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# Food Delivery Service and Restaurant: Friend or Foe?

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**Abstract.** With food delivery services, customers can hire delivery workers to pick up food on their behalf. To investigate the long-term impact of food delivery services on the restaurant industry, we model a restaurant serving food to customers as a stylized single-server queue with two streams of customers. One stream consists of tech-savvy customers who have access to a food delivery service platform. The other stream consists of traditional customers who are not able to use a food delivery service and only walk in by themselves. We study a Stackelberg game, in which the restaurant first sets the food price; the food delivery platform then sets the delivery fee; and, last, rational customers decide whether to walk in, balk, or use a food delivery service if they have access to one. If the restaurant has a sufficiently large established base of traditional customers, we show that the food delivery platform does not necessarily increase demand but may just change the composition of customers, as the segment of tech-savvy customers grows. Hence, paying the platform for bringing in customers may hurt the restaurant's profitability. We demonstrate that either a one-way revenue-sharing contract with a price ceiling or a two-way revenue-sharing contract can coordinate the system and create a win-win situation. Furthermore, under conditions of no coordination between the restaurant and the platform, we show, somewhat surprisingly, that more customers having access to a food delivery service may hurt the platform itself and the society, when the food delivery service is sufficiently convenient, and the delivery-worker pool is large enough. This is because the restaurant can become a delivery-only kitchen and raise its food price by focusing on food-delivery customers only, leaving little surplus for the platform. This implies that limiting the number of delivery workers can provide a simple yet effective means for the platform to improve its own profitability while benefiting social welfare.

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## 1. Introduction

The first pizza delivery order was placed by Queen Margherita of Italy during her visit to Naples in 1889. In recent years, food delivery has become an easily accessible service for commoners rather than a royal privilege. By simply swiping a smartphone, customers can order food via food delivery platforms such as Uber Eats, Grubhub, Postmates, and DoorDash. Food delivery is a booming industry. Online restaurant delivery sales are estimated to grow to $62 billion in 2022 from about $25 billion in 2019. Venture-capital firms invested $5 billion in U.S. food and grocery delivery services in 2018, more than four times the amount invested in 2017 (Haddon and Jargon 2019).

Adopting food delivery services, people with high opportunity costs can avoid the simple yet unproductive task of traveling to restaurants and waiting for food there, allowing them to devote this time to more fruitful tasks instead. Although the number of food delivery orders grows exponentially over the years, there are still people lagging behind (Steingoltz and Picciola 2019). Some people are not tech-savvy enough to operate digital devices such as smartphones, some are simply reluctant to try out the food delivery option, and some are sensitive to the delivery fee. These people still go to the restaurant as walk-in customers.

On the restaurant side, the benefit conferred by food delivery platforms is unclear. The current practice in the industry is for platforms to take 10%–25% of food revenue as a service fee from the restaurant and take a flat delivery fee of $3 per order from customers (Haddon and Jargon 2019). Platforms consider themselves as demand generators for restaurants. The head of Uber Eats in North America pointed out, "We exist for demand generation." However, restaurants feel differently. As the owner of a small restaurant chain in California put it, "We saw a direct correlation between the delivery services and the reduction of our income" (Isaac and Yaffe-Bellany 2019).

Our paper examines the relationship between a food delivery platform and a restaurant in a changing environment, with an increasing number of online customers brought in by the platform. In particular, we develop a stylized service chain model using queueing methodology. The restaurant serves food to customers, modeled as a single-server queue. The third-party platform with a pool of delivery workers offers a food delivery service to customers on the side. There are two streams of customers: *traditional* customers, who have no access to the platform and can only walk into the restaurant, and *tech-savvy* customers, who have access to the platform so that they can use the food delivery service in addition to the traditional walk-in option. The three parties of the restaurant, platform, and customers participate in a sequential game, where the restaurant first sets the food price to maximize its profit; then the platform determines the delivery fee (and delivery worker's wage) to maximize its profit; and last, according to the food price and delivery fee, customers decide whether to walk in or balk, or, if they are tech-savvy, to use the food delivery service.

If the restaurant has a large enough established base of traditional customers, we obtain the following main results.

First, in our base model with infinitely many delivery workers, we show that, in the sequential game, if the food delivery service is sufficiently convenient and the number of tech-savvy customers is sufficiently large, the restaurant finds it profitable to become a delivery-only kitchen, and then both the platform's profit and social welfare may drop sharply. In this case, to squeeze out tech-savvy customers' residual surpluses generated by the food delivery service, the restaurant raises its food price significantly; the price would otherwise be kept lower to accommodate walk-in customers. This hurts the food delivery platform's profit and social welfare. However, this phenomenon will not occur when the food delivery service is not sufficiently convenient, or the tech-savvy customer segment is not large enough. Although the platform's profit and social welfare are both (weakly) increasing in the arrival rate of tech-savvy customers, the platform may not increase demand for the restaurant but just change the composition of customers, as the segment of tech-savvy customers grows. In those cases, paying the platform to bring in customers hurts the restaurant's profitability.

Second, we prove that this service system could be improved, either through a one-way revenue-sharing contract with a price ceiling—in which the platform shares a fraction of its revenue with the restaurant under the condition that the restaurant caps its food prices—or a two-way revenue-sharing contract, in which the restaurant and platform each shares a precommitted fraction of its revenue with the other party. These coordinating contracts would effectively force the platform to share profits with the restaurant (compared with the equilibrium behavior without such a contract) to induce food price reduction. This seems the opposite of the current practice, where the restaurant marks up its regular menu price and shares a fraction of its revenue with the platform as commissions. We also verify the robustness of these two contracts in the case where there are no traditional customers.

Third, we discover that a delivery-worker pool of a limited size can curb the restaurant's self-interested desire to serve only the growing segment of food-delivery customers, avoiding damage to the platform and social welfare. This is because, when the cost of hiring delivery workers is high as a result of a tight labor market, in anticipation of the successive markup by the platform, the restaurant finds it unprofitable to charge a higher price, serve only the tech-savvy customers, and become a delivery-only kitchen. There are several implications of this result. Without any coordination with the restaurant, the platform has a unilateral way to avoid the potential damage to its profits induced by the restaurant's desire to turn into a delivery-only kitchen and reap the greatest surplus from its food delivery business. Somewhat counterintuitively, this requires the platform not to overgrow its labor pool and instead to cap the number of delivery workers registered with the platform. In contrast, the social planner who aims at maximizing total social welfare including delivery workers' total utility also has an implementable and effective way to regulate the service system by capping the size of the delivery-worker pool.

## 2. Literature Review

Our paper is related to the extensive literature on queueing economics, which dates back to Naor (1969). Hassin and Haviv (2003) and Hassin (2016) provide comprehensive reviews. We consider a stylized unobservable queueing model, which was first studied in Edelson and Hilderbrand (1975).

