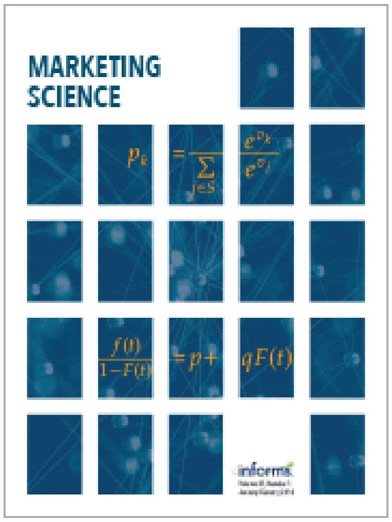

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Entry of Platforms into Complementary Hardware Access Product Markets

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Abstract. Access to a platform's services often requires consumers to use a complementary hardware product or service, for example, internet service is needed to access the YouTube platform. Typically, such *access* products are provided by third-party firms. More recently, however, some major platforms such as Google have themselves ventured into providing these access products. For example, Google Fiber provides access to YouTube. In this paper, we examine the effect of a platform's entry into an access product market when the profits from the platform's advertising business depend upon the quality of the access products. We develop a theoretical model to study this context and find that such an entry by the platform (i) can lead the platform to provide a higher quality access product than the third-party firms at a lower price, (ii) may, in contrast to the entry by a third-party firm, lead to a higher quality access product by both the platform as well as the firms, (iii) improves the platform's profits because of increased advertising revenue and/or additional profits from the access product sales, and (iv) increases consumer surplus even though the platform becomes more dominant because of its entry into the access product market. All the results are driven by the positive association between the platform's advertising profits and the quality of access products in the market.

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Keywords: two-sided markets • advertising • envelopment • quality competition • price competition • spokes model • vertical integration

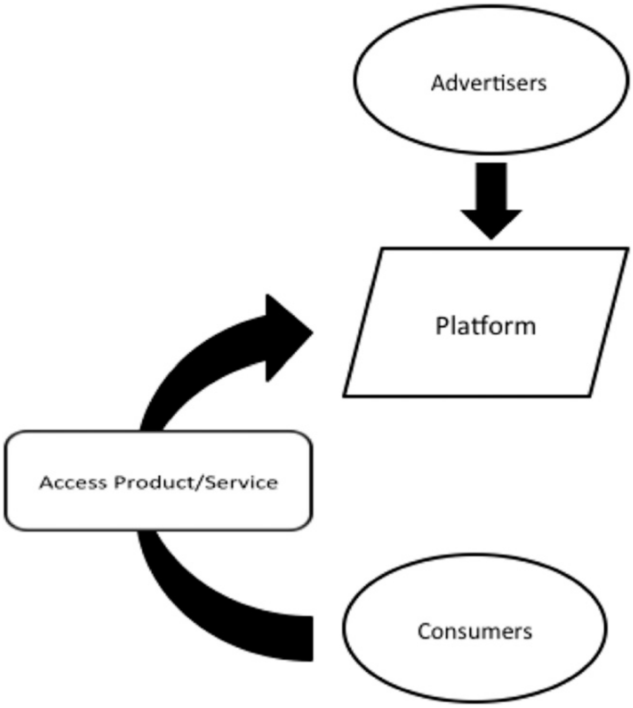
1. Introduction

The business model of two-sided platforms is based on creating an efficient way to match consumers with suppliers. These platforms typically expand the boundaries of their business by offering products and services to the consumers just like the supply side of the platform (Hagiu and Spulber 2013, Lee 2013). For example, Microsoft's Xbox platform expanded its business by publishing its own video games, such as *Halo*. Another way for platforms to expand their business is to focus on the consumer side rather than the supply side. Consumers often require a complementary hardware product or service to access the services provided by a platform (see Figure 1), and we refer to these products/services as *access* products. As an example, consider a smartphone or an internet service that is required to access the supply side of digital content platforms, such as YouTube, Google Search, etc.

Many two-sided platforms have entered into the business of selling access products even when established third-party firms existed to provide such products. For instance, Google, which owns YouTube, entered into the business of internet service provision through Google Fiber although big internet service providers (ISPs), such as Comcast and Charter, existed. Similarly, an increasing number of consumers access Google's content and search platforms through their smartphones. Google entered into the smartphone business with its Pixel phones though other Android phones, for example, Samsung Galaxy, already existed. Besides Google, Facebook has also adopted this approach. Virtual reality (VR) headsets are becoming popular for accessing Facebook because the value of social interactions are higher when people access the platform in a setting with virtual and augmented reality (Turk 2017). Facebook entered this access device market through its Oculus product alongside other VR headsets, such as HTC Vive and PlayStation VR.

In this paper, we investigate why platforms expand their business by providing access products. Clearly, entering into the access product market creates a new revenue stream for the platform. In addition, the platform can enter with a relatively higher quality access product that can increase the platform's revenues. For example, consider YouTube. A higher quality internet service allows consumers to enjoy a better

Figure 1. Role of Access Product or Service for a Platform



quality video streaming experience on YouTube. This induces consumers to consume more content on YouTube, thus allowing YouTube to show more ads to consumers and earn more advertising revenue (Gabbert 2017). Similarly, a better quality phone may allow consumers to search quickly and efficiently, inducing them to search more, which helps the Google Search platform in improving its advertising earnings.

However, a platform's entry increases competition in the access product market, and this increase in competition may influence an increase or a decrease in the qualities of competing access products. An increase in the quality of other access products benefits the platform as it earns higher advertising revenues from consumers who use these products. However, a reduction in the quality of other access products decreases the platform's earnings from consumers who utilize these products.

There has been an intense debate in previous literature since Schumpeter (1942) on the relationship between competition and innovation, and we know that, depending on the context, an increase in competition may increase or decrease innovation. We are interested in the context of mature markets in which the market is covered because this is the situation in many access products, such as smartphones and ISPs. In this context, we expect that entry reduces incentives to innovate for existing firms (Banker et al. 1998, Vives 2008, Goettler and Gordon 2011). Thus, one may suspect that entry of platforms in access product markets would reduce qualities of other access products.

Anecdotal evidence, however, suggests the opposite. For example, postentry of Google Fiber, existing ISPs improved their quality by investing in their infrastructure to provide better internet speeds (Davidson 2015, Levin and Downes 2018). Thus, entry of two-sided platforms into access product markets presents a puzzle, and we wish to understand why the entry of a platform creates incentives for existing firms to increase the quality of their access products.

In addition, it is noteworthy that platform-owned access products are generally higher in quality compared with existing offerings, yet they are available at a lower price than their competitors. For example, Google Fiber provides a higher internet speed (1 Gbps) at a lower price ($70 per month), whereas Xfinity provides a much lower speed (250 Mbps) at a higher price ($75 per month) in cities such as Atlanta and Austin.[1] Similarly, on comparing the price of Google's flagship phone Pixel with that of Motorola's flagship phone Moto Z in 2016, we note that the unlocked version of Moto Z was introduced at a price of $699 (Swider 2017) although the unlocked Pixel phone was launched at a price of $649 (McCann 2018).[2] We further note that Google's Pixel overall scored better in quality measures than Moto Z, including in the crucial aspects of performance and features.[3] In general, we expect that higher quality products would be sold at higher prices compared with lower quality products. However, this evidence shows that the platform's access products can be priced lower than their competitors even though they are of higher quality. This observation presents another piece of the puzzle related to platform entry, which is how entry by a platform creates incentives for its higher quality product to be priced lower than competing lower quality products.

1.1. Research Objective and Overview of Results

Given the preceding discussion, our main research objective is to study the competitive implications of a platform's entry into the access product market when (i) the platform's profits from advertising increase with the quality of access product used by a consumer and (ii) the market is relatively mature with limited scope for market expansion, for example, ISP market entry by Google Fiber and Google's smartphone market entry through Pixel phones.[4] We expand the scope of our analysis in the latter part of the paper to analyze the role of market expansion with platform's entry.

In order to study these questions, we analyze a theoretical model of quality–price competition with two existing third-party firms in the access product market and an entrant, which could either be another third-party firm or the platform that earns advertising profits through consumers who use the access products to utilize the platform's services. Our analysis yields some interesting theoretical results that are in line with our real-world observations. We first show that, when the platform enters the access product market, it can offer a higher quality product than the third-party firms at a lower price. This happens because the platform lowers its price below that of other access product providers to gain a relatively high market share. The loss in revenue from selling the access product at a lower price is more than offset by the additional advertising revenue the platform earns as a result of the relatively higher market coverage of the higher quality access product.

Second, we find that, unlike the entry of a third-party firm, the platform's entry into the access product market may lead both the firms and the platform to produce a higher quality product compared with the quality without the platform's entry. The intuition behind this result is that the platform accommodates the other firms by increasing its own price as they raise their qualities. The platform does this because provision of high-quality access products by its rivals enables it to earn higher advertising revenues. This price increase by the platform allows the other firms to increase their own prices, thus improving their marginal value of quality and leading to a higher equilibrium quality.

Third, we find that the platform always makes higher profits with its own entry as a result of either increased advertising revenue or additional profits from the sales of the access product or both. Finally, we show that the consumer surplus in the access product market is higher with the platform's entry even when the quality of the existing firms is lower than with a third-party firm entry because of the additional surplus provided by the platform's own higher quality access product.

The rest of the paper is organized as follows. In Section 2, we describe the prior literature and our positioning in the literature. Section 3 describes the model, and Section 4 presents the equilibrium features. Section 5 provides the analysis and the intuition in detail. In Section 6, we analyze the case of market expansion with entry and perform robustness checks on our results, and we summarize the paper in Section 7. All proofs are provided in Appendix A.

