Marketplace Scalability and Strategic Use of Platform Investment

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Abstract

The scalability of a marketplace depends on the operations of the marketplace platform as well as its sellers' capacities. In this study, we explore one strategy that a marketplace platform can use to enhance its scalability: providing an ancillary service to sellers. In our model, a platform can choose whether and when to provide this service to sellers and, if so, what prices to charge and which types of sellers to serve. While such a service helps small sellers, we highlight that the provision of such a service can diminish the incentives of large sellers to make their own investment, thereby reducing their potential output. When the output reduction by large sellers is substantial, the platform may not want to provide the ancillary service and, even if it does, it may choose to set a price higher than its marginal cost to motivate large sellers to scale. The platform may also choose to strategically delay the provision of the service.

Keywords: marketplace, scalability, platform strategy, platform investment

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1 Introduction

Marketplace platforms such as Airbnb, Craigslist, eBay, Uber, and Upwork have become increasingly influential in the global economy (e.g., Rochet and Tirole 2003; Iansiti and Levien 2004; Parker and Van Alstyne 2005; McIntyre and Srinivasan 2017). These platforms attract and facilitate transactions between buyers and sellers. One well-known feature of such marketplaces is their scalability. Previous research has focused on two sources of scalability. The first is rooted in indirect network effects, whereby a large number of buyers attracts more sellers and vice versa. The second is technological and hinges on the classic leveraging of fixed costs; once the requisite technological infrastructure is deployed (e.g., software and servers), a marketplace platform can serve additional transactions at trivial marginal costs.

The scalability of a marketplace, however, does not merely depend on the operations of the platform. The capacities of sellers can also constrain the scalability of the marketplace. In particular, small sellers (e.g., individuals selling products from their homes) may have limited capacity to increase their supply. Furthermore, even large sellers often need to incur additional costs to scale, such as renting storage space and purchasing software to manage logistics and after-sales services. In such cases, sellers' capacities constrain the scalability of the marketplace. As the business models of most platforms critically depend on the overall volume of transactions that flow through them, they must design their platforms with scalability in mind.

In this paper, we explore one strategy that a marketplace platform could use to enhance its scalability: providing an ancillary service to sellers that helps them to reduce the costs of running their business. For example, Amazon, Walmart, and Alibaba offer logistics and distribution services to third-party sellers, thereby allowing third-party sellers to use those platforms without incurring investments in warehouses and distribution capabilities. Didi, the dominant ride-sharing platform in China, leases vehicles to individuals who wish to drive for it. Such services, however, are not universally offered by all platforms and appear to involve strategic considerations. Certain marketplace platforms, such as Airbnb and Pinduoduo, do not offer such services. eBay, a pioneer in the e-commerce market, only recently began offering such a service.[1]

Why do some marketplace platforms choose to offer such services, but others do not or delay offering such services? When they do, what prices should they charge for these services? How does seller scalability (i.e., sellers' ability to offer such services themselves) affect such decisions? In this paper, we build a game-theoretical model to explore these questions. In our model, a continuum of sellers with different capacities is interested in entering the market and selling their products on a marketplace platform. All sellers need to use an ancillary service that is essential for transactions. The service can be purchased from a market or from the platform when it is offered. The platform decides whether or not to offer the service and the price of the service if it is offered. Importantly, we consider the scenario in which the sellers can also make an investment to provide the service themselves, which results in a low marginal cost and enables them to scale their production. We

[1] Our personal conversations with Pinduoduo confirm that its executives have deliberated over whether or not to offer a fulfillment service to its marketplace sellers but have chosen not to offer it at the moment.

refer to this scenario as the "scalable scenario" and analyze how this scalability affects the outcome of the game.

We show that, when the sellers cannot scale, their total output increases when the platform provides the service. In contrast, the provision of the platform service may decrease the total output when the sellers can scale. This output reduction effect arises because, when the platform offers the service, it diminishes the sellers' incentives to invest in their own services, thereby resulting in a higher marginal cost and lower total output.

We then explore the implication of the output reduction effect on the platform's decision to offer the ancillary service and the price it charges for this service. We show that, in general, the scalability of sellers makes the platform less likely to offer the service. Even if the platform offers the service, the scalability affects its pricing strategy. Relative to the non-scalable scenario, the platform may either increase its price to induce sellers with high capacities to invest in their ancillary services to scale or decrease its price to attract more sellers to enter the market. In particular, when the platform increases its price, it will set a price that is above its marginal cost. This result contrasts with the conventional wisdom that when a firm offers two complementary products (e.g., razors and blades), it is often optimal for the firm to offer one product below marginal cost in order to maximize total profit. Surprisingly, the scalability of large sellers may facilitate the entry of small sellers by encouraging the platform to set a low price.

We also find that, when network effects are sufficiently strong, the composition of the sellers influences the platform's decision to offer the ancillary service. In particular, when there are many large sellers, stronger network effects reduce the platform's incentive to offer the ancillary service. Finally, in a two-period model, we find that it can be optimal for the platform to delay offering the service in the second period only because the delay induces large sellers to invest in the ancillary service on their own in the first period.

Overall, our research shows that platform investment in ancillary services can change the composition and output levels of sellers that participate on the platform by altering sellers' cost structures and capacities. Importantly, the scalability of the sellers also affects the platform's investment and pricing decisions. Our research also shows that the timing of such platform investment is an important consideration for maximizing marketplace scalability.

Our work adds to the extant literature on platform strategies. Early work in this area has primarily focused on two-sided pricing strategies (e.g., Caillaud and Jullien 2003; Rochet and Tirole 2003; Parker and Van Alstyne 2005; Armstrong 2006; Rysman 2009; Weyl 2010; Jin and Rysman 2015). More recent studies have examined a variety of non-price strategic levers that platforms can use to grow their businesses, such as the strategic revelation of information (e.g., Tucker and Zhang 2010; Chellappa and Mukherjee 2021; Niculescu et al. 2018), the use of different business models (e.g., Economides and Katsamakas 2006; Hagiu and Wright 2014; Chen et al. 2016), product versioning (e.g., Bhargava et al. 2013), contractual relationships with third parties (e.g., Lee 2013; Hao et al. 2017), adjusting the degree of openness (e.g., Parker and Van Alstyne 2018; Huang et al. 2020), direct entry into third-parties' spaces (e.g., Gawer and Henderson 2007; Jiang et al.

2011; Huang et al. 2013; Hagiu and Spulber 2013), encouraging the participation of complementors (particularly small complementors, thus weakening the power of large ones) (e.g., Bhargava et al. 2021; Chen and Wu 2012; Hagiu and Wright 2020; Nagaraj and Piezunka 2018; Luo et al. 2018; Hukal et al. 2020), and entry into a new or adjacent market (e.g., Eisenmann et al. 2011; Zhu and Iansiti 2012).

A subset of this literature has examined platform investment decisions. Bakos and Katsamakas (2008) investigate a platform's optimal investment decision in creating network effects. Anderson et al. (2014) point out that, in industries such as the video game industry, a platform may not want to invest in platform performance because a high-performance platform discourages developers from participating. Tan et al. (2020) explore how platform investment in integration tools interacts with a platform's pricing decisions. Basu et al. (2019) and Chellappa and Mukherjee (2018) examine a platform's decision to offer authentication services. Bhargava (forthcomingb) studies how platforms can use infrastructure improvements to motivate content creators to supply more content. Huang et al. (2018) show that a platform's investment in knowledge seeding increases its users' knowledge contribution. Cui et al. (2020) show the value of investing in logistic services for e-commerce platforms. A few studies on net neutrality have examined internet service providers' incentives to expand network capacity and how such expansion affects content providers and consumers (e.g., Choi and Kim 2010; Cheng et al. 2011; Krämer and Wiewiorra 2012). Unlike these studies, in which only the platforms can make investments, both a platform and sellers can invest in the same service in our setting, and the timing of such an action can also be a strategic decision. In addition, our paper considers heterogeneous sellers who can decide their own output levels.

The remainder of the paper is organized as follows. Section 2 describes the model. Section 3 presents the main results. Section 4 extends the model. Section 5 concludes by discussing the managerial implications and future research opportunities. Table 1 provides the list of variables and their definitions, and the appendix provides all technical proofs.

2 The Model

2.1 The market

The market consists of a monopoly platform and potential sellers of mass one selling goods on the platform. The fixed entry cost to the market is f for each seller. The platform charges a commission rate of α for goods sold by the sellers on the platform. If the seller sells q unit of goods, and the total quantity of goods sold on the platform is denoted as Q, the seller earns a revenue of $R(Q, q)$. Note that because of network effects, more sellers can increase competition among sellers but can also attract more buyers, which result in more quantity sold. As a result, the revenue of each individual seller may be positively or negatively affected by the aggregate quantity purchased by consumers, depending on the relative strength of competition and network effects.[2] Consequently, both effects jointly influence a seller's entry decision. Denote $D(Q, q) = R'_q(Q, q)$.

[2] Other theoretical studies have used similar assumptions. See Bhargava (forthcominga) for an example.

Table 1: List of variables and their definitions

Variables	Definitions
q	Quantity of products sold by a seller.
Q	Total quantity of products sold.
$R(Q, q)$	The revenue function for sellers.
$D(Q, q)$	The marginal revenue function for sellers.
k	The capacity of each seller.
$G(k)$	The cumulative distribution function for sellers' capacities.
$\bar{k}$	The upper bound for sellers' capacities.
α	The commission rate.
$\bar{c}$	The marginal cost of the market service.
$\underline{c}$	The marginal cost of a seller's own service.
c	The marginal cost of the platform service.
p	The price of the platform service.
f	Sellers' fixed cost of entering the market.
F	Sellers' total fixed cost of entering the market and investing in own services.
TR	Total revenue earned by sellers.
Q^p	Total quantity of products sold using the platform service.
I	The platform's investment for providing the platform service.
I_N	The cutoff investment level for the platform in the non-scalable scenario.
I_S	The cutoff investment level for the platform in the scalable scenario.
$q^*(Q, p)$	The optimal level of production for sellers without capacity constraints.
$q_e(Q, p)$	The threshold for sellers to enter the market.
$q_s(Q, p)$	The threshold for sellers to be indifferent between platform service and own services.
Q_n	Total quantity of products sold in the non-scalable scenario without the platform service.
Q_s	Total quantity of products sold in the scalable scenario without the platform services.
$Q_N(p)$	Total quantity of products sold in the non-scalable scenario with the platform service.
$Q^p_N(p)$	Total quantity of products sold using the platform service in the non-scalable scenario.
$Q_S(p)$	Total quantity of products sold in the scalable scenario with the platform service.
$Q^p_S(p)$	Total quantity of products sold using the platform service in the scalable scenario.
π_n	The platform's profit in the non-scalable scenario without the platform service.
π_s	The platform's profit in the scalable scenario without the platform service.
$\pi_N(p)$	The platform's profit in the non-scalable scenario with the platform service.
$\pi_S(p)$	The platform's profit in the scalable scenario with the platform service.
$\bar{p}$	The threshold below which all sellers prefer the platform service over their own services in the scalable scenario.

The sellers are differentiated by their capacities. A seller with capacity k can produce up to k units. An alternative interpretation for the capacity is that a seller's marginal cost increases significantly at k so that its *de facto* quantity choice is bounded by k.[3] We assume that k is distributed with a continuous distribution function $G(k)$ over the support $[0, \bar{k}]$.

