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Pricing and quality strategies for an on-demand housekeeping platform with customer-intensive services

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Abstract

In this paper, we study an on-demand housekeeping platform in which suppliers have heterogeneous opportunity costs, and customers are sensitive to service quality, price, and waiting time. The platform charges fees from customers and divides revenue with service suppliers in a certain proportion. We analyze two types of market coverage, namely full market coverage and partial market coverage. We find that as the potential demand market capacity expands, the platform will choose to lower prices to attract more customers and service suppliers until it reaches the partial market, thereby obtaining higher revenue, and suppliers will provide lower quality services to serve more customers and thus obtain more wages. Moreover, we show that the partial market is more favorable to the platform than the full market. However, for service suppliers, the partial market is not always more favorable. Meanwhile, as customers are more sensitive to the service value, suppliers will tend to lower their service rates to improve service quality, and the platform will tend to set higher service prices. Interestingly, we observe that when the sensitivity of service value is relatively small, the sensitivity of service value has even the opposite effect on the platform's revenue and service suppliers' payoffs, as well as the equilibrium number of service suppliers in different market scenarios. In addition, different market scenarios also will lead to the opposite effect of the service cost on the optimal equilibrium price, arrival rate, and service rate. However, the increase in the service cost will lead to a decrease in platform revenue and service supplier payoffs and the number of service suppliers in both market scenarios.

Keywords: On-demand service, Housekeeping platform, Customer-intensive, Market capacity, Pricing and quality

1. Introduction

With the accelerating pace of life, the demand of modern urban residents for professional housekeeping services is increasing. Offline agents usually provide conventional housekeeping services, and customers often rely on face-to-face or telephone requests for services, which makes it very inconvenient to choose the appropriate supplier and information communication. Conventional housekeeping systems are becoming more challenging to meet customers' needs. However, on-demand housekeeping service platforms can well address this drawback to better match supply and demand as well as improve service quality and service satisfaction. In particular, during the coronavirus (COVID-19/SARS-CoV-2) outbreak, the on-demand housekeeping platform will ensure that customers receive timely service and can be more conveniently match the appropriate supplier (Choi, 2020). According to the National Technology Readiness Survey (NTRS) by Rockbridge Associates, the number of participants in the on-demand economy

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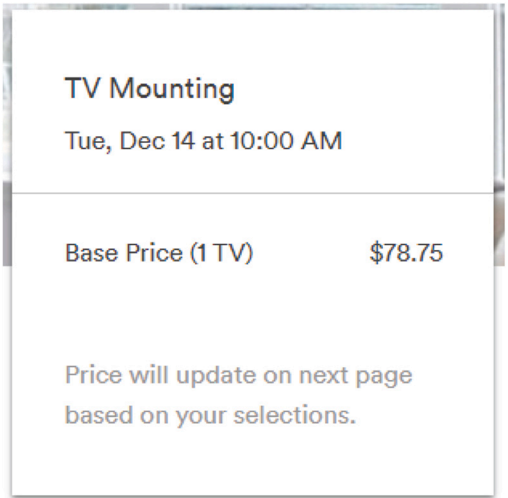

Fig. 1. TV mounting service charged by per-service on Handy.

has nearly tripled since 2016, with about 64.8 million consumers purchasing on-demand products or services in 2019 (compared to 24.9 million in 2016).[1] Similar to other on-demand platforms, such as ride-hailing (Didi, Uber), delivery services (Meituan, Doordash), healthcare services (ChunYu Doctor, Amwell), the on-demand housekeeping platforms have emerged and developed rapidly due to the existing problems in the conventional housekeeping service system, examples include Daoway, 58 daojia in China and Care.com, Handy in the U.S. NTRS estimated that total expenditure on the on-demand housekeeping services reached up to $15.1 billion in 2019 (compared to $12.8 billion in 2018), which accounts for 13.6% of expenditure for on-demand products and services.

The on-demand housekeeping platform's services can be divided into two categories. One is charged by the per-service price (e.g., neonatal care missionary, Tuina, personal care (such as hairdressing, beauty care, and cosmetics), and air conditioning cleaning), and the other is charged by the per-unit time price (e.g., home cleaning). For the first service category, the customers only need to pay a fixed service fee, which is not related to the service time (see Fig. 1). Hence, longer service time will not bring additional fees but will guarantee a more meticulous service or a higher quality of service that the customer can perceive. When there is an interaction between service speed and service quality, that is, the service speed chosen by service suppliers will affect the service quality perceived by customers, such services are defined as customer-intensive services (Anand et al., 2011; Liu et al., 2018; Ni et al., 2013). For this type of service (or customer-intensive service), the longer the service time, the higher the service quality perceived by the customers. For example, for the neonatal care missionary service in Daoway App, after the customer selects the supplier online and pays a fixed fee to the platform, the service supplier provides the customer with services such as newborn bathing, skincare, and standard newborn disease prevention courses. For this service, the service fee is fixed, and usually, the longer the service time, the higher the quality of service the customer perceives. Because the longer the service supplier's service, the more careful they can care for the newborn and the more knowledge and precautions they can provide about the newborn. However, longer service time will improve the perceived quality of service and increase the average waiting time for other customers. Therefore, service suppliers need to make service rate decisions to achieve an optimal "quality-speed trade-off". For the second service category, the customers need to pay for the service time, which is similar to the mileage-based charging of the transportation industry. This paper focuses on the first category of services (i.e., per-service price).

These on-demand housekeeping service platforms (e.g., Daoway, Handy, Care.com, and TaskRabbit) match the individual housekeeping suppliers (hereinafter referred to as she/her) and the customers (hereinafter referred to as he/his) in fast and efficient online services. The service suppliers on the platform will accept professional training, such as service awareness, service specifications, and skills (e.g., Care.com).[2] They are mutually independent but compete with each other to provide housekeeping services. For the services charged by a per-service price (e.g., neonatal care missionary), each supplier makes participation and service rate decisions based on individual payoff maximization. In addition, these platforms usually allow customers to choose suppliers as they wish and even write down their comments about the service quality. Customers can observe the service price and evaluate the service value based on the supplier's service rate or other customer reviews, thereby selecting a supplier accordingly. For example, Care.com points out that they show customers information about the service supplier they search for, including bio, work history and reviews, their experience, certifications and qualifications, and availability.[3] For service suppliers, their earnings

[1] https://rockresearch.com/on-demand-economy-research/.
[2] https://www.annualreports.com/Company/carecom-inc (p. 4).
[3] https://www.annualreports.com/Company/carecom-inc (p. 7).

depend on the service price and service rate. Although service suppliers can increase earnings by improving the service rate, it also leads to lower customer perceived service value, affecting the customer's supplier choice. Also, lower service rates enable customers to perceive higher service value but increase waiting time. These factors will ultimately determine the number of suppliers who provide services and the number of customers who finally choose the housekeeping services on the platform. Hence, to meet the customer's service requirement and keep the suppliers' earnings, an on-demand housekeeping platform should consider matching the independent service suppliers with the customers as efficiently as possible.

As these on-demand housekeeping service platforms flourish, they face operational challenges such as pricing strategies and matching supply–demand. In particular, when a platform grows rapidly, it will experience changes in the size of the customer base. It remains an open question, then, how platforms should respond to this change when the number of customer groups is at a different stage than service provision capacity. Based on different potential supply and demand states, the equilibrium can be divided into two types of market coverage. One is the partial market, where the potential demand is so massive that the price decision of the platform and the service rate decision of suppliers are not affected by the customer demand. This means that each participating supplier is essentially a local monopolist. The other is the full market, where the potential customer demand will affect the optimal decisions of the platform and suppliers, and suppliers need to compete fiercely to get customers. How different market coverage scenarios affect the pricing strategies of on-demand housekeeping service platforms and the service quality strategies of suppliers still needs to be answered. While on-demand service platforms have been rapidly growing, most existing studies focus on ride-hailing and delivery. Existing works have not yet investigated the pricing and quality competition of an on-demand housekeeping platform to the best of our knowledge.

Motivated by the above business practices and research gaps, the following questions will be explored: (1) How should housekeeping service platforms strategically choose its pricing to respond to independent suppliers and customers? (2) How do different supply–demand relationships (i.e., partial market and full market) affect platform and suppliers decisions? (3) What is the impact of different supply and demand relationships on the payoffs of all parties (platform, suppliers, and customers) and social welfare?

To answer the above questions, we introduce an analytical framework to examine how an on-demand housekeeping platform (and supplier) should set its service price (quality strategy) to match the individual customers and suppliers better. The customers arrive randomly according to the Poisson process, and the service process is based on the $M/M/1$ queuing model. The platform sets the service price for the customers, and customers join the platform and choose the service from the supplier providing the largest service utility if and only if their actual utility from seeking the housekeeping service is non-negative. The suppliers decide whether to participate in the platform based on their opportunity cost and compete for customers through service value and service rate. By analyzing our model in equilibrium, we characterize the optimal equilibrium decisions of each participator and compare the payoff of all parties under the two market coverage scenarios.

We summarize our main contributions as follows: First, our work broaden the existing studies by exploring the pricing and quality strategies of an on-demand housekeeping service platform. To the best of our knowledge, we are the first paper to analyze the operational performance of an on-demand housekeeping service platform based on analytical models. Second, we integrate the characteristics of service-intensive industries and on-demand housekeeping service platforms to study the types of services charged at per-service prices, which have not been touched by previous literature.

We have drawn some interesting findings from our analytical model, which provides a management reference for platform operators. First, we show that suppliers have greater market power in the partial market. In contrast, suppliers need to win customers through fierce competition in a full market due to the limited number of potential customers. For the platform, the revenue in the partial market is always better than in the full market, but for suppliers, the payoff in the partial market is not always optimal. Our finding is consistent with the observations of Anand et al. (2011), who argue that a partial market is preferable and more likely to emerge among customer-intensive services. Second, in both market coverage scenarios, when the platform increases the service price, the suppliers will choose to reduce the service rate and thus improve the service quality. When the service price is the same, the supplier will provide a higher service quality in the full market scenario than in the partial market scenario. Third, as the potential demand market capacity expands, the platform will lower service prices to attract more customers and service suppliers until it reaches the partial market, thereby obtaining higher revenue. Moreover, service suppliers will provide lower-quality services to serve more customers and thus obtain more wages. Fourth, we show that the customer's service value sensitivity significantly impacts the optimal equilibrium decision. As the sensitivity of service value increases in the partial market scenario, the number of participating suppliers, platform revenue, and suppliers' payoff will first decrease and then increase. In the full market scenario, however, as the sensitivity of service value increases, the number of participating suppliers, platform revenue, and suppliers' payoff always increase. Meanwhile, as the sensitivity of service value increases in both market scenarios, the optimal equilibrium arrival rate and service rate both decrease while the optimal equilibrium service price increases. Finally, different market scenarios will lead to the opposite effect of the service cost on the optimal equilibrium price, arrival rate, and service rate. As the suppliers' service cost increases, the optimal equilibrium price will increase (decrease) in the partial market (full market), and the equilibrium arrival rate and service rate will decrease (increase) in a partial market (full market). Meanwhile, the increase in service cost will decrease platform revenue and service suppliers' payoff, and the equilibrium number of service suppliers.

The rest of the paper is organized as follows. Section 2 reviews the relevant literature. Section 3 describes the problem and introduces the main model. Section 4 analyzes and compares the optimal results in the two market scenarios. Section 5 discusses the goal of maximizing social welfare. Section 6 conducts extensive numerical studies to analyze the optimal equilibrium results. Finally, Section 7 summarizes and concludes this paper and provides some future research directions. We present all the proofs in Appendix.