In the operations management literature, the paper by Feldman et al. (2021) is one of the first to study the operations of food delivery platforms and the closest to ours. The authors consider *one* stream of customers who choose between food delivery or dining in. Customers incur a waiting cost proportional to the total volume of food delivery and dine-in customers. They find that a one-way revenue sharing (RS) contract and several common modifications, such as commission caps and price floors, are ineffective at coordinating the system. Moreover, they show that a generalized RS contract, in which the platform pays the restaurant a fixed fee and a percentage of revenue, coordinates the restaurant and the platform to achieve the optimal centralized revenue. Our paper examines the platform using an unobservable queue model, with *two* streams of customers: one having access to the food delivery service and one not. The unobservable queue formulation is appropriate when restaurants do not broadcast their real-time queue length to the public, although their long-term average waiting time is inferable from their pages on Yelp or Google My Business. We focus on how the decentralized and centralized systems would change if there were more tech-savvy customers, which can shed light on how the industry evolves. We show that a one-way RS contract with a price ceiling can coordinate the service chain to maximize the total profit and that limiting the number of delivery workers available to the platform is an easy-to-implement tool to regulate the system.

Food delivery services allow customers with high opportunity costs to avoid waiting in a queue by paying delivery workers to pick up and deliver food from restaurants. A related theme in service systems is priority purchasing. Kleinrock (1967) introduces bribery for a position in a queue, where customers who pay a higher bribe will be placed ahead of those who pay a lower bribe. Lui (1985), Glazer and Hassin (1986), and Hassin (1995) (respectively, Balachandran 1972) analyze the heterogeneous (respectively, homogeneous) customers' bribing behavior in an unobservable (respectively, observable) queueing system. Other papers that explore priority pricing of services include Mendelson and Whang (1990), Van Mieghem (2000), Afèche and Mendelson (2004), and Afèche and Pavlin (2016). More recently, Lariviere (2020) shows that a priority scheme is superior to the first-in-first-out scheme for both the service provider's revenue and social welfare, but priorities often hurt the consumer surplus.

In a context closely related to that of our paper, Cui et al. (2020) study the line-sitting service, in which customers can hire surrogates to wait in line on their behalf. The authors compare line-sitting with priority purchasing in an unobservable queue model. In contrast, we focus on the interaction between the restaurant, the platform, and customers in a sequential game. We investigate the system-wide impacts of a growing segment of tech-savvy customers and the size of the delivery-worker pool, which have not been considered in their paper. Benjaafar et al. (2021) study the labor welfare in on-demand service platforms that crowdsource freelancers to serve customers. They show that the labor pool size has a nonmonotonic effect on labor welfare. In a different setting, we show that capping the labor pool size can effectively suppress the restaurant's self-interested desire to increase food prices and can improve the platform's profit and social welfare.

There is an extensive body of literature on supply chain contracting. For reviews of this literature, see Cachon (2003) and Lariviere (2016). Cachon and Lariviere (2005) demonstrate that a RS contract can coordinate a supply chain with a single retailer or multiple retailers competing in quantities. In a service operations setting, we demonstrate the effectiveness of a two-way RS contract and a one-way RS contract with a price ceiling.

Last, our work is related to an emerging literature on the operations of omnichannel retailing. Gallino and Moreno (2014) empirically show that offering a "buy-online, pick-up-in-store" (BOPS) option reduces online sales but increases offline sales. Gao and Su (2017a) examine the impact of the BOPS initiative on omnichannel store operations and show that BOPS may benefit or hurt the retailer, depending on the product characteristics. Other papers in this line of research include Gao and Su (2017b), Gao and Su (2018), Hu et al. (2021), Yuan and Roet-Green (2020), and Bar-on et al. (2021). Although these papers assume that the same firm owns both channels, in contrast, we focus on the strategic interaction between a restaurant serving offline/online customers and a platform that makes deliveries to online customers.

## 3. Base Model

We model a restaurant serving food to customers as a stylized single-server queue under the first-in-first-out discipline. The customers arrive according to a Poisson process. The food price is $p$. The food preparation time for a customer follows an independent and identically distributed exponential distribution with mean $1/\mu$. Upon getting the food, a customer receives a service reward $R$. We do not differentiate between customers who take out the food and those who dine in the restaurant. Thus, we assume that dine-in, walk-in-take-out, and food-delivery orders all generate the same service reward.

A third-party platform with a pool of $N$ delivery workers offers a food delivery service on the side. Any customer can pay the platform a flat delivery fee $\theta$ to have a delivery worker pick up and deliver food to her doorstep. For simplicity, we assume that one delivery worker fulfills at most one order per unit of time. This assumption aligns with the one-on-one delivery practice of some platforms such as Instacart (see, e.g., Deighton and Kornfeld 2017); other platforms may combine multiple delivery orders in one trip, so that delivery workers can pick up orders from several restaurants in the same area or deliver to various customers in the same neighborhood (see Chen and Hu 2021 for examples of batch processing in food delivery). Our model can be easily modified to allow for a general maximum number of orders delivered by each worker per time unit. However, such a modification may not easily capture same-side or cross-side externalities among customers and workers; we leave this for future research. Each delivery worker's opportunity cost $\sigma$ per unit of time follows a probability distribution. In our base model, we assume an ample supply of delivery workers, that is, $N \to \infty$, so that there are sufficient delivery workers to fill all the desired delivery orders. We relax this assumption and consider a finite delivery-worker pool in Section 6. In our base model, we normalize the delivery workers' opportunity cost to zero (see also Cui et al. 2020).

Customers incur a linear waiting cost with the marginal rate $c$ when they wait in the restaurant for food. By using the food delivery service, customers do not need to physically go to the restaurant, but instead, can wait for food at home, and put their time to better use. We assume that the food delivery service does not affect the quality of the food as perceived by customers. Let $\phi \in [0, c)$ denote the customers' waiting cost rate while using the food delivery service. To some extent, the value of $\phi$ measures the convenience of the food delivery service. If the platform provides a satisfactory and seamless service, the value of $\phi$ will be small; otherwise, if the food delivery service is not that convenient, the value of $\phi$ will be large and can be close to the offline waiting cost $c$.

Not all customers have access to a food delivery service at the moment when their demand arises. There are two streams of customers. One stream consists of *tech-savvy* customers who can access a food delivery service (but may not use it); the other stream consists of *traditional* customers who cannot. Let $\Lambda_1$ and $\Lambda_0$ denote the arrival rates of tech-savvy and traditional customers, respectively. When the need for food arises, a traditional customer has two options: walk in or balk. The tech-savvy customers are identical to the traditional customers, except that, when in need of food, they have one more option: using a food delivery service if they find this a better choice. These tech-savvy customers are the potential customers of the platform. For simplicity, we focus on the case of abundant *potential* demand from traditional customers, that is, $\Lambda_0 \geq \mu$, which applies to restaurants that have already established a large customer base before the introduction of food delivery services. In Section A of the online appendix, we analyze the case of $\Lambda_0 = 0$. The case of $0 < \Lambda_0 < \mu$ can be analyzed with much greater complexity but generates insights similar to the two extreme cases.