2.2 Ancillary services

An ancillary service—for example, an order fulfillment service—is required for each transaction. This service can be purchased from the market at a marginal cost of $\bar{c}$.[4] The sellers also have the option to offer this service themselves by making an investment $F - f$ and obtain a lower marginal cost of $\underline{c}$. The assumption captures the sellers' ability to tailor such services to their individual needs. This lower marginal cost enables the seller to scale up and produce more output. When this option is available, we refer to it as a **scalable** scenario, S. Otherwise, we refer to it as a **non-scalable** scenario, N.

Finally, the platform may also offer this service. For example, Amazon offers an order fulfillment service called Fulfillment by Amazon. If it does so, it incurs a fixed investment, I, and obtains a marginal cost, $c \in (\underline{c}, \bar{c})$. The platform charges p per unit for using the ancillary service.

For ease of exposition, we make the following assumption:

Assumption 1. *For any (Q, q):*

a. $R'_Q(Q, q) < 0$, $D'_Q(Q, q) < 0$, $D'_q(Q, q) < 0$;

b. $D(Q, 0) > \frac{\bar{c}}{1-\alpha}$, $R'_q(Q, \bar{k}) \leq 0$.

Assumption 1a follows the usual practice by assuming the revenue function, R, to be concave in quantities sold, q, and the more goods sold on the platform, the fiercer the competition and, thus, the lower the revenue despite the existence of network effects. We examine the opposite scenario in an extension.

Assumption 1b ensures that the sellers entering the market always choose an interior level of output, provided that the platform service would never be priced above $\bar{c}$.

2.3 Timeline

The timing of the game is as follows. First, the platform decides whether to offer the ancillary service and, if so, at what price. Second, the sellers decide whether to enter the market and, if so, which type of services to use among those available and the corresponding quantity to sell. Our solution concept is the sub-game perfect equilibrium.

[3] For example, the seller may have space constraint in its warehouse so that it could only produce up to k units.

[4] In the case of e-commerce platforms, for example, a number of third parties provide fulfillment services: see, for example, `https://www.nchannel.com/blog/3rd-party-fulfillment-services-fulfillment-by-amazon-fba-alternatives/`.

2.4 Sellers' behavior

Without loss of generality, we normalize the sellers' marginal cost of production to zero. Suppose that a seller's capacity constraint is not binding. When the seller uses a service with marginal cost $\tilde{c}$ and anticipates that the total quantity of products sold on the platform would be Q, the seller will choose an output level q to maximize:

$$\max_q (1-\alpha)R(Q,q) - \tilde{c}q.$$

The optimal output level $q^*(Q,\tilde{c})$ is therefore determined by the following first-order condition:

$$(1-\alpha)D(Q, q^*(Q,\tilde{c})) = \tilde{c}. \tag{1}$$

For ease of exposition, we make the following assumption:

Assumption 2. *For any $Q \geq 0$,*

$$0 < (1-\alpha)R(Q, q^*(Q,\bar{c})) - \bar{c}q^*(Q,\bar{c}) - f \ < (1-\alpha)R(Q, q^*(Q,\underline{c})) - \underline{c}q^*(Q,\underline{c}) - F. \tag{2}$$

Assumption 2 describes the behavior of sellers with sufficiently high capacities (and thus their optimal quantity is below their capacities) when the platform does not offer the service. The first inequality implies that these sellers prefer entering the market even if they have to use the market service. The second inequality implies that, when they can scale, these sellers prefer to do so and to use their own services over the market service.

2.5 Objectives

Formally, let TR denote the total revenue earned by all sellers. If the platform does not provide the ancillary service, it maximizes αTR. Whereas if the platform provides the ancillary service and charges a price p for each unit of goods served, it maximizes $\alpha TR + (p-c)Q^p - I$, where Q^p denotes the total quantity of products sold using the platform service and I denotes the platform's investment cost.

3 Analysis

In Section 3.1, we derive sellers' equilibrium decisions. In Section 3.2, we examine the platform's equilibrium decision—that is, whether the platform provides the service or not and, if it does, the price it charges for the service.

3.1 Sellers' equilibrium decisions

There are four scenarios to consider, depending on whether or not the platform provides the service and whether or not the sellers can scale.[5] We analyze sellers' behavior in three steps in each scenario. First, assuming that a seller enters, we derive the optimal quantity it produces. Second, we determine whether the seller will enter, depending on its capacity. Third, since sellers' entry decisions in equilibrium determine as well as depend on the total quantity (Q), we calculate the equilibrium total quantity.

3.1.1 Non-scalable sellers without the platform service

In this scenario, the sellers cannot scale and the platform service is unavailable. If a seller of capacity k enters the market and chooses a quantity $q \leq k$, its payoff is given by

$$(1-\alpha)R(Q,q) - \bar{c}q - f. \tag{3}$$

Note that if k exceeds $q^*(Q,\bar{c})$, the optimal quantity that maximizes Equation (3), the seller will produce $q^*(Q,\bar{c})$. Otherwise, it will produce k. By Assumption 2, sellers that produce $q^*(Q,\bar{c})$ have a positive payoff. Therefore, sellers with capacity $k \geq q^*(Q,\bar{c})$ will enter the market and have the same payoff, $(1-\alpha)R(Q,q^*(Q,\bar{c})) - \bar{c}q^*(Q,\bar{c}) - f$. For sellers with capacity $k < q^*(Q,\bar{c})$, their payoff, $(1-\alpha)R(Q,k) - \bar{c}k - f$, will increase in k. Define $q_e(Q,\bar{c})$ as the threshold quantity that satisfies

$$(1-\alpha)R(Q,q_e(Q,p)) - \bar{c}q_e(Q,\bar{c}) - f = 0.$$

It follows that sellers with $k < q_e(Q,\bar{c})$ will not enter the market. In addition, sellers with capacity $k \geq q_e(Q,\bar{c})$ will enter the market and produce $\min\{k, q^*(Q,\bar{c})\}$. Figure 1 illustrates seller payoff and entry decisions.

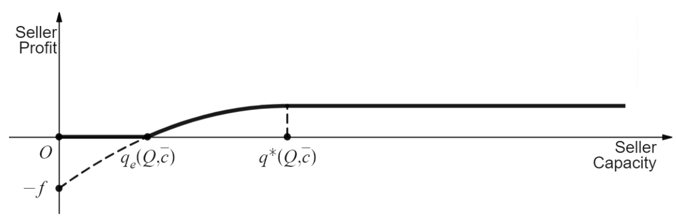


Figure 1: Seller payoff: Non-scalable sellers without the platform service

Define Q_n as the equilibrium total quality. Therefore, Q_n must satisfy the following:

$$Q_n = \int_{q_e(Q_n,\bar{c})}^{q^*(Q_n,\bar{c})} k dG(k) + \int_{q^*(Q_n,\bar{c})}^{\bar{k}} q^*(Q_n,\bar{c}) dG(k). \tag{4}$$

In Equation (4), Q_n appears on both sides of the equation. As Q_n increases, the LHS of the equation increases. For the RHS, $q^*(Q_n,\bar{c})$ decreases and $q_e(Q_n,\bar{c})$ increases with Q_n by Assumption

[5]The terms we use in the analysis below, "scalable" and "non-scalable," refer to seller scalability.

1, which implies that individual sellers' quantity decreases with the total quantity. As a result, the RHS decreases with Q_n. Thus, there is a unique solution to Equation (4).

Lemma 1 summarizes the discussion above.

Lemma 1. *When the platform does not provide the service and the sellers cannot scale, there exists a unique equilibrium such that:*

a. Sellers with $k < q_e(Q_n, \bar{c})$ do not enter the market;

b. Sellers with $q_e(Q_n, \bar{c}) \leq k < q^*(Q_n, \bar{c})$ use the market service and produce k;

c. Sellers with $k \geq q^*(Q_n, \bar{c})$ use the market service and produce $q^*(Q_n, \bar{c})$;

d. The equilibrium total quantity Q_n is determined by Equation (4).

It follows from Lemma 1 that the platform profit is given by

$$\pi_n = \alpha \left[\int_{q_e(Q_n,\bar{c})}^{q^*(Q_n,\bar{c})} R(Q_n, k) dG(k) + \int_{q^*(Q_n,\bar{c})}^{\bar{k}} R(Q_n, q^*(Q_n, \bar{c})) dG(k) \right].$$

3.1.2 Non-scalable sellers with the platform service

In this scenario, the sellers cannot scale and the platform provides the service at price p. Note that when $p > \bar{c}$, the platform service is dominated by the market service and thus no sellers would use it. In this case, the equilibrium outcome is identical to the previous scenario.

When $p \leq \bar{c}$, all sellers will use the platform service. If a seller of capacity k enters the market and chooses a quantity $q \leq k$, its payoff is given by

$$(1 - \alpha) R(Q, q) - pq - f. \tag{5}$$

As in the previous scenario, if k exceeds $q^*(Q, p)$—the optimal quantity that maximizes Equation (5)—the seller will produce $q^*(Q, p)$. Otherwise, it will produce k. By Assumption 2, sellers that produce $q^*(Q, p)$ have a positive payoff. Sellers with capacity $k \geq q^*(Q, p)$ will therefore enter the market and have the same payoff. For sellers with capacity $k < q^*(Q, p)$, their payoff will increase in k. Define $q_e(Q, p)$ as the threshold quantity that satisfies

$$(1 - \alpha) R(Q, q_e(Q, p)) - pq_e(Q, p) - f = 0.$$

Again, as in the previous scenario, sellers with $k < q_e(Q, p)$ will not enter the market, and sellers with capacity $k \geq q_e(Q, p)$ will enter the market and produce $\min\{k, q^*(Q, p)\}$. Note that when $p < \bar{c}$, $q^*(Q, p) > q^*(Q, \bar{c})$ because the sellers' marginal cost is lower. In addition, $q_e(Q, p) < q_e(Q, \bar{c})$, as entering the market is now more profitable. Figure 2 illustrates seller payoff and entry decisions in this scenario.

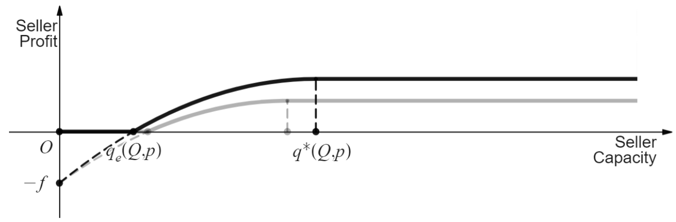


Figure 2: Seller payoff: Non-scalable sellers with the platform service

Finally, the equilibrium total quantity, $Q_N(p)$, satisfies the following condition:

$$Q_N(p) = \int_{q_e(Q_N(p),p)}^{q^*(Q_N(p),p)} k dG(k) + \int_{q^*(Q_N(p),p)}^{\bar{k}} q^*(Q_N(p),p) dG(k). \tag{6}$$

The same logic as that in the previous scenario can be used to show that $Q_N(p)$ is unique. Moreover, $Q_N(p)$ decreases with p. Lemma 2 summarizes our results:

Lemma 2. *When the platform service is priced at $p \leq \bar{c}$ and the sellers cannot scale, there exists a unique equilibrium such that:*

a. Sellers with $k < q_e(Q_N(p),p)$ do not enter the market;

b. Sellers with $q_e(Q_N(p),p) \leq k < q^*(Q_N(p),p)$ use the platform service and produce k;

c. Sellers with $k \geq q^*(Q_N(p),p)$ use the platform service and produce $q^*(Q_N(p),p)$;

d. The equilibrium total quantity $Q_N(p)$ decreases with p and is determined by Equation (6).