2. Literature review

Our work is primarily related to two streams of research: (1) customer-intensive service and (2) operational problems of the on-demand platform. For the first stream literature, the main emphasis is on rational customers choosing to join the queueing decision based on utility maximization. Most studies analyze the interaction of congestion (waiting time) and service quality from different lens: admission fees (Naor, 1969; Edelson and Hilderbrand, 1975); multiple competing service suppliers (Li and Lee, 1994; Armony and Haviv, 2003; Cachon and Harker, 2002; Allon and Federgruen, 2007); multiple customer classes (Mendelson and Whang, 1990); discretionary task completion (Hopp et al., 2007); diagnostic service (Wang et al., 2010). Unlike the above literature, we focus on an on-demand customer-intensive service platform (i.e., a housekeeping service platform) that captures the interaction of service value and service duration and the features of an on-demand platform.

The on-demand housekeeping service platform is essentially a customer-intensive service industry that emphasizes the interaction between service quality and service time (service duration). When considering the features of customer-intensive services, Anand et al. (2011) is the first to measure the relationship between service quality and service speed (service duration), in which service quality is considered as a linearly decreasing function of the service rate of the service provider. They divide equilibrium outcomes into partial and full markets and define a partial market as one in which the potential demand is "high enough" that the availability of potential customers does not constrain the service provider's optimal price and service rate decisions. In contrast, the full market is the opposite. Following Anand et al. (2011), Ni et al. (2013) study the price and service speed decisions of service suppliers when facing customers with different customer intensity under two market coverages and finds that no customer class is always attractive to the supplier. Zhao and Zhang (2019) build dynamic programming to study the dynamic quality and pricing decisions of a customer-intensive service system when considering online reviews and find that through online reviews, the supplier is forced to offer higher quality at higher prices for fewer customers, especially when the customer intensity is high. Pricing and service rate decisions for customer-intensive services have also been studied when considering forward-looking customers (Li et al., 2018) and social interactions (Li et al., 2019). The main difference between the above papers and our work is that they focus on the traditional employment relationship, where servers (equivalent to "suppliers" in our paper) are the employees of the service provider (equivalent to "platform" in our paper). Therefore, the service provider generally determines the service price and service rate; the server obeys the service provider arrangement and cannot decide whether to participate. In our study, however, service suppliers are independent individuals. Therefore, each supplier needs to make participation and service rate decisions strategically based on multiple factors such as opportunity cost, payoff, and service cost.

The work by Liu et al. (2018) is closely related to our paper and worth special mentioning. Liu et al. (2018) explore the pricing and quality problem for an on-demand healthcare service platform and similarly divides the equilibrium outcome into partial and full markets, and points out that in equilibrium, a higher commission rate always lowers doctor participation and service quality, but may increase the service price if competition is significantly lower. However, they mainly focus on the healthcare service platform, while we focus on the housekeeping service platform, which leads to differences in the model set. First, due to the professionalism and authority of the doctors, the doctors participating in the platform can decide the service prices. In contrast, the service price of the housekeeping service platform is decided by the platform. Second, they assume that each doctor's services price is different, while the price of housekeeping services is the same for all suppliers. Finally, Liu et al. (2018) consider the impact of the price control level of the platform on all parties. However, we focus on the system's performance under different market coverage scenarios and on the goal of maximizing social welfare.

The second stream of related literature considers the operational problems of the on-demand platform. Taylor (2018) points out that on-demand service platforms are one of the three types of sharing economy, the other two types are product sharing (Bian et al., 2021; Tian and Jiang, 2018; Feng et al., 2020) and freelancing (Hu and Zhou, 2021; Moreno and Terwiesch, 2014). The literature on on-demand platforms mainly focuses on supply–demand balance and pricing strategy, among which some scholars focus on *on-demand ride-hailing platforms*. Bai et al. (2019) analyze an on-demand ride-hailing platform's pricing strategy when considering the platform can use a fixed payment ratio and a time-based payment ratio to coordinate endogenous demand and endogenous supply, respectively. Zhong et al. (2019) analyze a ride-sharing platform that recruits permanent and/or temporary service suppliers and determines the subsidy level of temporary agents and/or the employment level of permanent agents in both monopoly and duopoly competition environments. When considering the characteristics of the customer and the type of service provider, Zhong et al. (2020) divides customers into two categories based on congestion sensitivity and proposes two customer-classified pricing strategies. Hu and Zhou (2019) study the performance of an on-demand platform that connects price-sensitive customers and wage-sensitive independent suppliers when commission contracts are used in uncertain market conditions. Guda and Subramanian (2019) consider an on-demand ride-hailing platform that faces uncertain supply and demand conditions in two adjacent market areas and two consecutive periods. They study how surging prices and information sharing affect the optimal platform pricing strategy and supply–demand balance. Yu et al. (2017) develop a two-phase dynamic game to find the best regulatory framework to help the Chinese government balance multiple goals across multiple stakeholders.

There are also some scholars who consider *on-demand healthcare or delivery services platforms*. Lin et al. (2021) consider the heterogeneity of care requests and service suppliers and analyze the matching strategy of the service platform for daily home healthcare demands. He et al. (2021) consider the heterogeneity of customer's delay sensitivity and product preferences, and analyze the influence of information structure on the design of incentive contracts for a general on-demand service platform. Kung and Zhong (2017) study three pricing strategies (i.e., membership-based pricing, transaction-based pricing, and cross-subsidization) for a two-sided platform with network externalities and shows that three strategies are equivalent when there is no time discount and consumers' order frequency is not sensitive to price. Hess et al. (2021) propose a meal delivery platform demand forecasting

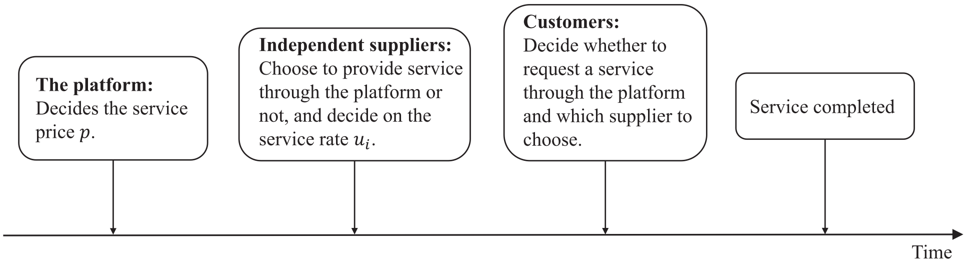

Fig. 2. Sequence of events.

algorithm based on classical forecasting and machine learning methods. Perboli et al. (2021) use a new variant of the bin packing model to analyze the on-demand economics that considers customer preferences and the integration of multiple delivery options. Liu et al. (2019) explore the pricing decision of an "online-to-offline" service platform when considering the provider's threshold participating quantity and the value-added service (VAS) and matching ability of the platform. Using a mixed-integer linear programming approach, Li et al. (2020) propose an assignment matching strategy for the joint optimization of matching and pricing for an O2O platform with multiple delivery point services. In contrast, our work focuses on exploring an on-demand housekeeping platform's pricing and quality strategy. Housekeeping service platforms are essentially customer-intensive services, and thus we consider the interaction between service quality and service time. However, the second stream of literature does not consider this interactive relationship. In addition, they all consider that the platform assigns a supplier to a customer from a common pool. In contrast, we consider that the customer will choose the optimal supplier to maximize individual utility. Meanwhile, we consider that service suppliers will make optimal service rate decision based on payoff maximization, which is not considered in the above papers.

In summary, our work considers an on-demand housekeeping service platform with customer-intensive service, which emphasizes the significant relationship between service value and service time. We are the first paper to explore the pricing and quality strategies of an on-demand housekeeping service platform from a model analysis perspective to the best of our knowledge. Meanwhile, we integrate the characteristics of housekeeping services and on-demand platforms to develop a theoretical model to explore the operational performance of the platform under different market coverage scenarios, which has not been touched on in the existing literature.

3. Problem formulation

We consider a representative customer-intensive service on a housekeeping on-demand platform, in which the representative service is charged by a per-service price. The platform sets the per-service price p paid by customers for the service and the wage βp received by suppliers to complete the service (where β is the wage rate). Without loss of generality, we assume that the wage rate set by the platform is exogenous. This is because, in practice, the wage rate set by the platform does not frequently change (Liu et al., 2018). For example, Handy and Allbetter charge a 20% commission for each service.[4] The number of potential service suppliers that can provide the service on the platform is N, and we use i to index the suppliers. To focus on the relationship between service quality and waiting time, we assume that all suppliers have the same technical level and proficiency but have a different opportunity cost r_i. Because the housekeeping type service (e.g., neonatal care missionary, personal care (such as hairdressing, beauty care), and air conditioning cleaning) is not complex and does not require the service supplies to have very professional technical skills. This type of service has a high degree of standardization, and housekeeping service platforms usually provide standardized training to ensure the professionalism and standardization of the services. Then, there is little difference in the level of service skills possessed by the suppliers. Meanwhile, the participating suppliers will incur the service cost k (e.g., transportation costs and equipment wear and tear costs) for each service completed. Then, the potential supplier will participate if and only if the expected payoff $(\beta p - k)\lambda_i$ is higher than the opportunity cost r_i (where λ_i is the demand rate of supplier i).

We assume that the service delivery process is based on an unobservable $M/M/1$ queuing model at each participating supplier. For services that are charged by per-service price, the housekeeping platform usually provides a list of suppliers for customers to choose from after customers have selected the services they need (e.g., Handy,[5] Care.com,[6] TaskRabbit.[7]) Customers will choose the supplier that maximizes utility based on service price, perceived service value, and waiting cost. Therefore, each potential supplier has an $M/M/1$ queuing model, and there are N parallel $M/M/1$ models in the entire system. The potential customers arrive randomly at rate Λ according to the Poisson process, where Λ can refer to the potential customer demand. The participating

[4] https://slate.com/business/2015/07/handy-a-hot-startup-for-home-cleaning-has-a-big-mess-of-its-own.html; https://www.dollarbreak.com/house-cleaning-jobs/.

[5] https://help.handy.com/hc/en-us/articles/215601287-How-do-I-request-a-professional-.

[6] https://www.care.com/child-care.

[7] https://www.taskrabbit.com/.

Table 1
Notations.

Variable	Definition
q_b	Benchmark service value
q_i	Actual service value of supplier i
u_i	Actual service rate of supplier i
u_b	Benchmark service rate
r	Opportunity cost of supplier
λ_i	Demand rate of supplier i
p	Per-service price
N	The number of potential suppliers
β	The wage rate of suppliers
n	The number of participating suppliers
α	The sensitivity of the service value to the service rate
c	Unit waiting cost of customers
k	Per-service cost of suppliers
Λ	Potential demand market
W	Expected waiting time

customers will incur a waiting cost c per unit time during the waiting process. If supplier i decides to participate in the service, she will set her service rate u_i (the number of customers served per unit time). In a typical customer-intensive service, a higher service rate means a lower service value (Anand et al., 2011). In Table 1, we summarize the notations used in the paper.