We assume that the kitchen's status is *unobservable* to all customers at the moment when their demand arises. As we study the long-term relationship between the restaurant and the platform, this assumption captures the first-order interaction by focusing on the customers' expected service experiences of the system over repeated interactions. As a standard assumption in the relevant literature and consistent with the focus on repeated interactions, all parameters are assumed to be common knowledge. There are other information structures for related settings (see, e.g., Debo and Veeraraghavan 2014, Kremer and Debo 2015, Cui and Veeraraghavan 2016, Wang and Hu 2020). We leave those alternative information structures for future research.

The food price $p$ is assumed to be the same for both walk-in and food-delivery customers, which is a practice of Uber Eats and a common assumption in the omnichannel literature. We first derive customers' equilibrium behavior under the food price $p$ and the delivery fee $\theta$. Following Edelson and Hilderbrand (1975), we assume that both tech-savvy and traditional customers use a symmetric mixed strategy to choose between the options available to them when arriving to the system. The traditional customers' strategy can be described by their joining rate $\lambda_{0W} \in [0, \Lambda_0]$, whereas tech-savvy customers' strategy can be expressed by a tuple of $(\lambda_D, \lambda_{1W})$, where $\lambda_D$ and $\lambda_{1W}$ are the joining rates of food-delivery and walk-in tech-savvy customers, respectively. Let $\lambda_W = \lambda_{0W} + \lambda_{1W}$ denote the total joining rate of walk-in customers. The effective arrival rate to the system is $\lambda = \lambda_W + \lambda_D$. As all customers need to be served by the kitchen, food preparation is the bottleneck, and hence the expected waiting time of all customers for food preparation is $1/(\mu - \lambda)$. Clearly, if $\Lambda_1 \geq \mu$, because of the lower waiting cost of using the food delivery service, the restaurant can obtain a higher profit by serving only food-delivery customers, in which case the restaurant becomes a delivery-only restaurant, also referred to as a "delivery-only kitchen" or "ghost kitchen."

Under the food price $p$ and the delivery fee $\theta$, the expected utility of (tech-savvy or traditional) walk-in customers is the service reward less the food price less the expected waiting cost; that is, $U_W(\lambda) = R - p - c/(\mu - \lambda)$. We focus on the food preparation process as the bottleneck and assume away the delivery time after the food is made if customers choose the food delivery service. This assumption is innocuous because the expected waiting cost due to the delivery delay can be factored into the delivery fee $\theta$ and does not qualitatively change our insights. The same assumption is also made in Feldman et al. (2021). Then the expected utility of food-delivery customers is the service reward less the food price less the delivery fee less the expected cost of waiting for food preparation; that is, $U_D(\lambda) = R - p - \theta - \phi/(\mu - \lambda)$. If customers choose to balk, they receive zero utility. As a tie-breaking rule, we assume that tech-savvy customers use food delivery services if the two options of using the service and walking in are equally attractive, that is, $U_D(\lambda) = U_W(\lambda) \geq 0$. This rule is innocuous because the platform can always lower its delivery fee by an infinitesimal amount to make the food delivery service more attractive with almost no impact on its profit.

Our model without a food delivery service (or equivalently, without any tech-savvy customers, that is, $\Lambda_1 = 0$) is essentially a classical unobservable queue model with sufficient demand, as $\Lambda_0 \geq \mu$. In this case, the traditional customers' equilibrium join-up-to level is $\mu - c/(R - p)$ (see, e.g., Edelson and Hilderbrand 1975), which is decreasing in the food price $p$. Lemma C.2 in the online appendix presents customers' equilibrium behavior in our model in the presence of the food delivery service.

## 4. Decentralized System

In this section, we study a decentralized system where the restaurant and the platform are operated independently to maximize their own profits. The interaction of the restaurant, the platform, and two streams of customers forms a sequential game. Consistent with the supply chain contracting literature, the sequence of events is as follows. First, the restaurant sets the food price $p$. Then, the platform sets the delivery fee $\theta$. At last, customers decide whether to join the queue or balk, and if they join and are tech-savvy, whether to use the food delivery service or to walk in, based on the food price $p$, delivery fee $\theta$ and their prior belief about the wait; in equilibrium, their prior belief is consistent with actual experiences over repeated interactions. Given the food price $p$ and the delivery fee $\theta$, the equilibrium joining behavior by customers at the third stage is characterized in Lemma C.2 in the online appendix. In the base model, the delivery-worker pool size $N$ is large enough that in equilibrium any tech-savvy customer who is willing to pay for the food delivery service can obtain it.

We use backward induction to derive the equilibrium food price $p^*$ and delivery fee $\theta^*$. Then we derive the restaurant's profit $\Pi^*$, the platform's profit $\pi^*$, and social welfare $S^*$ (i.e., the total surpluses from all stakeholders) in equilibrium.

**Proposition 1** (Equilibrium in Decentralized System). *If the food delivery service is sufficiently inconvenient or the number of tech-savvy customers is relatively low, the restaurant will not react to the introduction of the food delivery service and will operate in a delivery-irrelevant regime; an increasing number of tech-savvy customers benefits both the platform's profit and social welfare; however, it does not increase demand for the restaurant, and instead only changes the composition of customers. Otherwise, if the food delivery service is sufficiently convenient and the number of tech-savvy customers increases to a critical mass, the restaurant will switch to a delivery-only regime—it will raise its food price significantly and serve only food-delivery customers; the platform's profit, social welfare, and the restaurant's demand will suffer from this food-price surge; and if the food delivery service is sufficiently convenient and the number of tech-savvy customers is sufficiently high, the demand will increase beyond the level it had reached before the introduction of the food delivery service. Formally, there exist $\phi_1$ and $\lambda_1$ such that if* (i) *$\phi > \phi_1$ or* (ii) *$\phi \leq \phi_1$ and $\Lambda_1 \leq \lambda_1$, we have $p^*$ and $\lambda_D^* + \lambda_W^*$ stay as constants, as $\Lambda_1$ increases, whereas $\pi^*$, $S^*$, $\lambda_D^*$, and $-\lambda_W^*$ are weakly increasing in $\Lambda_1$. Otherwise, if $\phi \leq \phi_1$, we have $p^*|_{\Lambda_1 \leq \lambda_1} < p^*|_{\Lambda_1 > \lambda_1}$, $\pi^*|_{\Lambda_1 \nearrow \lambda_1} > \pi^*|_{\Lambda_1 \searrow \lambda_1}$, and $S^*|_{\Lambda_1 \nearrow \lambda_1} > S^*|_{\Lambda_1 \searrow \lambda_1}$, and furthermore, if $\phi < c/\left(2\sqrt{R\mu/c} - 1\right) \leq \phi_1$, we have $\lambda_D^* + \lambda_W^*|_{\Lambda_1 \leq \lambda_1} < \lambda_D^* + \lambda_W^*|_{\Lambda_1 \nearrow \mu}$.*