The platform thus earns

$$\pi_N(p) = \alpha \left[\int_{q_e(Q_N(p),p)}^{q^*(Q_N(p),p)} R(Q_N(p),k) dG(k) + \int_{q^*(Q_N(p),p)}^{\bar{k}} R(Q_N(p), q^*(Q_N(p),p)) dG(k) \right] + (p-c) Q_N^p(p),$$

where $Q_N^p(p) = Q_N(p)$ denotes the total quantity of products sold using the platform service.

3.1.3 Scalable sellers without the platform service

In this scenario, the sellers can scale and the platform does not provide the service. When a seller of capacity k enters the market, it decides whether or not to scale. If the seller does not scale, its payoff is identical to the one in Section 3.1.1. Otherwise, its payoff is given by

$$(1-\alpha)R(Q,q) - \underline{c}q - F. \tag{7}$$

Let $q^*(Q,\underline{c})$ be the optimal quantity that maximizes Equation (7). Similar to the previous analysis, if k exceeds $q^*(Q,\underline{c})$, the seller will produce $q^*(Q,\underline{c})$. Otherwise, it will produce k. Note that when sellers scale, the slope of its profit relative to q is higher than the corresponding slope when sellers do not scale. This implies that there exists a threshold quantity $q_s(Q,\bar{c})$, such that the seller's profit after scaling is higher if and only if its optimal quantity is greater than $q_s(Q,\bar{c})$.[6] For simplicity, we focus on the case where $q_s(Q,\bar{c}) \in (q^*(Q,\bar{c}), q^*(Q,\underline{c}))$, which is illustrated in Figure 3. The other cases can be similarly analyzed and provide similar insights. The case we discuss below is the only one in which all types of seller behaviors are covered. In particular, some sellers do not enter ($k < q_e(Q,\bar{c})$), some sellers enter but choose not to scale ($k \in [q_e(Q,\bar{c}), q_s(Q,\bar{c}))$), and some sellers enter and scale ($k \geq q_s(Q,\bar{c})$). For sellers that choose not to scale, some produce up to their capacities ($k \in [q_e(Q,\bar{c}), q^*(Q,\bar{c}))$), while others do not ($k \in [q^*(Q,\bar{c}), q_s(Q,\bar{c}))$). Similarly, for sellers that choose to scale, some produce up to their capacities ($k \in [q_s(Q,\bar{c}), q^*(Q,\underline{c}))$), while others do not ($k \geq q^*(Q,\underline{c})$).

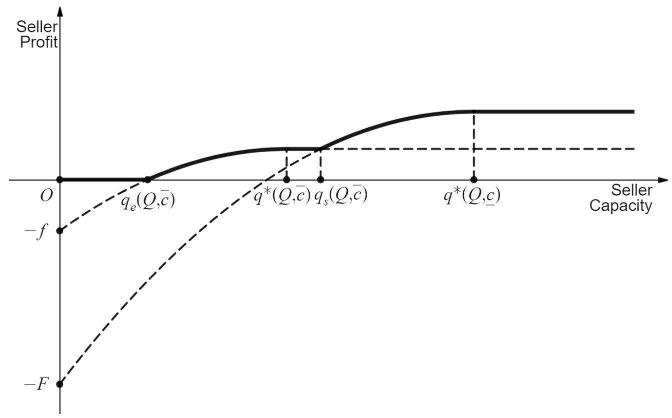


Figure 3: Seller payoff: Scalable sellers without the platform service

Given sellers' behaviors, the equilibrium total quantity, Q_s, satisfies the following condition:

$$Q_s = \int_{q_e(Q_s,\bar{c})}^{q^*(Q_s,\bar{c})} k dG(k) + \int_{q^*(Q_s,\bar{c})}^{q_s(Q_s,\bar{c})} q^*(Q_s,\bar{c}) dG(k) + \int_{q_s(Q_s,\bar{c})}^{q^*(Q_s,\underline{c})} k dG(k) + \int_{q^*(Q_s,\underline{c})}^{\bar{k}} q^*(Q_s,\underline{c}) dG(k). \quad (8)$$

The following lemma summarizes these results:

Lemma 3. *When the platform service is not provided and the sellers can scale, there exists a unique equilibrium such that:*

a. Sellers with $k < q_e(Q_s,\bar{c})$ do not enter the market;

b. Sellers with $q_e(Q_s,\bar{c}) \leq k < q^*(Q_s,\bar{c})$ use the market service and produce up to their capacity k;

c. Sellers with $q^*(Q_s,\bar{c}) \leq k < q_s(Q_s,\bar{c})$ use the market service and produce up to the optimal level $q^*(Q_s,\bar{c})$;

[6] In general, if the platform charges a price $p < \bar{c}$, it is possible that all sellers prefer the platform service to their own service and the threshold does not exist. In this case, we define $q_s(Q,p) = q^*(Q,\underline{c})$ for convenience of exposition.

d. Sellers with $q_s(Q_s, \bar{c}) \le k < q^*(Q_s, \underline{c})$ *use their own services and produce up to their capacity* k*;*

e. Sellers with $k \ge q^*(Q_s, \underline{c})$ *use their own services and produce up to the optimal level* $q^*(Q_s, \underline{c})$*;*

f. The equilibrium total quantity Q_s *is determined by Equation (8).*

The platform earns

$$\pi_s = \alpha \left[\int_{q_e(Q_s,\bar{c})}^{q^*(Q_s,\bar{c})} R(Q_s,k)dG(k) + \int_{q^*(Q_s,\bar{c})}^{q_s(Q_s,\bar{c})} R(Q_s,q^*(Q_s,\bar{c}))dG(k) + \int_{q_s(Q_s,\bar{c})}^{q^*(Q_s,\underline{c})} R(Q_s,k)dG(k) + \int_{q^*(Q_s,\underline{c})}^{\bar{k}} R(Q_s,q^*(Q_s,\underline{c}))dG(k) \right].$$

Note that when there is no competition effect, we have $\pi_s > \pi_n$ because when the platform does not provide the ancillary service, scalability enables sellers to increase their capacities, thereby generating more profits for the platform. Formally,

$$\pi_s - \pi_n = \alpha[\int_{q_s(\bar{c})}^{q^*(\underline{c})} [R(k) - R(q^*(\bar{c}))]dG(k) + \int_{q^*(\underline{c})}^{\bar{k}} [R(q^*(\underline{c})) - R(q^*(\bar{c}))]dG(k)] > 0.$$

For subsequent analysis, we continue to assume that when the platform does not offer the ancillary service, its profit is higher when sellers can scale.[7]

3.1.4 Scalable sellers with the platform service

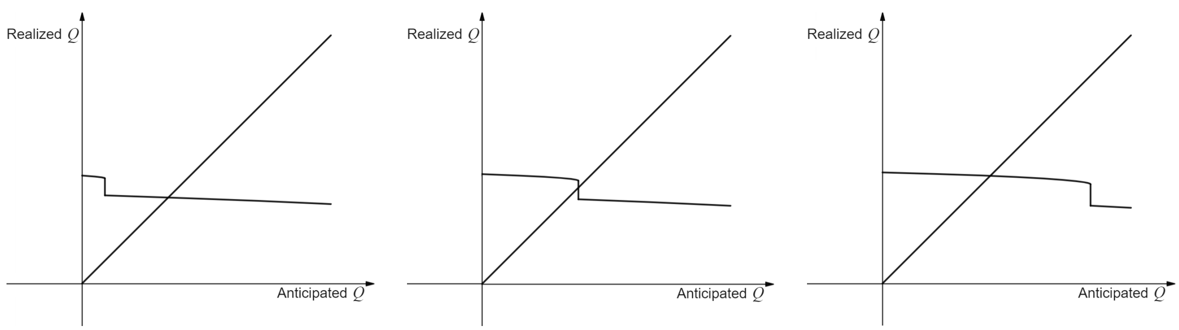
In this scenario, the sellers can scale and the platform provides the service at price p. When a seller of capacity k enters the market, it can decide whether or not to scale. If the seller does not scale, its payoff is identical to the one in Section 3.1.2. Otherwise, its payoff is given by Equation (7) in Section 3.1.3.

Different from the previous scenario, the determination of the total quantity is more complex in this scenario. To see this, note that when the platform sets $p = \bar{c}$, the analysis is identical to the one in Section 3.1.3 because the platform service is equally attractive as the market service. In this case, high-capacity sellers (i.e., $k > q^*(Q, \underline{c})$) strictly prefer scaling and using their own services (by Assumption 2) to using the platform service for all anticipated total quantity Q. However, when the platform sets $p < \bar{c}$, it is no longer guaranteed that the sellers will prefer their own services to the platform service. Their choice will depend on the anticipated total quantity Q, and it may be possible that these sellers are indifferent between their own services and the platform service.

This possibility of indifference implies that, for the same anticipated total quantity Q, there can be multiple realization of the actual quantity. The upper bound of the realization is that all high-capacity sellers scale and the lower bound is that none of these sellers scale. Figure 4 illustrates how the total quantity is determined and the vertical segment corresponds to the multiple realization of total quantity.

[7] We show that this holds when the competition effect is not exceedingly strong and provide a sufficient condition in the appendix.

As shown in Figure 4, there are three possibilities for how the total quantity is determined. Figure 4a corresponds to the case in which the platform charges a low price for its service. In this case, none of the high-capacity sellers will scale and they will all use the platform service. In Figure 4b, the platform charges an intermediate level of price, some high-capacity sellers will be indifferent between scaling and using the platform service. In Figure 4c, the platform charges a high price, and when high-capacity sellers scale, they will use their own service. For subsequent analysis, let $\bar{p} \in (\underline{c}, \bar{c})$ be the price level such that if the platform charges a price $p < \bar{p}$, then all sellers will prefer the platform service to their own services.[8] Note that in all these cases, the equilibrium total quantity is unique, which we denote as $Q_S(p)$.



