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Boosted by greater demand for convenience then turbo-charged by the COVID pandemic, online food delivery (OFD) has witnessed rapid growth over the past several years. Despite such growth, however, it is still unclear how incentives and payoffs of various parties are affected by the three-sidedness of the OFD market, which involves consumers, restaurants, and gig drivers—beyond the traditional two-sided setting. In this paper, we study the OFD platforms' optimal choices in a competitive setting where the platforms compete on both prices and service quality. Our analysis shows that conventional insights from two-sided platforms do not completely carry over to OFD markets. Specifically, we find that the three-sidedness may either soften or intensify the price competition in the buyer-seller market, consequently altering the subsidizing conditions of OFD platforms. While two-sided platforms generally get hurt by network effects due to the pressure to induce participation, OFD platforms are able to mitigate such negative impact by flexibly adjusting their service strategies. Yet, OFD platforms may not always be better off by introducing gig labor because additional leverage for competing platforms could lead to a prisoner's dilemma situation. We show further how the platforms' pricing and service strategies critically depend on the strength of network effects. With the rising of the gig economy, the question of employment status for gig workers has become an increasingly controversial issue in the U.S. and elsewhere. We address this by showing that the introduction of minimum wage regulation, although benefiting the gig drivers, may be welfare-diminishing to society at large. Our results can thus provide guidance to policymakers seeking a compromise between the interests of gig workers and society as a whole.

Key words: online food delivery; on-demand platform; gig economy; service innovation; multi-sided markets

1. Introduction

Online food delivery (OFD) services are reshaping how the world eats. Although deliveries from restaurants have been possible for many decades, OFD platforms make it much easier for consumers to order food from a variety of restaurants and have it delivered directly to their doors. Given its

convenience and, in a time of COVID, increased safety, the OFD market has experienced rapid growth and in fact is estimated to expand at a compound annual growth rate of 10% in the next few years (Statista 2020). Consistent with the trend of technology-enabled platforms playing an increasingly important role in the global economy (Feng et al. 2020), OFD platforms have emerged as part of a massive trend in the food delivery industry in the U.S. and around the globe (Feldman et al. 2021). In a leading example, DoorDash generated $2.9 billion in revenue in 2020, featuring a whopping growth rate of 241%, (Curry 2021a). A main competitor, Uber Eats, experienced revenue growth of $2.9 billion in 2021, an increase of 152% (Curry 2021b).

These digital platforms operate new business models providing on-demand services with part-time resources, namely *gig workers*. Collectively known as the sharing or gig economy (i.e., Airbnb, Uber, Lyft), this type of business has been widely embraced by consumers and has caused disruption and displacement to incumbents in various industries (Greenwood and Wattal 2017, Edelman et al. 2017, Zervas et al. 2017, Burtch et al. 2018). While researchers have mainly focused their studies of the sharing economy on cases where platforms play a mediating role between two groups (buyers and sellers), OFD platforms involve three groups —consumers, restaurants, and gig drivers. OFD platforms especially rely on gig labor to enable their delivery services, although hiring gig drivers is an expensive undertaking because these workers are part-time employees less likely to commit to working for only one platform. This opens an additional dimension to the competition among OFD platforms, who must fight not only for gig drivers but also for consumers and partner restaurants.

Meanwhile, creating a high-quality OFD experience for customers requires restaurants to invest in improving their service capabilities and integrating with OFD platforms, such as in the synchronization of business processes (DoorDash 2020, Helling 2022). Despite the potential for increased business, these additional requirements for restaurants could make participating in an OFD platform a less attractive option for a restaurant than staying with the traditional in-house dining business.

Moreover, consumer experience on OFD platforms is tied not only to food and price but also to delivery services, which require a joint effort from multiple parties (e.g., restaurants and gig drivers) involved. In this regard, online food delivery is a truly complex multi-sided marketplace

problem, where balancing the needs of all stakeholders, especially in the era of constant innovation, is challenging. Because of this complexity, the current scholarship regarding two-sided platforms might not be applicable to the context of OFD platforms, suggesting that understanding how the incentives and payoffs of various parties are affected by three-sided platforms is an important but understudied research area.

Yet, there has been no consensus regarding the optimal practices of OFD platforms. Many have adopted conventional competition strategies from two-sided markets through price markups and service fees, with critics noting that the fees charged by OFD platforms are too high and cut heavily into local restaurants' bottom lines (Schweitzer 2019). Meanwhile, fierce competition for funding drives the OFD platform to seek near-term revenue growth. These platforms fight to attract consumers through short-term promotions, discounts, and other giveaways which do not create lasting effects. Moreover, such subsidies are also not usually passed onto drivers who are typically gig workers hired as independent contractors and thus not protected by minimum wage laws, unlike traditional employees (Bose 2021). DoorDash, for one, has been criticized for using customer tips to underwrite driver wages (Carson 2019).

In spite of these challenges, there is also the opportunity for those platforms that can adapt to the business transition with innovative strategies to gain competitive advantages. In one effort, DoorDash has initiated improvement of their overall delivery quality by focusing on reducing errors by restaurants and drivers, translating into fewer refunds. Its biggest competitor, Uber Eats has also focused on better customer experience by improving delivery efficiency with new technology. Facing the interoperative relations among consumers, restaurants, and gig drivers, however, it is still not an easy task for the OFD platforms to turn those efforts into profits (Preetika and Haddon 2022). As suggested by Ahmad Anvari, a senior product leader at Uber: *"There are two sides to the Uber transportation platform: riders and drivers. With new products, such as Uber Eats, we've expanded to a more complex, multi-sided platform, adding on delivery partners, restaurants, and consumers."*, as shown in Figure 1 (MIT IDE 2018). Thus, answering how to properly manage and leverage the three-sidedness of the OFD market is critical to the success of OFD platforms.

Figure 1   Uber's View of OFD Platform Complexity and Growth

2-sided platform   **3-sided platform**
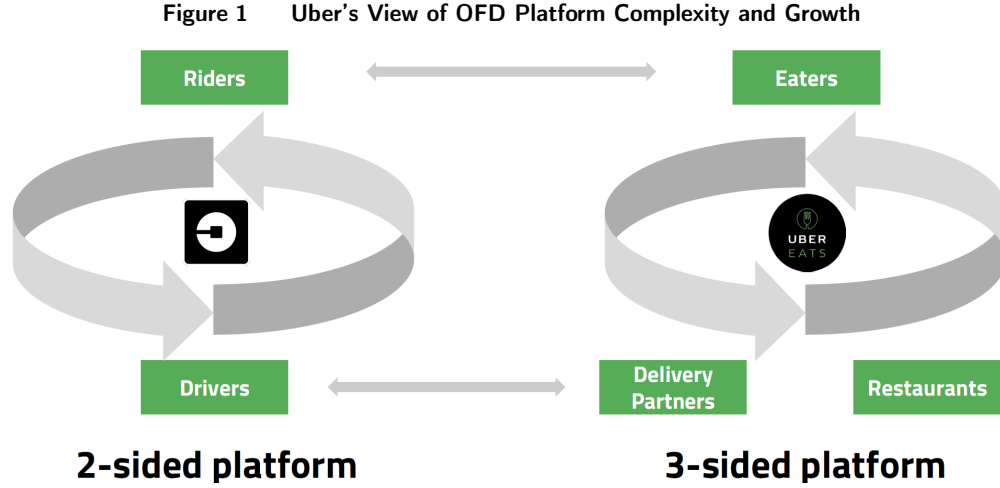
Source: Ahmad Anvari Presentation at the 2018 MIT Platform Strategy Summit

Motivated by these observations, we study OFD platform practices in a competitive market facilitated by gig labor. The extant literature has primarily focused on platforms' mediating role between sellers (restaurants) and buyers (consumers), without fully considering the three-sidedness of the market. In this study, we consider OFD platforms competing not only on price but also on service quality, and pose the following questions to guide our research:

1) *When do platforms have more incentives to leverage the three-sidedness in the OFD market?; 2) What are the unique features of such OFD market that might change our insights from the traditional two-sided markets?; and 3) How do the dynamics among the three parties affect OFD platforms' optimal strategies and equilibrium outcomes?*

To answer these research questions, we develop a game-theoretic model in which two platforms compete in an OFD market, making simultaneous pricing and service decisions bounded by acquired gig labor and affecting buyer-seller payoffs. Our goal is to provide a framework to model and study the optimal pricing and service strategy in OFD markets and to generate managerial insights for practitioners by offering them actionable strategies. To the best of our knowledge, this paper is among the first to formally study the three-sided market problem.

To better evaluate the implications of the three-sidedness of the OFD market, we first consider a benchmark two-sided market in which platforms serve as intermediaries between buyers and sellers. We derive the platforms' pricing strategies in the equilibrium and identify the optimal

subsidizing conditions before laying out the model foundation for each party in the OFD market and executing a full analysis vis-a-vis our research questions. We find that an OFD platform's incentive to leverage the market's three-sidedness hinges crucially on the relationship between consumer benefit from service improvement and the intensity of interaction in the buyer-seller market. We show further that the introduction of gig labor tilts the benchmark equilibrium by softening consumer price competition while intensifying restaurant price competition. We find, interestingly, that OFD platforms can exploit such an effect to alleviate the negative impacts of network effects as recognized in the two-sided market literature. However, despite such benefits, OFD platforms may still earn lower profits than their two-sided counterparts because the OFD market opens up a new dimension of platform competition. Furthermore, we conduct a set of comparative statics with respect to key parameters characterizing the dynamics of the rapidly-evolving OFD market. Overall, we find that due to the additional degree of freedom, OFD platforms are more flexible in adjusting their strategies, which leads to some intriguing counter-intuitive results in the equilibrium.

As we pointed out earlier, many OFD platforms have adopted conventional strategies derived from the study of two-sided markets, which could result in suboptimal outcomes relative to the potential from fully incorporating the three-sidedness factor into the analysis (Schweitzer 2019, Bose 2021, Carson 2019). Consumers are found to be sensitive to the quality of on-demand services such that they are willing to pay more for a premium experience (Findling 2017, Lardieri 2019, Hyken 2021), which provides an opportunity for competing platforms to exploit the dynamics of the three-sided OFD market. Yet, due to the interoperative relationship among the three sides, OFD platforms face more a complicated problem in deriving their optimal pricing and service strategies (Matyunina 2020, Singh 2021, Samsukha 2021). Our analysis thus provides valuable managerial insights regarding when and how platforms should transition from traditional price-based competition to competition on service innovation in the OFD market. As consumer expectations, business practices, and emerging technologies continue to shape the evolving, expanding industry, the long-term economics are unlikely to remain static. Tapping into new opportunities will require a comprehensive understanding of how overlapping economic forces affect a complex web of stakeholders (Ahuja

et al. 2021). In this vein, our findings provide useful guidelines for OFD platforms to constantly re-evaluate their strategies when the market environment changes.