The sequence of events of the entire service is as follows: First, the platform decides the optimal service price based on the goal of optimizing its revenue. Second, independent suppliers make participation and service rate decisions based on the platform's service price, wage rate, and service cost. Finally, customers decide whether to request a service and which supplier to choose based on service price, perceived service quality, and waiting cost. Fig. 2 depicts the sequence of events between the platform, service suppliers, and customers.

3.1. *Customers' queueing joining decision*

The potential customers then decide whether and from whom to get the service based on the expected waiting cost, the perceived service value, and the service price. The supplier's service value can be assessed through ratings and customer reviews on the platform. The customers' waiting cost is depicted by the average waiting time of unobservable queues. We denote the actual demand rate of supplier i as λ_i. The expected waiting time for a customer who chooses to get service from supplier i is

$$W(u_i,\lambda_i)=\begin{cases}\dfrac{1}{u_i-\lambda_i} & \lambda_i<u_i\\ +\infty & \lambda_i\geq u_i.\end{cases} \tag{1}$$

Following Anand et al. (2011) and Liu et al. (2018), we derive the supplier i's service value to a customer can be expressed as

$$q_i=q_b+\alpha(u_b-u_i). \tag{2}$$

where α indicates the sensitivity of the service value to the service rate and also captures the customer intensity of the service provided. The parameters u_b and q_b are denoted as the benchmark service rate and the benchmark service value, respectively, which are both exogenous. In the classical queuing model, the service value is usually assumed to be independent of the service rate. Following Anand et al. (2011) and Liu et al. (2018), we assume that the service value is affected by the service rate in a customer-intensive service industry. From Eq. (2), we show that when $\alpha=0$, the service value q_i is the same as that in the classic queuing model. The potential strategic customers can obtain the utility U_i of seeking service from supplier i based on expected waiting cost, perceived service value, and service price as

$$U_i(u_i,\lambda_i)=q_i-cW(u_i,\lambda_i)-p. \tag{3}$$

Then, customers choose the appropriate supplier to meet their service needs based on individual utility maximization.

3.2. *Suppliers' participation and service rate decision*

If service suppliers choose to participate in the platform and provide a customer-intensive housekeeping service, then they will obtain wage βp and incur service cost k for each completed service demand. Therefore, if supplier i chooses to participate, the actual payoff is $(\beta p-k)\lambda_i$. When the actual payoff of supplier i is greater than or equal to the opportunity cost r (i.e., $(\beta p-k)\lambda_i\geq r$), supplier i will choose to provide the service. Following Bai et al. (2019), to model the heterogeneity of opportunity costs between potential suppliers, we assume that there is a continuum of supplier types and the opportunity cost r is distributed over the range $[0,d]$. The cumulative distribution function of opportunity cost r is denoted as $G(r)$, which is strictly increasing. We have $G(0)=0$ and $G(d)=1$. Let ϕ be the proportion of suppliers who choose to provide the service, we have

$$\phi=\mathbb{P}\left\{r\leq(\beta p-k)\lambda_e\right\}=G[(\beta p-k)\lambda_e]. \tag{4}$$

where λ_e is the equilibrium number of customers seeking service from supplier i. Let n_e be the equilibrium number of participating suppliers, we have

$$n_e = \phi N = G[(\beta p - k)\lambda_e]N. \tag{5}$$

When service supplier i ($i \in 1, 2, \ldots, n_e$) decides to participate in the platform, she will decide her own service rate u_i to maximize the payoff Π_s^i. Then, we have

$$\Pi_s^i(u_i) = (\beta p - k)\lambda_e. \tag{6}$$

3.3. Platform revenue maximization

For the on-demand housekeeping platform, the goal is to maximize its revenue function Π_p by setting the per-service price p paid by the customers. Then, the housekeeping platform's revenue function can be written as

$$\Pi_p(p) = \min\left\{n_e\lambda_e, \Lambda\right\}(1-\beta)p. \tag{7}$$

where n_e is the equilibrium number of participating suppliers and λ_e is the equilibrium demand rate for each participating supplier. Then, $n_e\lambda_e$ means the equilibrium service demand from all participating suppliers. Note that when the potential demand Λ is greater than the equilibrium service demand $n_e\lambda_e$, which refers to the partial market coverage. In this case, each participating supplier is essentially a local monopolist. When the potential demand Λ is smaller than the equilibrium service demand $n_e\lambda_e$, suppliers are competing with each other for the service demand, which refers to as full market coverage.

4. Model analysis

We start with an analysis of customers' service supplier choice decisions. After knowing the per-service price p, the expected waiting time $W(u_i, \lambda_i)$ and the service rate of different suppliers u_i, the homogeneous customers will realize the utility of seeking service from different suppliers. When the utility obtained from supplier i is non-negative and greater than that from other suppliers, the customer will choose supplier i. Therefore, we can divide it into the following three cases:

(a) $U_i(u_i, \Lambda) \geq 0$ and $U_i(u_i, \Lambda) \geq U_j(u_j, 0)$, $(i \neq j)$. In this case, the actual demand at supplier i is Λ, and the utility of customers seeking service from supplier i is non-negative and higher than the utility when seeking service from supplier j with the actual demand of 0. Therefore, $\lambda_i = \Lambda$, that is, all market demands are gathered at supplier i.

(b) $U_i(u_i, 0) < 0$ or $U_i(u_i, 0) < U_j(u_j, \Lambda)$, $(i \neq j)$. In this case, the actual demand at supplier i is 0. The utility of customers seeking service from supplier i is negative or lower than the utility when seeking service from supplier j with the actual demand of Λ. Then it follows that $\lambda_i = 0$, which indicates that no customer will seek service from supplier i.

(c) $U_i(u_i, 0) \geq 0$ and $U_j(u_j, \Lambda) < U_i(u_i, \lambda_i) < U_j(u_j, 0)$, $(i \neq j, 0 < \lambda_i < \Lambda)$. In this case, the utility of customers seeking service from supplier i with actual demand λ_i is non-negative. This is lower than the utility from suppliers with the actual demand of 0 but greater than suppliers with the actual demand of Λ. There exists an equilibrium such that $U_i(u_i, \lambda_i) = U_j(u_j, \lambda_j) \geq 0$, $(0 < \lambda_i < \Lambda, 0 < \lambda_j < \Lambda)$. Then, the customer receives the same utility from all suppliers.

The service suppliers can make their own participation decision and service rate decision to maximize their payoff and avoid being stuck in the first two equilibrium cases when they know the service price and other suppliers' decisions. Therefore, only the third equilibrium is a stable one. The decision-making process is different for different market types. We consider two market coverage scenarios: partial market coverage and full market coverage. Next, we will analyze the decision-making process of all parties under different market coverage scenarios.

4.1. Partial market coverage

In a partial market (i.e., $\Lambda \geq n_e\lambda_e$), n_e is the equilibrium number of participating suppliers and λ_e is the equilibrium demand rate for each participating supplier. Note that there are enough potential customers so that the availability of customers does not constrain the suppliers' service rate decision and the platform's price decision. The perceived utility of participating customers decreases as the actual demand of the supplier from whom they seek service increases. In this case, the equilibrium result of the participating suppliers' service rate decision and customers' joining decision are

$$U_i(u_i, \lambda_i) = U_j(u_j, \lambda_j) = 0, (0 < \lambda_i < u_i, 0 < \lambda_j < u_j, i \neq j). \tag{8}$$

The above equation implies that the customers get the same utility from each supplier and the service utility is 0. In this case, the customer's surplus from the supplier's service is 0.

We assume that the participating service suppliers are identical except for opportunity cost. According to Eq. (8), when the symmetric equilibrium is reached, the actual demand at each participating supplier λ_e satisfies $q_i - p - c/(u_i - \lambda_e) = 0$. Hence, the equilibrium result can be expressed as

$$\lambda_{e1} = u_i - \frac{c}{(q_b + \alpha(u_b - u_i)) - p}. \tag{9}$$

Next, we derive the equilibrium service rates of participating service suppliers. When supplier i ($i \in \{1, 2, \ldots, n_{e1}\}$) decides to participate in the service, she will choose the service rate that maximizes her own payoff $\Pi_s^i(u_i)$. By substituting λ_{e1} into Eq. (6), we have

$$\Pi_s^i(u_i) = (\beta p - k)\left(u_i - \frac{c}{(q_b + \alpha(u_b - u_i)) - p}\right). \tag{10}$$

Note that $\lambda_i < u_i$ holds. We can easily know that the above payoff function (10) is a concave function with respect to u_i. Taking the first derivation of payoff function (10) with respect to the service rate u_i and defining the optimal service rate decision for supplier i as u_{e1}^*, we have

$$u_{e1}^* = \frac{q_b + \alpha u_b - \sqrt{\alpha c} - p}{\alpha}.$$

Since service suppliers are homogeneous except for opportunity costs, the service rate decision of supplier i is also the decision of all other participating service suppliers. Therefore, by substituting u_{e1}^* into λ_{e1}, we can obtain the actual equilibrium demand for each participating supplier as

$$\lambda_{e1} = \frac{q_b + \alpha u_b - 2\sqrt{\alpha c} - p}{\alpha}.$$

Next, we can rewrite the platform's revenue function as

$$\begin{aligned} \max_p \quad & \Pi_p(p) = n_e \lambda_e (1 - \beta) p \\ \text{s.t.} \quad & \beta p - k \geq 0 \\ & q_b + \alpha u_b - 2\sqrt{\alpha c} - p \geq 0. \end{aligned} \tag{11}$$

We know that the payoff of service suppliers participating in the service should be non-negative, so we get the first constraint $\beta p - k \geq 0$. This is because the platform needs to set service price to ensure that the actual equilibrium demand of each participating supplier is non-negative. Otherwise, the system would not exist. Then, we have the second constraint $q_b + \alpha u_b - 2\sqrt{\alpha c} - p \geq 0$. According to Eq. (5), we know that $n_e = G[(\beta p - k)\lambda]$ and $G(r)$ is the cumulative distribution function of the opportunity cost r. To simplify our analysis and obtain an explicit analytical solution, following Bai et al. (2019) and Liu et al. (2019), the distribution of the suppliers' opportunity cost is assumed to be uniformly distributed over $[0, d]$. In practice, service suppliers choosing to participate in a service depends mainly on the supplier feeling it is worthwhile (opportunity cost). The opportunity cost is essentially the perceived value of the supplier's outside options, which can be a combination of all supplier heterogeneity (e.g., skill level, education level). Therefore, different suppliers have different opportunity costs and are distributed in the range $[0, d]$.[8] Therefore, we can get $G(r) = r/d$. The equilibrium number of participating suppliers can be rewritten as

$$n_e = N\frac{(\beta p - k)\lambda_e}{d}. \tag{12}$$

From Eqs. (11) and (12), we can express the objective function of the platform $\Pi_p(p)$ as follows

$$\Pi_p(p) = \frac{N(\beta p - k)\lambda_e^2(1 - \beta)p}{d}. \tag{13}$$

Next, we can solve the revenue function $\Pi_p(p)$ subject to the two participating constraints (i.e., $\beta p - k \geq 0$ and $q_b + \alpha u_b - 2\sqrt{\alpha c} - p \geq 0$), and get the following proposition to show the optimal decisions and the corresponding optimal results.

Proposition 1. *In the partial market scenario ($\Lambda \geq n_e\lambda_e$), we have*

(a) *The optimal service price is* $p_1^* = \dfrac{(2\beta\theta + 3k) + \sqrt{(2\beta\theta + 3k)^2 - 16k\beta\theta}}{8\beta}$.