(a) Low price

(b) Intermediate price

(c) High price

Figure 4: Equilibrium total quantity: Scalable sellers with the platform service

Lemma 4. *When the platform service is provided at price p and the sellers can scale, there exists a unique equilibrium with at most five cases:*

a. Sellers with $k < q_e(Q_S(p), p)$ do not enter the market;

b. Sellers with $q_e(Q_S(p), p) \leq k < q^*(Q_S(p), p)$ use the platform service and produce their capacity k;

c. Sellers with $q^*(Q_S(p), p) \leq k < q_s(Q_S(p), p)$ use the platform service and produce $q^*(Q_S(p), p)$;

d. Sellers with $q_s(Q_S(p), p) \leq k < q^*(Q_S(p), \underline{c})$ use their own services and produce their capacity k;

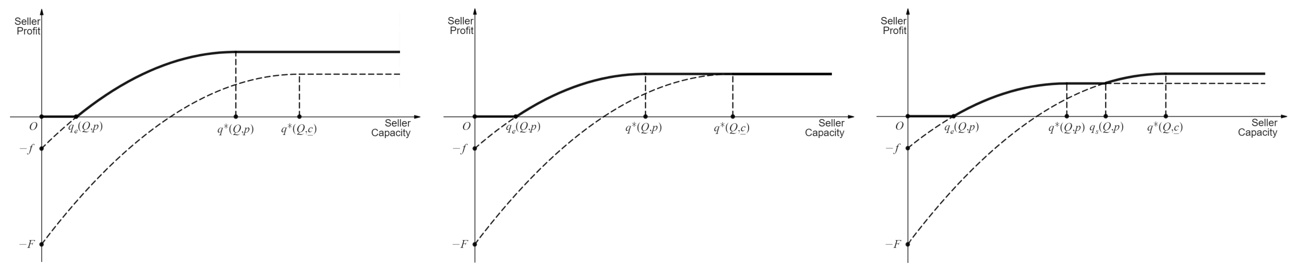
e. For sellers with $k \geq q^*(Q_S(p), \underline{c})$, a fraction $\lambda(p) \in [0, 1]$ use their own services and produce $q^*(Q_S(p), \underline{c})$; the remaining use the platform service and produce $q^*(Q_S(p), p)$;

[8] We can also show that when $p > \bar{p}$, some sellers will not use the platform service. The details are provided in the appendix.

f. The equilibrium total quantity $Q_S(p)$ satisfies the following:

$$
\begin{aligned}
Q_S(p) = \int_{q_e(Q_S(p),p)}^{q^*(Q_S(p),p)} k dG(k) + \int_{q^*(Q_S(p),p)}^{q_s(Q_S(p),p)} q^*(Q_S(p), p) dG(k) + \int_{q_s(Q_S(p),p)}^{q^*(Q_S(p),\underline{c})} k dG(k) \\
+ \int_{q^*(Q_S(p),\underline{c})}^{\bar{k}} [\lambda(p) q^*(Q_S(p), \underline{c}) + (1 - \lambda(p)) q^*(Q_S(p), p)] dG(k).
\end{aligned}
\tag{9}
$$

Note that the five cases do not always exist and there are three possibilities. Figure 5 illustrates the three possibilities. When the price of the platform service is low (Figure 5a), all sellers with $k \geq q^*(Q_S(p), p)$ will use the platform service, case (d) no longer exists, and $\lambda(p) = 0$ in case (e). When the price of the platform service is in the intermediate range (Figure 5b), case (d) again does not exist and $\lambda(p) \in (0, 1)$ in case (e). When the price of the platform service is high (Figure 5c), all five cases exist and $\lambda(p) = 1$ in case (e).



(a) Low price (b) Intermediate price (c) High price

Figure 5: Seller payoff: Scalable sellers with the platform service

The platform thus earns

$$
\begin{aligned}
\pi_S(p) =& (p - c) Q_S^p(p) + \alpha \Bigg[\int_{q_e(Q_S(p),p)}^{q^*(Q_S(p),p)} R(Q_S(p), k) dG(k) \\
&+ \int_{q^*(Q_S(p),p)}^{q_s(Q_S(p),p)} R(Q_S(p), q^*(Q_S(p), p)) dG(k) + \int_{q_s(Q_S(p),p)}^{q^*(Q_S(p),\underline{c})} R(Q_S(p), k) dG(k) \\
&+ \int_{q^*(Q_S(p),\underline{c})}^{\bar{k}} [\lambda(p) R(Q_S(p), q^*(Q_S(p), \underline{c})) + (1 - \lambda(p)) R(Q_S(p), q^*(Q_S(p), p))] dG(k) \Bigg],
\end{aligned}
$$

where

$$
Q_S^p(p) = \int_{q_e(Q_S(p),p)}^{q^*(Q_S(p),p)} k dG(k) + \int_{q^*(Q_S(p),p)}^{q_s(Q_S(p),p)} q^*(Q_S(p), p) dG(k) + \int_{q^*(Q_S(p),\underline{c})}^{\bar{k}} (1 - \lambda(p)) q^*(Q_S(p), p) dG(k)
$$

denotes the total quantity of products sold using the platform service. Note that when $p < \bar{p}$, the platform's profit function is the same as $\pi_N(p)$.

3.2 The platform's equilibrium decisions

In this section, we use the results from the previous section to analyze the platform's decision. We compare the platform's incentives to provide the service when the sellers can and cannot scale. Conditional on providing the service, we also compare platform prices under these two cases.

To facilitate the discussion, we first analyze how the total output of the sellers changes when the platform provides the service. Proposition 1 describes the change in total output in the non-scalable and scalable scenarios.

Proposition 1. *When the platform provides the service, the following holds:*

a. *In the non-scalable scenario, the total output produced by the sellers weakly increases.*

b. *In the scalable scenario, the total output produced by the sellers can decrease. When there are a sufficient number of sellers with high capacities, the total output will decrease if $\underline{c}/c$ is below a threshold.*

Proposition 1a shows that, by providing the service, the platform increases the total output by the sellers when they cannot scale. This is because when the platform service is not provided, the sellers will use the market service, which results in a marginal cost of $\bar{c}$. When the platform provides the service, it must charge a price that is weakly lower than $\bar{c}$ to attract the sellers. This results in a lower marginal cost for sellers and therefore increases their output.

Proposition 1b shows that unlike the non-scalable scenario, when the platform provides the service, we may observe an *output reduction effect*—that is, the provision of the platform service reduces the total output produced by the sellers. The output reduction effect arises when the price charged by the platform exceeds $\underline{c}$, which is the sellers' marginal cost when they use their own services. Specifically, when the platform provides the service, the sellers will no longer invest and use their own services; this increases their marginal cost of production and thus reduces their output. This happens when the sellers' marginal cost of using their own services is small relative to the platform's marginal cost of providing the service.

Next, we compare the platform's incentives to provide the service under the scalable and non-scalable scenarios. To investigate the platform's decision to offer the ancillary service, denote I_N as the cutoff investment cost at which the platform is indifferent between offering and not offering the ancillary service when the sellers cannot scale. Similarly, denote I_S as the corresponding investment level when the sellers can scale. Note that if $I_N \geq I_S$, there is a greater range of investment level that would allow the platform to offer the service in the non-scalable scenario. If the investment cost is uncertain, this suggests that the platform is more likely to provide the service in the non-scalable scenario. Otherwise, the platform is more likely to provide the service in the scalable scenario.

Proposition 2. *If $\pi_S(p)$ is increasing in p, where $p \in [\bar{p}, \bar{c}]$, then the platform is less likely to provide the platform service in the scalable scenario than in the non-scalable scenario.*

To see why Proposition 2 holds, recall that $\pi_S(p)$ is the platform's profit when it provides the service at price p and the sellers can scale. The comparison of the platform's profit under both the scalable and non-scalable scenarios yields two drivers for why the platform is less likely to provide the service in the scalable scenario. First, if the platform does not provide the service, its profit is higher when the sellers can scale: $\pi_s > \pi_n$, as discussed in Section 3.1.3. Here, scalability leads to higher total output, thereby resulting in greater platform profit.

Second, if the platform provides the service, its profit is in general weakly lower in the scalable scenario. This is because, to attract the sellers, the price range that the platform can charge is more constrained in the scalable scenario than that in the non-scalable scenario. Recall that $\bar{p}$ is the price threshold below which the sellers will use the platform service and not scale. When $p < \bar{p}$, note that the profit function under the non-scalable scenario is identical to that under the scalable scenario. Therefore, when the optimal price of the scalable scenario is below $\bar{p}$, the platform can replicate the same price choice and obtain a greater profit. Thus, this makes the platform more likely to provide the service. When $p \geq \bar{p}$, while the profit functions are no longer the same under the two scenarios, the logic in Proposition 1 suggests that the change in total output is again higher under the non-scalable scenario. Therefore, as long as the price charged by the platform is not too much lower than its marginal cost c ($\pi_S(p)$ increasing in p being a sufficient condition), the larger increase in total output brings greater profit gain in the non-scalable scenario. This again makes the provision of platform service more likely.

Proposition 2 describes the platform's decision on the extensive margin (i.e., whether the platform provides the service). Next, we examine the platform's decision on the incentive margin (i.e., the price the platform charges for its service).

Proposition 3. *If $\pi_S(p)$ is increasing in p, where $p \in [\bar{p}, \bar{c}]$, and conditional on providing the service, there exists a threshold, $\hat{c}$, such that the following holds:*

a. If $c > \hat{c}$, the platform increases its price in the scalable scenario relative to the non-scalable scenario. In this case, some sellers choose to scale to increase their output levels and fewer sellers enter the market in the scalable scenario;

b. If $c \leq \hat{c}$, the platform decreases its price in the scalable scenario relative to the non-scalable scenario. In this case, none of the sellers choose to scale and more sellers enter the market in the scalable scenario.

Conditional on providing the service, Proposition 3 shows that the platform may increase or decrease its price as we move from the non-scalable scenario to the scalable scenario, depending on the relative strength of the output reduction effect and the entry inducement effect. Recall that the output reduction effect occurs when the platform lowers its price and sellers may choose not to scale, thus reducing their output. The entry inducement effect occurs when the platform lowers its price and this induces more sellers to enter the market.

In Proposition 3a, the output reduction effect dominates the entry inducement effect, thereby leading the platform to charge a higher price. In Proposition 3b, the opposite holds and the platform strategically reduces its price to induce more entry. The condition in Proposition 3 shows that whether the platform increases or decreases its price depends on its marginal cost of providing the service. When the platform's marginal cost is higher, there is greater efficiency gain from having sellers scale and use their own service. Therefore, the platform increases its price to encourage them to do so. When the platform's marginal cost is lower, the efficiency gain from having the sellers scale is relatively small. As a result, the platform prefers to lower its price to attract more sellers.

4 Extensions

In this section, we extend our model in several directions. Section 4.1 examines how scalability affects the impact of network effects on the platform's decision to offer the platform service. Section 4.2 studies how scalability affects the optimal timing of provision of the ancillary service in a two-period version of the model.

For analytical tractability, we assume that there are two types of sellers: "low-type" sellers with capacity L and "high-type" sellers with capacity H ($L < H < \bar{k}$, where $\bar{k}$ is the maximum capacity, as defined in the main model). Let the mass of low-type sellers and high-type sellers be μ_L and μ_H, respectively. Low-type sellers will always produce to their capacities. High-type sellers will produce to their capacities when they use their own services. In addition, we assume that if the platform does not provide the service, low-type sellers will not enter the market. The exact conditions are stated in the technical appendix.[9]

4.1 Network effect

In the main model, we examined the case in which the competition effect dominates the network effect so that each seller's revenue decreases with the quantity of goods sold on the platform. In this section, we consider the case in which the network effect dominates the competition effect: each seller's revenue increases with the total quantity, Q.

Let the sellers' revenue be $R(q)\phi(a, Q)$. $R(q)$ is the baseline revenue function and $\phi(a, Q)$ captures the network effect, where a measures the strength of the network effect. In particular, $\phi(a, Q)$ increases with a and Q.

When the platform provides the service, the presence of the network effect implies that there may exist multiple equilibria. To highlight the impact of the network effect, we select the equilibrium in which the total quantity of goods sold is maximized.

Before analyzing the platform's decisions, we first describe the sellers' participation decisions under scalable and non-scalable scenarios.

Lemma 5. *There exist two price thresholds, p_l and p_h, such that the following holds:*

a. In the non-scalable scenario, suppose that the platform provides the service at price p:

[9] All propositions in the previous sections continue to hold with this two-type setup.

1. *When $p > \bar{c}$, low-type sellers do not enter the market, and high-type sellers use the market service;*
2. *When $p_l < p \leq \bar{c}$, low-type sellers do not enter the market, and high-type sellers use the platform service;*
3. *When $p \leq p_l$, both types of sellers use the platform service.*

b. *In the scalable scenario, suppose that the platform provides the service at price p:*

1. *When $p > p_h$, low-type sellers do not enter the market and high-type sellers use their own services;*
2. *When $p_l < p \leq p_h$, low-type sellers do not enter the market, and high-type sellers use the platform service;*
3. *When $p \leq p_l$, both types of sellers use the platform service.*

Lemma 5 shows that the low-type sellers coordinate on entering the market and using the platform service if and only if the platform service is priced below the threshold p_l, and the high-type sellers coordinate on using their own services if and only if the platform service is priced above the threshold p_h. As in the main model, the platform must price its service below a threshold to attract high-type sellers.

