

Off-Street Parking for TNC Vehicles to Reduce Cruising Congestion

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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 city’s 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 mobility-on-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.

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 ride-hailing 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 [12], 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 of these underutilized parking garages, the proposed business model will benefit passengers, drivers, garage operators, and the TNC platform without affecting the regular parking

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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 quantitatively 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 garage¹, 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:

- We argue that the parking service should be provided by the TNC platform rather than other third-party plat-

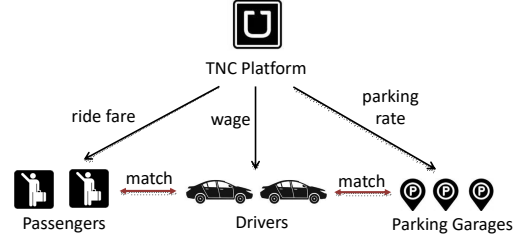


Fig. 1. The system diagram for the transportation market.

forms. 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 model².

- 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 demand³.
- 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 app-based 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 should be submitted periodically through the interface for financial settlements.

²We will show that TNC makes more profit by offering parking services.

³We will show that there are sufficient *idle* parking spaces to support the proposed business model using the San Francisco parking garage data.

¹We will show that drivers benefit from following the platform dispatch.

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 the next available driver to be dispatched. After passenger alights, each driver is dispatched to a parking garage (whenever available) until the next ride request arrives. 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 μ . 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 :

$$c = \alpha t_w + p_f. \quad (1)$$

where α 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. Typically, t_1 ranges between 5 – 30 seconds, while t_2 ranges between 3-7 minutes. Therefore, we neglect t_1 and assume that $t_w = t_2$. The pickup time t_w clearly depends on the density of idle TNC vehicles N_I . With slight abuse of notation, we denote t_w as $t_w(N - \lambda/\mu)$, then the arrival rate of passengers is captured by:

$$\lambda = F_p\left(\alpha t_w(N - \lambda/\mu) + p_f\right), \quad (2)$$

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_g minus the vehicle expenses. The gross wage w_g is set by the platform, which is 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. This is without loss of generality 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_g (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:

$$w_n = w_g - l\left(1 - \frac{\lambda}{N\mu}\right) + \frac{(l - p_g)Kr}{N} \quad (3)$$

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 cruising cost for all vehicles is $l\left(1 - \frac{\lambda}{N\mu}\right)$ 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:

$$N = F_d\left(w_g - l\left(1 - \frac{\lambda}{N\mu}\right) + \frac{(l - p_g)Kr}{N}\right). \quad (4)$$

We assume that $F_d(\cdot)$ is an increasing function, so that higher net wage indicates more supply of TNC drivers.

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 :

$$K = F_g(rp_g) \quad (5)$$

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 λ , 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 $i \geq k$, 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:

$$\begin{cases} X_0 = \pi_0 \frac{(N\rho)^N}{N!(1-\rho)} \\ X_i = \pi_0 \frac{(N\rho)^{N-i}}{(N-i)!}, \quad \forall 1 \leq i \leq N-1 \\ X_N = \pi_0, \end{cases} \quad (6)$$

where $\rho = \frac{\lambda}{N\mu}$ is the occupancy rate of TNC vehicles, and π_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

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

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 λp_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:

$$\min_{p_f, w_g, p_g} \lambda p_f - w_g N \quad (8)$$

$$\begin{cases} \lambda = F_p\left(\alpha t_w(N - \lambda/\mu) + p_f\right), \\ N = F_d\left(w_g - l\left(1 - \frac{\lambda}{N\mu}\right) + \frac{(l - p_g)Kr(\lambda, N, K)}{N}\right) \\ K = F_g(p_g r(\lambda, N, K)). \end{cases} \quad (9)$$

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.

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:

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

where λ_0 is the number of potential passengers (all passengers regardless of their travel mode), and ϵ 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:

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

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 [13].

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

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

where N_0 is the number of potential drivers, and η 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 earnings. We assume that the distribution of the reservation earning is captured by a log-normal distribution. In this case, the parking supply function F_g can be written as:

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

where $\operatorname{erf}(\cdot)$ denotes the error function, and u_0 and σ are the model parameters.

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

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

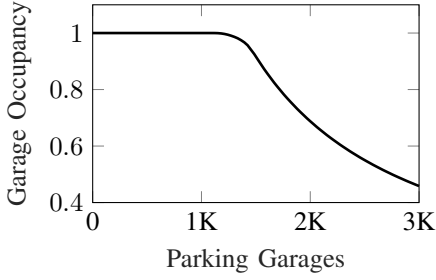


Fig. 2. Average occupancy rate of the parking garages as a function of K .