2. Related Literature

Our paper is related to two main streams of literature: (i) expansion of platform businesses and (ii) impact of competition and complementarity on innovation.

2.1. Expansion of Platform Businesses

Platforms expand their business either by entering new markets or by improving the demand from their current market. Entering new platform-based markets requires Schumpeterian innovation by platforms as two-sided network externalities create high entry barriers and, consequently, winner-takes-all situations. However, this is not the only approach to market entry. Eisenmann et al. (2011) proposes that platforms can also enter new markets using an envelopment strategy, which exploits shared relationships of users with multiple platforms and targets these users by harnessing the benefits of price discrimination and/or economies of scope to reduce the cost of common components between platforms.

Besides entering new markets to expand their business, platforms can also improve demand for existing services using different approaches. For example, they increase the diversity of supply-side offerings by investing in first-party content (Hagiu and Spulber 2013), create exclusivity arrangements with content providers (Lee 2013), or even act as merchants in which case they completely take over the supply side (Hagiu and Wright 2015, Abhishek et al. 2016).

Our paper studies a novel approach for platforms to extend their business by entering into hardware product markets that are used by consumers to access the platform's services.

2.2. Impact of Competition and Complementarity on Innovation

Our paper is related to the literature on how competition affects innovation. Schumpeter (1942) asserts that monopoly rents create higher incentive for firms to innovate. Arrow (1972), on the other hand, argues that competition results in higher incentives to innovate. Extant literature indicates that the relationship between competition and innovation is complex and depends upon a number of factors, such as how innovation and competition are measured, market characteristics, and nature of competition. As the combination of these factors changes, so does this relationship (e.g., Ma and Burgess 1993, Banker et al. 1998, Goettler and Gordon 2011). Vives (2008) find that, when competition increases as a result of entry of new firms, innovation typically reduces.

Our paper is also related to the literature on quality innovation by firms operating in complementary businesses. A general finding in this literature is that independent firms selling complementary products produce lower quality than an integrated firm (Economides 1999, Yalcin et al. 2013, Ha et al. 2016).

We consider a setting in which a platform's entry into a complementary business increases competition. The literature on competition suggests that quality may

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decrease because of entry, but the literature on innovation in complementary businesses suggests that quality may increase. Thus, we investigate a setting that allows us to ask the interesting question of what happens to quality of the product in a market when a platform enters a complementary business.

3. Model

In our setting, consumers can utilize the services provided by a platform using an access product. They need to purchase their own access product, but can use the platform's services for free. Further, third-party firms selling the access products do not incur a cost to make the platform's services available to the consumers. The platform earns advertising revenue for its services from the business side of the platform.

We analyze our research questions by considering the equilibrium outcomes under the following three scenarios.[5]

i. Two-firm benchmark: Two third-party firms compete in the access product market while the platform earns profits only from its advertising business.

ii. Third-party firm entry: Three third-party firms compete in the access product market while the platform earns profits only from its advertising business.

iii. Platform entry: Two third-party firms and the platform compete in the access product market, in which the platform earns profits from both product sales and its advertising business.

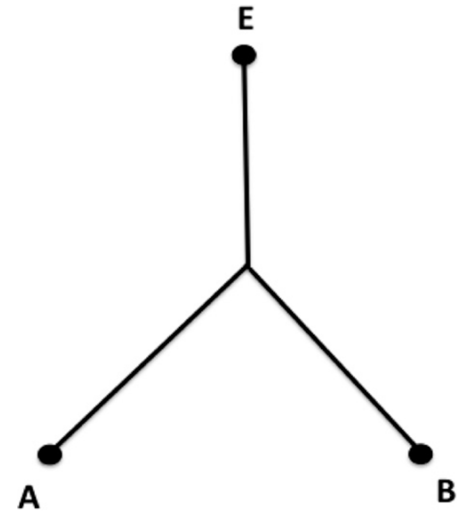
3.1. Firms

We use the spokes model (Chen and Riordan 2007) to represent the locations of the different access product firms in a horizontally differentiated market. The spokes model generalizes the standard Hotelling model by allowing multiple firms to compete in a market in which each firm can compete with all other firms (e.g., Caminal and Claici 2007).

We consider a setting in which there is no market expansion resulting from firm entry.[6] Therefore, we consider a model with three spokes in which each spoke is of length $\frac{1}{2}$. All the spokes terminate at the center and originate at the other end. In the two-firm benchmark case, the access product is sold by two firms, A and B. These firms are located at the origins of two of the spokes. The origin of the third spoke is empty and is denoted by E (see Figure 2).

A third firm may enter the market with its own access product, and it locates itself at the origin of the empty spoke. If the entering firm is a third-party seller, we represent it by T, and if the entering firm is the platform, we represent it by P. Further, in order to maintain brevity of notation, all spokes are represented by the same name as their origin, and whether we refer to the origin of the spoke, or the spoke itself is made clear by the context of the exposition.

Figure 2. Three-Spoke Model



3.2. Consumers

A unit mass of consumers are uniformly distributed over the entire spokes network. Thus, the total number of consumers on each spoke is $\frac{1}{3}$. A consumer on spoke $i \in \{A, B, E/T/P\}$ is represented by the location $x_i \in [0, \frac{1}{2}]$ on spoke i, and the origin of the spoke is at zero. Firm i is the most preferred brand for a consumer on spoke i, and the second preferred brand is $j \neq i$ with probability $\frac{1}{2}$, where $j \in \{A, B, E/T/P\}$. A consumer needs one unit of the access product and chooses between the most preferred brand and the second preferred brand if both of these are available. Consumers are assumed to have positive valuations for their first and second preferred brands only. This is a simplifying assumption, which has been made in several papers (Perloff and Salop 1985, Schulz and Stahl 1996), including Chen and Riordan (2007). One possible motivation for this assumption is consumers' imperfect information. When consumers have imperfect information, they must search to find product information. Because search is costly, consumers do not consider all the products.[7] If only one of these brands is available, the consumer purchases the access product from that firm. Note that each consumer has at least one of the alternatives present in the market in all the three cases.

We represent the utility of a consumer at x_i from buying the access product from firm j by U_{ij}. Then, the utility of a consumer x_i from the most preferred firm is $U_{ii} = \alpha + u(q_i) - \tau x_i - p_i$, and the utility from the second preferred firm is $U_{ij} = \alpha + u(q_j) - \tau(1 - x_i) - p_j \ \forall \ i, j \in \{A, B, E/T/P\}$, and $j \neq i$ (Wolinsky 1997), where τ is the per unit fit cost, p_i is the price, α is the base utility from the access product, and q_i is the quality of firm i that enhances user experience beyond the base utility by $u(q_i)$.[8] We assume $u'(q) > 0$ and $u''(q) \leq 0 \ \forall \ q \geq 0$, and $u(0) = 0$. The concavity assumption on $u(q)$ captures the idea that, although an increase in quality of the access product provides better access to the platform, allowing consumers to derive a higher utility, the marginal utility of quality steadily decreases. We assume that α is large enough so that the market is covered. We also assume $\tau = 1$ without any loss of generality. In the two-firm benchmark case, consumers on spoke E do not have their most preferred brand, implying $U_{EE} = 0$, but $U_{Ej} = \alpha + u(q_j) - (1 - x_E) - p_j \;\forall\, j \in \{A, B\}$.

3.3. Profit Function

Here, we first derive the demands for the firms selling the access products and then use these expressions to formulate the profit functions of the access product firms as well as the platform.

3.3.1. Product Firms. ***3.3.1.1. Two-Firm Benchmark.*** There are $(1/3) \cdot (1/2) = 1/6$ consumers on spoke A for whom B is the second preferred firm. Similarly, there are $\frac{1}{6}$ consumers on spoke B for whom A is the second preferred firm. Therefore, the size of this consumer segment is $\frac{1}{3}$, and these consumers are uniformly distributed on the line constituted by joining spokes A and B. For these consumers, the marginal consumer indifferent between firms A and B is given by $\alpha + u(q_A) - \bar{x}_{AB} - p_A = \alpha + u(q_B) - (1 - \bar{x}_{AB}) - p_B$ ($\Rightarrow \bar{x}_{AB} = (1 + u(q_A) - u(q_B) - p_A + p_B)/2$), where $\bar{x}_{AB}$ is the distance of the marginal consumer from firm A.[9] All consumers in this segment to the left of $\bar{x}_{AB}$ buy from firm A, and those to the right of $\bar{x}_{AB}$ buy from firm B.

The remaining consumers on spokes A and B whose second preferred firm is absent buy from A and B, respectively. Thus, this consumer segment provides a demand of $\frac{1}{6}$ for each firm.

All the consumers on spoke E are equally distributed between firms A and B as only one of these firms is their second preferred firm and their most preferred firm is absent. This consumer segment, therefore, provides a demand of $\frac{1}{6}$ for each firm.