We extend our baseline model in several directions to examine the impacts of alternative model specifications. To provide insight into the potential implications of minimum wage policy intervention, we extend our model to examine a case in which a policymaker sets a minimum wage rate in the gig labor market. We find that while gig drivers benefit from the minimum wage policy, consumers suffer because their surplus is further extracted by each OFD platform now forced to raise prices to offset their higher labor costs. Interestingly, although OFD platforms are forced to pay gig drivers a higher wage, their profits are still greater under the policy. The reason for such a counter-intuitive result is that the minimum wage policy lessens inter-platform competition in the gig labor market, which boosts the overall service quality level and indirectly softens the platform competition in the consumer market. We moreover show that social welfare does not always increase with the wage policy in effect, suggesting that such an intervention in the three-sided OFD market, in aiming to help one party, may have a significant impact on others. Implementing this kind of policy without a careful and comprehensive examination of its potential impacts may lead to unintentional negative outcomes felt society-wide.

The rest of the paper is organized as follows. We review the related literature in Section 2, then introduce our model settings in Section 3. Section 4 provides analysis of our baseline model and examines platforms' equilibrium strategies under various conditions, while we extend our model in Section 5. Finally, we summarize managerial implications and conclude in Section 6.

2.   Related Literature

To understand the potential mechanisms and unique characteristics regarding the OFD platforms and how the various parties involved are affected by the three-sidedness of the marketplaces, we draw from several streams of literature. It should be noted, however, that some critical features of our research also deviate from the existing literature in each stream.

First, our model builds on the theoretical literature on two-sided platforms and platform competition (i.e., Katz et al. 1985, Liebowitz and Margolis 1994, Conner 1995, Economides 1996, Baake

and Boom 2001, Caillaud and Jullien 2003, Rochet and Tirole 2003, Parker and Van Alstyne 2005, Argenziano 2008, Cabral 2011, Chen and Chen 2011, Cheng et al. 2011, Economides and Tåg 2012, Griva and Vettas 2011, Hagiu and Spulber 2013, Hagiu and Hałaburda 2014). In this stream, there have been multiple studies focused on platforms' pricing strategies that induce the two sides to participate, allowing the OFD platform to coordinate the service partnership between the buyers and sellers to maximize their profits as intermediaries. In one related example, Caillaud and Jullien (2003) investigate pricing strategies of matchmaking intermediaries with homogeneous participants on both sides, suggesting that consumer welfare is optimized when a limited number of firms offering undifferentiated services come to dominate the market, despite the inevitable reduction in service efficiency. Parker and Van Alstyne (2005), for their part, identify the optimal subsidization condition across two sides in the context of information products. Armstrong (2006) analyzes the scenario of a "competitive bottleneck" where one side multi-homes and the other one single-homes, a framework that has been widely adopted throughout the literature (Rochet and Tirole 2006, Economides and Tåg 2012, Hagiu and Spulber 2013, Hagiu and Hałaburda 2014) and facilitates understanding regarding two-sided markets and the effects of pricing strategies on market dynamics.

Some recent work in this literature stream reflects the growing research interest in non-pricing initiatives by platforms in two-sided markets. Some studies extend the literature by considering the level of network effects as an investment decision by the intermediary (Bakos and Katsamakas 2008, Dou et al. 2013, Anderson Jr et al. 2014), while others, such as Parker and Van Alstyne (2018), examine the decision trade-offs for a platform aiming for high growth and characterize the optimal level of platform openness and IP duration. Similarly, Niculescu et al. (2018) focus on the same-side network effects by considering an incumbent platform's strategic intellectual property sharing decision. Proceeding from the well-known "chicken-and-egg" problem in two-sided markets, Dou and Wu (2021) study the piggybacking strategy that has gained popularity among platforms and find that additional leverage by competing platforms may result in a prisoner's dilemma that leaves both parties worse off. Despite the emerging body of research, the effectiveness of non-pricing platform strategies on market configurations has yet to be fully investigated, especially in a three-sided market. Adding to the literature, our paper introduces the factor of OFD platforms' strategic

decisions about service quality level and shows how such decision-making is interoperative with the pricing decisions in the buyer-seller market, highlighting the necessity of studying OFD platforms in terms of the three-sided market problem.

Our research also connects to the stream of emerging literature on the sharing economy (gig economy) that has been receiving considerable attention from the research community. Fraiberger and Sundararajan (2017), for example, study the implications of P2P online rental markets for durable goods from a welfare perspective. While a few studies explore the sharing economy's economic impact on incumbents (Zervas et al. 2017, Cramer and Krueger 2016), others focus more on the societal implications of the gig economy. For example, Greenwood and Wattal (2017) examine Uber's effect on the rate of alcohol-related motor vehicle fatalities and find that the number of fatalities has decreased since the entry of Uber's ride-sharing services. In another socially-minded work, Edelman et al. (2017) investigate discrimination practices at Airbnb, calling for public attention and the potential redesign of the platform to improve its diversity, equity, and inclusion practices. While all these studies enrich our understanding of the standalone implications of the gig economy, our paper complements this research stream by extending to the interactions between the gig economy and multi-sided markets, which fundamentally changes the landscape of competition and brings new insights to the research community.

A third stream of emerging literature our work relates to is online food delivery services, with several analytical studies focusing on the platform from an operations perspective. For example, some studies examine the interplay between customers and on-demand agents, using a queuing model of a single platform (Taylor 2018, Chen et al. 2022, Farahani et al. 2022). Another group of papers explores ways to better utilize a platform's on-demand service, such as by applying blockchain technology (Choi et al. 2020) and design of user conduct (Mai et al. 2022). A growing number of empirical studies also supplement these analyses by bringing new insights into our understanding of the implications of online food delivery platforms, like those examining the value of OFD services to participating restaurants, with respect to demand forecast, as Karamshetty et al. (2020), and channel substitution effects (Li and Wang 2020). Focusing on OFD platforms' strategic decisions, Aziz and

Mehra (2021) examine how delivery speed expectations affect consumer purchase behaviors, while Tong et al. (2020) investigate the impact of different pricing schemes on future demand. Considering another aspect of how OFD services impact society, Babar et al. (2021) show that the entry of OFD platforms can lead to unhealthy dietary behaviors. While these studies deepen our understanding of the OFD market in distinct ways, most of them only focus on problems involving one or two active parties, leaving the three-sidedness feature unaddressed. In contrast to the existing research, we model the interdependence among consumers, restaurants, and gig drivers simultaneously so as to capture the nuanced dynamics of such a market.

Lastly, previous studies considering the three-sided market problem have fallen short in capturing its full dynamics. Seamans and Zhu (2013), for example, examine the impact of Craiglist's entry on US newspapers' advertising practices. The study models a newspaper that connects its subscribers with classified advertisers and display advertisers. However, because the study's authors assume that the two types of advertisers do not interact with each other directly and that subscriber demand is independent of the number of ads, the three-sided market they construct is rather more actually two two-sided markets linked by a common pool of subscribers. Bahrami et al. (2021) study an on-demand food and grocery delivery platform's pricing decisions in a three-sided market framework, showing that the equilibrium commissions and wages vary depending on whether the platform is a welfare or profit maximizer. Yet, in sharp contrast to the above two studies that consider a monopoly platform, we study the competition between two OFD platforms because the tension between the platforms, especially in the self-scheduling gig labor market (Zhang et al. 2022), is critical in modeling the full dynamics of the three-sided market.

3. Model

In this section, we lay out our study's basic model and assumptions. We consider a market where OFD platforms facilitate transactions between restaurants and consumers with help from gig drivers. Next, we provide detailed discussions of how each group is engaged with the transactions in the platforms.
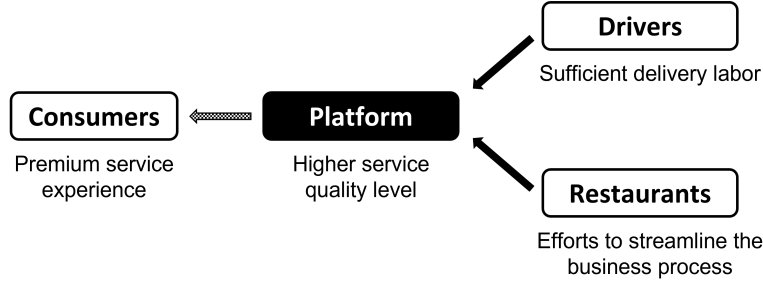
3.1. Platforms

In terms of OFD service, Uber Eats and DoorDash are the two major players in the United States. Similarly, in China, the market is mostly dominated by two competing firms called Ele.me and Meituan. To reflect the environment of competition between OFD platforms, we consider a setting in which two (indexed by $i \in \{1, 2\}$) compete by facilitating the interaction between restaurants (indexed by r) and consumers (indexed by c). Similar to a typical multi-sided market, each group (either restaurant or consumer) values the number of agents from the other group, which the literature commonly refers to as network effects (Armstrong 2006).

A key differentiating factor of our study is that the OFD platforms compete not only in pricing but also through non-pricing initiatives. Because of the on-demand feature of food delivery platforms, consumers are not only sensitive to the price of a service, but also to its quality, constrained by the capacity of assigned delivery workers (Benjaafar and Hu 2020). Even more important than pricing in providing consumers with a great OFD experience, platforms must innovate in various operational capacities such as setting up guidance and streamlining the business processes with their restaurant partners. Correspondingly, platforms have specified terms and conditions for merchants willing to participate. For example, DoorDash clearly states its brand guidelines in its merchant agreement that restaurants shall promptly comply with its terms for food, communication, and order fulfillment.[1] Similarly, Uber Eats states in its agreement that the platform may, at its sole discretion, deduct payment for any misconduct against its policy such as food safety, item accuracy, service level, and device maintenance.[2] Such standard operating procedures (SOP) that enable an experience beyond what competitors can offer are believed to be the key to long-term success for online food delivery platforms (Tech Crunch 2020). We abstract all the non-pricing service attributes a platform stipulates beyond basic operating quality as the platform's *service quality*—s_i, $\forall i \in \{1, 2\}$ in this study, on which we further elaborate below.