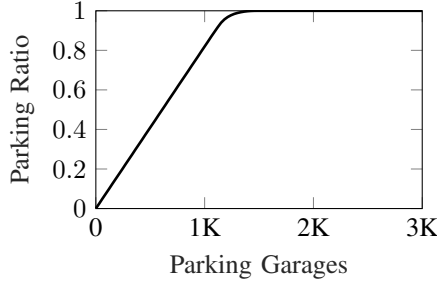


Fig. 3. Ratio of parked TNC vehicles out of all idle TNC vehicles as a function of K .

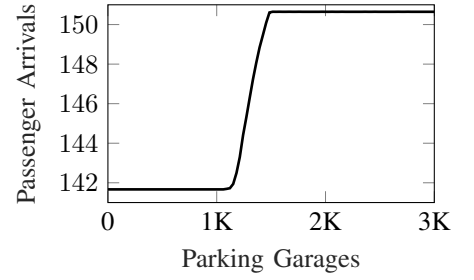


Fig. 4. Passenger arrival rate (per minute) as a function of K .

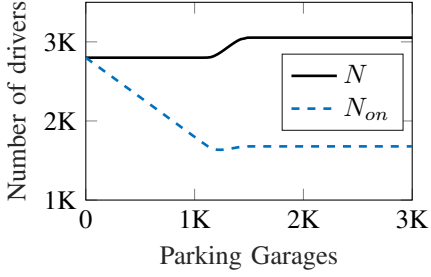


Fig. 5. Total number of drivers and number of on-road drivers (N_{on}) as a function of K .

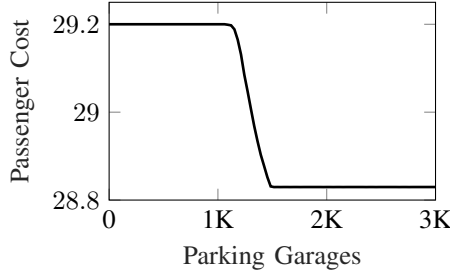


Fig. 6. Passenger travel cost (including time and money) as a function of K .

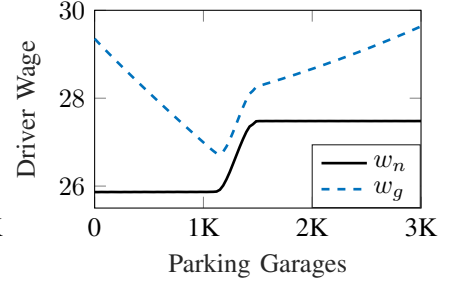


Fig. 7. Gross hourly wage and net hourly wage of TNC drivers as a function of K .

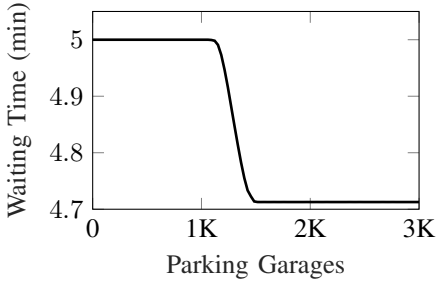


Fig. 8. Passenger waiting time (minute) as a function of K .

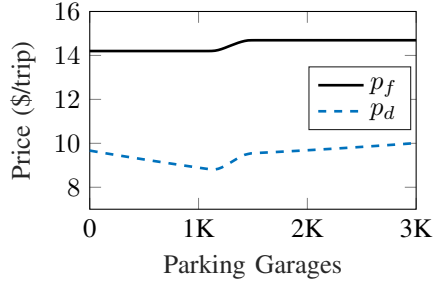


Fig. 9. Per-trip passenger fare and driver payment as a function of K .

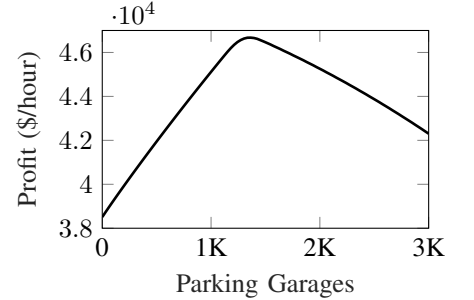


Fig. 10. Hourly platform profit (\$/hour) as a function of K .

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

$$\min_{p_f, w_g} \lambda p_f - w_g N \quad (15)$$

$$\begin{cases} \lambda = F_p \left(\alpha t_w (N - \lambda / \mu) + p_f \right), \\ N = F_d \left(w_g - l \left(1 - \frac{\lambda}{N \mu} \right) \right) \end{cases} \quad (16)$$

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

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

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

To understand how parking services affect the TNC business model, we will treat K as exogenous and solve (8) under

different values of K . These optimal decisions as a function of K reflect how parking provision affects the surplus of passenger, drivers, garage operators, and the TNC platform, and how many parking spaces are needed for the proposed business model. When K is given, the profit maximization problem (8) can be solved via enumeration.