We note that, ceteris paribus, food-delivery customers generate more surplus than walk-in ones, because of their lower marginal waiting cost. The restaurant can either set a high food price to extract more surplus from food-delivery customers while abandoning walk-in customers (i.e., in the delivery-only regime), or it can use a low food price to serve more (potentially walk-in) customers but leave the food-delivery customers' extra surplus for the platform to reap (i.e., in the delivery-irrelevant regime). The restaurant's optimal choice depends on the number of tech-savvy customers and the convenience of the food delivery service (or equivalently the waiting cost while using food delivery service $\phi$), which determine the food-delivery customers' residual surplus. When the food delivery service is convenient enough and the number of tech-savvy customers is sufficiently large, the restaurant will be more profitable focusing only on food-delivery customers and staying in the delivery-only regime; otherwise, it will prefer operating in the delivery-irrelevant regime.

We then illustrate Proposition 1 numerically. Specifically, we display the following equilibrium measures: (i) the restaurant's profit, the platform's profit, and the resulting social welfare; (ii) the food price and the delivery fee; and (iii) the joining rates of food-delivery and walk-in customers, and the resulting throughput, in equilibrium, as a function of the arrival rate of tech-savvy customers $\Lambda_1$, for $\phi = 0.4$, 0.3, and 0.1 in Figures 1–3, respectively. (In our setting with two segments of homogeneous traditional and tech-savvy customers, in equilibrium, all customers' surpluses will be extracted by the food price and/or delivery fee.) Under this setting where $R = 10$ and $\Lambda_0 = \mu = c = 1$, we have the threshold values in Proposition 1 as $\phi_1 \approx 0.3554 \in (0.3, 0.4)$ and $c/(2\sqrt{R\mu/c} - 1) \approx 0.1878$.

When the food delivery service is not so convenient (see, e.g., $\phi > \phi_1$ in Figure 1) or the arrival rate of tech-savvy customers is not high (see, e.g., $\phi \le \phi_1$ and $\Lambda_1 \le 0.55$ in Figure 2), the restaurant does not react to the introduction of the food delivery service, so it applies the same strategy as in an unobservable queue with only traditional customers for various $\Lambda_1$. However, when the food delivery service is relatively convenient (see, e.g., $\phi \le \phi_1$ in Figure 2), if the arrival rate of tech-savvy customers $\Lambda_1$ increases to a critical level $\lambda_1$, it becomes more beneficial for the restaurant to cater completely to the food-delivery customers. Then, the restaurant will abruptly increase its food price $p^*$ (see, e.g., the dash-dotted curve in Figure 2(b)) to drive away traditional customers all at once (see, e.g., the densely dotted curve in Figure 2(c)) and become a delivery-only kitchen. In response, the platform has to lower the delivery fee $\theta$ (see, e.g., the dashed curve in Figure 2(b)). As a result, the platform's profit and social welfare drastically drop in the neighborhood, whereas the restaurant's profit weakly increases, as shown in Figure 2(a).

When the arrival rate of tech-savvy customers $\Lambda_1$ increases, if the food price stays unchanged and the restaurant accommodates both the food-delivery and walk-in customers, the throughput at the restaurant stays constant (see, e.g., $\Lambda_1 \le 0.68$ in Figure 1(c) and $\Lambda_1 \le 0.55$ in Figure 2(c)). When the arrival rate of tech-savvy customers $\Lambda_1$ increases while that of traditional customers $\Lambda_0$ stays unchanged, the platform may bring in more food-delivery customers, but the traditional customers will join less often so that the throughput rate stays at $\mu - c/(R - p)$, which is the throughput in a classical unobservable queue with only traditional customers under price $p$, and their expected utility is zero. We note that this insight is general and independent of whether there is a contract between the restaurant and the platform. Thus, the food delivery service does not necessarily increase demand for the restaurant, especially when the restaurant has sufficient demand from traditional customers and the food price stays the same. The introduction of the food delivery service may simply change the composition of customers—it brings in more food-delivery orders while driving away traditional customers who used to walk in. This phenomenon occurs even when the number of traditional customers is unchanged, and will be more likely to occur as more traditional customers become tech-savvy over time.

Proposition 1 identifies two conditions under which the food delivery service does not benefit the restaurant: either the food delivery service is not sufficiently convenient, or it is but the number of tech-savvy customers is not large enough. Under either of the two conditions, the restaurant does not benefit from the food delivery service by obtaining a higher throughput. As a result, if the restaurant pays the platform for bringing in customers as seems to be the current practice by platforms such as Postmates, having more food delivery orders actually hurts the restaurant's profitability. Isaac and Yaffe-Bellany (2019) documented such an instance. After offering delivery through a platform in 2016, two pizzerias with the same owner, whom we quoted in the introduction, took a sharp turn from generating annual profits of \$50,000 to \$100,000 to losing \$40,000 a year. This was precisely because customers who used to order directly from the pizzerias switched to the platform, which forced the owner to pay commissions. The business owner said, "It was like death by a thousand cuts," and he eventually closed these two locations.

The food delivery service may increase demand at the restaurant compared with the scenario of no food delivery service, under a stricter condition than that

**Figure 1.** (Color online) Decentralized Equilibrium System Behavior as a Function of $\Lambda_1$ for $R = 10$, $\Lambda_0 = \mu = c = 1$, and $\phi = 0.4$