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[1] https://help.doordash.com/merchants/s/terms-of-service-us?language=en_US

[2] https://www.uber.com/legal/en/document/?country=united-states&lang=en&name=uber-eats-merchant-terms-and-conditions.

Figure 2   Impact of Service Quality on Three Sides

While service quality is an important factor in gaining competitive advantages in the traditional food and beverage industry (Kim et al. 2009, Cheng et al. 2012), it has often been ignored by OFD operators in the past, resulting in decreased customer satisfaction and intention (Annaraud and Berezina 2020). The literature has characterized the OFD service quality with multi-dimensional metrics such as reliability, assurance, security, system operation and traceability (Cheng et al. 2021). OFD consumers, meanwhile, are found to be sensitive mostly to the quality of delivery (e.g., speed, ease, or precision) and to the overall experience of OFD services including food quality, service convenience, and fulfillment accuracy (Benjaafar and Hu 2020, Frederick and Bhat 2021). So, because OFD services require cooperation among the platform, restaurants, and gig drivers, service quality cannot be achieved through the efforts of any single party alone (Ahuja et al. 2021). In practice, the leading OFD platforms use multiple metrics to measure their service quality in different dimensions, such as missing/inaccurate order rates, delays in accepting/delivering orders, and unaccepted orders. Owing to the on-demand nature of the service provided, service quality is one of the key determinants of business success. We accordingly consider service quality as a key decision variable in the OFD platform's problem-solving approach and define it as the comprehensive consumer perception towards OFD services, which requires a joint effort of the platform, restaurants, and gig drivers. In Figure 2, we illustrate how service quality affects the three parties – restaurants, gig drivers, and consumers.

3.2. Restaurants

A major component of OFD service is the partner restaurants, each of which is a profit-seeker aiming to maximize profit through operations. In order to reach as many customers as possible, restaurants

generally choose to be on multiple platforms (Cubho 2020), while newly entrant platforms make efforts to affiliate with restaurants already on incumbent platforms (Pototska and Harkushko 2020). We assume, then, that restaurants can choose to join more than one platform, or "multi-home", whereby their participation decision about one given platform is independent of their decision about another. For clarity's sake, we also assume that when a restaurant participates it receives β unit revenue for each consumer on the platform, where β can be considered as the seller-side network effect.[3]

Restaurants incur a participation cost by joining each platform, modeled as $c \cdot e_i + g$, where e_i is the restaurant's effort level needed to comply with platform i's service quality level s_i, c is the variable participation cost per unit effort level, and g is the fixed participation cost. We assume for any given platform service quality s_i, the effort level required is $\delta \cdot e_i$ so that $e_i = \dfrac{s_i}{\delta}$, where δ can be considered a restaurant's effort effectiveness factor. The rationale for this variable participation cost is that as platforms stipulate special requirements to meet the service quality s_i, restaurants have to continuously improve their core logistics associated with the platforms' service offerings, requiring substantial ongoing investment. A case in point is food temperature, which is usually no less important than its taste. As such, restaurants might have to revamp the delivery packaging so as to keep hot items hot and cold items cold while sticking to more eco-friendly options (Grubhub 2015, Tech Crunch 2020), while they must also integrate key business processes such as ordering, staffing, payment, and fulfillment. Failure to comply with the regulations and requirements may result in a monetary penalty or delisting from the marketplace.[4] While the variable participation cost component $c \cdot s_i$ is the same across all restaurants on a given platform, the fixed participation cost g is assumed to be uniformly distributed on $[0, G]$. Here, g can be considered as restaurant opportunity costs, such as serving dine-in consumers.

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[3] It is a common approach to model the average benefit per consumer in the literature on multi-sided markets (Rochet and Tirole 2003, Armstrong 2006).

[4] Handling extra online orders creates pressure for restaurants to accelerate their in-house operations so as to avoid conflicts between the dine-in and delivery services. With the rise of AI and machine learning, platforms may also learn about consumer preferences at a more granular level and develop more comprehensive personalized service offerings.

Restaurants need to pay in order to activate their business on a food delivery platform (Tjahyadi 2020, Escoffier 2021), although platforms could also choose to subsidize their partner restaurants to encourage participation. We thus denote the price paid by a participating restaurant to platform i as $p_{r,i}$, which can be positive, negative (subsidizing), or even zero, to accommodate all the possible scenarios. So, by joining platform i, a restaurant with fixed participation cost g makes a profit of

$$\pi_{r,i}(g) = \beta N_{c,i} - \frac{cs_i}{\delta} - p_{r,i} - g \ ,$$

where $N_{c,i}$ is the number of consumers on platform i. Given that, the marginal restaurant, which is indifferent between joining and not joining platform i, is characterized by $g_i^* = \beta N_{c,i} - \frac{cs_i}{\delta} - p_{r,i}$. Accordingly, restaurants with $g \leq g_i^*$ would join platform i, resulting in a participation rate of $\frac{g_i^*}{G}$, which gives rise to the following restaurant side demand function in the equilibrium as in Hagiu and Haɫaburda (2014) and Dou and Wu (2021):

$$N_{r,i} = \frac{\beta N_{c,i} - \dfrac{cs_i}{\delta} - p_{r,i}}{G} \ . \tag{1}$$

3.3. Consumers

We adopt the Hotelling model of product differentiation to analyze consumers' choice of platform. It has been reported that consumers are sticky in their preferences for food delivery platforms. While consumers have access to multiple platforms, 80% of consumers rarely switch from one platform to another (Sawyer 2017). Food delivery platforms also use differentiation strategies to carve out a market niche and maintain client loyalty, making it costly for consumers to multi-home. (Manning 2019). As discussed in the two-sided market literature, when one party chooses to multi-home, the tendency for the other party to do so decreases because the incremental benefits from joining another platform diminish (Rochet and Tirole 2003, Armstrong 2006, Economides and Tåg 2012, Hagiu and Haɫaburda 2014, Hagiu and Spulber 2013), and so we assume that consumers single-home. Unlike restaurants, consumers make their own decisions as to which platform to join, so the platforms must compete for consumer participation. This setup, also known as "competitive bottleneck" (Armstrong 2006), better reflects the market reality of the on-demand food delivery industry.

Consumers are uniformly distributed along the unit line with their location denoted by x, and platform 1 (2) sits at point zero (one) of the line. We use $t > 0$ to denote the level of horizontal differentiation or the intensity of competition between the competing platforms (Benjaafar et al. 2020). A smaller value of t implies a lower level of differentiation and higher competition intensity. In practice, differentiation arises from various sources, such as user interface (UI) design, transaction process, or consumer community. Consumers derive higher utility with more restaurants on the platform because they are then more likely to find a better match. Following the literature on multi-sided markets, we use α to denote the consumer-side network effect, which represents the utility consumers derive from one additional restaurant on the platform. Consumers derive additional utility from a higher level of service quality specified by the platforms (i.e., s_i, $\forall i \in \{1,2\}$). We thus define γ as the benefit per service quality level to the consumers, which can be viewed as the incremental value provided by the platforms beyond the value from the restaurants or ordered items alone.[5] In return, consumers pay certain user fees on a given platform, which could include service charges, delivery charges, or convenience charges in various contexts, the sum of which we call the consumer price $p_{c,i}$. Correspondingly, the net utility that consumer x derives from joining each platform $U_{c,i}(x)$ is given by

$$U_{c,1}(x) = v + \alpha N_{r,1} + \gamma s_1 - p_{c,1} - tx \ ,$$

$$U_{c,2}(x) = v + \alpha N_{r,2} + \gamma s_2 - p_{c,2} - t(1-x) \ ,$$

where v is the intrinsic value. We assume that v is sufficiently large so that the market is fully covered, allowing us to focus on the competition between platforms. Given the utility functions above, the number of participating consumers on each platform can be calculated as

$$N_{c,i} = \frac{\alpha(N_{r,i} - N_{r,j}) - (p_{c,i} - p_{c,j}) + \gamma(s_i - s_j) + t}{2t} \ , \quad \forall i,j \in \{1,2\} \quad and \quad i \neq j \ . \tag{2}$$

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[5] According to various studies, consumers value better OFD experience and they are willing to pay more for premium service (Findling 2017, Lardieri 2019, Hyken 2021).

3.4. Gig Drivers

To increase service quality through better responsiveness, platforms have to acquire additional delivery labor, so that an increase in service quality level is bounded by the additional gig drivers that the platform can hire (Benjaafar and Hu 2020). We model this relationship as follows.

$$s_i = \sigma \cdot L_{d,i} , \quad \forall i \in \{1, 2\} , \tag{3}$$

where $L_{d,i}$ is the total amount of gig labor on platform i and σ is a positive scale factor. Essentially, a higher level of service quality requires a larger capacity of the delivery team. We note that a higher level of service quality requires higher participation costs for partner restaurants, as discussed in Section 3.2.

Gig drivers are scarce resources for which a platform competes with its opponents (Sonnemaker 2021), self-scheduling their supply (Zhang et al. 2022) based on the wage earned from the platforms (Burtch et al. 2018). Consequently, their willingness to participate increases with the wage and so in reality, many gig drivers are associated with multiple platforms and can easily choose which platform to work for in real time. To model this phenomenon, we follow the literature on differentiated duopolies (i.e., Singh et al. 1984, Raju et al. 1995, Jerath and Zhang 2010) and assume that a representative gig driver working for two competing platforms maximizes their utility as follows.

$$\arg \max_{l_{d,1}, l_{d,2}} U_d = l_{d,1}(w_1 N_{c,1}) + l_{d,2}(w_2 N_{c,2}) - \frac{l_{d,1}^2 + l_{d,2}^2 + 2\phi l_{d,1} l_{d,2}}{2} ,$$

where $l_{d,i}$ is the amount of labor that the gig driver allocates to work for platform i. Note that w_i is the wage rate offered by platform i and $N_{c,i}$ is the expected number of participating consumers on platform i. Together, $w_i N_{c,i}$ represents the wage per unit of labor that the representative gig driver can earn by working for platform i. Given that, by solving the gig driver's optimization problem, we have:

$$l_{d,i}^* = \frac{w_i N_{c,i} - \phi w_j N_{c,j}}{1 - \phi^2} , \quad \forall i, j \in \{1, 2\} \quad and \quad i \neq j ,$$

where $\phi \in [0, 1)$ is the substitutability index (Abhishek et al. 2016) that captures the degree of differentiation between the two platforms from the gig driver's perspective. As ϕ increases, competition becomes more intense as the platforms become more substitutable for each other. This linear

competition model has two desirable features. First, as the differentiation between the two platforms increases (i.e., ϕ decreases), payment sensitivity $\dfrac{\partial l_{d,i}^*}{\partial (w_i N_{c,i})} = \dfrac{1}{1-\phi^2}$ decreases, which is consistent with the intuition that workers are less wage-sensitive to more differentiated positions. Second, the total labor amount $l_{d,1}^* + l_{d,2}^* = \dfrac{w_1 N_{c,1} + w_2 N_{c,2}}{1+\phi}$ also increases in the differentiation, meaning that more differentiated positions tap a larger labor market.[6] Now assuming the size of gig driver market is N_d, the total amount of gig labor on platform i equals $N_d \cdot l_{d,i}^*$ so that

$$L_{d,i} = \frac{w_i N_{c,i} - \phi w_j N_{c,j}}{1-\phi^2} N_d , \quad \forall i,j \in \{1,2\} \quad and \quad i \neq j . \tag{4}$$

Without loss of generality, we normalize N_d as 1 and make the following additional technical assumptions.