(b) *The equilibrium demand is* $\lambda_{e1} = \dfrac{\theta - p_1^*}{\alpha}$, *which is the total customers who want to be serviced at each supplier per unit time.*

(c) *The equilibrium service rate for each supplier is* $u_{e1} = \dfrac{\theta + \sqrt{\alpha c} - p_1^*}{\alpha}$.

(d) *The equilibrium number of participating suppliers is* $n_{e1} = \dfrac{N(\beta p_1^* - k)(\theta - p_1^*)}{\alpha d}$, *where* $\theta = q_b + \alpha\mu_b - 2\sqrt{\alpha c}$.

Proposition 1 shows that when the platform proposes a higher service price, the suppliers will provide service with higher quality, but this also leads to the number of customers that a single supplier can serve decreasing. Interestingly, increasing the service price does not always attract more service suppliers to join the platform. This is because when the service price is high, if the supplier does not reduce the service rate to improve the service quality, it will decrease the customers' utility. In addition, when the service rate decreases, the number of customers that a participating supplier can actually serve will also decrease. The supplier's payoff mainly depends on the service price and the number of customers. Increasing the service price will reduce the number of customers

[8] Such an assumption does not affect our main conclusions.

the supplier can actually serve. Therefore, due to the above two factors existing simultaneously, the strategy of increasing service price does not always attract more service suppliers.

Under the partial market coverage scenario, Anand et al. (2011) point out that in traditional customer-intensive services with a monopoly service provider, the equilibrium service rate is not affected by customer waiting cost. However, our work shows that in an on-demand housekeeping platform, the optimal service rate of service suppliers is affected by the customer waiting cost. One possible explanation is that the optimal service rate is decided by a monopolistic service provider in the traditional customer-intensive service, while in the on-demand housekeeping service platform, it is decided by each independent and competing supplier based on the maximization of individual payoff. In the on-demand housekeeping service platform, each service supplier faces the customer's choice, which will be affected by the customer's waiting cost. In traditional customer-intensive service industries, suppliers as a supply pool are uniformly arranged by a monopoly service provider. There is no competition among suppliers, so the optimal service rate is not affected by the customer waiting cost. This shows that, compared with traditional customer-intensive services, the on-demand service platform should pay attention to the impact of customer waiting cost on service suppliers to achieve more effective supply and demand matching.

4.2. Full market coverage

In this subsection, we will discuss the full market coverage scenario. In a full market, the demand for the on-demand housekeeping service platform is relatively small compared to the participating service suppliers (i.e., $\Lambda < \lambda_e n_e$). The availability of customers is constrained, and the equilibrium number of customers ultimately assigned to each supplier is given by $\lambda_e = \frac{\Lambda}{n_e}$. Note that the equilibrium number of participating suppliers is $n_e = N\frac{(\beta p - k)\lambda_e}{d}$, and holds in both market scenarios. Then, we have the equilibrium number of participating suppliers in a full market as

$$n_{e2} = \sqrt{\frac{N(\beta p - k)\Lambda}{d}}, \tag{14}$$

which in turn states that the equilibrium demand at each supplier is $\lambda_{e2} = \sqrt{\frac{d\Lambda}{N(\beta p - k)}}$. For participating supplier i ($i \in \{1, 2, \ldots, n_{e2}\}$), each customer seeking service from her will obtain utility U_i as

$$U_i(u_i, \lambda_i) = q_b + \alpha(u_b - u_i) - p - \frac{c}{u_i - \lambda_i}. \tag{15}$$

There exists an equilibrium situation so that $U_i(u_i, \lambda_i) = U_j(u_j, \lambda_j) \geq 0$, $(0 < \lambda_i < u_i, 0 < \lambda_j < u_j)$. Obviously, there are an infinite number of equilibrium results in a full market, but these are not stable. That is, a small disruption will diverge away from the equilibrium (we prove it in detail in the next three paragraphs after Lemma 1). Lemma 1 lists the conditions of the stable equilibrium service rate for the participating service suppliers.

Lemma 1. *Given any $\beta p \geq k$, there are an infinite number of equilibrium service rates for the participating suppliers when the service rate $u_i \in [\underline{u}, \overline{u}]$, where $\overline{u} = \frac{S + \alpha\lambda_{e2} + \sqrt{(S + \alpha\lambda_{e2})^2 - 4S\alpha\lambda_{e2}}}{2\alpha}$, $\underline{u} = \frac{S + \alpha\lambda_{e2} - \sqrt{(S + \alpha\lambda_{e2})^2 - 4S\alpha\lambda_{e2}}}{2\alpha}$, and $S = q_b + \alpha u_b - p$.*

From Lemma 1, we know that the service suppliers' equilibrium service rate decisions belong to the range $[\underline{u}, \overline{u}]$. In this case, the corresponding customer utility is non-negative. However, customers are more scarce in the full market scenario than in the partial market scenario. As a result, service suppliers are more cautious about their customers in the face of fierce competition generated by customer scarcity, especially when they decide on the service rate.

From Eq. (6), we know that the payoff of participating suppliers Π_s^i is strictly increasing in actual demand λ_i (where $0 < \lambda_i < u_i$). When the service rate of each participating supplier is at the same level, the suppliers have an incentive to change their service rate within the range $u_i > \lambda_i$ to improve the customers' service utility, and improving their competitiveness and attracting more customers.

According to the proof of Lemma 1, there exists a unique solution u_i^* to maximize the customers' utility $U_i(u_i, \lambda_i)$. We first denote $u_i^* = \lambda_i + \sqrt{\frac{c}{\alpha}}$. When given the service price p, we know that all the non-negative values of the customers' utility are equilibrium solutions, but only u_i^* is a stable equilibrium (see Fig. 3). We can find that the customers' utility increases with u_i when $u_i \in [\underline{u}, u_i^*]$, which indicates that a small increase in u_i will increase the customers' utility and attract more customers. In this case, the equilibrium result is divergent. However, the equilibrium result is convergent when u_i is greater than u_i^*. This is because when $u_i \in [u_i^*, \overline{u}]$, the utility of customers will decrease, and the supplier has no incentive to deviate from the equilibrium u_i^*. In this case, the only stable equilibrium will exist in $u_i = u_i^*$, and the actual demand at each supplier will be Λ/n_e. Therefore, we have the service suppliers' equilibrium service rate is $u_{e2} = u_i^*$.

In addition, the customers' utility will increases with u_i when $u_i < u_i^*$. Although a larger u_i means serving more customers per unit time and reducing the waiting time, it also reduces the service quality perceived by customers. When $u_i < u_i^*$, the decrease in waiting cost caused by increasing the service rate will be greater than the decrease in service value. Therefore, the customers will tend to choose a supplier with a higher service rate in this case. But when $u_i \geq u_i^*$, the customers' utility will decrease as u_i increases. This is because when u_i exceeds a threshold, the reduction in waiting cost caused by an increase in u_i will be less than the reduction in service value. Thus the customers tend to choose suppliers with lower service rate. Based on the above analysis, we can summarize the results in the following lemma.

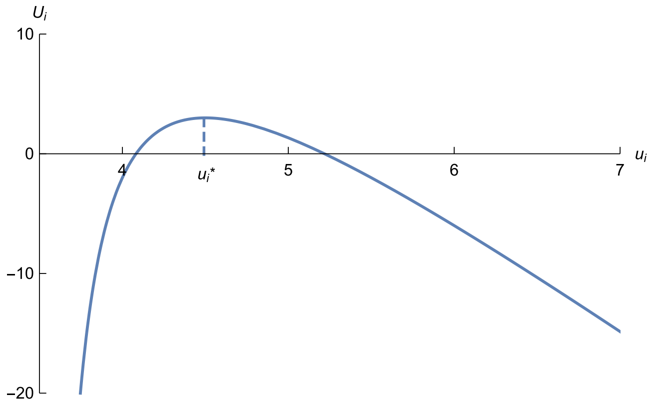

Fig. 3. Equilibrium service rate in a full market ($q_b = 50$, $\alpha = 10$, $u_b = 5$, $c = 10$, $k = 5$, $\beta = 0.7$, $p = 42$, $N = 100$, $d = 120$, $\Lambda = 250$).

Lemma 2. *Given any $\beta p \geq k$, there exists a unique equilibrium solution of service rate among participating suppliers, that is,*

$$u_{e2} = \sqrt{\frac{d\Lambda}{N(\beta p - k)}} + \sqrt{\frac{c}{\alpha}},$$

and the utility that the customers receive from each participating supplier is

$$U(p) = q_b + \alpha u_b - 2\sqrt{\alpha c} - \alpha\sqrt{\frac{d\Lambda}{N(\beta p - k)}} - p.$$

Next, we have the platform's objective function as

$$\max_{p} \quad \Pi_p(p) = (1-\beta)p\Lambda \tag{16}$$
$$\text{s.t.} \quad \beta p - k \geq 0.$$

In the full market scenario, the equilibrium service capacity $n_{e2}\lambda_{e2}$ is always equal to the potential arrival rate Λ. In this case, the platform's optimal pricing decision cannot be derived from its objective function. By solving the first-order derivative of $U(p)$ with respect to p, we have

$$\frac{1}{2}\alpha\beta\sqrt{\Lambda d/N}(\beta p - k)^{\frac{-3}{2}} - 1 = 0.$$

Denote $\hat{p} = \left(\left(\frac{\alpha\beta\sqrt{\Lambda d/N}}{2}\right)^{\frac{2}{3}} + k\right)/\beta$, we easily get that $\hat{p} > k/\beta$. When $p \geq \hat{p}$, $U(p)$ is strictly decreasing in p. When $p < \hat{p}$, $U(p)$ is strictly increasing in p. Also, due to $\Pi_p(p)$ is a strictly increasing function of p in the full market scenario, the platform will try its best to set a higher per-service price. Let p_4 and p_5 be the two real roots of p at $U(p) = 0$, respectively (where $p_5 > p_4$, $\hat{p} > k/\beta$, and $p_5 > \hat{p}$, thus p_5 meets the constraints of platform's objective function). According to the relationship between $U(p)$ and p, the platform will inevitably choose a larger p to make the utility of customers be exactly 0, that is, $p_2^* = p_5$. When $U(\hat{p}) < 0$, all customers exit the market. When $U(\hat{p}) = 0$, the platform can only choose $\hat{p}$ as the optimal service price since $\Pi_p(\hat{p}) > 0$.

According to the above analysis, we can see that when given the equilibrium arrival rate λ_{e2} and the equilibrium service rate u_{e2}, the utility of customers is not a decreasing function of service price p. When $p < \hat{p}$, the utility of customers is strictly increasing in p. When the service price increases, although the actual paid by customers increases, the service value also improves. When p is relatively small, the increase of the former is less than the latter's, which eventually leads to the customers' utility increases with the service price. When $p \geq \hat{p}$, the increment of the former is greater than the increment of the latter. Thus the customers' utility decreases as the service price increases.

To sum up, in the full market scenario, the optimal decisions of the platform and service suppliers can be summarized in the following proposition.

Proposition 2. *In the full market scenario ($\Lambda < n_e\lambda_e$), we have*

(a) *The optimal service price is* $p_2^* = p_5$.

(b) *The equilibrium demand is* $\lambda_{e2} = \sqrt{\frac{d\Lambda}{N(\beta p_2^* - k)}}$.

(c) *The equilibrium service rate for each supplier is* $u_{e2} = \sqrt{\frac{d\Lambda}{N(\beta p_2^* - k)}} + \sqrt{c/\alpha}$.