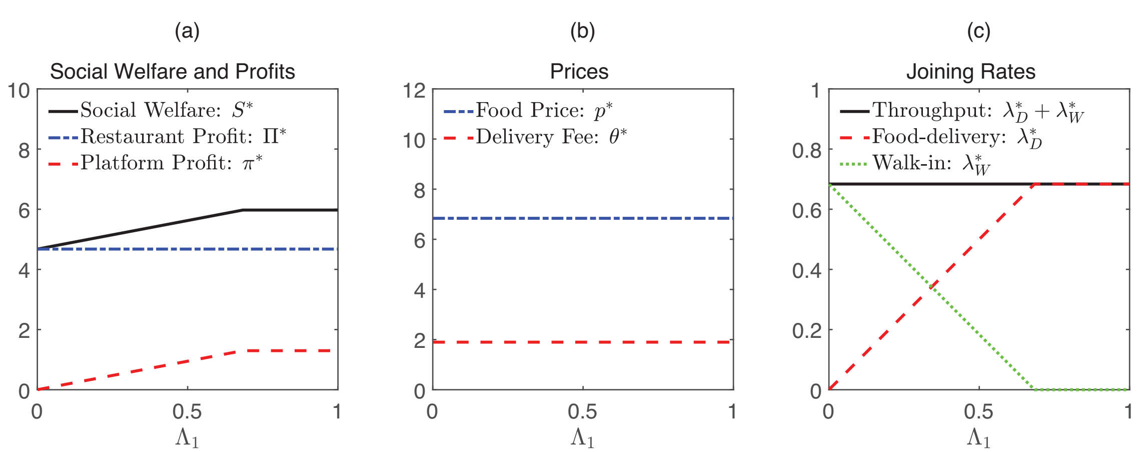
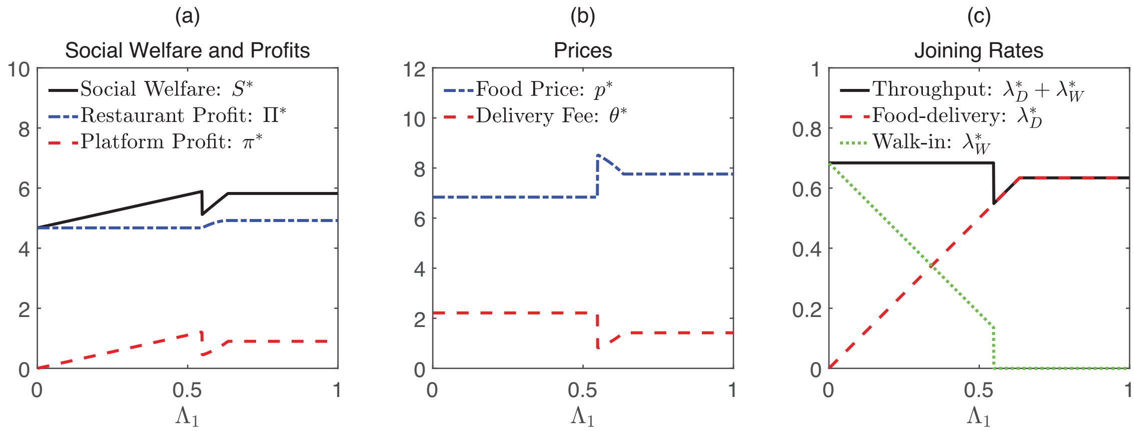


**Figure 2.** (Color online) Decentralized Equilibrium System Behavior as a Function of $\Lambda_1$ for $R = 10$, $\Lambda_0 = \mu = c = 1$, and $\phi = 0.3$

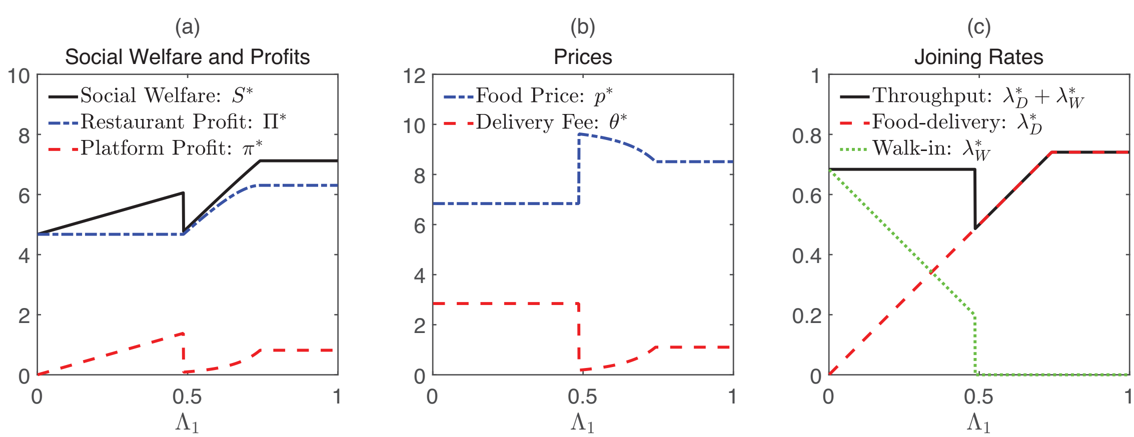



for a delivery-only regime: the arrival rate of tech-savvy customers becomes significantly high and the food delivery service is highly convenient (see, e.g., $\Lambda_1 > 0.6838$ in Figure 3(c) where $\phi = 0.1$). The restaurant's optimal choice of turning away traditional customers and operating in a delivery-only regime makes it more difficult for the platform to raise demand for the restaurant—the potential arrival rate of tech-savvy customers needs to rise significantly beyond the critical mass at which the restaurant would switch to the delivery-only regime. It may not be a simple task for the platform to prove its helpfulness in demand creation to the restaurant.

Our result here suggests that the no-contract relationship, that is, the decentralized system studied in this section, may not be ideal, especially when the food delivery service is convenient and the arrival rate of tech-savvy customers is high. In those circumstances, the increasing demand rate of tech-savvy customers may jeopardize social welfare and the platform's profitability. Thus, the platform or the social planner may want to coordinate actions by the restaurant and platform as the number of food delivery orders grows, which motivates us to explore approaches to coordinating the service system.

As a remark, in our base model, we assume abundant demand from traditional customers, that is, $\Lambda_0 \geq \mu$, so an increase in food-delivery customers will inevitably turn away some traditional customers. In practice, there are also cases with no traditional customers, that is, $\Lambda_0 = 0$. For example, think about new restaurants without an established customer base or restaurants during the pandemic that were barred from having dine-in customers. For this case, see Proposition A.1 in the online appendix. There we show that the restaurant prefers the delivery-only regime to the delivery-irrelevant one, especially when the arrival rate of tech-savvy customers $\Lambda_1$ is low—the restaurant will not be able to attract more customers by setting a low food price, and it can only focus

**Figure 3.** (Color online) Decentralized Equilibrium System Behavior as a Function of $\Lambda_1$ for $R = 10$, $\Lambda_0 = \mu = c = 1$, and $\phi = 0.1$



on extracting more residual surplus from food-delivery customers by charging a high food price. Moreover, the platform that connects a restaurant with no traditional customers to a growing pool of tech-savvy customers will certainly increase demand for the restaurant. In this case, the platform will be able to fulfill its stated mission of demand creation. However, there are other much-debated issues such as high commissions charged by food delivery platforms (see, e.g., Tkacik 2020) that we leave for future research.

## 5. Centralized System

In this section, we consider the profit maximization problem of controlling the food price and delivery fee from the perspective of a centralized owner of the food catering system.