Therefore, demands for firm A and B are $D_A = \bar{x}_{AB}/3 + 1/6 + 1/6$ and $D_B = (1 - \bar{x}_{AB})/3 + 1/6 + 1/6$, respectively. Substituting $\bar{x}_{AB}$ in the demand functions, we get

$$D_i = \frac{1}{2} + \frac{u(q_i) - u(q_j) - p_i + p_j}{6} \quad \forall\, i, j \in \{A, B\}, \text{ where } j \neq i. \tag{1}$$

3.3.1.2. Third-Party Firm Entry and Platform Entry. With three firms on the spokes network, all consumers have both of their alternatives available in the market. Therefore, we consider the three segments of consumers for whom the preferred firms are A and B, A and T, and B and T. Therefore, we have three marginal consumers, $\bar{x}_{AB}$, $\bar{x}_{AT}$, and $\bar{x}_{BT}$, who are indifferent between A and B, A and T, and B and T, respectively. All the consumers to the left of $\bar{x}_{AB}$ buy from A, and those to the right of $\bar{x}_{AB}$ buy from B. Similarly, all the consumers to the left of $\bar{x}_{BT}$ buy from B, and the rest buy from T, and consumers to the left of $\bar{x}_{AT}$ buy from A, and the rest buy from T.

Consequently, the demands for the firms A, B, and T are $D_A = \bar{x}_{AB}/3 + \bar{x}_{AT}/3$, $D_B = (1 - \bar{x}_{AB})/3 + \bar{x}_{BT}/3$ and $D_T = (1 - \bar{x}_{AT})/3 + (1 - \bar{x}_{BT})/3$, respectively. Substituting $\bar{x}_{AB}$, $\bar{x}_{AT}$, and $\bar{x}_{BT}$ in the demand functions, we get

$$D_i = \frac{1}{3} + \frac{2u(q_i) - u(q_j) - u(q_k) - 2p_i + p_j + p_k}{6} \quad \forall\, i, j, k \in \{A, B, T\}, \text{where } i \neq j, k \text{ and } j \neq k. \tag{2}$$

The demand formulation for the access product firms and the platform in the platform entry case is the same as in the third-party firm entry.

Once the demands for firms are formulated, we can write the profit functions of firms for any of the three cases by incorporating the prices of the access products and the cost of quality creation. For firm i, taking the cost of developing a product of quality q_i to be $\frac{cq_i^2}{2}$, where $c > 0$, and assuming the marginal cost of the product to be zero, we write the profit functions of the firms as follows:

$$\pi_i = p_i D_i - \frac{cq_i^2}{2}.$$

3.3.2. Platform. We represent the revenue from the platform's advertising per consumer when the consumer uses an access product of quality q by $\phi(q; a)$. We assume that this revenue earned from advertisers increases with the quality of the access product. As discussed in the introduction, this relationship ensues because, as the quality of the access product increases, the consumers consume more of the platform's services, allowing the platform to show more or better advertisements to consumers, thus increasing its revenues. However, because the consumers cannot indefinitely increase their consumption of the platform's services as the access product quality increases, we assume that the marginal advertising revenue per consumer weakly decreases with quality, implying $\phi(q; a)$ is concave in q. Further, the parameter a captures the strength of the relationship between the revenues generated from the platform's advertising services and the access product quality. Accordingly, we have $\phi_q > 0$, $\phi_a > 0$, $\phi_{qq} \leq 0$, and $\phi(0; a) = 0$.

When the platform enters the market with its own access product, it generates revenue from two sources: its advertising business and sales of its access product; otherwise, it earns only from the advertising business.

We write the profit function of the platform as the following:

$$\pi_P = \begin{cases} \phi(q_A)D_A + \phi(q_B)D_B & \text{Two-firm benchmark;} \\ \phi(q_A)D_A + \phi(q_B)D_B \\ \quad + \phi(q_T)D_T & \text{Third-party firm entry;} \\ p_P D_P - \frac{cq_P^2}{2} + \phi(q_A)D_A \\ \quad + \phi(q_B)D_B + \phi(q_P)D_P & \text{Platform entry.} \end{cases} \tag{3}$$

Note that, for brevity, we suppress the notation $\phi(q; a)$ to just $\phi(q)$ in expressing the platform's profit function and hereinafter.

3.4. Timeline

The game proceeds in three stages. In the first stage, qualities are determined simultaneously by the respective firms. In the second stage, all firms simultaneously decide their prices. Finally, consumers buy an access product after observing the qualities and prices of all the products, and profits of the access product firms and the platform are realized. We use backward induction to solve for equilibrium prices and qualities.

4. Equilibrium Features

In this section, we present our analysis solving the game between the firms and the platform. We use superscripts b, t, and m appended with an asterisk to denote equilibrium values in the two-firm benchmark case, the third-party firm entry case, and the platform entry case, respectively.[10]

4.1. Two-Firm Benchmark

We solve the first-order conditions of the two profit functions, π_A and π_B, with respect to prices, p_A and p_B, and obtain the expressions for price as a function of qualities as follows: $p_i^b(q^b) = 3 + (u(q_i) - u(q_j))/3$ for $i \in \{A, B\}$ and $i \neq j$, where $q^b = \{q_A, q_B\}$ is a vector of all the qualities in the benchmark case. After substituting these prices into $\pi_i \; \forall\, i \in \{A, B\}$ and then differentiating it with respect to quality, we obtain the marginal value of quality for firm i as:

$$\frac{\partial \pi_i}{\partial q_i} = \frac{1}{27}\left(9 - u(q_j) + u(q_i)\right)u'(q_i) - cq_i,$$

where $j \neq i \in \{A, B\}$.

4.2. Third-Party Firm Entry

We use backward induction as in the two-firm benchmark case to obtain the second-stage prices $p_i^t(q^t) = 1 + (2u(q_i) - u(q_j) - u(q_k))/5 \; \forall\, i \neq j \neq k \in \{A, B, T\}$, where $q^t = \{q_A, q_B, q_T\}$ represents all the qualities with third-party firm entry. Again, after substituting these prices into $\pi_i \; \forall\, i \in \{A, B, T\}$ and then differentiating it with respect to quality, we get the marginal value of quality for firm i as:

$$\frac{\partial \pi_i}{\partial q_i} = \frac{4}{75}\left(5 - u(q_j) - u(q_k) + 2u(q_i)\right)u'(q_i) - cq_i,$$

where $j \neq k \neq i \in \{A, B, T\}$.

4.3. Platform Entry

Note that parametric function ϕ does not impact the equilibrium prices and qualities in the two-firm benchmark case or in the third-party firm entry case because the platform plays no strategic role in the access product competition. However, the platform affects the price and quality competition in the access product market when it launches its own product.

We solve the first-order conditions with respect to price to get the equilibrium prices as functions of the qualities (see Table 1). We denote them by $p_i^m(q^m)$ for $i \in \{A, B, P\}$, where $q^m = \{q_A, q_B, q_P\}$ is a vector of all the qualities with platform entry.[11] Using the prices obtained in Table 1, we obtain the marginal value of quality for the two access product firms and the platform, which can be found in Appendix A.1. We present a comparison of the equilibrium qualities between the firms and the platform in the platform entry case in our first lemma.

Lemma 1. *In the Platform entry case, $q_P^{m*} > q_A^{m*} = q_B^{m*}$.*

The lemma states that, when the platform enters the market, the quality of the platform's access product is higher than that of firms A and B. This happens because the marginal value of quality is higher for the platform than the firms because of the presence of quality-dependent revenues from the platform's advertising business in addition to sales revenues. Using this finding, we obtain our next result comparing the prices of the access product of the platform with those provided by the firms.

Lemma 2. *The price of the platform's access product is lower than the price of the firms' access products, that is, $(\phi(q_P^{m*}) - \phi(q_A^{m*}))/(u(q_P^{m*}) - u(q_A^{m*})) > 3/2$.*

In order to explain the intuition behind this result, we examine the price expressions in Table 1. The first term (= 1) comes from the pricing power resulting from horizontal differentiation. The second term captures any compensation for the difference in qualities between the competing firms. In equilibrium, this term is

Table 1. Prices as a Function of Quality with Platform Entry

Firm	Price
A	$p_A^m(q^m) = 1 + \frac{2u(q_A) - u(q_P) - u(q_B)}{5} + \frac{\phi(q_A) + \phi(q_B) - 2\phi(q_P)}{10}$
B	$p_B^m(q^m) = 1 + \frac{2u(q_B) - u(q_P) - u(q_A)}{5} + \frac{\phi(q_A) + \phi(q_B) - 2\phi(q_P)}{10}$
P	$p_P^m(q^m) = 1 + \frac{2u(q_P) - u(q_A) - u(q_B)}{5} + \frac{3(\phi(q_A) + \phi(q_B) - 2\phi(q_P))}{10}$

positive for the platform and negative for the two firms because $q_P^{m*} > q_A^{m*} = q_B^{m*}$ (Lemma 1).

The third term in the price expression arises because of the platform's incentives from its advertising business. This term has a negative sign because $\phi_q > 0$ and the quality of the platform's access product is higher than that of the firms in equilibrium. The negative sign of this term reflects the platform's incentive to increase the market coverage of its own product, which is the highest quality product in the market, by reducing its price so that it can get relatively higher revenues from its services business. Further, the higher the impact of quality on the platform's advertising revenue (larger ϕ_q), the higher will be the extent of price reduction by the platform.

In the case of the firms, the negative sign of the third term captures the effect of price competition on their prices resulting from the lowering of prices by the platform. However, the magnitude of this term is smaller for the firms compared with the magnitude of the corresponding term for the platform because the direct incentive of the platform to reduce its price is stronger than the indirect effect of price competition on the firms. Therefore, the price of the platform becomes lower than that of the firms when ϕ_q is relatively large.

Combining the findings from these two lemmas, we obtain our first main insight into the nature of the equilibrium when the platform enters with its own access product.

Proposition 1. *Even though the quality of the platform's access product is higher than that of the other firms, its price is lower when* $(\phi(q_P^{m*}) - \phi(q_A^{m*}))/(u(q_P^{m*}) - u(q_A^{m*})) > 3/2$.