ASSUMPTION 1.

$$\alpha + \beta < 2\sqrt{Gt} .$$

ASSUMPTION 2.

$$\sigma^2 < \frac{G\delta^2(8Gt - \alpha^2 - 6\alpha\beta - \beta^2)}{c^2(2Gt - \alpha\beta) - cG(\alpha+\beta)\gamma\delta + G^2\gamma^2\delta^2} .$$

ASSUMPTION 3.

$$c \leq \frac{(\alpha+\beta)\delta(2+\phi)}{\gamma\sigma^2} .$$

Assumptions 1 and 2 ensure the platform profit function will be well behaved,[7] while Assumption 3 guarantees that the number of participating restaurants in the equilibrium is non-negative, i.e., $N_{r,i} \geq 0$.

In Figure 3, we illustrate how the OFD platforms interact with their three sides via the key parameters and decision variables. The timeline of the game has two stages. In stage 1, the two

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[6] We have also considered other models of competition, such as the Hotelling or price differentiation models, and our insights would stay qualitatively the same under these alternatives.

[7] Assumption 1 simply restricts the strength of the network effects and is similar to those in the two-sided markets literature. Likewise, Assumption 2, in the context of OFD market, restricts the wage in the gig labor market; otherwise, the optimal platform prices/wage rates extend to infinity, which is trivial and less interesting.

Figure 3   Interactions among Consumers, Restaurants, and Drivers in Competing OFD Platforms
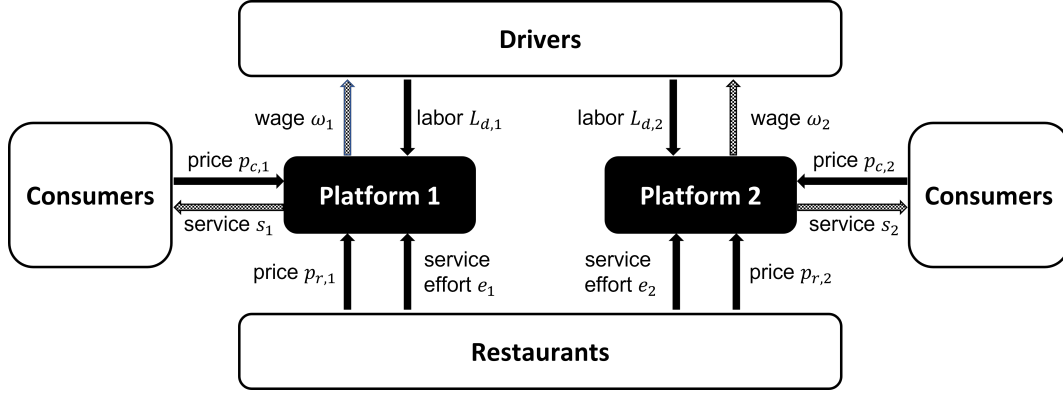
platforms simultaneously decide their consumer price, restaurant price, and service quality level. In stage 2, consumers choose to join either platform 1 or 2, while restaurants in turn decide whether to participate in platforms 1, 2, or both, and gig drivers allocate their labor across the two platforms. Then, all payoffs are realized.

Table 1   Summary of Notation

Parameters	Definition
β	restaurant-side network effect
δ	restaurant effort effectiveness factor
c	restaurant variable participation cost per unit effort level
e_i	restaurant effort level for platform i's service quality level
g	restaurant fixed participation cost, $g \in U[0, G]$
t	strength of consumer preference
α	consumer-side network effect
γ	consumer benefit per service quality level
σ	scale factor between delivery labor and service quality level
ϕ	substitutability index for gig drivers across platforms
$\pi_{r,i}$	restaurant profit by joining platform $i \in \{1, 2\}$
$U_{c,i}$	consumer utility by joining platform $i \in \{1, 2\}$
$N_{r,i}$	number of participating restaurants on platform $i \in \{1, 2\}$
$N_{c,i}$	number of participating consumers on platform $i \in \{1, 2\}$
$l_{d,i}^*$	representative gig driver's labor allocation on platform $i \in \{1, 2\}$
$L_{d,i}$	total amount of gig labor on platform $i \in \{1, 2\}$
w_i	wage rate offered by platform $i \in \{1, 2\}$
$p_{r,i}$	restaurant price for platform $i \in \{1, 2\}$, decision variable
$p_{c,i}$	consumer price for platform $i \in \{1, 2\}$, decision variable
s_i	service quality level of platform $i \in \{1, 2\}$, decision variable

4. Analysis

In this section, we derive the equilibrium using backward induction. First, for any given set of prices $p_{c,i}$, $p_{r,i}$, and the service quality level s_i, we characterize the optimal participation decisions for the consumers and restaurants, as well as the gig labor required. We then examine the platforms' decisions on prices and the service quality level by simultaneously solving their individual maximization problems. All proofs are provided in the online appendix unless otherwise specified, and we summarize the notations used in this paper in Table 1

4.1. Benchmark

We start with the benchmark case in which neither platform provides delivery services, that is, $s_i = s_j = 0$, $\forall i \neq j$. This resembles the setup of prior literature in a two-sided market, i.e., where the platforms serve as intermediaries between buyers and sellers by providing matching services. Then we have:

$$N_{r,i}^b = \frac{\beta N_{c,i}^b - p_{r,i}^b}{G},$$
$$N_{c,i}^b = \frac{\alpha(N_{r,i}^b - N_{r,j}^b) - (p_{c,i}^b - p_{c,j}^b) + t}{2t}.$$

Each platform chooses $p_{c,i}^b$ and $p_{r,i}^b$ to maximize its respective profit, supplying the following maximization problem:

$$\arg\max_{p_{c,i}^b, p_{r,i}^b} \Pi_i^b = p_{c,i}^b N_{c,i}^b + p_{r,i}^b N_{r,i}^b .$$

Lemma 1 summarizes the equilibrium outcomes.

LEMMA 1. *In the benchmark two-sided market, the equilibrium prices and profits are given by*

$$p_{c,i}^{b*} = t - \frac{\beta(3\alpha + \beta)}{4G} ,$$
$$p_{r,i}^{b*} = \frac{\beta - \alpha}{4} ,$$
$$\Pi_i^{b*} = \frac{t}{2} - \frac{\alpha^2 + 6\alpha\beta + \beta^2}{16G} .$$

Lemma 1 suggests that the equilibrium prices and platform profits in the benchmark two-sided market critically depend on the strength of network effects. Specifically, stronger network effects

reduce the buyer price, shown as $\dfrac{\partial p_{c,i}^{b*}}{\partial \alpha} < 0$ and $\dfrac{\partial p_{c,i}^{b*}}{\partial \beta} < 0$, while also decreasing platform profits, as $\dfrac{\partial \Pi_i^{b*}}{\partial \alpha} < 0$ and $\dfrac{\partial \Pi_i^{b*}}{\partial \beta} < 0$. These results are consistent with the findings in the prior literature on two-sided markets, which suggests that since cross-side network effects intensify competition and reduce platform profits (see Armstrong 2006, Anderson Jr et al. 2014, Hagiu and Hałaburda 2014, Dou and Wu 2021), platforms may have incentives to mitigate them.

Following Lemma 1, we derive the platforms' subsidizing strategies as shown in Corollary 1.

COROLLARY 1. *In the benchmark two-sided market, the platforms' subsidizing conditions are: subsidizing buyers if and only if $t < t^{b*}$; subsidizing sellers if and only if $\beta < \beta^{b*}$, where $t^{b*} = \dfrac{\beta(3\alpha + \beta)}{G}$ and $\beta^{b*} = \alpha$.*

The implications of this corollary are two-fold. On one hand, a platform would subsidize buyer participation if buyer stickiness on the platform is weak (i.e., $t < t^{b*}$). Otherwise, the platform tends to charge buyers a positive price because pricing power comes from the differentiation between platforms. Note that such threshold value (t^{b*}) is a function of the network effects (α and β), indicating that in a market that features stronger interaction between buyers and sellers, it is more likely for buyers to be subsidized. And then, on the other hand, sellers are subsidized if the seller-side network effect (β) is weak; otherwise, they have to pay a positive price. Intuitively, in the former case, the incentives for sellers to join a platform are relatively small, so it is necessary to attract them with subsidies. It is also notable that the threshold value (β^{b*}) is a function of the buyer-side network effect (α), suggesting that sellers are more likely to be subsidized when buyers derive higher utility from their presence, bringing a stronger cross-side benefit.

4.2. OFD Market

Next, we derive the equilibrium under the OFD market, where the platforms provide not only matching services but also delivery (i.e., $s_i, s_j > 0, \ \forall i \neq j$).

Each platform chooses $p_{c,i}$, $p_{r,i}$ and s_i to maximize its profit, which gives the following maximization problem of platform i.

$$\arg \max_{p_{c,i}, p_{r,i}, s_i} \ \Pi_i = p_{c,i} N_{c,i} + p_{r,i} N_{r,i} - (w_i N_{c,i}) L_{d,i},$$

$$s.t. \ s_i > 0.$$

Solving Equations (2) and (1) simultaneously for $N_{c,i}$ and $N_{r,i}$ gives the numbers of participating consumers and restaurants in equilibrium as a function of the decision variables.

$$N_{c,i} = \frac{1}{2} + \frac{(G\gamma\delta - c\alpha)(s_i - s_j) - G\delta(p_{c,i} - p_{c,j}) - \alpha\delta(p_{r,i} - p_{r,j})}{2\delta(Gt - \alpha\beta)} ,$$

$$N_{r,i} = \frac{\beta}{2G} + \frac{\beta[(G\gamma\delta - c\alpha)(s_i - s_j) - \alpha\delta(p_{r,i} - p_{r,j}) - G\delta(p_{c,i} - p_{c,j})]}{2G\delta(Gt - \alpha\beta)} - \frac{p_{r,i}}{G} - \frac{c}{G\delta}s_i .$$

Combining Equations (3) with (4), we can write the wage rate w_i as a function of a platform's decision variables as well.

$$w_i = \frac{s_i + \phi s_j}{\sigma N_{c,i}} . \tag{5}$$

When the two platforms compete in the OFD market, we show the equilibrium in Lemma 2.