**Lemma 1** (Optimal Monopoly Prices). *If the restaurant sets the optimal monopoly food price $p^o$, the platform will choose the optimal monopoly delivery fee $\theta^o$ as its best response. (The expressions of $p^o$ and $\theta^o$ are given by (C.3) and (C.4) in the online appendix.) Moreover, the optimal monopoly food price $p^o$, the total price $p^o + \theta^o$, and the corresponding restaurant's profit $\Pi^o$ are weakly decreasing in $\Lambda_1$. The optimal monopoly delivery fee $\theta^o$, the corresponding throughput ${\lambda^o}_D + {\lambda^o}_W$, the platform's profit $\pi^o$, and social welfare $S^o$ are weakly increasing in $\Lambda_1$.*

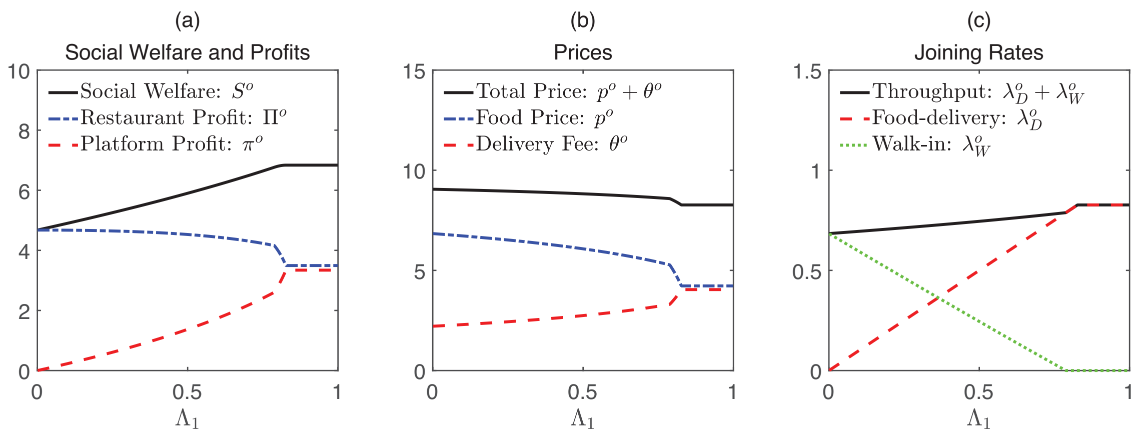
From Lemma 1, we see that it is not necessary for the centralized owner to dictate both the food price and delivery fee. Instead, the centralized owner can achieve the monopolistically optimal solution by regulating only the food price. Under the optimal monopoly food price, the platform will voluntarily set the delivery fee at the centrally optimal level. The reason is that, given the optimal monopoly food price, the centralized owner's goal is to set the delivery fee to extract the maximum surplus from food-delivery customers, which is also the platform's goal in a decentralized system.

The optimal monopoly food price $p^o$ and delivery fee $\theta^o$ maximize not only the aggregated profit but also social welfare. Because of our unobservable queue assumption and customers' homogeneity in their service reward and marginal waiting cost, the centralized owner can extract all customer surplus as profit by setting the food price and delivery fee (see chapter 3 of Hassin and Haviv 2003 for a single-segment problem). Thus, the centralized owner's goal of maximizing the aggregated profit aligns perfectly with the social planner's goal of maximizing social welfare; however, when setting the food price at $p^o$, the social planner can also achieve various surplus distributions between the platform and customers by varying the delivery fee, which is different from that under the profit maximization by the centralized owner. Moreover, in observable queues, the social planner's incentive does not align perfectly with the profit maximizer's—the social welfare maximizing price is greater than the profit maximizing price (see chapter 2 of Hassin and Haviv 2003). We expect the same misalignment in the observable version of our model.

To illustrate the analytical results of Lemma 1, we plot the optimal performance measures as a function of the arrival rate of tech-savvy customers $\Lambda_1$ in Figure 4 (similar to what we have in Figure 2). Lemma 1 shows that the optimal throughput increases in the arrival rate of tech-savvy customers $\Lambda_1$. As we discussed in Section 3, if the food price $p$ stays the same when $\Lambda_1$ increases, the traditional customers will join less often so that the throughput stays at $\mu - c/(R-p)$. Thus, when $\Lambda_1$ increases, the centralized owner needs to lower the food price $p$ to attract more traditional customers (see, e.g., the dash-dotted curve in Figure 4(b)). At the same time, when the food price is reduced, the food-delivery customers have more residual surplus, so the centralized owner needs to raise the delivery fee $\theta$ to reap it from food-delivery customers (see, e.g., the dashed curve in Figure 4(b)). Here, the social planner may use delivery fees other than $\theta^o$—as long as all tech-savvy customers use the food-delivery service, the delivery fee only changes the distribution of surpluses between the platform and customers, whereas social welfare stays the same. In general, the centralized owner reduces the total price $p + \theta$ paid by the food-delivery customers when $\Lambda_1$ increases, because of the congestion caused by a higher throughput (see, e.g., the solid curves in Figure 4, (b) and (c)).

Lemma 1 also sheds light on the coordination of the restaurant's and the platform's operations in the decentralized system. There are two important features in any coordinating scheme that can maximize the aggregated profit of the restaurant and the platform. The first is, as mentioned in the centralized solution, when the arrival rate of tech-savvy customers $\Lambda_1$ increases, the restaurant needs to set the food price at $p^o$, which decreases in $\Lambda_1$, to attract more customers to purchase from the restaurant. Then, the platform's best response is to set the delivery fee at $\theta^o$, which increases in $\Lambda_1$, to extract the residual surplus generated by having a lower food price (see, e.g., Figure 4(b)). As a result, the restaurant's direct profit from food sales decreases while the platform's profit from the delivery service increases as the segment of tech-savvy customers $\Lambda_1$ grows (see, e.g., Figure 4(a)). The second feature is that it is essential for the platform to share its delivery profit with the restaurant to incentivize the restaurant's participation in this coordinating effort. Our result suggests that the current practice—that the restaurant marks up its regular menu price and shares a portion of its revenue with the

**Figure 4.** (Color online) Centralized Optimal System Behavior as a Function of $\Lambda_1$ for $R = 10$, $\Lambda_0 = \mu = c = 1$, and $\phi = 0.3$




platform by paying a commission—does not seem able to coordinate the service system.

Next, we propose two RS contracts with the previous two features that can perfectly coordinate the service system. Of course, to negotiate and enforce such a RS contract calls for the engagement of both parties. The restaurant's and the platform's profit levels in a decentralized system—shown in Proposition C.4 and Corollary C.3 in the online appendix—represent the lower bounds of both parties' profit targets in a RS contract. Then their bargaining power can determine how they will divide the extra surplus generated through this coordination.