(d) *The equilibrium number of participating suppliers is* $n_{e2} = \sqrt{\frac{N(\beta p_2^* - k)\Lambda}{d}}$.

From Proposition 2, we find that when the platform increases the service price, the service suppliers will lower the service rate to improve the service quality. Because the number of customers is relatively small in the full market scenario, competition among suppliers will be more intense. Also, as the platform sets a higher service price, the equilibrium demand will decrease while the equilibrium number of service suppliers will increase. This further exacerbates the supply–demand imbalance (decreasing demand and increasing supply), which leads service suppliers to reduce service rates and offer higher service quality to attract customers.

In addition, note that service suppliers in the on-demand service platform can choose whether to provide services as independent individuals, while in the traditional service industry, service suppliers are arranged as a supply pool by the provider. According to Anand et al. (2011)'s result, we find that the equilibrium number of service suppliers in the on-demand service platform is always no higher than that in the traditional service industry when the potential service suppliers are the same in both scenarios. However, we show that the equilibrium service rate in the on-demand service platform is always no less than that in the traditional service industry. A possible explanation is that the decrease in the equilibrium number of service suppliers prompts service suppliers to increase the service rate. Therefore, on-demand housekeeping service platforms should develop more incentives to increase their attractiveness to suppliers and ensure sufficient numbers of suppliers to provide services.

4.3. Comparative statics: Partial market and full market

This subsection will compare and analyze the differences in the optimal results under the two market coverage scenarios.

Proposition 3. *Given any per-service price p ($\frac{\beta}{k} \le p \le q_b + \alpha u_b - 2\sqrt{\alpha c}$), we always have $\Pi_{p1} \ge \Pi_{p2}$, $\Pi_{s1} \ge \Pi_{s2}$, $u_{e1} \ge u_{e2}$; for the participating customers, their equilibrium utility will be 0 for both market scenarios.*

Proposition 3 implies that the suppliers and the platform will benefit more in a partial market. However, the customers can get a higher service quality in a full market scenario when the platform's price is the same. Because there are fewer customers and more competitive suppliers in a full market, service suppliers need to provide higher service quality to compete for customers.

According to the analysis in Sections 4.1 and 4.2, we can see that each decision variable is a continuous function of the market capacity Λ. When $\Lambda \ge \lambda_e n_e$, that is, in a partial market, each decision variable is a constant function of Λ (see Proposition 1). In the partial market scenario, the platform's revenue Π_{p1} and the suppliers' payoff Π_{s1} are

$$\Pi_{p1} = n_{e1}\lambda_{e1}(1-\beta)p = \frac{N(\beta p - k)(1-\beta)p(\theta - p)^2}{\alpha^2 d},$$

$$\Pi_{s1} = (\beta p - k)\lambda_{e1} = \frac{(\beta p - k)(\theta - p)}{\alpha}.$$

We know that the platform's revenue and the suppliers' payoff are also constant functions of Λ. Note that when $\Lambda < \lambda_e n_e$, that is, in the full market scenario, we have

$$\Pi_{p2} = \Lambda(1-\beta)p,$$

$$\Pi_{s2} = (\beta p - k)\sqrt{\frac{d\Lambda}{N(\beta p - k)}},$$

$$u_{e2} = \sqrt{\frac{d\Lambda}{N(\beta p - k)}} + \sqrt{c/\alpha}.$$

It is easy to see that the revenue of the platform Π_{p2}, the payoff of participating suppliers Π_{s2} and the equilibrium service rate u_{e2} are strictly increasing functions of Λ. Therefore, $\Pi_{p1} \ge \Pi_{p2}$, $\Pi_{s1} \ge \Pi_{s2}$, $u_{e1} \ge u_{e2}$ always holds. Also, a comparative analysis without a given service price can be seen in Fig. 4. By comparing consumer surplus in two market scenarios, we find that consumer surplus is completely extracted whether under the full market or the partial market. Moreover, we consider that the platform is in a monopolistic position, and there is no competitive pressure. From the perspective of customers, consumers' surplus can be increased by delegating pricing power to service suppliers or adding other platform competitors.

Meanwhile, it is interesting to note that, whether in the full or partial market, given the equilibrium arrival rate of customers and the equilibrium service rate of suppliers, the waiting cost of customers is constant and equal in both cases. Because the average waiting time, that is, the difference between the equilibrium service rate and the equilibrium arrival rate, is always equal to $\sqrt{c/\alpha}$, and it will not change with the market capacity. This conclusion is consistent with Anand et al. (2011). In traditional customer-intensive services, where servers (equivalent to "suppliers" in our paper) are the employees of the service provider (equivalent to "platform" in our paper). Under the equilibrium result, the customer's waiting cost is always the same in both market scenarios. This also means that the more sensitive customers are to the service rate (i.e., α increases), the higher customer waiting cost regardless of market coverage.

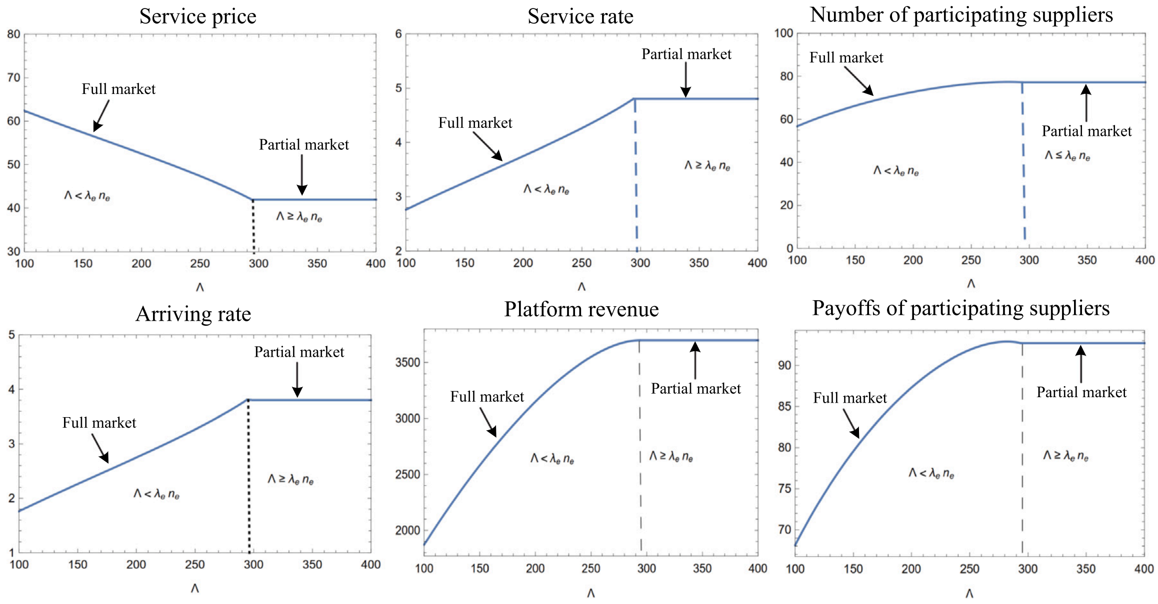

Fig. 4. The decision of different parties under two market scenarios..

5. Social welfare

In this section, we discuss that a not-for-revenue platform (e.g., a platform owned by a nonprofit organization or government agency) considers the platform's revenue and the welfare of suppliers and customers when making optimal decisions. Benjaafar et al. (2021) point out that some labor unions believe the on-demand platforms relying on independent suppliers expand the labor pool and will damage the payoffs of independent suppliers. Yu et al. (2017) finds that governments in developed countries have raised legal concerns to protect labor and customer rights and fair pricing issues on those emerging platforms. For example, Care.com is subject to various U.S. and foreign laws, including user privacy, consumer protection, telecommunications, securities law compliance, online payment services.[9] We would like to analyze how on-demand housekeeping service platforms should strategically choose their pricing strategies and the impact on suppliers and customers when considering social welfare. Therefore, we integrate the platform's revenue and the payoffs of suppliers and customers into the objective function.

We denote that social welfare includes the platform's revenue, total consumer surplus, and independent service suppliers' payoff. Similar to Cui et al. (2007), we use the platform's "equitable payoff" parameter $\gamma \in [0,1]$ to reflect the different importance the platform places on its revenue and social welfare. For example, when $\gamma = 0$, the platform does not care about social welfare, consistent with the basic model in Section 4. When $\gamma = 1$, the platform believes that social welfare is as important as the platform's revenue. Next, we will discuss the optimal results for different market coverage scenarios separately.

Proposition 4. (a) *In the partial market scenario, the total customer surplus is always zero, regardless of whether the platform considers social welfare or not.*

(b) *The optimal price is* $p_1^* = \frac{\sqrt{(k(2\beta\gamma+2s+t)+2\beta\theta s)^2-16\beta k s(2\gamma k+\theta t)}+k(2\beta\gamma+2s+t)+2\beta\theta s}{8\beta s}$, *and the rest of the optimal results still hold as in Proposition 1, where* $s = \beta\gamma - \beta + 1$, $t = 2\beta\gamma - \beta + 1$.

From Proposition 4, in the partial market, the consumers' total surplus will be wholly reduced to 0 by the suppliers through the service rate decision since the number of potential customers is sufficiently large. Even when the platform's objective function considers social welfare, the customers' surplus will also be 0. This indicates that at this time, each supplier is a local monopolist and can fully increase its payoff by extracting customer welfare. In addition, we show that the optimal price of the platform is not monotonic with the "equitable payoff" parameter γ. What is more, regardless of whether the platform considers social welfare factors, the optimal results of customers and suppliers are not affected.

When consider the full market scenario, the objective function of the platform is $\Pi = \Pi_p + \gamma(S_c + S_s)$. First, the platform's revenue is $\Pi_p = \Lambda(1-\beta)p$. The payoff of an individual participating supplier is $\Pi_s = \lambda_e(\beta p - k)$, thus the surplus of all suppliers is $S_s = \Lambda(\beta p - k)$. For an individual customer, his utility is given by $U(p) = \theta - \alpha\sqrt{\frac{d\Lambda}{N(\beta p - k)}} - p$. The total surplus of all participating customers is $S_c = \Lambda U(p)$. Unlike in the partial market scenario, before the platform makes a price decision, each customer's utility is non-negative. Then, the objective function of the not-for-revenue platform can be expressed as $\Pi = \Lambda[(1-\beta)p + \gamma((\beta p - k) + U(p))]$.

[9] https://www.annualreports.com/Company/carecom-inc (p. 26).

Proposition 5. (a) *In the full market scenario, the optimal price for the platform is given with*

$$p_2^* = \begin{cases} [(\frac{\alpha\beta\gamma\sqrt{\Lambda d/N}}{2(\gamma-1)(1-\beta)})^{\frac{2}{3}} + k]/\beta, & if\ \gamma \in (0,1)\ and\ p_4 \le \bar{p} \le p_5, \\ p_4, & if\ \gamma \in (0,1)\ and\ \bar{p} < p_4, \\ p_5, & if\ \gamma \in (0,1)\ and\ \bar{p} > p_5, \\ p_5, & if\ \gamma \in \{0,1\}. \end{cases}$$

(b) *The optimal price is increasing with γ when $\gamma \in (0,1)$ and $p_4 \le \bar{p} \le p_5$.*

Proposition 5 shows that in the full market scenario and when the platform considers social welfare, the optimal price decision of the platform is not only related to the "equitable payoff" parameter γ but also to the relative size of extremum $\bar{p}$, p_4 and p_5. This is because, in a full market, the platform needs to get the optimal price from the perspective of customer utility. In addition, when the objective function of the platform is to maximize its revenue, the customer's utility is always 0. However, when the platform considers social welfare in the full market scenario, the customers may get some positive welfare. Interestingly, when the platform believes that the platform's revenue and social welfare are equally important, the customer's welfare will not increase but will remain zero.