LEMMA 2. *The equilibrium price and service quality chosen by each platform in the OFD market are given by*

$$p_{c,i}^* = t - \frac{\beta[G(3\alpha + \beta)\delta^2(2 + \phi) - c\sigma^2(c\alpha + G\gamma\delta)]}{2G[2G\delta^2(2 + \phi) - c^2\sigma^2]} , \tag{6}$$

$$p_{r,i}^* = \frac{c^2\alpha\sigma^2 - G\delta[c\gamma\sigma^2 + (\alpha - \beta)\delta(2 + \phi)]}{4G\delta^2(2 + \phi) - 2c^2\sigma^2} , \tag{7}$$

$$s_i^* = \frac{\delta\sigma^2[2G\gamma\delta - c(\alpha + \beta)]}{4G\delta^2(2 + \phi) - 2c^2\sigma^2} . \tag{8}$$

We note from Lemma 2 that the consumer benefit per service quality level γ has to be large enough (i.e, $\gamma > \gamma^* = \frac{c(\alpha + \beta)}{2G\delta}$) to ensure a positive service quality (i.e., $s_i^* > 0$), that is, high enough for the platforms to remain operative in the OFD business.[8] If consumers do not draw higher satisfaction from the premium experience, then the market will not value higher service quality, resulting in a lower effort to improve it. Note that the threshold value γ^* is a function of the sum of cross-side network effects in the consumer-restaurant market (i.e., $\alpha + \beta$),[9] indicating that in a market that features strong cross-side interaction, platforms have less incentive to improve service quality.

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[8] We normalize the minimum service quality level to 0, above which ensures a positive amount of gig labor.

[9] Hereafter, we call it the network effects for simplicity.

The platforms exhibit some unique behavior that would not be observed in the traditional two-sided markets. With the three-sided dynamics, service quality is not a standalone decision in that the influence of each platform's strategy on one party could have unexpected implications on the other two parties as well. To examine the equilibrium dynamics, we summarize the main characteristics in the following propositions, in which we focus on non-trivial scenarios where the platforms choose a positive service quality level, as specified in Lemma 2 (i.e., $\gamma > \gamma^*$).
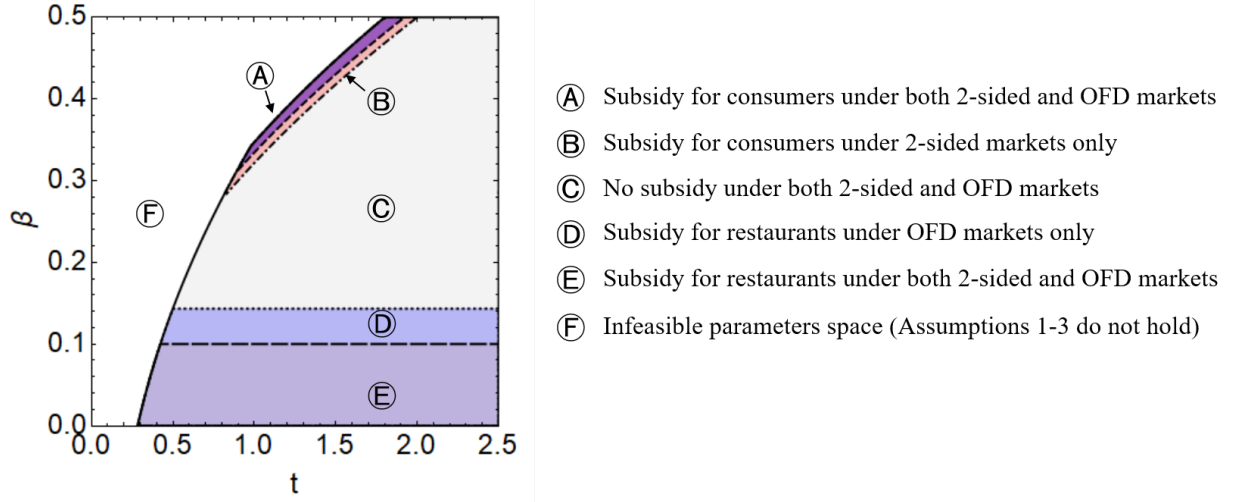
PROPOSITION 1. *Compared to the benchmark two-sided market, the OFD market softens price competition on the consumer side but intensifies it on the restaurant side, that is, $p_{c,i}^* > p_{c,i}^{b*}$ and $p_{r,i}^* < p_{r,i}^{b*}$.*

Proposition 1 shows how the rise of the OFD market impacts platform pricing strategies. Because consumers value delivery services in addition to preference-matching, OFD platforms have a means of attracting consumers through higher service quality, not simply cutting prices. As a result, the price competition is softened in the consumer market, which allows the platform to charge a higher consumer price than in the two-sided benchmark. Restaurants, for their part, incur a participation cost due to the inconvenience and disutility of complying with the OFD platforms' service quality level requirement. To compensate for this participation cost, OFD platforms lower prices to remain attractive to their partner restaurants, intensifying the price competition on the restaurant side.

COROLLARY 2. *In the OFD market, the platforms' subsidizing conditions are: subsidizing consumers if and only if $t < t^*$; subsidizing restaurants if and only if $\beta < \beta^*$, where $t^* = \dfrac{\beta[G(3\alpha + \beta)\delta^2(2 + \phi) - c\sigma^2(c\alpha + G\gamma\delta)]}{2G[2G\delta^2(2 + \phi) - c^2\sigma^2]}$ and $\beta^* = \alpha + \dfrac{c(G\gamma\delta - c\alpha)\sigma^2}{G\delta^2(2 + \phi)}$.*

Corollary 2 shows that an OFD platform is willing to subsidize consumer participation if it is less differentiated from its rival (i.e., $t < t^*$). Otherwise, the platform will charge a positive price to consumers. Meanwhile, an OFD platform would subsidize restaurants only if the restaurant-side network effect β is weak. The rationale for this set of results is consistent with that for the benchmark two-sided market. Yet, in contrast, we find that the subsidizing conditions have changed dramatically

Figure 4   Comparison of Conditions for Subsidization Strategy in OFD and 2-Sided Markets

Ⓐ Subsidy for consumers under both 2-sided and OFD markets

Ⓑ Subsidy for consumers under 2-sided markets only

Ⓒ No subsidy under both 2-sided and OFD markets

Ⓓ Subsidy for restaurants under OFD markets only

Ⓔ Subsidy for restaurants under both 2-sided and OFD markets

Ⓕ Infeasible parameters space (Assumptions 1-3 do not hold)

Notes. $\delta = \phi = \sigma = 1$, $\alpha = c = 0.1$, $\gamma = 1.5$, and $G = 0.05$.

across the two markets. It can thus be shown that $t^* < t^{b*}$, indicating that compared with the benchmark two-sided market, OFD platforms are less likely to subsidize consumer participation. In additional contrast, though, we also find that $\beta^* > \beta^{b*}$ so that restaurants are more likely to be subsidized in the OFD market than in the benchmark two-sided market. Figure 4 illustrates the subsidizing conditions.

In addition to impacts on platform pricing strategies and subsidizing conditions, the OFD market also displays nontrivial implications of platform profits, as summarized below.

PROPOSITION 2. *In the OFD market, the equilibrium platform profits increase in the consumer-side network effect, that is,* $\dfrac{\partial \Pi_i^*}{\partial \alpha} > 0$ *if and only if* $\alpha < \tilde{\alpha}$*; increase in the restaurant-side network effect, that is,* $\dfrac{\partial \Pi_i^*}{\partial \beta} > 0$ *if and only if* $\beta < \tilde{\beta}$*, where*

$$\tilde{\alpha} = \frac{2G^2\sigma^3[2c\gamma\sigma^2(1+\phi) - 3\beta\delta(2+\phi^2)] + c^2G\delta\sigma^2[2\beta\sigma(5+2\phi) - c\gamma\sigma^2] - c^4\beta\sigma^4}{2G\delta^2[G\delta^2(2+\phi)^2 - c^2\sigma^2]},$$

$$\tilde{\beta} = \frac{2G^2\sigma^3[2c\gamma\sigma^2(1+\phi) - 3\alpha\delta(2+\phi^2)] + c^2G\delta\sigma^2[2\alpha\sigma(5+2\phi) - c\gamma\sigma^2] - c^4\alpha\sigma^4}{2G\delta^2[G\delta^2(2+\phi)^2 - c^2\sigma^2]}.$$

Proposition 2 suggests that platform profits increase in the network effects when they are moderate, an interesting result highlighting one of the distinctions between the benchmark and the OFD market. We know from Lemma 1 that platform profits tend to be reduced by cross-side

Figure 5   **Impact of Network Effects on Profits in OFD Markets**
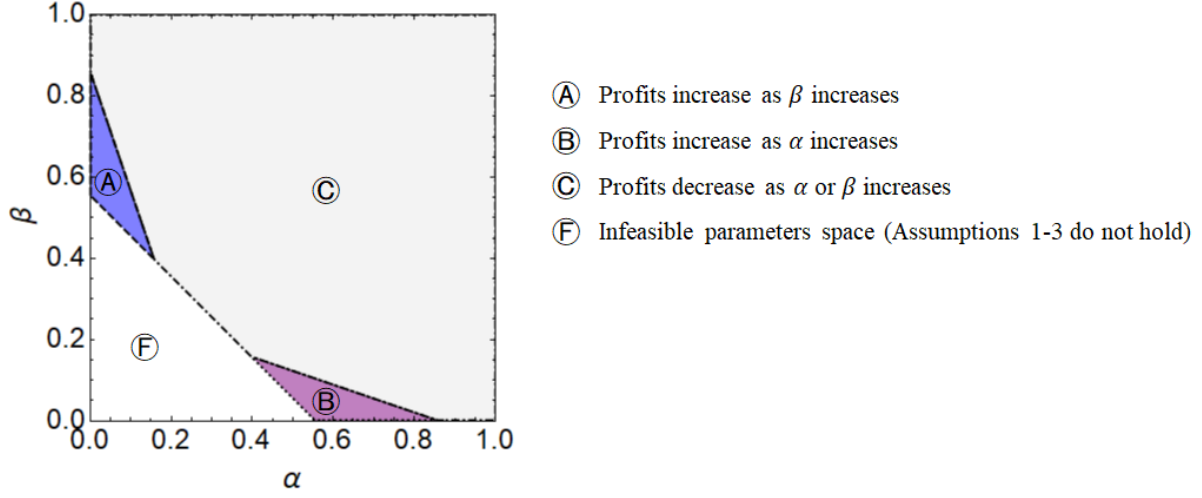
Notes. $\delta = \phi = c = \gamma = 2.5$, $\sigma = t = 1$, and $G = 5$.