This result highlights that the well-known result that higher quality products are priced higher (Tirole 1988) may not hold in this case. As described earlier, the main reason for this finding is the platform's incentives from its advertising business, that is, to increase the market coverage of the highest quality product. As mentioned in the introduction, this is also in line with our observations that, in certain cities, Google Fiber provides a higher internet speed (1 Gbps) at a lower price compared with other ISPs, such as Xfinity,[12] and that Google's Pixel phone was considered better than Moto Z in many key aspects, and still it was available for a lower price.

Although the subsidy mechanism is used in both the razor blades model and the platform model to drive a firm's profits, the way in which the subsidy mechanism is used in the two models is different. In the razor blades model, a subsidy is provided on the primary product (razor) to entice the consumers to buy this product. The firm makes profits by selling the secondary product (blades) at relatively high prices to the consumers who purchased the primary product. In the platform model, a subsidy is provided to one side of the market (typically consumers) to drive market growth on this side. The firm makes profits by selling its services to the other side of the market (typically the supply side). A comparison of the subsidy mechanism in the tying model, and the platform model is recorded in Parker and Van Alstyne (2005) and Rochet and Tirole (2003), in which they conclude that the use of subsidies in the context of tying and platforms is fundamentally different. In our context of platforms, we analyze a situation in which consumers enjoy a full subsidy as the use of the platform's services is free for them. We find that, in such situations, the platform may want to further extend the subsidy through the access products by providing higher quality products at relatively low prices (compared with access products provided by third-party access product firms).

In the following section, we compare the equilibrium values of qualities, profits, and consumer surpluses across the three cases to provide more insights into why a platform may choose to enter the access product market and how the effect of this entry differs from the entry of a third-party firm.

5. Analysis

5.1. Effect of Entry on Quality

Here, we lay down how the qualities of access products in the two-firm benchmark case differ compared with the qualities in the third-party firm entry case.

Lemma 3. *Compared with the two-firm benchmark case, the qualities of all the access products in the third-party firm entry case are lower, that is,* $q_i^{t*} < q_i^{b*}\ \forall\ i \in \{A, B\}$.

This lemma establishes that, in our context, increased competition resulting from entry by a symmetric firm in the market leads to a reduction in the equilibrium quality. We wish to examine whether entry by the platform results in reduction of equilibrium qualities of access products just as in the case of third-party firm entry or an increase in equilibrium qualities of these products. We present our findings in the next result.

Proposition 2. *A sufficient condition for* $q_P^{m*} > q_i^{m*} > q_i^{b*}\ \forall\ i \in \{A, B\}$ *is*

i. $\phi'(q_i^{b*})/u'(q_i^{b*}) > \Delta$ *when* $\phi'(q)/u'(q)$ *weakly decreases with* q; *or*

ii. $\phi'(0)/u'(0) > \Delta$ *when* $\phi'(q)/u'(q)$ *increases with* q, *where* $\Delta = 25/(5 - \phi(q_P) - u(q_P)) - 4$.

In order to explain the intuition behind the result, we consider the reaction function of a firm (say A) in the two-firm benchmark case and the platform entry case, which can be expressed as follows:

$$\frac{d\pi_A^b}{dq_A} = p_A^b(q^b)\left(\underbrace{\frac{\partial D_A^b}{\partial q_A}}_{\substack{\text{Direct}\\\text{Effect}}} + \underbrace{\frac{\partial D_A^b}{\partial p_B}\frac{dp_B^b(q^b)}{dq_A}}_{\text{Strategic Effect}}\right) - cq_A = 0.$$

$$\frac{d\pi_A^m}{dq_A} = p_A^m(q^m)\left(\underbrace{\frac{\partial D_A^m}{\partial q_A}}_{\substack{\text{Direct}\\\text{Effect}}} + \underbrace{\sum_{k\in\{B,P\}}\frac{\partial D_A^m}{\partial p_k}\frac{dp_k^m(q^m)}{dq_A}}_{\text{Strategic Effect}}\right) - cq_A = 0.$$

We now write down the values of the direct and strategic effects in the two cases as follows:

5.1.1. Direct Effect.

$$\frac{\partial D_A^b}{\partial q_A} = \frac{u'(q_A)}{6};$$
$$\frac{\partial D_A^m}{\partial q_A} = \frac{u'(q_A)}{3}.$$

5.1.2. Strategic Effect.

$$\frac{\partial D_A^l}{\partial p_k} = \frac{1}{6}, \text{ where } k \in \{B, P\} \text{ and } l \in \{b, m\};$$
$$\frac{dp_B^b(q^b)}{dq_A} = -\frac{u'(q_A)}{3};$$
$$\frac{dp_P^m(q^m)}{dq_A} = \frac{3\phi'(q_A)}{10} - \frac{u'(q_A)}{5};$$
$$\frac{dp_B^m(q^m)}{dq_A} = \frac{\phi'(q_A)}{10} - \frac{u'(q_A)}{5}.$$

Proposition 2 establishes that, when the slope of ϕ with respect to quality is large relative to the slope of u, all the equilibrium qualities of access products with platform entry become higher than the quality in the two-firm benchmark case. Comparing the results in Lemma 3 with Proposition 2, we observe that an increase in competition in the access product markets through the platform's entry may have the opposite effect compared with an increase in competition through entry by a symmetric access product provider. There is also some anecdotal evidence in support of this proposition, which shows that, postentry of Google Fiber, the incumbent ISPs in the cities improved their service (Davidson 2015).

The reason for this behavior can be understood by observing that, in the platform entry case, the direct effect on demand for firm A is positive ($= \frac{u'(q_A)}{3}$) and independent of ϕ, just as it is in the two-firm benchmark case. However, unlike in the benchmark case, the strategic effect for firm A with the platform's entry becomes positive or smaller in magnitude (if it is negative) when the slope of ϕ with respect to quality is high enough. When this strategic effect becomes sufficiently large, the equilibrium response of firm A (and firm B) is to raise its quality.

To understand the reason why firm A raises its quality, we consider its incentives given the qualities of the platform and firm B. As ϕ_q increases, the platform gets a higher marginal value of quality from firm A's product because it earns higher revenue from advertising to consumers who access the platform through firm A's product. Hence, when A increases its quality, the platform has an incentive to accommodate firm A by raising its own price (note that $\frac{dp_P^m(q^m)}{dq_A}$ becomes positive when ϕ_q is large). Further, as the platform raises its price, firm B also has an incentive to increase its price (note that $\frac{dp_B^m(q^m)}{dq_A}$ also becomes positive when ϕ_q is relatively large). Overall, the platform's ability to earn from advertising creates an incentive to increase its price rather than to decrease its price when a competing firm raises quality. This incentive of the platform increases the marginal value of quality for the firm, leading it to produce a higher quality.

To develop further insights into the comparison of qualities, platform's profits, and consumer surplus across the three cases, we obtain closed-form solutions for quality by making two simplifying assumptions: $u(q) = q$ and $\phi(q; a) = aq$, where $a > 0$;[13] that is, both the consumer utility and the platform's advertising profit linearly increase in quality.[14] We get a unique subgame perfect Nash equilibrium in each case. The equilibrium values of qualities in the two-firm benchmark are given by $q_A^{b*} = q_B^{b*} = q^{b*} = \frac{1}{3c}$. Similarly, the equilibrium qualities in the third-party firm entry case are given by $q_A^{t*} = q_B^{t*} = q_T^{t*} = q^{t*} = \frac{4}{15c}$. The equilibrium values of qualities in the platform entry case are:

$$q_A^{m*} = q_B^{m*} = \frac{(4+a)(25c - 4(1+a)^2)}{15c(25c - (1+a)(4+3a))} \text{ and}$$
$$q_P^{m*} = \frac{4(1+a)(25c - (1+a)(4+a))}{15c(25c - (1+a)(4+3a))}.$$

See Appendix A.5 for equilibrium conditions. We present the comparative statics of the difference between the platform's equilibrium quality (q_P^{m*}) and firm A's equilibrium quality (q_A^{m*}) with respect to parameters a and c in the following lemma.

Lemma 4. *In the platform entry case,*
i. $q_P^{m*} - q_A^{m*}$ *increases with respect to* a.
ii. $q_P^{m*} - q_A^{m*}$ *decreases with respect to* c.

The quality gap between the platform and the firms increases with a because the platform earns more per unit of quality (because of advertising revenue) and, hence, has a higher marginal benefit from raising quality than the firms. The quality dominance of the platform reduces with c because, for a given value of a, as c increases, the firms and the platform have an incentive to decrease their quality. However, the platform decreases its product quality at a higher rate than the firms as the marginal cost is higher for the platform because of its higher quality. The higher rate of decrease reduces the gap between the platform's quality and the firm's quality as c increases.

We obtain our next two corollaries by comparing the equilibrium values of qualities across the two-firm benchmark case and the platform entry case.

Corollary 1. (i) $q_A^{m*} = q_B^{m*} > q^{b*}$ *when* $a > 1$ *and* $c > \hat{c}$, *and* (ii) $q_A^{m*} = q_B^{m*} \leq q^{b*}$ *otherwise.*

This corollary says that the equilibrium quality of the firms (as well as of the platform from Lemma 1) in the platform entry case is higher than the benchmark quality when a and c are large. In order to explain the result, we compare the incentives of quality creation of firm A at equilibrium in the two cases. The marginal value of quality of firm A at $q_B = q_A$ is given by $p_A^b(q^b) \cdot \frac{dD_A^b}{dq_A} - cq_A = \frac{1}{3} - cq_A$ in the two-firm benchmark case and by $p_A^m(q^m) \cdot \frac{dD_A^m}{dq_A} - cq_A = (1 - ((1+a)(q_P - q_A))/5) \cdot (4+a)/15 - cq_A$ in the platform entry case.