**Proposition 2** (RS Contracts). *The following RS contracts can coordinate the system and achieve the maximum aggregated profit.*

(i) *One-way RS contract with a price ceiling—The platform allocates a fraction $\gamma_1$ of its revenue to the restaurant while the restaurant cannot set a food price higher than $p^o$.*

(ii) *Two-way RS contract—Both the restaurant and the platform agree that a fraction $\gamma_2$ of their aggregated revenue be allocated to the restaurant.*

*There always exists a range of sharing fractions that make both parties weakly better off than they would be without any contract. In particular, the sharing fractions in (C.5) (respectively, (C.6)) of the online appendix achieve a win-win for both parties under the one-way RS contract with a price ceiling (respectively, two-way RS contract).*

Proposition 2 provides two contracts to coordinate the system and arbitrarily share the maximized total profit. In the proposed one-way RS contract, the food price is capped at $p^o$. Because the restaurant's profit increases with the food price $p$ on $[0, p^o]$ in the decentralized system (see Section C.3 in the online appendix), the restaurant will self-interestedly set the food price at $p^o$.

Without this price ceiling, the food price chosen by the self-interested restaurant will surpass $p^o$, which leads to a suboptimal total revenue for the whole service chain. Different from Feldman et al. (2021) who show that a one-way RS contract cannot achieve the profit of a centralized system and often performs worse for the restaurant than having no delivery service, we show that a one-way RS contract with a price ceiling—a mild modification—can coordinate the system to achieve the maximum aggregated profit. On the other hand, in the two-way RS contract, neither food price nor delivery fee is specified, and both parties just agree to share part of their revenue with each other so that each party earns a given fraction of the total revenue. Under this contract, the restaurant's profit becomes an affine transformation of the aggregated profit of the service system, so the restaurant will set the optimal monopoly food price $p^o$. Under both contracts, the platform promises to share a fraction of its profit with the restaurant, which enforces the latter's engagement in such coordinating contracts.

Proposition 2 specifies closed-form expressions of the ranges of sharing fractions that can achieve a win-win situation for both the restaurant and platform. In general, such a range can be obtained by taking ratios of the profit levels of the restaurant and platform in the decentralized system over the centralized total profit.

We close this section with two remarks. First, we also verify the robustness of the results of Lemma 1 and Proposition 2 under the condition of no traditional customers, that is, $\Lambda_0 = 0$ (see Lemma A.1 and Proposition A.2 in the online appendix). The same insights hold. Second, in our base model, we assume that the restaurant is unable to price-differentiate between walk-in and food-delivery customers. Thus, the food price stays the same for all purchases. However, if the restaurant was allowed to set different food prices for food-delivery and walk-in customers as $p^o + \theta^o$ and $p^o$, where $p^o$ and $\theta^o$ are given in Lemma 1, the restaurant could extract all social welfare as profit—the platform and customers would have zero surpluses. Note that, in this case, the platform would still provide a food delivery service to tech-savvy customers, because the cost of hiring delivery workers is assumed to be zero in the base model.

## 6. Finite Delivery-Worker Pool

In this section, we extend our base model with an infinite pool of delivery workers by assuming that the platform has a delivery-worker pool of size $N < \infty$. We assume that the delivery workers' opportunity cost per unit of time $\sigma$ follows a distribution on $[0, \beta]$ with the cumulative distribution function denoted by $F(\cdot)$. When the platform sets the guaranteed delivery wage at $w \in [0, \beta]$ per unit of time, the expected supply of delivery workers is $\nu(w) = N \cdot F(w)$.

As with the base model, we study a decentralized system where the restaurant and the platform participate in a Stackelberg game. The setting is exactly the same as in the base model, except that in the second stage, the platform decides on and posts a wage $w$ for delivery workers together with the delivery fee $\theta$ for customers. The game can be solved using backward induction as well. Recall our assumption that one delivery worker fulfills at most one order per unit of time. Lemma C.2 characterizes the tech-savvy customers' demand $\lambda_D$, unconstrained by the supply of delivery workers, for the food delivery service under delivery fee $\theta$. The joining rate of food-delivery customers is the minimum of demand and supply of delivery workers, that is, $\min(\lambda_D, \nu(w))$. The platform's revenue is the product of the delivery fee and the joining rate of food-delivery customers, that is, $\theta \cdot \min(\lambda_D, \nu(w))$. The platform pays $w \cdot \nu(w)$ per unit of time to those $\nu(w)$ numbers of delivery workers. Thus, under delivery fee $\theta$ and delivery wage $w$, the platform's profit is $\pi(p, \theta, w) = \theta \cdot \min(\lambda_D, \nu(w)) - w \cdot \nu(w)$, and the delivery workers' total utility is $u_D(\theta, w) = w \cdot \nu(w) - N \int_0^w x \, dF(x)$, which is part of social welfare in this extension. We characterize the equilibrium behavior as follows.

**Proposition 3** (Impact of Delivery-Worker Pool Size on Restaurant). *Consider the decentralized system. When the delivery-worker pool size is capped at a specific level, the restaurant operates in a delivery-irrelevant regime, with no response to the introduction of the food delivery service. Otherwise, the restaurant operates in a delivery-only regime when the tech-savvy segment is sufficiently large. Formally, when $\sigma$ follows the uniform distribution over $[0, \beta]$, $\mu^2 \beta \le cN$ and $\phi \le \phi_1$, there exist thresholds $\bar{N}$ and $\bar{\Lambda}_T$ such that if $N \le \bar{N}$, in equilibrium the restaurant's food price $p^*$ and profit $\Pi^*$ stay at $p^*(\Lambda_1) = R - \sqrt{Rc/\mu}$ and $\Pi^*(\Lambda_1) = (\sqrt{R\mu} - \sqrt{c})^2$ for all $\Lambda_1$. If $N > \bar{N}$ and $\Lambda_1 > \bar{\Lambda}_T$, in equilibrium the restaurant sets a food price $p^*(\Lambda_1) \ge R - \sqrt{Rc/\mu}$.*

In the decentralized system with a finite delivery-worker pool, Proposition 3 shows that, as in the base model, the restaurant has two operating regimes: (i) the delivery-irrelevant regime, where the restaurant behaves the same as in an unobservable queue with only traditional customers, and (ii) the delivery-only regime, where the restaurant becomes a delivery-only kitchen and serves only the food-delivery customers. For the restaurant, the delivery-worker pool size $N$ affects the maximum profit in the delivery-only regime but has no impact in the delivery-irrelevant regime. For the platform, when the delivery-worker pool size $N$ increases, it becomes less costly to hire delivery workers to fulfill the same unconstrained demand for the food delivery service from the tech-savvy customers, which benefits the platform for a fixed food price. However, when $N$ reaches a certain level $\bar{N}$ and there is a sufficiently number of tech-savvy customers, the restaurant finds it more beneficial to shift to the delivery-only regime. That is, the restaurant will raise the food price significantly and squeeze more residual surplus from the platform, which can cause the platform's profit to drop sharply, in spite of the benefit of accessing a cheaper labor pool. This phenomenon is similar to what has been shown in the case of the infinite delivery-worker pool in our base model (see, e.g., Figure 2(a)). However, before $N$ increases to this threshold of $\bar{N}$, the restaurant does not find it beneficial to make such a regime shift.