network effects because of intensified pressure to induce participation. There then exists an incentive for platforms in a two-sided market to find ways to mitigate such network effects (Armstrong 2006). According to Proposition 2, however, platform profits do not always decrease in the network effects in the OFD market. If the network effects are not sizable, then OFD platforms can actually benefit from stronger cross-group externalities. This is because when the network effect becomes stronger on either the consumer or restaurant side, OFD platforms can strategically adjust the service quality level. In this way, the platforms can re-balance the profits between the two sides, as it can be shown that the equilibrium service quality level of each platform decreases in the network effects (i.e., $\frac{\partial s_i^*}{\partial \alpha} < 0$ and $\frac{\partial s_i^*}{\partial \beta} < 0$). Therefore, by lowering the service quality level, OFD platforms can mitigate the negative impacts of network effects to a certain extent. Figure 5 illustrates such a unique phenomenon in the three-sided OFD market.

COROLLARY 3. *Platform profits are lower in the OFD market than in the benchmark two-sided market, that is, $\Pi_i^* < \Pi_i^{b*}$.*

Despite the alleviated negative impacts of network effects in the OFD market, platforms still earn lower profits, compared to their two-sided counterparts, an interesting result considering the fact that the price increase on the consumer side is larger than the price decrease on the restaurant

side, that is, $p_{c,i}^* - p_{c,i}^{b*} > p_{r,i}^{b*} - p_{r,i}^*$. In fact, the revenue from the consumer-restaurant market alone is higher in the OFD market than in the benchmark two-sided market. Such benefit is nevertheless outweighed by the cost of acquiring gig drivers, resulting in a net loss for the OFD platforms. Overall, Corollary 3 implies that although the existence of the gig labor market alleviates the negative impacts of the network effects on platform profits, it opens up a new dimension of platform competition, the cost of which overshadows the benefit, making the OFD platforms worse off. Such a result indicates that additional leverage for competing platforms may not always be beneficial because it could lead to a prisoner's dilemma, as shown in Dou and Wu (2021).

Next, to gain further insights into the fast-evolving OFD market, we examine the impact of changes in key parameters that characterize the market environment of OFD platforms. To begin with, we look at how consumers' benefit from better service affects platforms' strategic choices and equilibrium outcomes.

PROPOSITION 3. *The impact of a change in the consumer benefit per service quality level γ on the equilibrium results is summarized as follows:*

    (i) The service quality s_i^* increases in γ.

    (ii) The consumer price $p_{c,i}^*$ increases in γ.

    (iii) The restaurant price $p_{r,i}^*$ decreases in γ.

    (iv) The number of participating restaurants $N_{r,i}$ decreases in γ.

Proposition 3(i) suggests that if the consumer benefit per service quality level γ is higher, the platforms will increase their service quality level in the equilibrium. This result is in line with our expectations because if consumers place value on high-quality service, the platforms should try to respond to consumer needs by improving service quality for a better overall experience. Doing so also allows platforms to extract more surplus from consumers in terms of the price $p_{c,i}^*$ (Proposition 3(ii)). This better service, however, comes at a cost on the restaurant side in terms of their willingness to participate on the platform. Recall that partner restaurants incur additional costs in meeting the platform's service requirements, making it more difficult for the restaurants

to remain strategically aligned with these requirements as service quality increases. As a result, the platforms have to lower the entry barrier by reducing the price paid by restaurants to join the platform $p_{r,i}^*$ (Proposition 3(iii)). Despite this effort by the platforms, the disutility incurred by the restaurants cannot be fully compensated by the lower price, leading to a shrinking restaurant base $N_{r,i}$ (Proposition 3(iv)). Taken together, Proposition 3 implies that if consumers are more sensitive to service quality, platforms become pickier on the restaurant side, shifting the marketplaces towards the consumer side.

PROPOSITION 4. *The impact of a change in the restaurant variable participation cost c on the equilibrium results is summarized as follows:*

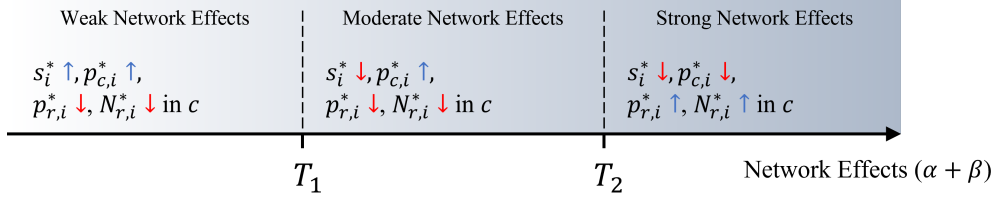*(i) The service quality s_i^* increases in c if and only if $\alpha + \beta < T_1$.*

(ii) The consumer price $p_{c,i}^*$ increases in c if and only if $\alpha + \beta < T_2$.

(iii) The restaurant price $p_{r,i}^*$ decreases in c if and only if $\alpha + \beta < T_2$.

(iv) The number of participating restaurants $N_{r,i}$ decreases in c if and only if $\alpha + \beta < T_2$,

where $T_1 = \dfrac{4cG\gamma\delta\sigma^2}{2G\delta^2(2+\phi)+c^2\sigma^2}$ and $T_2 = \dfrac{G\gamma\delta}{c} + \dfrac{c\gamma\sigma^2}{4\delta+2\delta\phi} > T_1$.

Restaurants are a key player in the OFD market, and the business environment they face can vary dramatically over time. Here we investigate how the platforms would optimally respond to a change in the restaurant cost factor. Regarding the choice of the service quality level, one might intuitively expect that when the restaurant variable participation cost c increases, the platforms would lower the service quality so as to alleviate the stringent requirement on restaurants. However, Proposition 4(i) shows this statement is not always the case. In particular, when the network effects are weak (i.e., $\alpha + \beta < T_1$), the platforms choose to increase service quality rather than decrease it. The reason for this counter-intuitive result is that in a market with weak network effects, consumer utility from participation is dominated by service quality (represented by γ), as opposed to the value of the food or selection of participating restaurants. In such case, when c increases, its negative impact on restaurants' participation and further on the consumers' utility is limited, while a higher service quality level greatly improves the consumer experience. Given that, platforms are able to

Figure 6   Impact of Restaurant Variable Participating Cost c

Weak Network Effects	Moderate Network Effects	Strong Network Effects
$s_i^*\uparrow, p_{c,i}^*\uparrow,$ $p_{r,i}^*\downarrow, N_{r,i}^*\downarrow$ in c	$s_i^*\downarrow, p_{c,i}^*\uparrow,$ $p_{r,i}^*\downarrow, N_{r,i}^*\downarrow$ in c	$s_i^*\downarrow, p_{c,i}^*\downarrow,$ $p_{r,i}^*\uparrow, N_{r,i}^*\uparrow$ in c

T_1 T_2 Network Effects $(\alpha+\beta)$

remain appealing to consumers by increasing the service quality level. At the same time by stabilizing the consumer base, this approach mitigates the restaurants' loss of willingness to participate due to an increase in the variable participation cost c.

Parts (ii) and (iii) highlight the platforms' adjustments on pricing strategies. In particular, if the network effects are not too strong (i.e., $\alpha+\beta < T_2$), as the restaurant variable participation cost increases, the platforms choose to increase the consumer price but decrease the restaurant price. The reason for this result is that under weak network effects, consumer participation would not dramatically affect the restaurants' utility, and vice versa. In that sense, when the restaurant variable participation cost increases, the platforms do not have to worry much about the cross-side impact on the consumer market caused by the reduction of restaurants' willingness to participate. Instead, they are more concerned about the direct impact on the restaurant market. Therefore, the platforms choose to lower their price of participation in order to encourage more restaurant partnerships, but at the same time extract more surplus from the consumer side to recover the loss of revenue on the restaurant side. Conversely, if the network effects are strong enough (i.e., $\alpha+\beta > T_2$), platforms are better off encouraging restaurant participation through an indirect mechanism rather than a direct one. As the restaurants can substantially benefit from consumer participation under strong network effects, the platforms can easily compensate the restaurants for an increase in c by inducing more consumers. It is thus in the platforms' best interests to lower the consumer price to mitigate the negative impact of higher c, and then receive subsequent compensation from the restaurant side.

Part (iv) shows how the number of participating restaurants changes with respect to the difficulty of complying with the platforms' service requirements. When the network effects are moderate, the direct impact dominates the cross-side impact, which, combined with the platforms' pricing

strategy, leads to a reduction in restaurant participation. In contrast, when the network effects are strong enough, the cross-side impact dominates the direct impact, in which case there will be more restaurants operating on the platforms.

Overall, by comparing (i) with (ii) - (iv), we find that as the restaurant variable participation cost increases, the platforms do not necessarily increase their service quality level, but if they do they always choose a pricing strategy that favors the restaurants. Similarly, as the restaurant variable participation cost decreases, the platforms do not have to lower their service quality level, but if they do then they always choose a pricing strategy that favors consumers. Our study further extends the scope of research beyond consumers and restaurants to consider the dynamics of the gig labor market that plays such a unique facilitating role in OFD services. We accordingly analyze the implication of delivery market competition as follows.

PROPOSITION 5. *The impacts of a change in the delivery substitutability index ϕ on the equilibrium results are summarized as follows:*

(i) The service quality s_i^* decreases in ϕ.

(ii) The consumer price $p_{c,i}^*$ decreases in ϕ.

(iii) The restaurant price $p_{r,i}^*$ increases in ϕ.

(iv) The number of participating restaurants $N_{r,i}$ increases in ϕ.