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 of K clearly has three distinct regimes:

- When $K \leq 1091$, 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 $1091 \leq K \leq 1485$, 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 $K = 1404$.
- When $K \geq 1485$, 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 integrating parking services into the TNC platform will benefit 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 $\text{Profit}(K)$ 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 $\text{Profit}(K)$ represents the platform profit. Let K^* denote the profit-maximizing parking provision. We introduce the following theorem:

Theorem 1: Assume that for $0 \leq K \leq \bar{K}$, the profit maximization problem (8) with exogenous K has a unique optimal solution, then there exists $K_1 < K_2 < \bar{K}$ such that

- (i) $\lambda^*(K) = \lambda^*(0)$, $N^*(K) = N^*(0)$, $\forall 0 \leq K \leq K_1$,
- (ii) $\lambda^*(K) = \lambda^*(K_2)$, $N^*(K) = N^*(K_2)$, $\forall K_2 \leq K \leq \bar{K}$,
- (iii) $\lambda^*(K^*) > \lambda^*(0)$ and $c^*(K^*) < c^*(0)$
- (iv) $N^*(K^*) > N^*(0)$ and $w_n^*(K^*) > w_n^*(0)$,
- (v) $\text{Profit}^*(K^*) > \text{Profit}(0)$.

The proof of Theorem 1 is deferred to the journal version of this paper due to space limit. In Theorem 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 $K^* = 1404$. This only accounts for less than 1% of the 166,500 parking spots in the parking garages and commercial

lots of San Francisco. At this optimal solution, compared to the case of $K = 0$, passenger arrival rate increases by 5.4% (from 141.7/min to 149.2/min), the number of drivers increases by 7.6% (from 2800 to 3014), the number of on-road drivers reduces by 41% (from 2800 to 1666), the passenger travel cost reduces by 1.1% (from 29.2/trip to 28.9/trip), the driver net hour wage increases by 5.3% (from \$25.86/hour to \$27.23/hour), and the platform profit increases by 21.6% (from \$38,509/hour to \$46,658/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 the regular parking demand.

REFERENCES

- [1] Uber. Form S1 Registration Statement. U. S. Securities and Exchange Commission, 2019.
- [2] Peter Cohen, Robert Hahn, Jonathan Hall, Steven Levitt, and Robert Metcalfe. Using big data to estimate consumer surplus: The case of uber. Technical report, National Bureau of Economic Research, 2016.
- [3] B. Schaller. Empty Seats, Full Streets. Fixing Manhattan Traffic Problem. Schaller Consulting, December 2017.
- [4] NYCTLC. Improving efficiency and managing growth in New York's for-hire vehicle sector. New York City Taxi and Limousine Commission, 2019.
- [5] Sen Li, Hamidreza Tavafoghi, Kameshwar Poolla, and Pravin Varaiya. Regulating tncs: Should uber and lyft set their own rules? *Transportation Research Part B: Methodological*, 2019.
- [6] Sen Li, Kameshwar Poolla, and Pravin Varaiya. Congestion surcharge and wage regulation on tncs: a case study for san francisco. *arXiv preprint arXiv:2003.02550*, 2020.
- [7] CNBC. In win for uber and lyft, judge strikes down new york city's cruising cap. Reuters, 2019. <https://www.cnbc.com/2019/12/23/in-win-for-uber-judge-strikes-down-new-york-citys-cruising-cap.html>.
- [8] Zhengtian Xu, Yafeng Yin, and Liteng Zha. Optimal parking provision for ride-sourcing services. *Transportation Research Part B: Methodological*, 105:559–578, 2017.
- [9] Claudio Ruch, Sebastian Hörl, Roman Ehrler, Milos Balac, and Emilio Frazzoli. How many parking spaces does a mobility-on-demand system require? 2019.
- [10] Daniel Kondor, Paolo Santi, Kakali Basak, Xiaohu Zhang, and Carlo Ratti. Large-scale estimation of parking requirements for autonomous mobility on demand systems. *arXiv preprint arXiv:1808.05935*, 2018.
- [11] Albert YS Lam, JQ James, Yunhe Hou, and Victor OK Li. Coordinated autonomous vehicle parking for vehicle-to-grid services: Formulation and distributed algorithm. *IEEE Transactions on Smart Grid*, 9(5):4356–4366, 2017.
- [12] SFpark. <http://sfpark.org/>.
- [13] Nikita Korolko, Dawn Woodard, Chiwei Yan, and Helin Zhu. Dynamic pricing and matching in ride-hailing platforms. Available at SSRN, 2018.