First, note that parameter a impacts the marginal value only in the platform entry case but not in the two-firm benchmark case. Second, in the platform entry case, a affects the marginal value of quality both positively and negatively. The positive effect is due to an increase in the total demand effect, $\frac{dD_A^m}{dq_A}$ $(= (4+a)/15)$ because the direct effect on demand $(= \frac{1}{3})$ is independent of a, and the strategic effect $(= (a-1)/15)$ increases with a. The negative effect of a is due to a decrease in price, $p_A^m(q^m)$ $(= 1 - \frac{(1+a)(q_P - q_A)}{5})$, as $q_P - q_A$ is positive (from Lemma 1) and increases with a (Lemma 4(i)). However, the negative effect of a on price is mitigated at high values of c as $q_P - q_A$ is relatively low when c is large (Lemma 4(ii)). Thus, overall, the positive effect of a dominates when both a and c are large, leading the firms to produce a higher quality than the benchmark quality. Otherwise, the negative effect dominates, which results in firms producing a lower quality than the benchmark quality.

Corollary 2. (i) $q_P^{m*} < q^{b*}$ *when* $a < \frac{1}{4}$ *and* $c > \tilde{c}$, *and* (ii) $q_P^{m*} \geq q^{b*}$ *otherwise.*

The first part of Corollary 2 points to the situation in which the entry of the platform has similar quality implications as any third-party firm entry; that is, all the qualities are lower with the entry of a new firm (Lemma 3).[15] This happens because, when a is small, the platform's incentives are similar to that of a third-party firm. Specifically, the marginal benefit of quality of the platform with its own entry is given by $\frac{4}{75}(1+a)(5+2(1+a)(q_P - q_A))$, which increases with a as $q_P - q_A$ increases with a and decreases with c as $q_P - q_A$ decreases with c (Lemma 4). Therefore, the platform does not have enough incentive to produce a high-quality product when a is very small and c is relatively large. Otherwise, the platform produces a higher quality than the benchmark quality.

5.2. Effect of Entry on Profits of the Platform

Comparing the profit of the platform in the two-firm benchmark case to that in the third-party entry case, we find that the platform profits reduce as a result of entry of a new product in the market. The result is stated in the following corollary to Lemma 3.

Corollary 3. $\pi_P^{b*} > \pi_P^{t*}$.

The reason for the finding in Corollary 3 is that the equilibrium qualities in the third-party firm entry case are lower than the qualities in the two-firm benchmark case, causing the platform to earn lower revenues from advertising with the entry of a new third-party firm into the access product market.

Next, we compare the profits of the platform in the two-firm benchmark case with that in the platform entry case. From Corollary 1(i), we see that the platform's entry results in higher qualities for all the firms compared with the benchmark case. Under such scenarios, the platform always earns higher revenue from advertising compared with the benchmark because all consumers use products of higher quality than the benchmark. Corollary 2(i) shows the case in which the platform earns lower revenues from advertising with its own entry because the qualities of the firms and the platform are lower compared with the benchmark qualities. Hence, revenues from the platform's advertising business can be higher or lower compared with the benchmark. When the platform's advertising profits are lower compared with benchmark, its entry would be beneficial only if the profits from sales of its access product can make up for the loss in the platform's advertising profits.

Note that the profits of the platform in the two-firm benchmark case are higher than its profits with third-party firm entry. Therefore, in order to identify when the platform's entry is profitable, we compare the total profits of the platform when it enters (sum of the profits from product sales and advertisements) with its profits in the benchmark case. We report the results of this comparison in the next proposition.

Proposition 3. *The platform earns higher profits with its own entry compared with the two-firm benchmark case; that is,* $\pi_P^{m*} > \pi_P^{b*}$.

Proposition 3 clarifies that the entry strategy is always profitable for the platform. To further analyze why the platform gains through entry, we focus on identifying whether it is the new source of revenue from product sales or higher revenues from the platform's advertising business that generates higher profits. Let π^{m*}_{Ps} denote equilibrium platform profits from product sales and π^{m*}_{Pa} the platform's profit from advertising in the platform entry case, in which $\pi^{m*}_{Ps} + \pi^{m*}_{Pa} = \pi^{m*}_{P}$.

Corollary 4. *Compared with the two-firm benchmark case, in the platform entry case,*

i. *The platform loses from product sales ($\pi^{m*}_{Ps} < 0$) but gains revenues from advertising ($\pi^{m*}_{Pa} > \pi^{b*}_{P}$) when $a > \frac{1}{4}$ and $c < \grave{c}$.*

ii. *The platform gains from product sales ($\pi^{m*}_{Ps} > 0$) but loses revenues from advertising ($\pi^{m*}_{Pa} < \pi^{b*}_{P}$) when $a < \frac{1}{2}$ and $c > \acute{c}$.*

iii. *The platform gains from both the sources in the rest of the parameter ranges.*

The expressions for parameter thresholds of c are algebraically tedious and, therefore, not mentioned here (see appendix). The intuition behind part (i) of the preceding proposition is as follows. When a is high, the platform has an incentive to create a high quality to gain from revenues from the platform's advertising business. When c is not too high, the platform creates such a high quality that it earns a negative profit from product sales. Therefore, the overall profit of the platform is higher because of revenues from advertising. For part (ii) of the result, we already know from Corollary 2(i) that all the equilibrium qualities in the platform entry case can be lower than the benchmark quality when a is small and c is high. This leads to lower revenues from the platform's advertising services in the platform entry case compared with the two-firm benchmark case. Hence, the overall profits of the platform are higher because of positive profits from product sales.

5.3. Effect of Platform Entry on Consumer Surplus

In this section, we analyze the implications of the platform's entry into the access product market for consumer surplus (CS).

We know that the qualities with entry of a third-party firm reduce compared with the benchmark case (Lemma 3). However, because of the presence of an additional firm, the fit cost of the products to consumers as well as the prices are lower. Hence, consumer welfare may increase or decrease with a third-party firm entry compared with the two-firm benchmark case. We present a formal comparison of the consumer surplus in the two cases in the following lemma.

Lemma 5. *The consumer welfare in the case of third-party firm entry is higher than in the two-firm benchmark case.*

This lemma implies that the impact of lower prices and lower fit cost with the third-party firm entry dominates the effect of lower qualities, thus improving overall consumer surplus.

From Corollary 2(i), we know that the platform's entry can cause all the qualities to be lower than the two-firm benchmark quality. Here, we present another lemma comparing the equilibrium qualities in third-party firm entry and platform entry cases.

Lemma 6. (i) $q^{m*}_{P} > q^{t*}\ \forall\, c$, *and* (ii) $q^{t*} > q^{m*}_{A} = q^{m*}_{B}$ $\forall\ c < (4(1+a)(2+a))/25$.

The platform always produces a higher quality than a third-party entrant because its marginal value of quality is higher than such an entrant because, unlike a third-party firm, it also earns revenue from the quality-dependent advertising business. From the second part of the lemma, we can see that the firms' qualities in the platform entry case are lower than even in the third-party firm entry case when c is small. To understand the intuition behind the result, recall from the discussion of Corollary 1 that, as c decreases, the negative effect of a on price strengthens relative to the positive effect of a on demand. Thus, at very low values of c, the quality of firms drops below the quality in the third-party firm entry case.

Therefore, the consumers might be worse off because of entry of the platform compared with the entry of a third-party firm. In order to gain clarity on the direction of the change in consumer welfare, we compare the consumer surplus in the third-party entry case with that in the platform entry case.

Proposition 4. *The consumer surplus in the platform entry case is higher than in the third-party firm entry case.*

When comparing the third-party firm entry with the platform's entry, we note that both cases have the same level of competition (number of firms). Hence, the relative surpluses now depend on the equilibrium qualities and prices, and we find that consumer welfare is higher with the platform's entry. The reason is that, although firms may have lower qualities in the platform entry case compared with the third-party firm entry case and, hence, generate lower surpluses for their consumers, the platform's access product always provides a higher surplus to its consumers as its quality is higher than the quality with third-party firm entry, and its price is also relatively low.

6. Robustness Checks

In this section, we confirm the robustness of our findings in two ways. First, we allow for market expansion with new entry by analyzing the spokes model with an arbitrarily large number of spokes. Note that we showed our results in Propositions 1 and 2 using general forms of concave functions for consumer utility and the platform's advertising revenue per consumer. However, because of analytical intractability, we could not show our results in Propositions 3 and 4 using those functions. Therefore, as a second robustness check, we conduct a numerical analysis to confirm our results in these two propositions.

6.1. Market Expansion

Here, we consider a spokes model with N spokes, in which $N \geq 4$. This setup ensures that there are at least two empty spokes in the two-firm benchmark case, thus allowing for market expansion with the entry of a new firm at one of the empty spokes. The market expansion becomes possible in this model because the first preferred firm for the consumers on the empty spokes is not available. Further, even the second preferred firm for some of these consumers is not available because it may be the one on one of the other empty spokes. Therefore, such consumers do not purchase any access product. However, when a third-party firm or the platform enters on one of the empty spokes, the first preferred firm becomes available for all consumers on that spoke. In addition, the entering firm (or the platform) becomes the second preferred firm for some consumers on the other empty spokes. Therefore, entry results in market expansion as more consumers purchase the access products. For analytical tractability, we continue to assume that $\phi(q)$ and $u(q)$ are linear. The details of the analysis are provided in Appendix A.14.

