solution, compared to the case of K = 0, passenger arrival rate increases by 3.7% (from 150.6/min to 156.2/min), the number of drivers increases by 5.9% (from 3053 to 3234), the number of on-road drivers reduces by 43% (from 3053 to 1748), the passenger travel cost reduces by 0.8% (from 28.83/trip to 28.61/trip), the driver net hour wage increases by 4% (from \$27.48/hour to \$28.58/hour), and the platform profit increases by 18.6% (from \$48,879/hour to \$57,981/hour).

## V. CONCLUSION

This paper investigated a novel business model that integrates parking services in the ride-hailing platform to reduce cruising congestion of TNC vehicles. The business model consists of a TNC platform, a group of passengers and drivers, and a number of parking garages. The platform provides app-based user interfaces that connect the passengers, drivers, and the parking garages. It matches passengers to drivers for ride-hailing services, and matches vacant TNC vehicles to unused parking garages to reduce cruising costs. The central thesis is that by enabling the sharing of idle parking spaces between garage operators and the TNC platform, the proposed business model will unlock the potential of the unused parking resources to benefit passengers, drivers, garage operators, and the TNC platform, and in the meanwhile curb cruising congestion without affecting regular parking demand.

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