6. Numerical studies

In this section, we perform some numerical studies to illustrate the variation of the optimal decision under different market coverage scenarios and the impact of the relevant important parameters (i.e., the sensitivity of the service value to the service rate, the distribution dispersion of opportunity cost, suppliers service cost, and customers waiting cost) on the optimal decisions and the corresponding optimal results. Without loss of generality, we considered empirically adjusted parameters to support our numerical study, some of which were derived from verbal inquiries to Daoway platform employees. We consider a platform with $N = 100$ potential suppliers offering per-service price type services (e.g., neonatal care missionary, Tuina, personal care, air conditioning cleaning). The platform charges the customer a price p for each service and pays a wage $\beta p = 0.7p$ to the supplier who provides the service, where the wage rate $\beta = 0.7$ is obtained from verbal inquiries from Daoway platform employees. Following Bai et al. (2019) and Liu et al. (2019), we assume that the opportunity cost of the supplier is uniformly distributed over $[0, d]$, where $d = 120$. We consider the supplier's benchmark (average) service rate as $u_b = 5$; however, the supplier will decide the optimal service rate u_i based on individual payoff maximization. For each service, the provider will incur a cost $k = 5$, which includes material costs, transportation costs, etc. We assume that there are potential customers $\Lambda = 250$ in the market, and customers' benchmark service value for each service is $q_b = 50$, and customers' sensitivity coefficient for service rate is $\alpha = 10$. Meanwhile, customers incur a unit time waiting cost $c = 10$.[10]

We first consider the changes in the decision for each party in the two market scenarios, including the optimal price decision of the platform, the equilibrium number of participating suppliers, the equilibrium service rate, and the arriving rate. We also consider the changes in the platform's revenue and the payoffs of suppliers. Let $\Lambda \in [100, 400]$, we can obtain Fig. 4 (note that the line on the left side of $\Lambda = n_e\lambda_e$ represents the full market, while the line on the right side represents the partial market).

Note that when the potential arrival rate Λ exceeds the threshold $\Lambda = n_e\lambda_e$, the decisions of suppliers and platform are no longer affected by the number of customers, which is equivalent to a monopoly situation. When the value of Λ is less than the threshold, we know that the smaller the Λ, the smaller the demand market and the more intense the competition between suppliers. First, with the decrease in potential market demand, service suppliers tend to reduce service rates to improve service quality to attract customers. Moreover, as the reduction of potential market demand leads to improved service quality (service rate), the platform tends to raise the service price. Second, we see both service suppliers and platform being able to increase payoffs as the potential market demand increases. This is because the improvement of suppliers' service rate and the customer arrival rate increases the number of customers served by service suppliers and thus increases suppliers' payoffs. Also, increasing customer arrival (customer demand) will increase the platform's revenue.

Next, we consider the impact of α on the optimal decisions of all parties, which helps us understand the impact of the sensitivity of service value to the service rate on the optimal results. From Fig. 5, we can find that the impact of α on the decisions of all parties (i.e., platform and service suppliers) is very different in the two market scenarios. The analysis starts with the full market coverage, where the trend is relatively simple. First, when the customers' sensitivity of service value to the service rate increases, the suppliers reduce the service rate to meet customer service quality needs. In this case, customers will perceive higher service value, and the platform will tend to raise the service price. Second, we find that as α increases, customer arrival rates decrease, although customers receive higher perceived service quality. This is because service suppliers reduce service rates resulting in increased customer waiting time, and the platform increases the service price. Third, with the increase of α, although the service suppliers reduce the service rate and thus reduce the number of customers they can serve, the participating service suppliers can still improve their payoffs due to the increase in the service price. Also, the platform can get more revenue by raising the service price.

Then, we analyze the impact of the sensitivity of customer perceived service value to the service rate on the optimal outcomes in the partial market. First, as α increases, the optimal customer arrival rate, and supplier service rate decrease while the service price increases. This conclusion is the same as that in the full market scenario. We show that the equilibrium service rate is always a

[10] Here, we assume the above parameters are used in all instances unless stated otherwise.

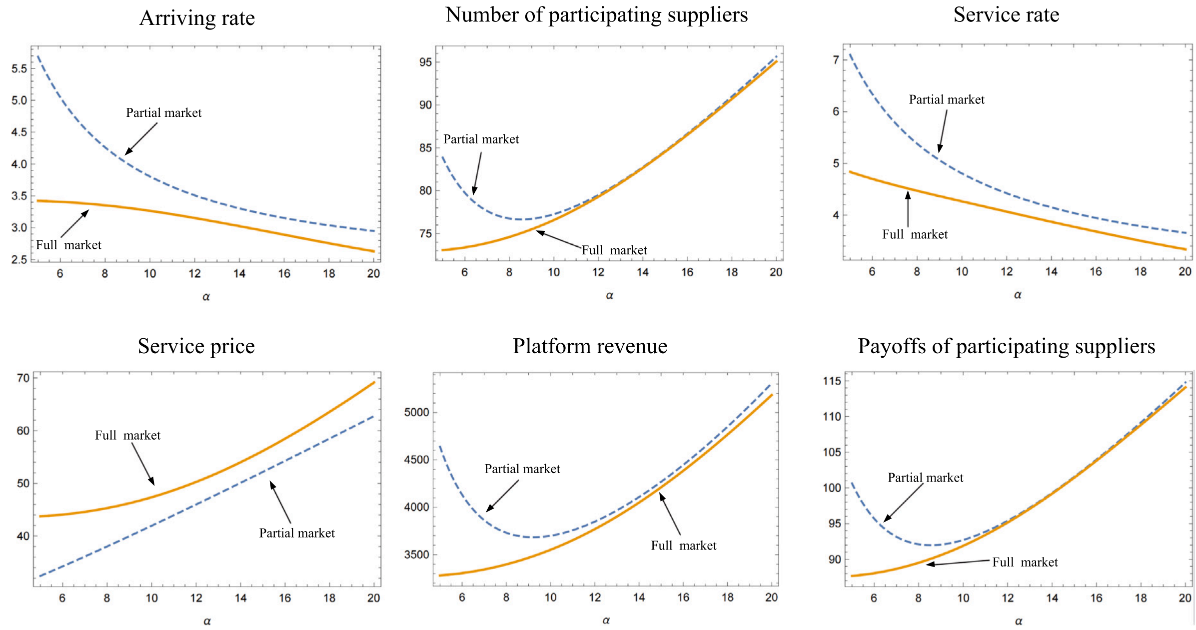

Fig. 5. The effect of α under two market scenarios.

decreasing function of α in both market scenarios. This conclusion is consistent with Anand et al. (2011). Second, we show that the number of participating service suppliers first decreases and then increases with increasing α. Meanwhile, the payoffs of participating service suppliers and platform also decrease and then increase as α increases. A possible explanation is that when the α is relatively small, the reduction in customer arrival rate makes each service supplier serve fewer customers, which reduces the payoffs of the service suppliers and thus the number of participating suppliers. However, when α is relatively large, the reduction of the service rate of the service suppliers and the increase of the service price enables the participating suppliers to obtain more payoffs, which in turn attracts more service suppliers to participate. Similarly, the platform revenue is also affected by the interaction between the number of participating suppliers and the service price, so that it first decreases and then increases with the increase of α. Interestingly, when α is relatively large, we find that the results of the full market and the partial market are almost the same, especially from the suppliers' perspective (see the number of participating suppliers and the payoffs of participating suppliers). This is because for the service suppliers, if the customers have very high requirements for the service value, once suppliers choose to participate, they will face increasingly fierce competition, so they can only continuously reduce their service rate. When the service rate is getting lower and lower, due to the capacity limitation of the full market, only fewer customers can be obtained in a full market compared to in a partial market. However, we can see that the service price of the full market will be higher than that of the partial market, resulting in the same payoffs for the suppliers in the two market scenarios. For the platform, a partial market is always more favorable, especially when the customers have lower sensitivity of the service value to the service rate. Therefore, such platforms should increase their efforts to expand the potential customer market, especially when the market reflects that customers are not that sensitive to the service value to the service rate.

As mentioned above, we assume that the opportunity cost of suppliers is uniformly distributed over $[0, d]$. As d increases, the distribution dispersion of suppliers' opportunity costs increases. From Fig. 6, we can draw the following conclusions. First, we find that when the distribution dispersion is increased, the number of suppliers who choose to participate in the platform will decrease, which is in line with actual practice. This is because the increase of d also means that more service suppliers have higher opportunity costs, which leads to more service suppliers not choosing to join the platform to provide services. Second, once service suppliers choose to participate, the service rate decision of service suppliers in a partial market will no longer be affected by the opportunity cost's distribution dispersion. However, in a full market, service suppliers' service rates increase with d. Third, as d increases, the platform does not change the service price in the partial market but tends to lower the service price in the full market. This is because, in the partial market, the service capacity of the service suppliers has been saturated, and even if the number of participating suppliers decreases, the service suppliers cannot improve the service rate, and the platform will not change the service price. Fourth, in both market scenarios, the platform's revenue continuously decreases as d increases. Meanwhile, with the increase of d, the payoffs of participating suppliers remain unchanged in the partial market but first increase and then decrease in the full market.

Furthermore, we consider the impact of the service suppliers' service cost k on the optimal results. As shown in Fig. 7, we have the following conclusions. First, it is easy to understand that as the service cost increases, the number of suppliers who choose to participate in the platform will decrease in both market scenarios. Second, in a partial market, as the service cost of service

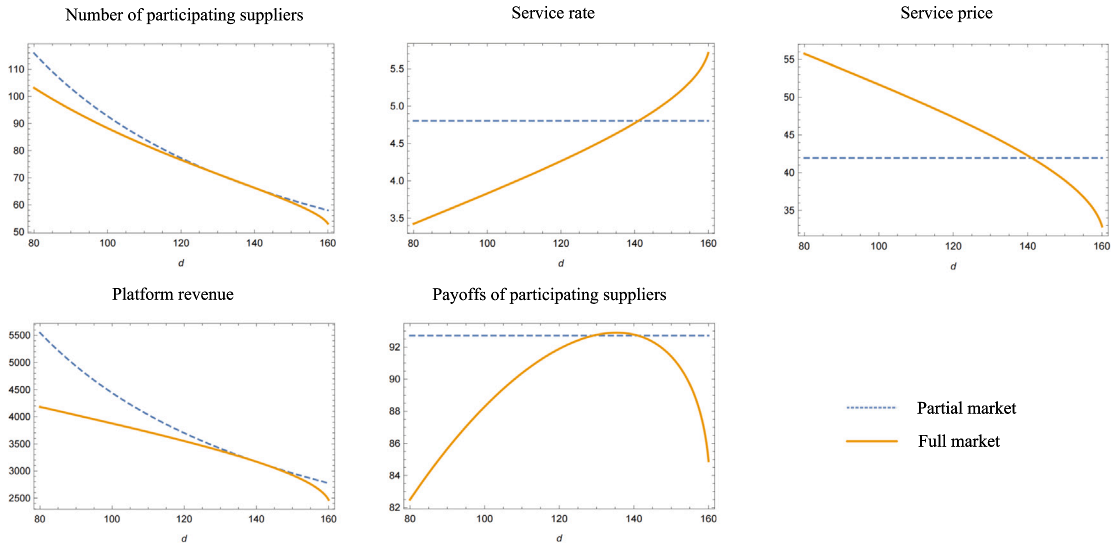

Fig. 6. The effect of d under two market scenarios.