We find that the platform's product quality is higher, but its price is lower than the firms when $a > \frac{3}{2}$. Therefore, Proposition 1 holds in this setting. There also exist parameter ranges in which all the qualities with platform entry are higher than the qualities in the two-firm benchmark and the third-party entry cases. Therefore, existence of the result in Proposition 2 is also confirmed.

We also find that the platform earns higher profits than the benchmark case and the third-party firm entry case. Hence, the finding reported in Proposition 3 is confirmed. Finally, we find the consumer welfare is always higher with platform entry compared with a third-party firm entry. Hence, Proposition 4 is also confirmed.

6.2. Numerical Analysis with Strictly Concave $u(q)$ and $\phi(q)$

In this section, we wish to analyze if the results in Propositions 3 and 4 hold when we consider a consumer utility function and a platform's advertising profit function that are strictly concave in quality. Specifically, we assume $u(q) = q^{\kappa}$ and $\phi(q) = aq^{\kappa}$, where $0 < \kappa < 1$.

The analysis of the model with strictly concave consumer utility and platform advertising profit ($u(q) = q^{\kappa}$ and $\phi(q) = aq^{\kappa}$, where $\kappa < 1$) is much more algebraically tedious than the analysis with a linear utility or profit function. For all three cases, we solve the pricing stage analytically to obtain expressions for the prices as a function of qualities. Next, to determine the equilibrium qualities, we substitute the prices into the profit functions and try to solve the first-order conditions with respect to quality. The solution to this stage is analytically intractable, so we conduct a comprehensive numerical analysis. We consider integer values of c ranging from 1 to 20 and $a \in \{0.125, 0.25, 0.5, 1, 2, 4, 6, 8\}$ while keeping $\kappa = 0.5$. We find 50 points (qualities) from this parameter space that satisfy the equilibrium conditions, and plot Figure 3 using these points.

In Figure 3(a), we plot (q_A^{m*}, q^{b*}) for different sets of parameter values as points and $q^{b*} = q_A^{m*}$ as a straight line. Thus, any point below the line refers to an equilibrium in which $q_A^{m*} > q^{b*}$. We find parameter values in which all the equilibrium qualities are higher with the platform's entry compared with the two-firm benchmark case ($q_P^{m*} > q_A^{m*} > q^{b*}$), which is in line with Corollary 1(i). Similarly, for checking Propositions 3 and 4, we plot (π_P^{m*}, π_P^{b*}) and (CS^{m*}, CS^{t*}) in Figure 3, (b) and (c), respectively. We find that all the points lie below the line in both graphs, supporting Propositions 3 and 4. Thus, our analysis confirms that the primary insights can continue to hold in the analyzed parameter space when we consider $\kappa < 1$.

7. Summary and Future Work

In this paper, we introduce the concept of access products needed by consumers to access services provided by platforms and study why dominant platforms, such as Google and Facebook, enter into the access product businesses, such as internet service provision, smartphones, etc., in which established third-party access provider firms already exist. We analyze a setting in which the market for these platforms and the access products is already covered, but there is scope for improvement in a platform's business through an increase in the quality of access products in the market. To examine how entry by a platform in a related access product market impacts access product qualities and the platform's profits and welfare, we develop a theoretical model of quality and price competition among two third-party firms and an entrant in the access product market that could be another third-party firm or the platform. The key factor in our model is the complementarity between the quality of the access products and profits from the advertising business of the platform. Our analysis yields several interesting findings and uncovers new reasons behind platform expansion.

We find that entry of the platform into the access product market can lead to a reversal of the usual high quality–high price result. Specifically, the platform's product can be of higher quality than that of the third-party firms while being offered at a lower price when the platform's advertising business is profitable enough. This happens because the platform benefits from increases in the revenues from advertising as the

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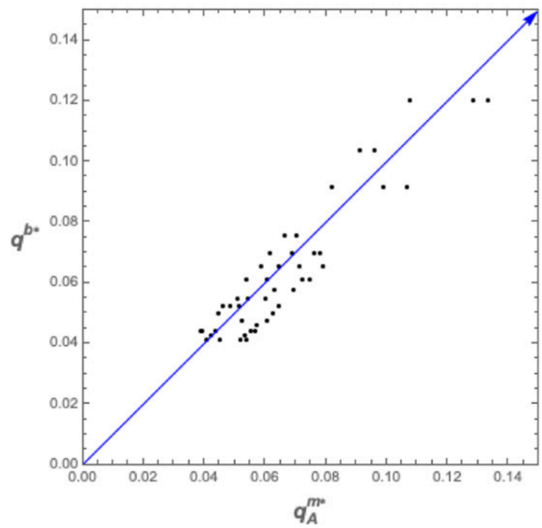
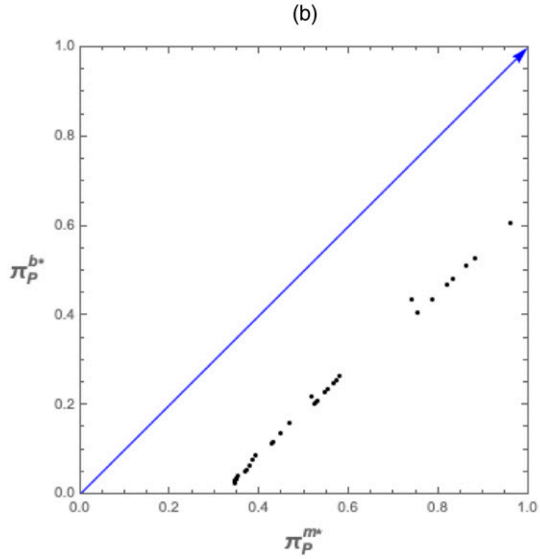
Figure 3. (Color online) Plots of a Firm's Equilibrium Qualities, Platform's Profits, and Consumer Surplus for $u(q) = \sqrt{q}$ and $\phi(q) = a\sqrt{q}$

(a)



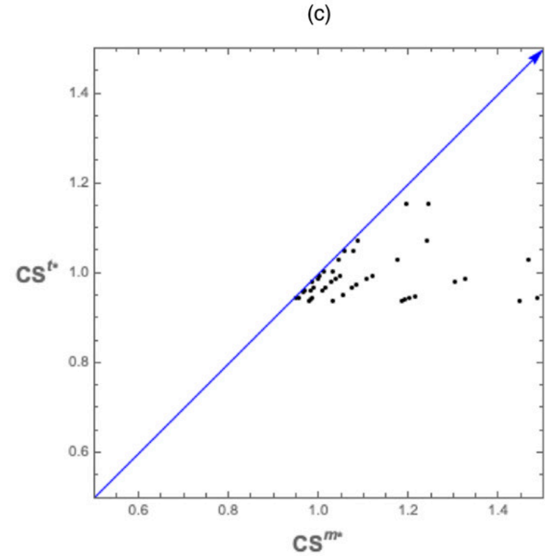
Firm $A's$ quality can be higher with Platform entry than in the benchmark case

(b)



Platform's profits are higher with Platform entry than in the benchmark case

(c)



Consumer surplus is higher with Platform entry than with Third-party firm entry

market coverage of the highest quality access product (the platform's product) increases.

We also find that, unlike the entry of a symmetric third-party firm, entry of the platform into the access product market can increase the quality of all the firms in the market. This happens because the platform benefits from higher platform advertising revenues as qualities of the access provider firms increase. This creates an incentive for the platform to increase the price of its own access product when the other access provider firms increase their qualities. In turn, this creates an incentive for the access provider firms to raise their qualities.

When the forces of competition dominate the incentives described here, the qualities of all the access products might also decrease with the platform's entry. However, we find that the platform always has an incentive to expand by entering the access product market as total profits of the platform increase because profits from product sales more than compensate for the losses in its advertising business.

We also analyze the welfare implications of the entry of a platform with the access product market. Contrary to common belief, we find that a platform's entry into this access product market increases consumer welfare as it makes the market more competitive compared with the entry of a third-party firm. The benefits of a platform's entry to consumers come from a lower price for a possibly higher quality product. We also establish our results in the context when the market expands with entry.

Our approach has several limitations, which provide interesting directions for future research. One natural extension of our work would be to study this entry strategy when there are competing platforms. It might also be interesting to analyze this strategy for platforms when the platform charges a price to the consumers and/or the access provider firms to access the platform. Further, in this paper, we only endogenized the quality of the access products and not the quality of the platform's services or its advertising efficiency. It would be useful to analyze the consequences of endogenizing the qualities of both the platform service and the access products.