Recall that delivery substitutability measures the competition in the gig drivers' labor market. If ϕ is high, it will be more difficult for the platforms to acquire gig drivers, therefore limiting their ability to increase service quality. As a result, the service quality in the equilibrium decreases when the competition in the delivery labor market becomes intense. Meanwhile, lower service quality reduces the utility consumers enjoy from making use of the platforms. In that case, the platforms can no longer extract the same level of surplus from consumers, compared to a less competitive delivery labor market, resulting in a decrease in the consumer price. The restaurants, for their part, become relatively relaxed in coordination with the platforms as delivery labor creates a bottleneck to improving the service quality. The requirement to improve their core logistics becomes less stringent

and their entry barrier tends to decrease, leading to more restaurants willing to participate on platforms, who are also able to charge a higher restaurant price. Based on the results above, we investigate the implications of market dynamics on the profits of the OFD platforms in the following proposition.

PROPOSITION 6. *The impacts of a change in γ, c, and ϕ on the platform profits Π_i^* are summarized as follows:*

(i) The platform profits decrease in γ.

(ii) The platform profits increase in c if and only if $\alpha + \beta > \dfrac{c\gamma\sigma^2[2G\delta^2(2+3\phi) - c^2\sigma^2]}{4G\delta^3(1+\phi)(2+\phi) - 2c^2\delta\sigma^2} := T_3$.

(iii) The platform profits increase in ϕ.

Proposition 6 shows several additional counter-intuitive results, beginning in part (i), which reveals that an increase in consumer benefit per service quality level γ will actually reduce platform profits. As discussed in Proposition 3, when γ increases, the platforms increase service quality and charge more on the consumer side. Higher service quality also imposes additional requirements or costs on restaurants, however, reducing their willingness to participate and consequently the platforms' revenue from the restaurant side, while the platforms incur higher wage costs in acquiring gig drivers. Because the disutility incurred by the restaurants and the cost of the driver-side wage war cannot be fully compensated by the additional gains from the consumer side, the total profits decrease.

Then, part (ii) shows that the platforms can benefit from a higher restaurant variable participation cost when the network effects are strong. Intuitively, one might think the platform profits would decrease with more stringent service requirements because they can reduce the restaurants' willingness to participate. However, as suggested by Proposition 4, the platforms are capable of adopting the pricing strategy that shifts the profitability burden from one side to another, lowering the price for one side and increasing it for the other, allowing the platforms to flexibly mitigate the negative impact of a higher c. Note that this approach is only feasible when the network effects are strong, and the cross-side impact dominates the direct impact in the multi-sided market. Otherwise,

Table 2   **Impact of Market Parameters on Equilibrium Results**

Parameters	Conditions on Network Effects $(\alpha + \beta)$	Decision Variables			Profits
		s_i^*	$p_{c,i}^*$	$p_{r,i}^*$	Π_i^*
γ: consumer benefit per service quality		$\uparrow$	$\uparrow$	$\downarrow$	$\downarrow$
ϕ: gig drivers substitutability		$\downarrow$	$\downarrow$	$\uparrow$	$\uparrow$
	weak	$\uparrow$	$\uparrow$	$\downarrow$	$\downarrow$
c: restaurant variable participation cost	moderate	$\downarrow$	$\uparrow$	$\downarrow$	$\uparrow$ iff $\alpha + \beta > T_3$
	strong	$\downarrow$	$\downarrow$	$\uparrow$	$\uparrow$

Notes. Weak, moderate, and strong $\alpha + \beta$ indicate the parameter space where $\alpha + \beta < min[T_1, T_2, T_3]$, $min[T_1, T_2, T_3]$ $\leq \alpha + \beta < max[T_1, T_2, T_3]$, and $max[T_1, T_2, T_3] \leq \alpha + \beta$, respectively.

the decrease in restaurants' willingness to participate, based on the increased variable participation cost, cannot be fully compensated even by such profitability shift strategy.

Lastly, part (iii) shows that the platforms can be better off when the delivery labor market becomes more competitive. As discussed in Proposition 5, a higher value of the delivery substitutability ϕ lowers the service quality level s_i, softening the wage competition between the platforms in acquiring gig labor to improve service. Although this in turn lowers the consumer price $p_{c,i}$ and platform revenue from the consumer side, the loss is fully compensated as the restaurant price $p_{r,i}$ and the number of participating restaurants both increase in the delivery substitutability (Proposition 5). In this way, platforms can shift their focus to profitability on the restaurant side and avoid a wage war in the delivery labor market. Overall, the benefits fully cover the loss of differentiation and the platforms end up enriched.

5.   Model Extensions

In this section, we consider several model extensions to examine the robustness of our results and to gain further insights under alternative model assumptions.

5.1.   Regulated Delivery Market

One unique feature of the gig economy is that workers are generally considered independent contractors rather than full-time employees, and are thus denied the basic protection of labor laws like minimum wage and overtime pay that apply to any other regular employees, even in temporary or seasonal positions. Criticized by many advocates as a form of labor discrimination, these practices

embraced by the world's largest ride-sharing and product delivery companies have led to legal battles regarding the status and entitlements of gig workers. The public sector has responded with an effort to better regulate labor practices in the gig economy to protect workers' rights and improve social welfare. In one successful measure, California legislators passed a bill to provide wage and benefits protection to gig workers (CBS News 2019), with similar legislative efforts made by other states and countries (Shur 2019, Spiggle 2021). Our study thus aims to offer novel societal insights to these policymakers.

In this section, we examine an extended model where the delivery market is regulated by public authorities. Specifically, we consider a scenario in which a social planner, in order to protect the interest of gig drivers, sets a minimum wage rate $\underline{w}$. By such regulation, the wages paid by the platforms operating in the delivery market must be higher than or equal to the minimum wage rate (i.e., $w_i \geq \underline{w}$, $\forall i \in \{1, 2\}$). We are interested in how the minimum wage policy would affect platform choice regarding the service quality level and whether consumers would benefit or lose out with such regulation.

LEMMA 3. *In an OFD market with a minimum wage rate, $\underline{w}$, the equilibrium price and service quality chosen by each platform are given by*

$$\text{If } \underline{w} < \frac{\delta\sigma(1+\phi)[2G\gamma\delta - c(\alpha+\beta)]}{2G\delta^2(2+\phi) - c^2\sigma^2} \quad,$$

$$p_{c,i}^{m*} = t - \frac{\beta[G(3\alpha+\beta)\delta^2(2+\phi) - c\sigma^2(c\alpha+G\gamma\delta)]}{2G[2G\delta^2(2+\phi) - c^2\sigma^2]} \quad,$$

$$p_{r,i}^{m*} = \frac{c^2\alpha\sigma^2 - G\delta[c\gamma\sigma^2 + (\alpha-\beta)\delta(2+\phi)]}{4G\delta^2(2+\phi) - 2c^2\sigma^2} \quad,$$

$$s_i^{m*} = \frac{\delta\sigma^2[2G\gamma\delta - c(\alpha+\beta)]}{4G\delta^2(2+\phi) - 2c^2\sigma^2} \quad.$$

otherwise

$$p_{c,i}^{m*} = \frac{\dfrac{\beta[(3\alpha+\beta)\delta(1+\phi) - c\underline{w}\sigma]}{G\delta} - \dfrac{4(t+\underline{w}^2 - t\phi^2)}{1-\phi}}{4(1+\phi)} \quad,$$

$$p_{r,i}^{m*} = \frac{1}{4}\left(\beta - \alpha - \frac{c\underline{w}\sigma}{\delta(1+\phi)}\right) \quad,$$

$$s_i^{m*} = \frac{\underline{w}\sigma}{2(1+\phi)} \quad.$$

According to Lemma 3, if the minimum wage rate is not too high, the optimal prices and service quality remain the same as the baseline model. Intuitively, in such case, the platforms are willing to pay gig drivers at a wage rate higher than the minimum. As a result, the wage constraint is not binding. Yet, if minimum wage goes beyond a threshold value and the cost of acquiring gig labor increases, each platform will still choose to increase its service quality level so as to remain competitive against its rival. Meanwhile, OFD platforms will increase the consumer price but reduce the restaurant join-in price, following a similar rationale as competition in the gig labor market is softened by the minimum wage policy.

Besides the direct impact of minimum wage on the platform pricing and service quality decision, we are also interested in how various other parties are affected by such regulation. So, we examine the implications of the minimum wage policy on consumers, platforms, and society as a whole, focusing on the nontrivial equilibrium where the wage constraint is binding.

PROPOSITION 7. *Compared with the baseline model, the implications of the minimum wage policy are as follows:*

(i) Consumer surplus is lower.

(ii) Platform profits are higher.

(iii) Social welfare is higher or lower depending on various factors, so that when $\phi \leq \phi_{\underline{\omega}}$,

the social welfare is higher if and only if $\alpha + \beta < T_4$ or $\underline{\omega} > \underline{\omega}_1$; when $\phi > \phi_{\underline{\omega}}$, the social welfare

is higher if and only if $\alpha + \beta < T_4$ and $\underline{\omega} < \underline{\omega}_1$, where

$$\phi_{\underline{w}} = \frac{3c^2\sigma^2}{4G\delta^2} - 1 \ ,$$
$$T_4 = \frac{\gamma(4G\delta^2 + c^2\sigma^2)}{c\delta(4+\phi)} \ ,$$
$$\underline{w}_1 = \frac{\delta\sigma(1+\phi)[3c^3(\alpha+\beta)\sigma^2 - 2c^2G\gamma\delta\sigma^2 + 8G^2\gamma\delta^3(3+\phi) - 4cG(\alpha+\beta)\delta^2(5+2\phi)]}{[4G\delta^2(1+\phi) - 3c^2\sigma^2][2G\delta^2(2+\phi) - c^2\sigma^2]} \ .$$

Part (i) of Proposition 7 shows that consumers are worse off when the minimum wage policy is in effect. This is because although these consumers derive additional utility from higher service quality levels, they must also pay a higher price to participate in an OFD platform. The platforms,