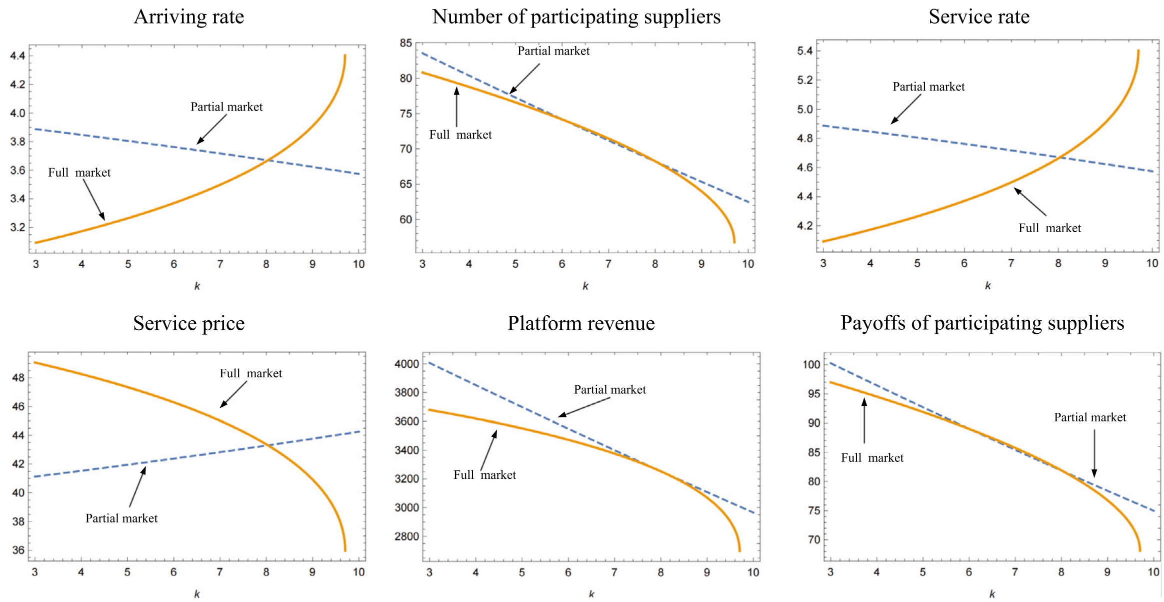

Fig. 7. The effect of k under two market scenarios.

suppliers increases, the platform tends to increase the service price, while service suppliers tend to reduce the service rate, and the optimal arrival rate also decreases. However, in a full market, as the service cost of service suppliers increases, the platform tends to lower the service price, the service suppliers tend to increase the service rate and the optimal arrival rate increases. In both market scenarios, due to the difference in potential market demand, the platform and the service suppliers will make opposite optimal decisions, resulting in opposite trends in the optimal arrival rate. In the two market scenarios, the platform will choose different pricing strategies to cope with the decrease in the number of service suppliers. The reason for this difference is that in a full market, the number of potential customers is limited. The loss of customers has a greater impact on the platform. The platform's focus is to increase the number of customers that can be served per unit time. In a partial market, the number of potential customers is vast, and the impact of losing suppliers is more significant. Higher service prices and lower service rates are more profitable for the service suppliers. Because, as shown in Fig. 5, the service suppliers only need to reduce the service rate slightly. As a result, the platform tends to raise the price to retain service suppliers. Finally, as the service cost of service suppliers increases, the payoffs of the platform and the service suppliers will decrease in both market scenarios.

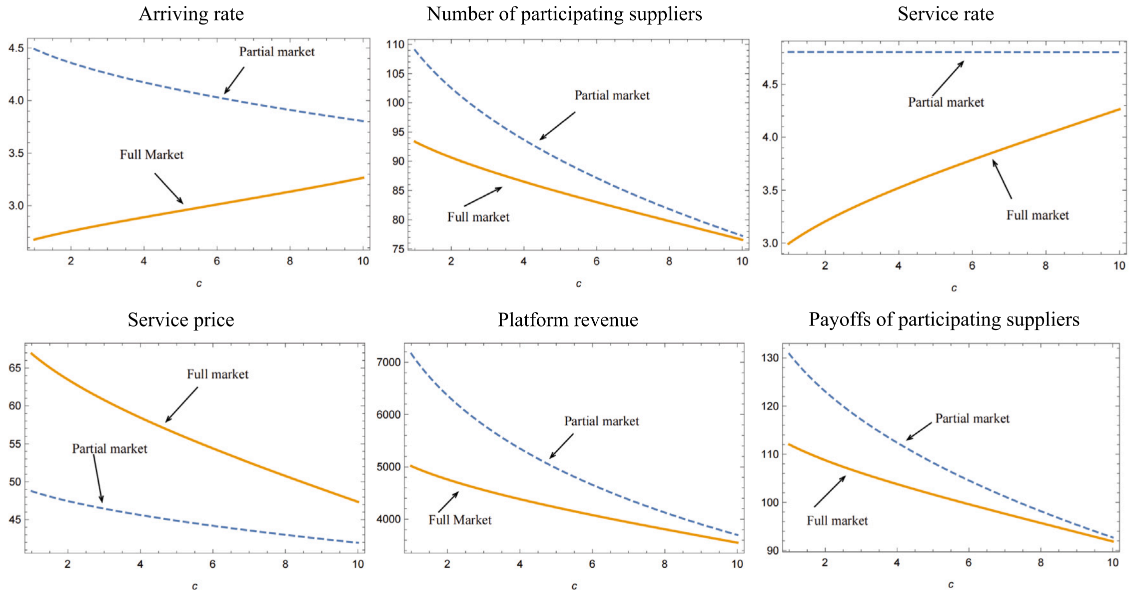

Fig. 8. The effect of c under two market scenarios.

Finally, we examine the impact of customer unit waiting cost c on the optimal results. From Fig. 8, we find that in the full market scenario, as the customer waiting cost increases, the equilibrium service rate of service providers increases. Also, the platform tends to lower the service price to attract more customers. However, the number of participating service suppliers will decrease when affected by the service price and service rate. In the partial market scenario, the equilibrium service rate of service suppliers fluctuates very little as the customer waiting cost increases. However, unlike the full market scenario, the arrival rate of customers is still lower even though the platform also tends to lower the service price. This is because there are sufficient potential customers in the partial market. The decrease in the number of participating service suppliers will increase the customer waiting time, thus decreasing the customer arrival rate. In both market scenarios, platform and service suppliers' payoffs decrease as the customer waiting cost increases.

7. Conclusion

The conventional housekeeping service system has drawbacks such as weak matching ability, low selectivity, and inability to guarantee service quality. On-demand service platforms connecting housekeeping service suppliers and customers have shown up, aiming to quickly and efficiently integrate decentralized housekeeping service resources and customer requests. This paper focused on housekeeping services charged by the per-service price, study the supply–demand balance, platform pricing, and equilibrium decisions among suppliers and customers. This paper aims to provide a better understanding of the operations of such platforms and provide practical management suggestions to platform operators.

This paper reveals that the market type will fundamentally affect the optimal equilibrium decision of the platform. For the customers, whether in a partial or full market, their surplus will be completely extracted. For the suppliers, a partial market is better than a full market in most cases. This is because, in a partial market, the suppliers have greater market capacity. They can extract the entire surplus of customers by changing the service rate. Due to fierce competition, they need to give away a portion of their payoffs to the customers in a full market. Although the suppliers follow a revenue-giving behavior in a full market, the customers do not get its surplus. Because the platform again extracts the customers' surplus by setting the price. Therefore, the platform actively extracts the customers' surplus in a full market. While in a partial market, the platform does it passively. From the perspective of customers, decentralized decision-making on service prices by suppliers or the introduction of multiple platforms of the same type to compete can improve the expected utility for customers.

Meanwhile, this paper reaches some interesting conclusions through a series of numerical analyses. First, when the potential demand market becomes larger, the platform will choose to lower prices to attract more suppliers and more customers at the same time. Second, when the customers are more sensitive to the service quality, the equilibrium number of suppliers in a full market shows an upward trend. This is because as customer sensitivity to service quality increases, the platform increases the service price, which will increase the supplier's payoff. In a partial market, the equilibrium number of suppliers decreases first and increases as the customer sensitivity to service quality increases. Compared to a full market, the reason for the result difference is that when α is small, suppliers need to significantly reduce the service rate to gain more customers, resulting in a decline in the payoff. However, when α is large, the suppliers' payoff in the full market is the same as in a partial market, which leads to the same conclusion in both market scenarios. Third, we find that the equilibrium number of suppliers always decreases as the opportunity cost distribution dispersion increases, as does the platform's revenue. The participating suppliers' decisions in a partial market are not affected by the distribution dispersion, so the platform's price setting is not affected. The suppliers in a full market have a lower market power than in a partial market, and their decision after participating will be affected by the distribution dispersion. Finally, as the service cost increases, the equilibrium number of suppliers, the payoff of suppliers, and the platform's revenue will decrease. As the service cost increases, the platform will use different price strategies (i.e., raise service price or lower service price) to maximize revenue in the different market scenarios.

With the above analysis, we derive the following management insights. First, the platform's optimal price is a non-increasing function of potential demand when given a wage rate. In the case of increasing demand, the platform needs to reevaluate its current pricing scheme when making pricing decisions under partial market and cannot simply choose a high price. Second, when the potential demand is high, the platform should shift its focus from customers to independent service suppliers, especially when the service cost of suppliers is high; it can retrieve suppliers by increasing the service price. Third, for an on-demand service platform with customers who are highly sensitive to service rates, it can satisfy customers' demand by setting the higher price to attract more suppliers and reduce the service rate, eventually leading to higher payoffs.

We conclude by pointing out some limitations of our model and potential directions for future research. First, to simplify the model analysis and obtain an explicit solution, we assume that the opportunity cost of suppliers is uniformly distributed. However, in reality, the distribution of supplier opportunity costs may be more complex, and therefore considering the opportunity costs in other forms may obtain more interesting conclusions. Second, we assume that each service supplier will only serve one platform. In reality, many service suppliers will provide service through two (or more) platforms. It is worth exploring how this behavior of service suppliers will affect platform pricing and quality strategies, and customer behavior. Third, we assume that all service suppliers with the same technical level and proficiency. Because the technical threshold of housekeeping services is relatively low, we ignore the differences in suppliers' technical level and proficiency in our model. Then, it is worth further exploring the impact on platform performance when the supplier's skill level is heterogeneous.

CRediT authorship contribution statement

Jianjun Yu: Conceptualization, Visualization, Supervision. **Yanli Fang:** Conceptualization, Methodology, Software, Writing – original draft. **Yuanguang Zhong:** Methodology, Visualization, Validation, Supervision. **Xiong Zhang:** Methodology, Software, Writing – review & editing. **Ruijie Zhang:** Visualization, Investigation, Validation.

Data availability

No data was used for the research described in the article.