Next, we show that the main result holds even when the network effect dominates the competition effect.

Proposition 4. *Under the assumptions, the following holds:*

a. *The platform is less likely to provide the platform service in the scalable scenario than in the non-scalable scenario.*

b. *Conditional on providing the service, the platform decreases its price in the scalable scenario, relative to the non-scalable scenario.*

Proposition 4a follows the same reasoning as Proposition 2 in our main model—that is, relative to the non-scalable scenario, under the scalable scenario, the platform's maximum possible profit by providing the service is lower and the platform's profit by not providing the service is higher. Proposition 4b follows the same reasoning as Proposition 3b in our main model. Essentially, when the sellers can scale, the platform must charge a lower price to attract them.

We now turn to examine how the strength of the network effect affects the platform's decision to provide the platform service. For simplicity, suppose there is no investment cost, or $I = 0$.

Corollary 1. *Under the assumptions, the following holds:*

a. *In the non-scalable scenario, the platform always provides the service.*

b. *In the scalable scenario, when the network effect is sufficiently strong, the platform either provides the platform service and prices below p_l to serve both types, or does not provide the platform service.*

Corollary 1 shows that when the network effect dominates, seller scalability continues to affect the platform's decision to provide the service. When the sellers cannot scale, Corollary 1a states the intuitive result that the platform will provide the service because the revenue from the service can increase the platform's profit. This incentive is particularly strong with the network effect because, by providing the service (and thus lower the marginal cost of the sellers), the network effect further increases the total output.

Corollary 1b states that in the scalable scenario, however, the platform may not want to provide the platform service, so that the high-type sellers can scale and enjoy a lower marginal cost for the ancillary service. In this case, the network effect operates through two channels. First, the total quantity sold is higher when there are more sellers. This can be achieved when the platform provides the service, charges a price below p_l, and attracts the low-type sellers. Second, the total quantity sold is higher when the high-type sellers can scale. This can be achieved when the platform does not provide the service. When the network effect is sufficiently strong, rather than profiting from the platform service, the platform prefers to maximize the total output, which generates commission. As a result, one of the channels becomes the optimal choice for the platform. Note that these two channels capture the entry inducement effect and output reduction effect, respectively. Proposition 5 provides the condition regarding which channel dominates.

Proposition 5. *In the scalable scenario, the provision of platform service depends on the ratio of mass of high-type sellers to that of low-type sellers:*

a. When the ratio is low, as the network effect becomes stronger, the platform is more likely to provide the platform service.

b. When the ratio is high, as the network effect becomes stronger, the platform is less likely to provide the platform service.

When the sellers can scale, Proposition 5 shows that the platform's decision to provide the service is affected by the composition of the sellers. When the ratio of high-type sellers over low-type sellers is low (i.e., we have many low-type sellers), the entry inducement effect is dominant. Even if the platform suffers a loss from providing the service, it will still do so to increase the total number of sellers. In contrast, when the ratio is high (i.e., we have many high-type sellers), the output reduction effect is dominant. The best way to leverage network effect is not to provide the service in order to encourage sellers to scale.

4.2 Optimal timing

Consider the following two-period version of our main model, where everything is the same for the second period except that, if the sellers have already scaled in the first period, in the second period they only incur the cost of entry, f, since they do not have to scale again. This implies that the fixed fee per period for a seller that scales in the first period is reduced to $(F + f)/2$.

When there are two periods, the timing of offering the ancillary service becomes a strategic choice for the platform. For example, the platform may offer the service in the first period or may choose to delay the offering to the second period. We also assume that once the service is offered, the platform will not stop offering the service. The proposition below shows that the sellers' ability to scale affects this strategic choice. In particular, the sellers' ability to scale incentivizes the platform to delay the provision of its service.

Proposition 6. *Under the assumptions, the following holds:*

a. In the non-scalable scenario, delay is never optimal.

b. In the scalable scenario, there exists a parameter range in which it is optimal for the platform to provide the service only in the second period.

To see why Proposition 6a holds, notice that the characteristics of the high-type and low-type sellers do not change over time in the non-scalable scenario. As a result, the platform's choice to offer the service can be determined period-by-period. This implies that it will offer the service in the second period if and only if it offers the service in the first period. Thus, delay is never optimal.

With regard to Proposition 6b, once the high-type sellers scale, their cost of using the ancillary service decreases. Consider the case in which it is relatively difficult to induce the entry of low-type sellers. To attract the low-type sellers in the first period, the platform has to set a relatively low price. This low price, however, also attracts the high-type sellers, thereby deterring them from scaling. By not offering the service in the first period, the platform incentivizes the high-type sellers to scale. In the second period, the platform attracts only low-type sellers. The high-type sellers continue to use their own services, and each produces an output that is higher than when it uses the platform service. The gain from this extra output implies that delayed provision of service can benefit the platform.

5 Conclusions

In this paper, we study how marketplace sellers' ability to scale affects a platform's strategic investment in an ancillary service. While such a service will increase the output of small sellers, we highlight that the provision of such a service can diminish large sellers' incentives to make their own investment, thereby reducing their potential output. We also find that, under certain conditions, the platform can increase its profits by strategically delaying the provision of this ancillary service.

Our study has important implications for platform owners. First, we show that their scalability depends on the scalability of the entire ecosystem and not just on themselves. As a result, marketplace platforms need to develop a deep understanding of the economics of their sellers, particularly those who have the resources to support and invest in their own businesses.

Second, we provide a framework to illustrate that the scalability of the sellers influences the type of sellers the platform serves and the platform's pricing strategies, and, in turn, affects the composition of the sellers on the platform. For example, by charging a high service price, the platform may motivate the high-type sellers to scale and use their own services, thereby avoiding the output-reduction effect. Following this intuition, platforms may not want to charge a very low price for their ancillary services. Indeed, even after Amazon began to offer fulfillment services, many sellers continue to use their own fulfillment services.[10]

Finally, the timing of the investment into ancillary services both depends on and is affected by the composition and scalability of sellers. Take the Chinese e-commerce platform, Pinduoduo, as an example: it did not choose to imitate its rivals such as JD and Alibaba and offer fulfillment services to its sellers. This decision provided impetus to its sellers to scale, resulting in many large sellers on its marketplace. After many sellers have made investments, our result suggests that Pinduoduo may find it profitable to offer a fulfillment service.

We have made a few simplifying assumptions in developing our model. First, our analysis implicitly assumes that changes in seller size have negligible effects on their bargaining power over the platform. When this assumption does not hold, the platform needs to take sellers' bargaining power into consideration. For example, as sellers expand their output levels, they gain greater bargaining power over the platform and this can reduce the platform's profitability. At the same time, they may also have greater bargaining power over their suppliers, potentially resulting in greater revenue for themselves and, hence, greater profit for the platform. In such cases, the platform could use the ancillary service as a strategic tool to influence the relative bargaining power of sellers. In addition, the sellers in our model differ in their abilities to scale. Future research can explore other types of differences among marketplace sellers that may affect their bargaining power and therefore their platforms' decisions to offer ancillary services.

Second, we do not consider the platform's decision to adjust its commission rate because our analysis focuses on the introduction of an ancillary service by an existing platform (i.e., the platform has already set the commission rate and may find it difficult to change given that many sellers are already operating on the platform). In cases where the platform jointly determines both commission rate and the price of the ancillary service, we can show that our results continue to hold under certain assumptions.[11]

Third, we do not consider the platform's decision to use non-linear pricing for its ancillary service. Because we consider a continuum type of sellers, considering price discrimination becomes analytically intractable. However, when all sellers have sufficiently high capacities, we can show that our main results continue to hold under two-part tariff pricing. Essentially, when sellers can scale, their outside options are more attractive. This implies that to attract these sellers to use the ancillary service, the platform has to extract less value, resulting in lower platform profit. This makes the platform less likely to provide the service.

Fourth, we do not explicitly model sellers' heterogenous cost structures. Instead, their heterogenous capacities capture the differences in their cost structures—when sellers reach their capacity, their marginal cost of producing another unit increases dramatically. While this setup is consistent with settings where sellers face some physical constraints, future research could explore settings

[10]See, for example, `https://www.sellerapp.com/amazon-fbm.html`.

[11]We include these results in an online appendix.

with different cost structures.

Furthermore, we assume that the market service is exogenously given. In particular, we assume that the platform's decision to offer the service does not affect the entry and pricing decisions of third-party providers of the market service. Moreover, it is possible for a platform to offer the service after learning from third-party service providers. Incorporating these decisions into our model introduces another layer of dynamic strategic interactions.

Future research could also examine how firms strategically use their investments to affect other players in broader settings. For example, some airlines (such as Lufthansa) provide aircraft-maintenance services to other airlines. While this strategy may reduce entry barriers for new airlines, it also reduces small airlines' imperatives to grow. In such a case, platform investment turns competing firms into "frenemies"—they cooperate while competing with each other. We believe that how firms strategically use investments to manage their relationships with each other, in both marketplace and non-marketplace settings, would be a fascinating area of future research.

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Appendix

Proof of Lemma 1. The description of seller behavior in parts a to c immediately follows from the discussion in the main text. We now show that Equation (4) in part d has a unique solution. To do so, first recall that $q^*(Q,p)$ is defined by $(1-\alpha)D(Q,q^*) = p$. The implicit function theorem implies that $q^*(Q,p)$ decreases in both Q and p.

Similarly, recall that $q_e(Q,p)$ is defined by $(1-\alpha)R(Q,q_e) - pq_e - f = 0$. Because for any pair of (Q,p), $q_e(Q,p) < q^*(Q,p)$, this implies that $q_e(Q,p)$ increases in both Q and p.

The LHS of Equation (4) is strictly increasing in Q_n. The derivative of the RHS with respect to Q_n is

$$-\frac{\partial q_e(Q_n,\bar{c})}{\partial Q} q_e(Q_n,\bar{c}) g(q_e(Q_n,\bar{c})) + \int_{q^*(Q_n,\bar{c})}^{\bar{k}} \frac{\partial q^*(Q_n,\bar{c})}{\partial Q} dG(k) < 0,$$

where the inequality follows because $q^*(Q,p)$ decreases in Q and $q_e(Q,p)$ increases in Q. That is, the RHS is strictly decreasing in Q_n. Since the RHS is bounded by

$$0 \leq \int_{q_e(Q_n,\bar{c})}^{q^*(Q_n,\bar{c})} k dG(k) + \int_{q^*(Q_n,\bar{c})}^{\bar{k}} q^*(Q_n,\bar{c}) dG(k) \leq \int_0^{\bar{k}} k dG(k),$$

there exists a unique Q_n that satisfies Equation (4). □

Proof of Lemma 2. The proof for parts a to c follows immediately from the discussion in the main text. For any p, the proof of part d follows that of Lemma 1 by replacing Q_n with $Q_N(p)$ and $\bar{c}$ with p. Since the RHS of Equation (6) decreases in both Q_N and p, the implicit function theorem suggests that $Q_N(p)$ weakly decreases in p, which completes the proof.