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Appendix A

A.1. Proof of Lemma 1

Substituting the price expressions from Table 1 into the profit functions, we get the profits π_i as a function of qualities. We now look at the marginal value of increasing quality $\frac{\partial \pi_i}{\partial q_i}$ for the three firms.

$$\begin{aligned}\frac{\partial \pi_A}{\partial q_A} &= \frac{1}{150}(4u'(q_A)+\phi'(q_A))(10+\phi(q_A)+\phi(q_B)\\ &\quad -2\phi(q_P)+4u(q_A)-2u(q_B)-2u(q_P))-cq_A,\\ \frac{\partial \pi_B}{\partial q_B} &= \frac{1}{150}(4u'(q_B)+\phi'(q_B))(10+\phi(q_A)+\phi(q_B)\\ &\quad -2\phi(q_P)-2u(q_A)+4u(q_B)-2u(q_P))-cq_B,\\ \frac{\partial \pi_P}{\partial q_P} &= \frac{4}{75}(u'(q_P)+\phi'(q_P))(5-\phi(q_A)-\phi(q_B)\\ &\quad +2\phi(q_P)-u(q_A)-u(q_B)+2u(q_P))-cq_P.\end{aligned}$$

In equilibrium, all three derivatives must simultaneously equal zero. One can see that, at any $q_A^m = q_B^m = q_P^m = q^m$, we have $\frac{\partial \pi_A}{\partial q_A} = \frac{\partial \pi_B}{\partial q_B}$, but $\frac{\partial \pi_P}{\partial q_P} - \frac{\partial \pi_A}{\partial q_A} = \frac{\partial \pi_P}{\partial q_P} - \frac{\partial \pi_B}{\partial q_B} = \frac{\phi'(q^m)}{5} > 0$. Therefore, in equilibrium, $q_A^{m*} = q_B^{m*} \neq q_P^{m*}$. Now, because of concavity of the profit function in quality, that is, $\frac{\partial^2 \pi}{\partial q^2} < 0$, $\frac{\partial \pi_P}{\partial q_P} = 0$ at some $q_P^{m*} > q_A^{m*}$. □

A.2. Proof of Lemma 2

In equilibrium, $q_B = q_A$. Then, we have $p_P^m(q^m) - p_A^m(q^m) = \frac{3(u(q_P)-u(q_A))}{5} - \frac{2(\phi(q_P)-\phi(q_A))}{5}$.

Therefore, we have $p_P^{m*} < p_A^{m*}$ when $\frac{\phi(q_P^{m*})-\phi(q_A^{m*})}{u(q_P^{m*})-u(q_A^{m*})} > \frac{3}{2}$.

For example, with $\phi(q) = aq$ and $u(q) = q$, $p_P^{m*} - p_A^{m*} = \frac{a(3-2a)}{25c-(1+a)(4+3a)} < 0$ for $a > \frac{3}{2}$ if $c > \bar{c}$, where $\bar{c}$ is defined in Appendix A.5. □

A.3. Proof of Lemma 3

We have $\frac{\partial \pi_i^b}{\partial q_i} = \frac{1}{27}(9 - u(q_j) + u(q_i))u'(q_i) - cq_i$. In equilibrium, both firms produce the same quality because of symmetric competition. Let $q_A^{b*} = q_B^{b*} = q^{b*}$. Therefore, we have $\frac{u'(q^{b*})}{3q^{b*}} = c$.

Similarly, we have $\frac{\partial \pi_i^t}{\partial q_i} = \frac{4}{75}(5 - u(q_j) - u(q_k) + 2u(q_i))u'(q_i) - cq_i$. In equilibrium, all three firms produce the same quality because of symmetric competition. Let $q_A^{t*} = q_B^{t*} = q_T^{t*} = q^{t*}$. Therefore, we have $\frac{4u'(q^{t*})}{15q^{t*}} = c$. $\frac{u'(q^{b*})}{3q^{b*}} = c$ and $\frac{4u'(q^{t*})}{15q^{t*}} = c$ together imply that

$$\frac{q^{t*}}{q^{b*}} = \frac{4u'(q^{t*})}{5u'(q^{b*})}. \tag{A.1}$$

Suppose $q^{b*} \leq q^{t*}$. Then, the left-hand side of (A.1) is weakly greater than one. Also, then, $u'(q^{t*}) \leq u'(q^{b*})$ as $u''(q) \leq 0$. But this leads to a contradiction as the right-hand side of (A.1) now becomes less than one. Therefore, $q^{b*} > q^{t*}$. □

A.4. Proof of Proposition 2

$\frac{d\pi_A^b}{dq_A} = 0$ implies $\frac{u'(q_A)}{9}(3 + \frac{u(q_A)-u(q_B)}{3}) = cq_A$. Because we know that there is a symmetric solution in this case, the equilibrium value of q_A is obtained by substituting $q_A = q_B$ in this equation. Thus, we get q_A^{b*} by solving $\frac{u'(q_A)}{3} = cq_A$. Next, consider the reaction function of firm A in the platform entry case. Using the fact that $q_B = q_A$ in equilibrium, we get $\frac{(4u'(q_A)+\phi'(q_A))(5-\phi(q_P)+\phi(q_A)-u(q_P)+u(q_A))}{75} = cq_A$. q_A^{m*} satisfies this equation.

We want to find conditions in which $q_A^{b*} < q_A^{m*}$. A sufficient condition for $q_A^{b*} < q_A^{m*}$ is $\frac{(4u'(q_A)+\phi'(q_A))(5-\phi(q_P)+\phi(q_A)-u(q_P)+u(q_A))}{75} > \frac{u'(q_A)}{3}$ $\forall\, q_A \leq q_A^{b*}$; that is, the marginal benefit of increasing quality is higher with platform entry. This inequality can be rewritten as $\frac{\phi'(q_A)}{u'(q_A)} > \frac{25}{5-\phi(q_P)+\phi(q_A)-u(q_P)+u(q_A)} - 4$ as $5 - \phi(q_P) + \phi(q_A) - u(q_P) + u(q_A) > 0$ for $p_A^m(q^m) > 0$. A lower bound of $5 - \phi(q_P) + \phi(q_A) - u(q_P) + u(q_A)$ is $5 - \phi(q_P) - u(q_P)$ as $\phi(q_A)$, $u(q_A) > 0$. Substituting this value of the lower bound in the right-hand side of the inequality, we get an upper bound of the expression that we represent by Δ. When $\frac{\phi'(q)}{u'(q)}$ is weakly decreasing in q, a sufficient condition for $q_A^{m*} > q_A^{b*}$ is $\frac{\phi'(q_A^{b*})}{u'(q_A^{b*})} > \Delta$. On the other hand, when $\frac{\phi'(q)}{u'(q)}$ is increasing in q, a sufficient condition for $q_A^{m*} > q_A^{b*}$ is $\frac{\phi'(0)}{u'(0)} > \Delta$. As for the relationship between q_P^{m*} and q_A^{b*}, from Lemma 1, we already know that $q_P^{m*} > q_A^{m*}$. □

A.5. Equilibrium Conditions for Section 5

We first check the second-order conditions for equilibrium stability at both the second (price) stage and the first (quality) stage. Let

$$M_p^b = \begin{bmatrix} \frac{\partial^2 \pi_A^b}{\partial p_A \partial p_A} & \frac{\partial^2 \pi_A^b}{\partial p_A \partial p_B} \\ \frac{\partial^2 \pi_B^b}{\partial p_B \partial p_A} & \frac{\partial^2 \pi_B^b}{\partial p_B \partial p_B} \end{bmatrix} = \begin{bmatrix} -\frac{1}{3} & \frac{1}{6} \\ \frac{1}{6} & -\frac{1}{3} \end{bmatrix}, \textit{and}$$

$$M_p^l = \begin{bmatrix} \frac{\partial^2 \pi_k^l}{\partial p_k \partial p_k} & \frac{\partial^2 \pi_k^l}{\partial p_k \partial p_A} & \frac{\partial^2 \pi_k^l}{\partial p_k \partial p_B} \\ \frac{\partial^2 \pi_A^l}{\partial p_A \partial p_k} & \frac{\partial^2 \pi_{A1}^l}{\partial p_A \partial p_A} & \frac{\partial^2 \pi_A^l}{\partial p_A \partial p_B} \\ \frac{\partial^2 \pi_B^l}{\partial p_B \partial p_k} & \frac{\partial^2 \pi_B^l}{\partial p_B \partial p_A} & \frac{\partial^2 \pi_B^l}{\partial p_B \partial p_B} \end{bmatrix} = \begin{bmatrix} -\frac{2}{3} & \frac{1}{6} & \frac{1}{6} \\ \frac{1}{6} & -\frac{2}{3} & \frac{1}{6} \\ \frac{1}{6} & \frac{1}{6} & -\frac{2}{3} \end{bmatrix}$$

for $(l,k) \in \{(t,T),(m,P)\}$. The eigenvalues of M_p^b are $-\frac{1}{2}$ and $-\frac{1}{6}$, and the eigenvalues of M_p^t and M_p^t are $-\frac{5}{6}$, $-\frac{5}{6}$, and $-\frac{1}{3}$. M_p^b, M_p^t, and M_p^m are all negative definite as all their eigenvalues are negative.