Proposition 3 implies that, under no contract between the restaurant and platform, the delivery-worker pool size may be a useful lever for the platform and social planner. By limiting the size of this pool, the platform can limit the restaurant's tendency to become a delivery-only kitchen, a situation that may hurt the platform's profit and social welfare because of the potential price increased by the restaurant. (Section B.1 of the online appendix provides a more detailed discussion of the impact of the delivery-worker pool size $N$ on social welfare when there is sufficient demand from tech-savvy customers. Social welfare could be hurt by a larger delivery-worker pool despite more workers getting hired, because of the possible price increase by the restaurant.) More importantly, by limiting the delivery-worker pool size, the platform may reap all surpluses from the introduction of the food delivery service.

Proposition 3 also provides the social planner with a simple yet effective approach to improving social welfare. Recall that, in Section 5, we demonstrate the practicality of a RS contract to maximize social welfare. However, the RS contract needs participation from both the restaurant and platform. Negotiating and enforcing such a contract may be costly. Alternatively, the social planner can regulate the number of delivery workers registered with the platform to improve social welfare, especially when the demand rate of tech-savvy customers is high enough and the food delivery service is sufficiently convenient. Although such regulation does not lead to optimal social welfare, it generates a reasonably good outcome and can be easy to implement—it aligns with the platform's interest, so the platform is less likely to push back.

In general, the closed-form solution of the sequential game under a general opportunity cost distribution may not exist. We adopt a numerical approach to deriving all desired performance measures in Section B of the online appendix (for opportunity costs following uniform and beta distributions) and demonstrate that our insights continue to hold for various opportunity cost distributions.

## 7. Conclusion

The food delivery service is an innovative and economically sensible business model that allows people with high opportunity costs to outsource the task of waiting in line to people with low opportunity costs to reduce their own waiting cost. The recent explosion of information technology has enabled the food delivery business to expand so that more people have access to it. In this paper, we study a stylized single-server restaurant with a third-party platform providing a food delivery service to customers on the side. There are two streams of customers. The traditional customers cannot access this food delivery service, while the tech-savvy customers can. The interplay of the four parties—the restaurant, the food delivery platform, the traditional and tech-savvy customers—forms a sequential game. We solve the game analytically for decentralized and centralized systems, under the condition of abundant traditional customers that applies to restaurants with a strong existing customer base.

We discover that the platform does not necessarily increase demand for the restaurant, especially when the food price remains unchanged and there are sufficient traditional customers. Then, if the restaurant has to pay the platform for bringing in customers, the more orders made through the platform, the greater loss the restaurant may incur. Moreover, we show that when the pool of delivery workers is large, the platform's profit may decline sharply when the number of tech-savvy customers, which represents the potential market for the food delivery service, increases to a critical level. This happens because, when the arrival rate of tech-savvy customers is sufficiently high, the restaurant may find it more profitable to cater only to the food-delivery customers and will raise its food price significantly to extract more surpluses from them. This action hurts the platform's profit. On the other hand, this will not happen when the number of delivery workers is limited. In such a situation, the platform's capacity to provide the food delivery service is capped, so the restaurant cannot benefit from concentrating only on tech-savvy customers. Similar results hold for social welfare, for the same reason.

These results have several implications. When there is no contract between the restaurant and itself, the platform may not gain from a larger potential market for the food delivery service. If the arrival rate of tech-savvy customers is high, it may be more beneficial for the platform to limit the number of delivery workers so that the restaurant does not have the incentive to serve only food-delivery customers, which will hurt the platform's profit. More importantly, such a cap by the platform can leave all the extra surpluses generated by the food delivery service to the platform itself. Under the same condition of no contract between the restaurant and the platform, the social planner may not prefer a high arrival rate of tech-savvy customers, who can use the food delivery service to reduce their waiting costs. The social planner can improve social welfare by regulating the delivery-worker pool size to curb the restaurant's interest in keeping the food price high. Finally, our study generates insights into the contracts that coordinate a food catering system and maximize the total profit obtained by the restaurant and the platform. When the number of tech-savvy customers increases, a coordinating contract will incentivize the restaurant to reduce its food price and thereby attract more orders. At the same time, the platform will raise its delivery fee to extract the residual surpluses from food-delivery customers. Hence, it is essential for the platform to share its food delivery profit with the restaurant, not the other way around, so that the restaurant is motivated to take part in the coordination.

In practice, restaurants can set up in-house food delivery services or use third-party food delivery platforms. Before delivery apps were introduced, some restaurants, especially pizza restaurants, had their own in-house food delivery services. Now even those pizza businesses are split on whether to work with apps like Uber Eats (Melton 2021). By going with a food delivery platform, a restaurant can lower its delivery cost and enjoy the otherwise expensive-to-build digital infrastructure, thanks to the provision of resources such as drivers and capital by the platform. But there are also downsides in working with delivery platforms. First, restaurants with their own drivers can provide faster average delivery times thanks to dedicated services, particularly in the suburbs, where delivery platforms still lack driver networks. Second, because of the current practice of the platform charging a commission for each order, which gives restaurants an incentive to mark up their menu prices on the app, eaters can find it more expensive to order from the app than directly from the restaurant. After all, restaurants need to balance the pros and cons. For those that already maintain an in-house fleet, the platforms can be used contingently, for example, when in-house drivers are busy. Regardless of whether a restaurant has dedicated drivers, our results shed light on the forms of coordinating contracts when the restaurant is dealing with food delivery platforms.

Our model has limitations. First, we assume that the restaurant uses the same unchanged capacity to cope with the growing market of tech-savvy customers. Winkler and Jones (2019) report Uber's cofounder's new startup CloudKitchens—a bet on the food-delivery boomlet. The firm buys cheap real estate, often near city centers, and builds delivery-only kitchens to rent to restaurants that can prepare food exclusively for delivery. The attempt to add such an industrial-production component to food delivery aims to solve key logistics hurdles by creating capacity that is not tethered to restaurants that also serve dine-in customers. However, implementing this idea still faces many practical challenges. Consideration of the restaurant's existing dine-in capacity and potentially new delivery-only capacity can be a fruitful direction to explore. Second, we assume that customers have a homogeneous waiting cost while waiting for food offline. Third, our model does not consider the cross-side or same-side externalities among customers and drivers, for example, the externalities generated through spatial pooling that the delivery fee may hinge on. Last, we assume that if customers choose food delivery, there is no delivery delay after the food is made, and no quality difference in food between offline and online orders. Our results may change (respectively, should still qualitatively hold) when the loss of food quality with online orders is significant (respectively, minor). We leave relaxing those assumptions and enriching the current model for future research.

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