□

Proof of Lemma 3. The proof for parts a to e follows immediately from the discussion in the main text. We next prove part f. Since $q_s(Q,p)$ is defined by

$$\max_q \{(1-\alpha)R(Q,q) - pq - f\} = (1-\alpha)R(Q,q_s) - \underline{c}q_s - F$$

and, for any relevant pair of (Q,p),

$$q^*(Q,p) < q_s(Q,p) < q^*(Q,\underline{c}),$$

this implies that $q_s(Q,p)$ increases in Q and decreases in p.

As in the proof of Lemma 1, the LHS of Equation (8) is strictly increasing in Q_s. The derivative of the RHS with respect to Q_s is

$$\begin{aligned} &-\frac{\partial q_e(Q_s,\bar{c})}{\partial Q} q_e(Q_s,\bar{c}) g(q_e(Q_s,\bar{c})) + \frac{\partial q_s(Q_s,\bar{c})}{\partial Q}[q^*(Q_s,\bar{c}) - q_s(Q_s,\bar{c})] g(q_s(Q_s,\bar{c})) \\ &+ \int_{q^*(Q_s,\bar{c})}^{q_s(Q_s,\bar{c})} \frac{\partial q^*(Q_s,\bar{c})}{\partial Q} dG(k) + \int_{q^*(Q_s,\bar{c})}^{\bar{k}} \frac{\partial q^*(Q_s,\underline{c})}{\partial Q} dG(k) < 0, \end{aligned}$$

that is, the RHS is strictly decreasing in Q_s. Since the RHS is again bounded by the interval $[0, \int_0^{\bar{k}} k dG(k)]$, there exists a unique Q_s that satisfies Equation (8). □

Sufficient conditions for $\pi_s > \pi_n$ in footnote 5. We formally state the conditions in the following manner. Suppose that the following two regularity conditions hold: $\exists \mu > 0$ such that $\max_{k \in [0,\bar{k}]} g(k) \leq$

μ and $\exists\kappa > 0$ such that $\min_{Q,q} |D'_q(Q,q)| \geq \kappa$.

In this case, there exists $M > 0$ such that $\pi_s > \pi_n$ if $\max_{Q,q} |D'_Q(Q,q)| \leq M$. We next prove this statement.

Denote

$$\Pi_n(Q) = \int_{q_e(Q,\bar{c})}^{q^*(Q,\bar{c})} R(Q,k)g(k)dk + \int_{q^*(Q,\bar{c})}^{\bar{k}} R(Q,q^*(Q,\bar{c}))g(k)dk,$$

and, thus, $\pi_n = \alpha\Pi_n(Q_n)$. Consider the following decomposition:

$$\pi_s - \pi_n = \alpha[\frac{1}{\alpha}\pi_s - \Pi_n(Q_s)] + \alpha[\Pi_n(Q_s) - \Pi_n(Q_n)].$$

The first term is positive; moreover

$$\begin{aligned}
&\frac{1}{\alpha}\pi_s - \Pi_n(Q_s) > \int_{q_s(Q_s,\bar{c})}^{\bar{k}} [R(Q_s, q_s(Q_s,\bar{c})) - R(Q_s, q^*(Q_s,\bar{c}))]g(k)dk \\
&= [1 - G(q_s(Q_s,\bar{c}))] \int_{q^*(Q_s,\bar{c})}^{q_s(Q_s,\bar{c})} D(Q_s,q)dq \geq [1 - G(q_s(\bar{k},\bar{c}))] \int_{q^*(Q_s,\bar{c})}^{q_s(Q_s,\bar{c})} D(\bar{k}, q_s(\bar{k},\bar{c}))dq \\
&> [1 - G(q^*(\bar{k},\underline{c}))][q_s(Q_s,\bar{c}) - q^*(Q_s,\bar{c})]D(\bar{k}, q^*(\bar{k},\underline{c})) \geq [1 - G(q^*(0,\underline{c}))][q_s(0,\bar{c}) - q^*(0,\bar{c})]\frac{\underline{c}}{1-\alpha},
\end{aligned}$$

which is a positive constant. Without loss of generality, we regard $D(0,q)$ for any $q \geq 0$ as exogenous and, thus, all functions evaluated at $Q = 0$ do not rely on the values of $D'_Q(Q,q)$. Thus, this positive constant does not rely on the values of $D'_Q(Q,q)$.

Since the second term, $\alpha[\Pi_n(Q_s) - \Pi_n(Q_n)]$, is negative, we need to show that when the competition effect is bounded by some constant M, the absolute value of the second term is also bounded, such that the first term dominates the second term when M is sufficiently small.

Specifically, suppose that $\max_{Q,q} |D'_Q(Q,q)| \leq M$, which implies

$$R'_Q(Q,q) = R'_Q(Q,0) + \int_0^q D'_Q(Q,s)ds \geq -Mq$$

or $|R'_Q(Q,q)| \leq Mq$.

To find a bound for the absolute value of the second term, note that

$$|\Pi_n(Q_s) - \Pi_n(Q_n)| \leq (Q_s - Q_n) \max_Q |\frac{\partial \Pi_n(Q)}{\partial Q}| < \bar{k} \max_Q |\frac{\partial \Pi_n(Q)}{\partial Q}|,$$

and, thus, we only need to examine

$$\begin{aligned}
|\frac{\partial \Pi_n(Q)}{\partial Q}| &\leq |\int_{q_e(Q,\bar{c})}^{q^*(Q,\bar{c})} R'_Q(Q,k)g(k)dk| + |\int_{q^*(Q,\bar{c})}^{\bar{k}} R'_Q(Q,q^*(Q,\bar{c}))g(k)dk| \\
&\quad + |\int_{q^*(Q,\bar{c})}^{\bar{k}} D(Q,q^*(Q,\bar{c}))\frac{\partial q^*(Q,\bar{c})}{\partial Q}g(k)dk| + |\frac{\partial q_e(Q,\bar{c})}{\partial Q}R(Q,q_e(Q,\bar{c}))g(q_e(Q,\bar{c}))| \\
&\leq M\bar{k} + \frac{\bar{c}}{1-\alpha}\frac{|D'_Q(Q,\bar{c})|}{|D'_q(Q,\bar{c})|} + \frac{|R'_Q(Q,q_e(Q,\bar{c}))|}{D(Q,q_e(Q,\bar{c})) - D(Q,q^*(Q,\bar{c}))}\frac{f + \bar{c}q_e(Q,\bar{c})}{1-\alpha}\mu \\
&\leq M\bar{k} + \frac{\bar{c}}{1-\alpha}\frac{M}{\kappa} + \frac{M}{\kappa}\frac{q_e(\bar{k},\bar{c})}{q^*(\bar{k},\bar{c}) - q_e(\bar{k},\bar{c})}\frac{f + \bar{c}\bar{k}}{1-\alpha}\mu
\end{aligned}$$

For simplicity, denote

$$X = \frac{q_e(\bar{k}, \bar{c})}{q^*(\bar{k}, \bar{c}) - q_e(\bar{k}, \bar{c})}, e_0 = q_e(0, \bar{c}), r_0 = q^*(0, \bar{c}),$$

and, thus,

$$X < \frac{e_0 + \frac{M}{\kappa} X \bar{k}}{r_0 - \frac{M}{\kappa}\bar{k} - e_0 - \frac{M}{\kappa} X \bar{k}} \Leftrightarrow \frac{M}{\kappa}\bar{k}X^2 - (r_0 - 2\frac{M}{\kappa}\bar{k} - e_0)X + e_0 > 0 \Rightarrow X < \frac{\sqrt{4\frac{M}{\kappa}\bar{k}e_0}}{2\frac{M}{\kappa}\bar{k}} \Leftrightarrow \frac{M}{\kappa}X < \sqrt{\frac{Me_0}{\kappa\bar{k}}}.$$

Therefore,

$$|\Pi_n(Q_s) - \Pi_n(Q_n)| < \bar{k} \max_Q |\frac{\partial \Pi_n(Q)}{\partial Q}| \leq M\bar{k}[\bar{k} + \frac{\bar{c}}{(1-\alpha)\kappa}] + \sqrt{M}\sqrt{\frac{e_0\bar{k}}{\kappa}\frac{(f + \bar{c}\bar{k})\mu}{1-\alpha}}.$$

Hence, when M is sufficiently small, the second term will be dominated by the first term and, therefore, $\pi_s > \pi_n$. □

Proof of Lemma 4. Different from the proofs in Lemmas 1–3, we first prove part f to establish the existence and uniqueness of the equilibrium. For any price p, define Q_m by

$$(1-\alpha)R(Q_m, q^*(Q_m, p)) - pq^*(Q_m, p) - f = (1-\alpha)R(Q_m, q^*(Q_m, \underline{c})) - \underline{c}q^*(Q_m, \underline{c}) - F,$$

that is, the total quantity under which sellers with sufficiently high capacity constraints (specifically, those with $k > q^*(Q_m, \underline{c})$) are indifferent between the platform service and their own services. We refer to this as the mixed state.

Under this definition, Q_m is only well-defined for $p > \underline{c}$; if, instead, $p \leq \underline{c}$, all sellers would strictly prefer the platform service to their own services. Also note that, at Q_m, we have

$$q_s(Q_m, p) = q^*(Q_m, \underline{c}).$$

When sellers anticipate the total quantity to be Q_m, sellers with sufficiently high capacity constraints can either use the platform service and produce $q^*(Q_m, p)$ or use their own services and produce $q^*(Q_m, \underline{c})$. Therefore, the realized total quantity ranges from

$$\underline{Q} = \int_{q_e(Q_m,p)}^{q^*(Q_m,p)} kdG(k) + \int_{q^*(Q_m,p)}^{q^*(Q_m,\underline{c})} q^*(Q_m, p)dG(k) + \int_{q^*(Q_m,\underline{c})}^{\bar{k}} q^*(Q_m, p)dG(k)$$

to

$$\bar{Q} = \int_{q_e(Q_m,p)}^{q^*(Q_m,p)} kdG(k) + \int_{q^*(Q_m,p)}^{q^*(Q_m,\underline{c})} q^*(Q_m, p)dG(k) + \int_{q^*(Q_m,\underline{c})}^{\bar{k}} q^*(Q_m, \underline{c})dG(k).$$

When sellers anticipate the total quantity to be $Q > Q_m$ (or $p < \underline{c}$, so that there is no mixed state), sellers with sufficiently high capacity constraints would prefer the platform service to their own services; then, the realized total quantity becomes

$$\int_{q_e(Q,p)}^{q^*(Q,p)} kdG(k) + \int_{q^*(Q,p)}^{\bar{k}} q^*(Q, p)dG(k),$$

which is decreasing in Q, as we have shown in the proof of Lemma 1. Moreover, when Q approaches Q_m from the right side, the realized total quantity approaches $\underline{Q}$.

When sellers anticipate the total quantity to be $Q < Q_m$, sellers with sufficiently high capacity constraints would prefer their own services to the platform service; then, the realized total quantity becomes

$$\int_{q_e(Q,p)}^{q^*(Q,p)} kdG(k) + \int_{q^*(Q,p)}^{q_s(Q,p)} q^*(Q,p)dG(k) + \int_{q_s(Q,p)}^{q^*(Q,\underline{c})} kdG(k) + \int_{q^*(Q,\underline{c})}^{\bar{k}} q^*(Q,\underline{c})dG(k),$$

which is decreasing in Q, as we have shown in the proof of Lemma 3. Moreover, when Q approaches Q_m from the left side, the realized total quantity approaches $\bar{Q}$.

To summarize, as the anticipated total quantity Q increases, the realized total quantity is decreasing overall and is bounded by $[0, \int_0^{\bar{k}} kdG(k)]$, as in the previous lemmas. Therefore, there exists a unique $Q_S(p)$, such that the realized total quantity and the anticipated total quantity coincide at $Q_S(p)$. This establishes the existence and uniqueness of the equilibrium.