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Appendix

Proof of Proposition 1

Note that the wage rate set by the platform is an exogenous variable. We first try to find the first-order derivative of the platform's revenue with respect to the per-service price p. We have

$$\frac{d\Pi_p}{dp} = \frac{N(1-\beta)}{d}[(\beta p - k)\lambda_e^2 + \beta p \lambda_e^2 - \frac{2(\beta p - k)p\lambda_e}{\alpha}], \tag{17}$$

We find that the first-order derivative of the platform revenue crosses zero for one time at the point $\lambda_e = 0$, which is $p_1 = q_b + \alpha\mu_b - 2\sqrt{\alpha c}$ on the other hand. However, when the on-demand platform decides to set the optimal price as p_1, no demand will come, the on-demand platform will never accept this price.

Besides p_1, the first-order derivative of the platform revenue crosses zero when the following equation holds:

$$(\beta p - k)\lambda_e + \beta p \lambda_e - \frac{2(\beta p - k)p}{\alpha} = 0. \tag{18}$$

By substituting $\lambda_{e1} = \frac{q_b + \alpha\mu - 2\sqrt{\alpha c} - p}{\alpha}$ and $\theta = q_b + \alpha\mu_b - 2\sqrt{\alpha c}$ into the above equation, we can obtain the following equation.

$$(\beta p - k)(\theta - 3p) + \beta p(\theta - p) = 0. \tag{19}$$

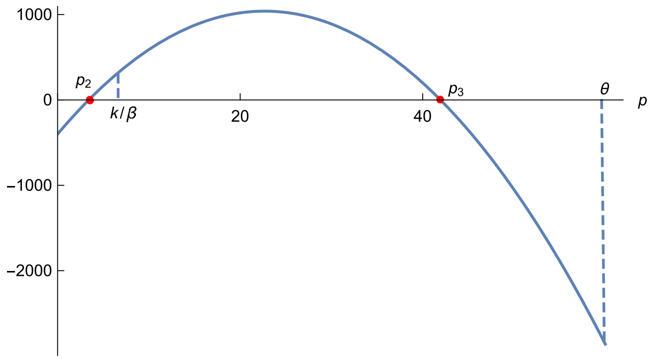

Fig. 9. The optimal per-service price decision for on-demand platform in a partial market. Parameters: $q_b = 50$, $\alpha = 10$, $u_b = 5$, $c = 10$, $k = 5$, $\beta = 0.7$.

There are two solutions for the above equation: $p_2 = \dfrac{2\beta\theta + 3k - \sqrt{(2\beta\theta + 3k)^2 - 16k\beta\theta}}{8\beta}$ and $p_3 = \dfrac{2\beta\theta + 3k + \sqrt{(2\beta\theta + 3k)^2 - 16k\beta\theta}}{8\beta}$. The revenue of the on-demand platform Π_p is decreasing in p for $p \leq p_2$ and $p \geq p_3$ while increasing in p for $p_2 < p < p_3$. When p_3 is within the range of $(\frac{k}{\beta}, \theta)$, which is a result of the two restrictions in Eq. (11), it will be the optimal price decision for the on-demand platform.

Next we will prove p_3 is within range $(\frac{k}{\beta}, \theta)$. We first take $p = \frac{k}{\beta}$ into the first-order derivative of the platform's revenue $\Pi_p'(p)$, we have

$$\Pi_p'(\frac{k}{\beta}) = k(\theta - \frac{k}{\beta}), \tag{20}$$

and apparently $\Pi_p'(\frac{k}{\beta}) > 0$. Then, we substituting $p = \theta$ into $\Pi_p'(p)$, we have

$$\Pi_p'(\theta) = (\theta\beta - k)(\theta - 3\theta), \tag{21}$$

We can easily prove that $\Pi_p'(\theta) < 0$. Fig. 9 shows the first-order derivative of the platform's revenue with respect to the per-service price p and the relative position of $(p_2, \Pi_p'(p_2))$, $(p_3, \Pi_p'(p_3))$, $(\theta, \Pi_p'(\theta))$, $(\frac{k}{\beta}, \Pi_p'(\frac{k}{\beta}))$.

Fig. 9 depicts that $\Pi_p'(\frac{k}{\beta}) > 0$, $\Pi_p'(\theta) < 0$ and p_3 is within range $(\frac{k}{\beta}, \theta)$, which means $p = p_3$ is the optimal decision for the on-demand platform. ■

Proof of Lemma 1

We first analyze the relationship between service utility and service rate in a full market and find out if there are any equilibrium service rates. The first-order derivative of each participating customer's utility with respect to service rate u_i is $\frac{\partial U_i(u_i,\lambda_i)}{\partial u_i} = -\alpha + \dfrac{c}{(u_i - \lambda_i)^2}$, and the second-order derivative of the each participating customer's utility is

$$\frac{\partial^2 U_i(u_i, \lambda_i)}{\partial u_i^2} = -\frac{2c}{(u_i - \lambda_i)^3}$$

We know that $\dfrac{\partial^2 U_i(u_i, \lambda_i)}{\partial u_i^2}$ is always negative when $u_i > \lambda_i$, which means $U_i(u_i, \lambda_i)$ is a strictly concave function about u_i (see Fig. 9). After calculation, the two real roots are $\underline{u}$ and $\overline{u}$, respectively. Within range$[\underline{u}, \overline{u}]$, the utility for customers is non negative. Recall that the equilibrium situation satisfies $U_i(u_i, \lambda_i) = U_j(u_j, \lambda_j) \geq 0, (0 < \lambda_i < u_j, 0 < \lambda_j < u_j)$ in a full market, which states any point in this interval is a possible equilibrium service rate, but whether these equilibriums are stable requires further analysis. ■

Proof of Lemma 2

The proof of this lemma is straightforward, and thus the details are omitted here. ■

Proof of Proposition 2

The proof of this proposition is similar to that of Proposition 1, and thus the details are omitted here. ■

Proof of Proposition 3

The proof of this proposition is straightforward, and thus the details are omitted here. ■

Proof of Proposition 4

The payoff of an individual participating supplier Π_s is $\Pi_s = \lambda_e(\beta p - k)$, which means the surplus of all participating suppliers S_s is equal to $S_s = n_e \Pi_s$. The objective function of the platform is $\Pi = \Pi_p + \gamma(S_c + S_s) = n_e\lambda_e[(1-\beta)p + \gamma(\beta p - k)]$. To obtain the optimal price of the platform, we first find the first-order derivative function of the total residual with respect to price p. $\frac{d\Pi}{dp} = \lambda_e \frac{N}{d\alpha}[-\theta kt - 2\gamma k^2 + p(2\beta\gamma k + 2s(\beta\theta + k) + kt) - 4s\beta p^2]$. Denote $-\theta kt - 2\gamma k^2 + p(2\beta\gamma k + 2s(\beta\theta + k) + kt) - 4\beta s p^2$ as $\nabla(p)$. Let $\frac{d\Pi}{dp} = 0$, we have $\lambda_e = 0$ and $\nabla(p) = 0$. The on-demand platform will never accept this price when $\lambda_e = 0$ because no demand will come if they do so. The two solutions, denoted as $p1$ and $p2$, for $\nabla(p) = 0$ are two stationary points.

$$p1 = \frac{-\sqrt{(k(2\beta\gamma + 2s + t) + 2\beta\theta s)^2 - 16\beta ks(2\gamma k + \theta t)} + k(2\beta\gamma + 2s + t) + 2\beta\theta s}{8\beta s},$$

$$p2 = \frac{\sqrt{(k(2\beta\gamma + 2s + t) + 2\beta\theta s)^2 - 16\beta ks(2\gamma k + \theta t)} + k(2\beta\gamma + 2s + t) + 2\beta\theta s}{8\beta s}.$$

We can easily find that when $p < p1$ and $p > p2$, Π is a strictly decreasing function of p. However, when $p1 \le p \le p2$, Π is a strictly increasing function of p. Next, we figure out whether $p2$ is in the feasible domain. As mentioned in Section 4.2, p is within $[\frac{k}{\beta}, \theta]$. When $p = \frac{k}{\beta}$, we have

$$\nabla(\frac{k}{\beta}) = 2ks\left(\theta - \frac{k}{\beta}\right) + kt\left(\frac{k}{\beta} - \theta\right) = \left(\theta - \frac{k}{\beta}\right)(2ks - kt).$$

This is because $\frac{k}{\beta} < \theta$ and $0 < \beta < 1$, $\nabla(\frac{k}{\beta}) > 0$ always holds. When $p = \theta$, we have

$$\nabla(\theta) = 2\beta(-\gamma k\frac{k}{\beta} + \gamma\theta k + ks\frac{\theta}{\beta} - \theta^2 s) = 2\beta\left(\frac{k}{\beta} - \theta\right)(\theta s - \gamma k).$$

For $\theta > k \ge 0$ and $s > \gamma \ge 0$, so $\theta s - \gamma k$ is always positive. Therefore, $\nabla(\theta) < 0$ holds, which means $p2$ is within the feasible domain while $p1$ is not. To sum up, the optimal price $p_1^* = p2$. ■

Proof of Proposition 5

Similarly, we first find the first-order derivative of the platform's objective function with respect to price and let it equal 0 when $\gamma \in (0,1)$. Then we have

$$\bar{p} = [(\frac{\gamma\alpha\beta\sqrt{\Lambda d/N}}{2(\gamma-1)(1-\beta)})^{\frac{2}{3}} + k]/\beta.$$

We can find that when $p \le \bar{p}$, Π increases with p. When $p > \bar{p}$, Π decreases with p. Then, $p = \bar{p}$ will make a maximum Π. It is easy to know $\bar{p} > k/\beta$, which means $\bar{p}\beta - k > 0$. And we need to make sure $U(\bar{p}) \ge 0$. In Section 4.2, we have shown $U(p) \ge 0$ when $p_4 \le p \le p_5$. So the optimal price for the platform is $\bar{p}$ if $\bar{p} \in [p_4, p_5]$. However, when $\bar{p} < p_4$, $U(\bar{p})$ is negative, the utility for participating customers should be non-negative and total welfare Π is decreasing with p when $p > \bar{p}$. The platform will choose p_4. Correspondingly, when $\bar{p} > p_5$, p_5 is the optimal price.

Next, we will explore the relation between $\bar{p}$ and γ.

$$\frac{d\bar{p}}{d\gamma} = -\frac{2}{3\beta}[\frac{\alpha\beta\gamma\sqrt{\Lambda d/N}}{2(\gamma-1)(1-\beta)}]^{-\frac{1}{3}}\frac{2\alpha\beta\sqrt{\Lambda d/N}(1-\beta)}{4(1-\gamma)^2(1-\beta)^2} < 0.$$

When γ increases, $\bar{p}$ increases.

The above discusses the situation when $\gamma \in (0,1)$. When $\gamma = 0$, it means the platform does not care about social welfare at all. This is the same as in Section 4.2. In this case, the optimal price is p_5. When $\gamma = 1$, the platform believes that social welfare is as important as platform revenue. The objective function becomes

$$\Pi = \Lambda(p - \beta p + \beta p - k + \theta - \alpha\sqrt{\frac{d\Lambda}{N(\beta p - k)}} - p) = \Lambda(-k + \theta - \alpha\sqrt{\frac{d\Lambda}{N(\beta p - k)}}),$$

which is an increasing function with respect to p. Meanwhile, p needs to satisfy $\beta p - k \ge 0$ and $U(p) \ge 0$. So the platform will set p_5 as the optimal price. ■

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