Figure 7   **Impact of Minimum Wage Policy on Social Welfare**

(a) $\alpha + \beta < T_4$ (b) $\alpha + \beta > T_4$
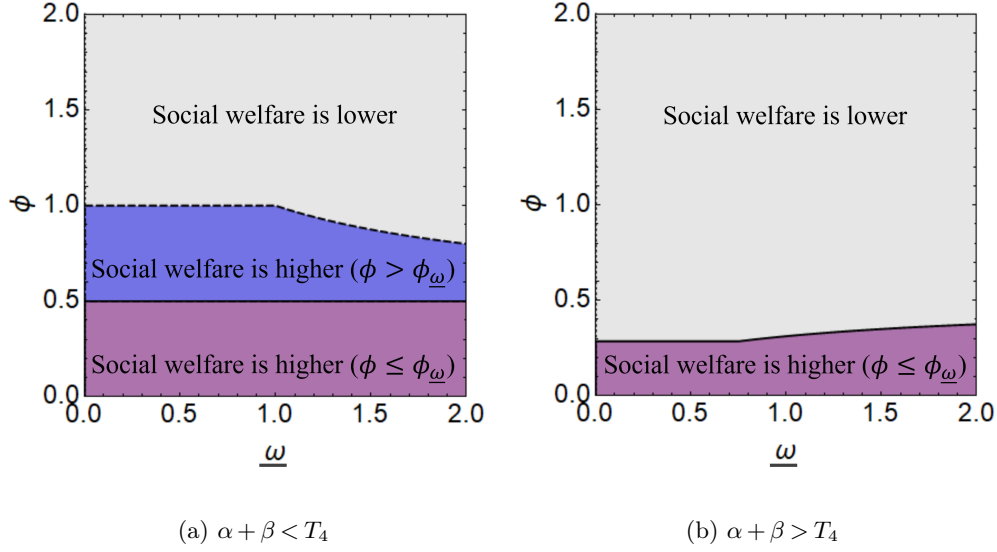
Notes. $\delta = \sigma = c = \alpha = 1$, $t = 2$, $\gamma = 2.5$, and $G = 0.5$. $\beta = 0.5$ for (a) and $\beta = 0.75$ for (b).

as a result, are able to extract more surplus from consumers, who come out on the losing end. Interestingly, as suggested by part (ii) of the proposition, OFD platforms are better off when they are forced to pay gig drivers a higher wage. The reason for such a counter-intuitive result is that the minimum wage policy lessens platform competition in the gig labor market, boosting the overall service quality and indirectly softening platform competition in the consumer market. Platforms are then able to charge consumers higher prices and thus enjoy higher profits. We find further that society is not necessarily better off with the minimum wage policy, despite the higher quality service for consumers and improved surplus for gig drivers. The main reason for this finding is that the benefits achieved from the minimum wage policy come at the expense of discouraging restaurant participation, resulting in lower consumer surplus. If those costs cannot be fully compensated by the benefits, social welfare is going to take a loss due to the minimum wage policy. Our findings suggest that although the minimum wage policy can benefit gig drivers as intended, a social planner would need to carefully evaluate potential implications because it can significantly cost the other two parties involved in the market, thus hurting the overall social welfare. Figure 7 illustrates the minimum wage policy's impact on social welfare.

5.2. Consumer Same-side Negative Network Externality

In the baseline model, we assume that consumer utility derived from joining a platform is higher if there are more restaurants participating on it, or if it provides services with higher quality. In an OFD market, though, the same consumer's utility may be reduced if there are too many other consumers on the same platform, which could lead to long delays or deteriorated services. So, in this section, we would like to examine how consumers' same-side negative externality affects the equilibrium outcomes. We use $\rho \cdot N_{c,i}$ to denote consumer disutility from joining platform i with the expected number of participating consumers being $N_{c,i}$. The net utility that consumer x derives from joining each platform $U_{c,i}(x)$ becomes:

$$U_{c,1}(x) = v + \alpha N_{r,1} - \rho N_{c,1} + \gamma s_1 - p_{c,1} - tx ,$$

$$U_{c,2}(x) = v + \alpha N_{r,2} - \rho N_{c,2} + \gamma s_2 - p_{c,2} - t(1-x) .$$

Ceteris paribus, we obtain the equilibrium prices and service quality levels. While our main results remain qualitatively the same, we find another interesting result.

PROPOSITION 8. *Platform profits increase with consumer same side negative externality,* $\dfrac{\partial \Pi_i^*}{\partial \rho} > 0.$

Intuitively, one might expect platforms to be hurt by this negative consumer utility, yet Proposition 8 suggests the exact opposite result, in that platforms actually benefit from consumer same-side negative network externality. We find that in an OFD market where platforms compete for consumers, the presence of the negative externality strengthens platform differentiation, enabling each platform to charge a higher consumer price, as it can be verified that $\dfrac{\partial p_i^*}{\partial \rho} > 0$. Therefore, although the same-side negative externality reduces consumers' utility derived from participation, OFD platforms could leverage such effect to further differentiate from their rivals and consequently benefit from it.

5.3. Commission-based Restaurant Price

In the baseline model, we assume that each platform charges restaurants a lump-sum price for participation. In reality, though, OFD platforms can also charge them commission-based fees for

every order placed, and so in this section, we investigate the implications of the commission charges. We denote the average commission fee of participating restaurants as λ. For the tractability of the model, we assume λ to be exogenous and the same across the two platforms. Analysis suggests that our main results still hold for any given $\lambda \in (0,1)$, indicating the robustness of our findings. In addition, we have the following proposition.

PROPOSITION 9. *The equilibrium consumer price increases in the commission fee if and only if* $\beta < \alpha + 2\lambda + \dfrac{c[G\gamma\delta - c(\alpha + 2\lambda)]\sigma^2}{2G\delta^2(2+\phi)}.$

Interestingly, the equilibrium consumer price is not monotonic in the commission fee. In one regard, an increase in commission charges discourages restaurant participation, motivating each platform to lower their respective consumer price to boost sales and indirectly compensate for the losses incurred from the resulting drop in restaurant partnerships. Nevertheless, higher commission charges also weaken the network benefits on the restaurant side because the increased revenue from greater consumer activity is eroded by the per-transaction payment. With the cross-side externality being lessened, each platform loses the incentive to lower consumer prices. Overall, whether the equilibrium consumer price will increase or decrease with respect to the commission fee depends on the relative strength of β and λ.

6. Discussions and Conclusions

The rise of the sharing economy has stimulated the transformation of digital platforms that have not yet been comprehensively addressed in the literature. In this paper, we seek to fill a gap by exploring the pricing and service strategies of online food delivery platforms in a three-sided market. We provide an analytical framework that focuses on the key trade-offs: on one hand, OFD platforms aim to provide better quality service that satisfies consumers' increasing desire for a premium experience. On the other hand, such practices incur additional costs to business partners and demand extra gig labor. We demonstrate that the strength of network effects is crucial to OFD platforms' incentives to leverage the three-sidedness of the marketplace, filling a gap in the research where the conventional wisdom about two-sided markets does not fully apply. In doing so, we offer solutions as to how

platforms should respond to changes in a rapidly evolving food delivery market. Our results provide a set of actionable managerial implications for the OFD platforms, participating stakeholders, and regulatory authorities.

6.1. Managerial and Policy Implications

Our analysis reveals a novel approach for OFD platform competition on service facilitated by gig labor in a market where consumers value service quality besides the variety of restaurant selections. Instead of treating delivery as a standard service that provides consumers only basic value, OFD platforms could launch premium programs targeting certain high-end markets where consumers are less price sensitive towards a premium service experience. In the two-sided ride-hailing market, for example, Uber provides premium options in its Uber Black service, offering luxury ride experiences at extra cost. Our study suggests a similar idea can be applied to the OFD market with platforms leveraging market three-sidedness. As the designation "premium" now applies to food and delivery service quality, a simultaneous adjustment of the three sides of the market is needed. In response, our model prescribes the optimal strategies for OFD platforms operating in such markets.

Our findings further suggest that the restaurants' participation cost in the OFD market plays a key role in driving the platforms' equilibrium decisions and outcomes. In this regard, the recent and dramatic changes in the business environment for restaurants may bring new challenges and opportunities to OFD platforms. For example, pandemic-related restrictions have, to some extent, led to a food delivery boom. However, facing labor shortages and the return of on-site dining customers, restaurants may choose to scale back on delivery orders which are often generally less profitable (Haddon and Rana 2021), posing a challenge to OFD platforms around how to induce restaurant participation. Meanwhile, the demand for delivery-only kitchens has also skyrocketed amid the lockdown, led by pioneers such as REEF Technology, which uses parking lots as service sites. (Guszkowski 2021). These so-called "ghost" or "dark" kitchens produce delivery orders but are attached to no physical restaurant or storefront, allowing them to cut down on labor and real estate costs while better integrating with OFD platforms. Our results provide useful guidelines to deal with

these challenges and opportunities, which are not straightforward given their critical dependence on market characteristics.

Conventional wisdom suggests that differentiation is generally beneficial to firms, and many OFD platforms have indeed introduced incentive programs to the gig labor market to increase the supply of drivers (Gridwise 2021). Yet surprisingly, our analysis shows that such practices could unintentionally hurt OFD platforms due to intensified competition on service offerings. So, unless the OFD space can keep up its explosive growth, platforms might want to more carefully justify aggressive incentive programs that cost millions of dollars to operate.

Lastly, from a policymaker's perspective, it is worth noting that although a minimum wage can provide certain employment protections to gig drivers, such benefits come at the cost of consumer surplus. Interestingly, while OFD platforms could welcome the enforcement of a minimum wage in the gig labor market, society as a whole might be burdened by the policy. Policymakers would have to carefully weigh the potential effects of the minimum wage policy before intervening in the three-sided OFD market.

6.2. Future Research Directions

We conclude this study by pointing out some directions for future research. Given that we examine just how restaurants participate on three-sided OFD platforms, future research can examine restaurants' strategic decisions at a more detailed level. To look at one example, OFD platforms such as DoorDash provide a platform (DoorDash Merchant) on which restaurants can make strategic choices about pricing and types of food to sell (Li and Wang 2020). Because such an extension analysis would be technically challenging given the number of decision-making problems in the current model, however, we leave it to future research. We also focus on service quality as a metric on which OFD platforms compete, so it would be worthwhile to study a model that incorporates other types of non-pricing controls, such as how Uber Eats can import external user traffic from their existing Uber user base and implement a piggybacking strategy. There is in fact a growing number of studies on piggybacking in two-sided platforms (Dou and Wu 2021), so future research can extend this stream of literature by examining such strategy in three-sided markets. Furthermore, our model

assumes the linear impact of service quality level on the restaurants and the gig workers. Future research can extend our work by examining some alternatives. While our baseline model focuses on a fixed fee payment model in the consumer-restaurant market, it might be worth looking into the implications of other pricing schemes in the future. Finally, our findings generate testable hypotheses that could be of great interest to both academics and practitioners, the empirical validation of which would also add a meaningful contribution.

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