Finally, we check that the total quantity $Q_S(p)$ can be expressed as Equation (9). The behavior of sellers described in parts a to e follows from the discussion below. If the price p is sufficiently low and sellers with sufficiently high capacity constraints prefer the platform service to their own services, then take $\lambda(p) = 0$ and note that

$$q_S(Q_S(p),p) = q^*(Q_S(p),\underline{c}),$$

as we assumed, and the total quantity reduces to

$$Q_S(p) = \int_{q_e(Q_S(p),p)}^{q^*(Q_S(p),p)} kdG(k) + \int_{q^*(Q_S(p),p)}^{\bar{k}} q^*(Q_S(p),p)dG(k).$$

If the price p is sufficiently high and sellers with sufficiently high capacity constraints prefer their own services to the platform service, then take $\lambda(p) = 1$ and the total quantity reduces to

$$\begin{aligned} Q_S(p) = &\int_{q_e(Q_S(p),p)}^{q^*(Q_S(p),p)} kdG(k) + \int_{q^*(Q_S(p),p)}^{q_s(Q_S(p),p)} q^*(Q_S(p),p)dG(k) \\ &+ \int_{q_s(Q_S(p),p)}^{q^*(Q_S(p),\underline{c})} kdG(k) + \int_{q^*(Q_S(p),\underline{c})}^{\bar{k}} q^*(Q_S(p),\underline{c})dG(k). \end{aligned}$$

If the price p is intermediate and sellers with sufficiently high capacity constraints are indifferent between their own services and the platform service (i.e., the mixed state), then $\lambda(p) \in (0,1)$ and, again,

$$q_S(Q_S(p),p) = q^*(Q_S(p),\underline{c}),$$

and the total quantity $Q_S(p)$ falls in the range of

$$\underline{Q} = \int_{q_e(Q_S(p),p)}^{q^*(Q_S(p),p)} kdG(k) + \int_{q^*(Q_S(p),p)}^{q^*(Q_S(p),\underline{c})} q^*(Q_S(p),p)dG(k) + \int_{q^*(Q_S(p),\underline{c})}^{\bar{k}} q^*(Q_S(p),p)dG(k)$$

and

$$\bar{Q} = \int_{q_e(Q_S(p),p)}^{q^*(Q_S(p),p)} kdG(k) + \int_{q^*(Q_S(p),p)}^{q^*(Q_S(p),\underline{c})} q^*(Q_S(p),p)dG(k) + \int_{q^*(Q_S(p),\underline{c})}^{\bar{k}} q^*(Q_S(p),\underline{c})dG(k),$$

as we have shown above. □

Existence of threshold $\bar{p}$ in footnote 6. Denote $Q_m(p)$ as the total quantity in the mixed state for any price $p > \underline{c}$ and recall that $Q_m(p)$ is defined by

$$\max_q\{(1-\alpha)R(Q_m, q) - pq - f\} = \max_q\{(1-\alpha)R(Q_m, q) - \underline{c}q - F\}.$$

Thus, following the implicit function theorem and the envelope theorem, we know that $Q_m(p)$ increases in p.

Further, denote the realized total quantity as a set-valued function $\tilde{Q}(Q, p)$ of price p and the anticipated total quantity Q. We know from the proof of Lemma 4 that $\tilde{Q}(Q, p)$ has a unique value for $Q \neq Q_m(p)$ and is overall decreasing in Q. Moreover, when $Q > Q_m(p)$, sellers with sufficiently high capacity constraints would prefer the platform service to their own services. Thus,

$$\tilde{Q}(Q, p) = \int_{q_e(Q,p)}^{q^*(Q,p)} k dG(k) + \int_{q^*(Q,p)}^{\bar{k}} q^*(Q, p) dG(k)$$

decreases in p when $Q > Q_m(p)$.

Next, we proceed to show the existence of a price threshold $\bar{p}$. Suppose that the platform service dominates their own services when the platform service is priced at $p = p_1$ and the equilibrium total quantity is Q_1. We want to show that at any price $p_2 < p_1$, the platform service also dominates their own services in the participation equilibrium.

Suppose that, when the platform service is priced at $p = p_2 < p_1$, the participation equilibrium is in the mixed state and the equilibrium total quantity is $Q_2 = Q_m(p_2)$. Therefore, we know that

$$Q_2 = Q_m(p_2) < Q_m(p_1) < Q_1.$$

Meanwhile, since $\tilde{Q}(Q, p)$ is overall decreasing in Q, we have

$$Q_2 = Q_m(p_2) \geq \min\{\tilde{Q}(Q_2, p_2)\} \geq \tilde{Q}(Q_1, p_2),$$

and since $Q_1 > Q_m(p_1) > Q_m(p_2)$, we further have

$$\tilde{Q}(Q_1, p_2) > \tilde{Q}(Q_1, p_1) = Q_1,$$

which leads to a contradiction.

Suppose instead that when the platform service is priced at $p = p_2 < p_1$, the participation equilibrium exhibits $Q_2 < Q_m(p_2)$ and their own services dominates the platform service. In this case, there exists $p_3 \in (p_2, p_1)$, where the participation equilibrium once again falls in the mixed state and leads to a contradiction.

In summary, when the platform service is priced at $p_2 < p_1$, the participation equilibrium always exhibits $Q_2 > Q_m(p_2)$ and the platform service dominates their own services; thus, there exists a threshold $\bar{p}$, such that the platform service dominates their own services if and only if $p < \bar{p}$.

Furthermore, we note that when $p = \underline{c}$, the platform service always dominates their own services, and when $p = \bar{c}$, the platform service never dominates their own services by assumption. Thus, the threshold $\bar{p}$ must lie between $\underline{c}$ and $\bar{c}$, which completes our proof. □

Proof of Proposition 1. For part a, note that when the sellers cannot scale, if the platform prices its service at $\bar{c}$, we have

$$Q_n = Q_N(\bar{c}).$$

When the platform provides the service, it will be priced weakly lower than $p \leq \bar{c}$. Recall that

$Q_N(p)$ decreases in p for $p \leq \bar{c}$ as we have shown in Lemma 2, which completes the proof.

For part b, let Q^* be the solution to

$$Q = q^*(Q, \underline{c})$$

and consider a truncated distribution where $G(Q^*) = 0$—that is, all sellers are of sufficiently high capacities. We show that for this truncated distribution, part b holds. Part b will then also hold for distributions sufficiently close to this truncated distribution.

When $G(Q^*) = 0$, for any p, $Q_S(p) = Q^*$ and $\lambda(p) = 1$ solves Equation (9). Note that a necessary condition for $\lambda(p) = 1$ is that all sellers prefer their own services over the platform service, or

$$(1-\alpha)R(Q^*, q^*(Q^*, p)) - pq^*(Q^*, p) - f \leq (1-\alpha)R(Q^*, q^*(Q^*, \underline{c})) - \underline{c}q^*(Q^*, \underline{c}) - F.$$

This puts a lower bound on p that we denote as p^*.

Therefore, when the platform services are priced at $p \in (p^*, \bar{c})$, $Q_S(p) = Q^*$ is constant in p. Moreover, when the platform services are priced at $p \in (\bar{p}, p^*)$, the market must be in the mixed state and, hence, $Q_S(p) = Q_m(p)$, which is increasing in p. This implies that

$$Q_s = Q_S(\bar{c}) = Q_S(p^*) > Q_S(\bar{p})$$

and, thus, the total output produced by the sellers can decrease when the platform provides the service.

We now show that as c increases, the platform will price above $\bar{p}$ in the scalable scenario. We denote

$$\tilde{p}_S = \arg\max_{p \in [\bar{p}, \bar{c}]} \pi_S(p) \geq \bar{p},$$

$$\tilde{p}_N = \arg\max_{p \leq \bar{p}} \pi_N(p) \leq \bar{p}.$$

We have

$$\frac{d}{dc}[\max_{p \in [\bar{p}, \bar{c}]} \pi_S(p) - \max_{p \leq \bar{p}} \pi_N(p)] = -Q_S^p(\tilde{p}_S) + Q_N^p(\tilde{p}_N) \geq 0,$$

as long as

$$Q_N^p(\tilde{p}_N) \geq Q_N^p(\tilde{p}_S) \geq Q_S^p(\tilde{p}_S), \tag{10}$$

which we prove below.

Therefore, when c is sufficiently large, or the ratio $\underline{c}/c$ is sufficiently small, the platform would price above $\bar{p}$, and the total output weakly decreases if the platform service is provided. Furthermore, even if the platform prices below $\bar{p}$, as long as the optimal price $\tilde{p}_N$ is still in the neighborhood of $\bar{p}$, we still have $Q^S(\tilde{p}_N) < Q_s$.

We now proceed to prove inequalities (10). We first show that for $p \leq \bar{c}$, $Q_S(p) \geq Q_N(p)$.

When $p \leq \bar{p}$, the participation equilibrium coincides in the non-scalable and scalable scenarios and, thus, $Q_S(p) = Q_N(p)$.

When $p \geq \bar{p}$, suppose first that the sellers are in the mixed state and $Q_S(p) = Q_m(p)$. If $Q_N(p) > Q_m(p)$, then

$$Q_N(p) = \tilde{Q}(Q_N(p), p) \leq \min\{\tilde{Q}(Q_m(p), p)\} \leq Q_m(p),$$

which leads to a contradiction. Therefore, $Q_N(p) \leq Q_m(p) = Q_S(p)$.

Now, suppose instead the sellers with sufficiently high capacity constraints prefer their own services to the platform service. From the expression of $\tilde{Q}(Q,p)$ we note that the RHS is larger if these sellers use their own services than if these sellers use the platform service. Therefore, we have, again in this case, $Q_S(p) \geq Q_N(p)$. This completes the proof that for $p \leq \bar{c}$, $Q_S(p) \geq Q_N(p)$.

Next, we show that $Q_N^p(p) \geq Q_S^p(p)$. Note that $Q_N^p(p) = Q_N(p)$. In addition, since $Q_S(p) \geq Q_N(p)$,

$$\begin{aligned} Q_S^p(p) &\leq \int_{q_e(Q_S(p),p)}^{q^*(Q_S(p),p)} k dG(k) + \int_{q^*(Q_S(p),p)}^{\bar{k}} q^*(Q_S(p),p) dG(k) \\ &\leq \int_{q_e(Q_N(p),p)}^{q^*(Q_N(p),p)} k dG(k) + \int_{q^*(Q_N(p),p)}^{\bar{k}} q^*(Q_N(p),p) dG(k) = Q_N^p(p). \end{aligned}$$

This completes the proof of inequalities (10), and thus completes the proof of part b. □

Proof of Proposition 2. Note that $I_N = \max_{p\leq\bar{c}} \pi_N(p) - \pi_n$, and $I_S = \max_{p\leq\bar{c}} \pi_S(p) - \pi_n$. Further, denote $\hat{p}_N = \arg\max_{p\leq\bar{c}} \pi_N(p)$, $\hat{p}_S = \arg\max_{p\leq\bar{c}} \pi_S(p)$, and $\eta(p) = [\pi_N(p) - \pi_n] - [\pi_S(p) - \pi_s]$. Thus, a sufficient condition for $I_N \geq I_S$ is $\eta(\hat{p}_S) \geq 0$ because

$$I_N - I_S = [\pi_N(\hat{p}_N) - \pi_n] - [\pi_S(\hat{p}_S) - \pi_s] \geq [\pi_N(\hat{p}_S) - \pi_n] - [\pi_S(\hat{p}_S) - \pi_s] = \eta(\hat{p}_S) \geq 0.$$

When $\pi_S(p)$ increases in p over $[\bar{p}, \bar{c}]$, $\hat{p}_S$ would either fall in $(0, \bar{p})$ or take the value $\bar{c}$. We now show that $\eta(\hat{p}_S) \geq 0$ in both cases.

If $\hat{p}_S < \bar{p}$, since $\pi_N(p) = \pi_S(p)$ and $\pi_s > \pi_n$, we have

$$\eta(\hat{p}_S) = [\pi_N(\hat{p}_S) - \pi_n] - [\pi_N(\hat{p}_S) - \pi_s] = \pi_s - \pi_n > 0.$$

If $\hat{p}_S = \bar{c}$, we have

$$\eta(\bar{c}) = [\pi_N(\bar{c}) - \pi_n] - [\pi_S(\bar{c}) - \pi_s] = (\bar{c} - c)[Q_N^p(\bar{c}) - Q_S^p(\bar{c})] \geq 0.$$

□

Proof of Proposition 3. First, we examine how the relationship between $\hat{p}_S$ and $\bar{p}$ affects the intensive margin.

When $\hat{p}_S \leq \bar{p}$, since $\pi_S(p) = \pi_N(p)$ for $p \leq \bar{p}$, $\hat{p}_S$ must be maximizing $\pi_N(p)$ on the interval $(0, \bar{p}]$. Since $\hat{p}_N$ maximizes $\pi_N(p)$ on the interval $(0, \bar{c}]$, then either $\hat{p}_N \geq \bar{p} \geq \hat{p}_S$ or $\hat{p}_N = \hat{p}_S$. Either way, we have $\hat{p}_S \leq \hat{p}_N$—that is, the platform decreases its price.

When $\hat{p}_S > \bar{p}$, since $\pi_S(p)$ increases in p on $[\bar{p}, \bar{c}]$, then $\hat{p}_S = \bar{c} \geq \hat{p}_N$—that is, the platform increases its price.

We have shown in the proof of Proposition 1 that the platform is more likely to price above $\bar{p}$ as c increases. Therefore, there exists a threshold $\hat{c}$, such that the platform prices above $\bar{p}$ if and only if $c > \hat{c}$. This completes the proof for both parts a and b. □

Conditions for extensions. For the ease of exposition, we impose the following regularity conditions for the extensions. First, we assume that for any total quantity Q, $D(Q, L) \geq \frac{\bar{c}}{1-\alpha}$ and $D(Q, H) \geq \frac{c}{1-\alpha}$. The first expression ensures that low-type sellers will produce to their capacities when they enter. the second expression ensures that high-type sellers will produce to their capacities when they use their own services.

Next, we assume that when the platform does not provide the platform service, low-type sellers will not enter the market, and high-type sellers will enter the market and scale. A sufficient condition for this is that for any Q, $(1-\alpha)R(Q, L) - \bar{c}L - f \leq 0$ and $0 \leq \max_{q\leq H}\{(1-\alpha)R(Q, q) - \bar{c}q - f\} \leq (1-\alpha)R(Q, H) - \underline{c}H - F$.

Finally, for the network effect extension, we assume that $F - f < (c - \underline{c})H$, that is, the gain from using one's own service is sufficiently large. We also assume that when the platform reduces its service price, it first attracts the high-type sellers, and then attracts the low-type sellers. $\square$

Proof of Lemma 5. Let p_l be the maximum price for all low-type sellers to coordinate on using the platform service and p_h be the minimum price for all high-type sellers to coordinate on using their own services. Given the assumption above, we have $p_l < p_h$. Notice that $p_h < \bar{c}$. The behavior of the sellers described in parts a and b of the lemma immediately follows.

$\square$

Proof of Proposition 4. Denote $q^{**}(Q,p) = \min\{q^*(Q,p), H\}$. When the platform service is not provided, the platform earns in the non-scalable scenario

$$\pi_n = \mu_H \alpha R(q^{**}(Q_H(\bar{c}), \bar{c}))\phi(a, Q_H(\bar{c})),$$

where $Q_H(p)$ solves $Q = \mu_H q^{**}(Q,p)$. In the scalable scenario, its profit is

$$\pi_s = \mu_H \alpha R(H)\phi(a, \mu_H H) \geq \pi_n.$$

When the platform service is provided, the high-type sellers use the platform service since $p_h > p_l$. Therefore, in either scenario, if $p \leq p_l$, the platform earns

$$\pi(p) = \mu_L \alpha R(L)\phi(a, Q_L(p)) + \mu_H \alpha R(q^{**}(Q_L(p), p))\phi(a, Q_L(p)) + (p - c)Q_L(p),$$

where $Q_L(p)$ solves $Q = \mu_L L + \mu_H q^{**}(Q,p)$, and if $p > p_l$, the platform earns

$$\pi(p) = \mu_H \alpha R(q^{**}(Q_H(p), p))\phi(a, Q_H(p)) + (p - c)Q_H(p).$$

Suppose the platform service is priced at some $\hat{p}_S$ in the scalable scenario, then $\hat{p}_S < p_h < \bar{c}$; thus, the platform could have priced at $\hat{p}_S$ in the non-scalable scenario and earned the same profit. In other words,

$$I_N = \max_{p \leq \bar{c}} \pi(p) - \pi_n \geq \max_{p \leq p_h} \pi(p) - \pi_s = I_S,$$

that is, the platform is less likely to provide the platform service in the scalable scenario. This proves part a.

When the platform service is provided in the non-scalable scenario, the optimal price $\hat{p}_N$ either falls in $(p_h, \bar{c})$ and thus, is larger than $\hat{p}_S$, or in $(0, p_h)$ and coincides with $\hat{p}_S$. Either way, we have $\hat{p}_N \geq \hat{p}_S$—that is, the platform decreases its price. This proves part b. $\square$

Proof of Corollary 1.
For part a, when $p = \bar{c}$, high-type sellers use the platform service instead of the market service. Compared to not providing the service, the platform earns an extra profit of

$$\pi(\bar{c}) - \pi_n = (\bar{c} - c)Q_H(\bar{c}) > 0.$$

Therefore, the platform always provides the platform service in the non-scalable scenario.

For part b, the platform prefers not providing the service to providing the service at a price between p_l and p_h if

$$\mu_H \alpha R(H)\phi(a, \mu_H H) \geq \max_{p_l < p < p_h} \mu_H \alpha R(q^{**}(Q_H(p), p))\phi(a, Q_H(p)) + (p - c)Q_H(p).$$

Note that if a is sufficiently large, by our assumption, $p_h = \underline{c} + \frac{F-f}{H} < c$. This implies that the RHS of the expression above is bounded by

$$\mu_H \alpha R(q^{**}(Q_H(p_l), p_l))\phi(a, Q_H(p_l)) \leq \mu_H \alpha R(H)\phi(a, \mu_H H).$$

This proves part b. □

Proof of Proposition 5. When the platform does not provide the platform service, it earns

$$\pi_s = \mu_H \alpha R(H)\phi(a, \mu_H H).$$

When the platform prices below p_l, it earns

$$\max_{p \leq p_l} \pi(p) = \max_{p \leq p_l}\{\mu_L \alpha R(L)\phi(a, Q_L(p)) + \mu_H \alpha R(q^{**}(Q_L(p), p))\phi(a, Q_L(p)) + (p - c)Q_L(p)\}.$$

For any μ_L, there exists a sufficiently large a such that high-type sellers' capacity constraint is binding for any $p \leq p_l$, in which case the platform will choose $p = p_l$ and earn

$$[\mu_L R(L) + \mu_H R(H)]\alpha\phi(a, \mu_L L + \mu_H H) + (p_l - c)(\mu_L L + \mu_H H).$$

For part a, when μ_L is sufficiently large, the profit difference between providing and not providing the service for the platform becomes

$$\begin{aligned}
&[\mu_L R(L) + \mu_H R(H)]\alpha\phi(a, \mu_L L + \mu_H H) - \mu_H R(H)\alpha\phi(a, \mu_H H) + (p_l - c)(\mu_L L + \mu_H H) \\
=&\mu_L R(L)\alpha\phi(a, \mu_L L + \mu_H H) + \mu_H R(H)\alpha[\phi(a, \mu_L L + \mu_H H) - \phi(a, \mu_H H)] + (p_l - c)(\mu_L L + \mu_H H).
\end{aligned}$$

Notice that the RHS increases in a. Therefore, the platform is more likely to provide the service as the network effect becomes stronger. This proves part a.

For part b, when $\mu_L = 0$, the platform's optimal profit when pricing below p_l is equal to

$$\mu_H R(H)\alpha\phi(a, \mu_H H) + (p_l - c)\mu_H H < \mu_H R(H)\alpha\phi(a, \mu_H H),$$

that is, the platform prefers not providing the platform service for sufficiently large a. Since $\pi(p)$ is continuous in μ_L, the profit difference is negative for sufficiently small μ_L. In other words, when the ratio of mass of high-type sellers to that of low-type sellers is high, the platform will not provide the service when the network effect is sufficiently strong. This proves part b. □

Proof of Proposition 6.
For part a, in the non-scalable scenario, since the sellers cannot scale, the platform's decision on whether to provide the service is the same across two periods, and thus the platform service is either provided in both periods, or is never provided.

For part b, we examine a case in which there is no competition effect and show that the platform may prefer to delay the provision of its service. The continuity of the profit function of the platform implies that the same conclusion holds when the competition effect is small.

For simplicity, we assume that the investment cost for the platform is zero. We show in the end that the results continue to hold as long as the investment cost is smaller than a certain threshold.

In the scalable scenario, we show that the platform would, under certain conditions, delay the provision through the following steps:

Step 1: Suppose the platform prefers not providing to providing in a single period, and high-type sellers prefer using platform service at price p_l in both periods to using their own services in both periods, then the platform prefers never providing the platform service to providing in both periods.

To see this, note that if the platform service is not provided in either period, the platform receives twice the profit of not providing in a single period.

On the other hand, if the platform service is provided (and used) in both periods: either the high-type sellers use their own services in both periods, in which case the platform must have priced below p_l to attract low-type sellers, but then high-type sellers would have switched to platform service; or the high-type sellers use their own services in at most one period, in which case we can treat the two periods as independent, and the platform earns at most twice the maximum profit of a single period. This proves Step 1.

Step 2: Suppose that it is profitable for the platform to attract low-type sellers entering the market, i.e.,

$$\alpha R(L) + (p_l - c)L = R(L) - cL - f > 0,$$

then it is never optimal for the platform to never provide the service.

Suppose instead that the platform service is (optimally) never provided, and high-type sellers would use their own services in both periods. Then low-type sellers either use the market service or stay out in the second period. If low-type sellers use the market service, it is a profitable deviation for the platform to price the platform service at $\bar{c}$ since $\bar{c} > c$. If low-type sellers stay out, it is also a profitable deviation for the platform to price the platform service at p_l if $p_l > \underline{c}$. This proves that the platform must provide the service.

Finally, suppose that the investment cost is positive. In this case, Step 1 continues to hold as long as the investment cost is smaller than half of the profit difference between non-scalable and scalable scenarios in a single period. For Step 2, as long as

$$I < \mu_L \min\{R(L) - cL - f, (\bar{c} - c)L\},$$

it remains a profitable deviation for the platform to attract low-type sellers in the second period. This proves part b. □