Let us denote the profit functions of the firms as functions of qualities as $\pi_{i1}^l(q_i, q_{-i})\ \forall\ i \in \{A, B, E/T/P\}$ and $l \in \{b, t, m\}$. Let

$$M^b = \begin{bmatrix} \frac{\partial^2 \pi_{A1}^b}{\partial q_A \partial q_A} & \frac{\partial^2 \pi_{A1}^b}{\partial q_A \partial q_B} \\ \frac{\partial^2 \pi_{B1}^b}{\partial q_B \partial q_A} & \frac{\partial^2 \pi_{B1}^b}{\partial q_B \partial q_B} \end{bmatrix} = \begin{bmatrix} \frac{1}{27} - c & -\frac{1}{27} \\ -\frac{1}{27} & \frac{1}{27} - c \end{bmatrix},$$

$$M^t = \begin{bmatrix} \frac{\partial^2 \pi_{T1}^t}{\partial q_T \partial q_T} & \frac{\partial^2 \pi_{T1}^t}{\partial q_T \partial q_A} & \frac{\partial^2 \pi_{T1}^t}{\partial q_T \partial q_B} \\ \frac{\partial^2 \pi_{A1}^t}{\partial q_A \partial q_T} & \frac{\partial^2 \pi_{A1}^t}{\partial q_A \partial q_A} & \frac{\partial^2 \pi_{A1}^t}{\partial q_A \partial q_B} \\ \frac{\partial^2 \pi_{B1}^t}{\partial q_B \partial q_T} & \frac{\partial^2 \pi_{B1}^t}{\partial q_B \partial q_A} & \frac{\partial^2 \pi_{B1}^t}{\partial q_B \partial q_B} \end{bmatrix} = \begin{bmatrix} \frac{8}{75} - c & -\frac{4}{75} & -\frac{4}{75} \\ -\frac{4}{75} & \frac{8}{75} - c & -\frac{4}{75} \\ -\frac{4}{75} & -\frac{4}{75} & \frac{8}{75} - c \end{bmatrix}, \textit{and}$$

$$M^m = \begin{bmatrix} \frac{\partial^2 \pi_{P1}^m}{\partial q_P \partial q_P} & \frac{\partial^2 \pi_{P1}^m}{\partial q_P \partial q_A} & \frac{\partial^2 \pi_{P1}^m}{\partial q_P \partial q_B} \\ \frac{\partial^2 \pi_{A1}^m}{\partial q_A \partial q_P} & \frac{\partial^2 \pi_{A1}^m}{\partial q_A \partial q_A} & \frac{\partial^2 \pi_{A1}^m}{\partial q_A \partial q_B} \\ \frac{\partial^2 \pi_{B1}^m}{\partial q_B \partial q_P} & \frac{\partial^2 \pi_{B1}^m}{\partial q_B \partial q_A} & \frac{\partial^2 \pi_{B1}^m}{\partial q_B \partial q_B} \end{bmatrix}$$

$$= \begin{bmatrix} \frac{8}{75}(1+a)^2 - c & -\frac{4}{75}(1+a)^2 & -\frac{4}{75}(1+a)^2 \\ -\frac{1}{75}(1+a)(4+a) & \frac{1}{150}(4+a)^2 - c & \frac{1}{150}(a-2)(4+a) \\ -\frac{1}{75}(1+a)(4+a) & \frac{1}{150}(a-2)(4+a) & \frac{1}{150}(4+a)^2 - c \end{bmatrix}.$$

The eigenvalues of M^b are $\frac{2}{27} - c$ and $-c$ and of M^t are $\frac{4}{25} - c$, $\frac{4}{25} - c$, and $-c$. M^b and M^t are negative definite if all its eigenvalues are negative, implying $c > \frac{4}{25}$. M^m is negative definite iff all the eigenvalues of $M_s^m = \frac{M^m + (M^m)'}{2}$ are negative as M^m itself is not symmetric. The eigenvalues of M_s^m are $\frac{1}{25}(4 + a - 25c)$, $\frac{1}{50}(a(3a+7) - \sqrt{(a+1)^2(a(11a+24)+16)} + 4 - 50c)$, and $\frac{1}{50}(a(3a+7) + \sqrt{(a+1)^2(a(11a+24)+16)} + 4 - 50c)$. Therefore, we require $c > \underline{c} = \frac{1}{50}(a+1)(3a + \sqrt{a(11a+24)+16} + 4) > \frac{4}{25}$.

We further require $c > \bar{c} = \text{Max}\{\frac{(1+a)(4+5a)}{25}, \frac{4+a(5+6a)}{25}\} > \underline{c}$ for $q_i^{m*} > 0$, $p_i^{m*} > 0$, and $\frac{2}{3} > D_i^{m*} > 0\ \forall\ i \in \{A, B, P\}$. Note that the maximum demand for a product can only be $2/3$ as half of the consumers on the two nonfocal spokes do not consider the product. We assume $c > \bar{c}$ throughout the main text of the paper. As mentioned in Endnote 9, we only consider the interior solutions because we are interested in equilibria in which all three products (two third-party firm products A and B and the platform's product P) have a positive market share in the customer segments in which they compete. Otherwise, the platform's product covers the whole market in the segments in which it competes with product A or B, and the two third-party firm products, A and B, get demand from the market segments in which only the two of them compete. Therefore, our choice of parameters avoids the unrealistic scenario in which *all* the consumers who consider a third-party firm product (A or B) and the platform's product choose to buy the platform's product.

We also check for any profitable, unilateral, nonlocal deviation when a firm reduces its price such that all exclusive and nonexclusive consumers of this firm choose to buy from it. We check for these deviations for the firms and the platform in all the three cases. Further, we also check a firm's incentives to deviate by catering to only its exclusive consumers in the two-firm benchmark case. Note that this second type of deviation is only possible in the two-firm benchmark case and not in the two cases of entry as all the consumers have both their choices available when all the three spokes are occupied. We find that no such profitable deviations are possible when $c > \bar{c}$ and α is large enough in all three cases.

In order to check for a profitable, nonlocal deviation, we first find the price to which a firm deviates to cover its targeted market (as described) given the equilibrium prices of the other firms and the equilibrium qualities of all the firms. Then, we calculate the profit of the firm by deviating and find that, as long as $c > \bar{c}$ and α is large enough, the profits are always higher without deviating for any firm (or the platform).

A.5.1. Relevance of the Parameter Ranges in the Real World.

The interior solutions exist only when c is larger than some threshold ($\bar{c}$, which is positive and an increasing function of a). This is because, when quality is less costly to produce (c is small), the platform produces a very high quality and charges a low price and covers the entire market segment in which it competes, leading to a corner solution. Note that a very similar argument could be made if $c > \bar{c}$ is interpreted as the range in which a is relatively small (because $\bar{c}$ increases with a).

We want to ensure that these parameter values are pertinent in reality. However, we do not have any empirical data about the prevailing values of the parameters c and a in any context of platform entry. However, we do not observe any empirical data about the prevailing values of the parameters c and a in any context of platform entry. Hence, we cannot directly determine whether $c > \bar{c}$ holds in reality. Therefore, we adopt an indirect approach consisting of three steps. First, we assume several sets of parameter values of c and a in which the interior solutions exist and calculate the ratio of (i) a third-party firm's revenue to its fixed cost of quality creation and (ii) the platform's advertising revenue to its product sales revenue at each such set of parameter values. The ratios represent the parameters of interest. Next, we access publicly available data to empirically determine the values of these two ratios in the real world. Finally, if the values of the ratios we observe empirically are similar to values we calculated numerically in the previous step, then we have evidence that the parameter values we consider result in outcomes that are also observed empirically. Therefore, the set of parameter values that we consider in our analysis are consistent with reality.

To implement the approach, we pick 1,000 random sets of points (i.e., pairs of values of parameters c and a) in which $c > \bar{c}$ is satisfied and numerically calculate the equilibrium values of the two ratios based on our model. We depict the values of these ratios in a scatter plot in Figure A.1. For expositional purposes, we only show the points at which the two ratios are less than 20 and 4, respectively, as most of the points lie in this region. The whitespace to the left of the solid line in the figure represents the parameter range in which the condition $c > \bar{c}$ does not hold.

We now check if these points reflect the values of the ratios we observe in the real world. To that end, we consider the value of the two ratios in the U.S. ISP market. We first look at Verizon's (a third-party firm) revenue to its fixed cost ratio. Verizon's \$23 billion investment in a fiber-optic internet service upgrade in the mid-2000s (Chang 2009) has been followed by about \$30 billion of yearly wireline revenue for over a decade for the company.[16] This implies that the revenue generated by firms is about 13 (~ 30*10/23) times their investment in quality. Next, we analyze the ratio of Google's advertising revenues to its revenues from Google Fiber services. Google earned about \$500 million from Fiber in 2018 (Baumgartner 2019) by being available in markets covering a population of about two million consumers.[17] As Google earns close to \$250 per user on average in the United States primarily through advertising (Filloux 2019), its total advertising revenue from Fiber markets is also around \$500 million. This makes the ratio of platform's ad revenue to product revenue around one. As we can observe in the figure, there exist plenty of valid data points (at which $c > \bar{c}$ holds) even in a small elliptical region surrounding both the ratio values (13 and 1), that is, the point (13, 1). Further, note that points that do not satisfy this criterion lie very far from the observed values of the ratios.

As a secondary check of the feasibility of the valid parameter range in the real world, note from Figure A.1 that the values of the two equilibrium ratios cover a wide range of values. This provides further evidence that the considered parameter values are very likely to exist in the real world.

A.6. Proof of Lemma 4

$q_P^{m*} - q_A^{m*} = \frac{5a}{25c-3a^2-7a+4} > 0.$

i. $\frac{\partial(q_P^{m*}-q_A^{m*})}{\partial a} = \frac{5(25c+3a^2-4)}{((a+1)(3a+4)-25c)^2} > 0 \ \forall \ c.$

ii. $\frac{\partial(q_P^{m*}-q_A^{m*})}{\partial c} = -\frac{125a}{((a+1)(3a+4)-25c)^2} < 0 \ \forall \ a.$ □

A.7. Proof of Corollary 1

$q_A^{m*} - q^{b*} = \frac{\frac{(a+4)(25c-4(a+1)^2)}{25c-(a+1)(3a+4)}-5}{15c} > 0 \ \forall \ a > 1$ and $c > \hat{c} = \mathrm{Max}\{\frac{(4a^3+9a^2+a-4)}{25(a-1)}, \bar{c}\}$, where $\bar{c}$ is defined in Appendix A.5. □

A.8. Proof of Corollary 2

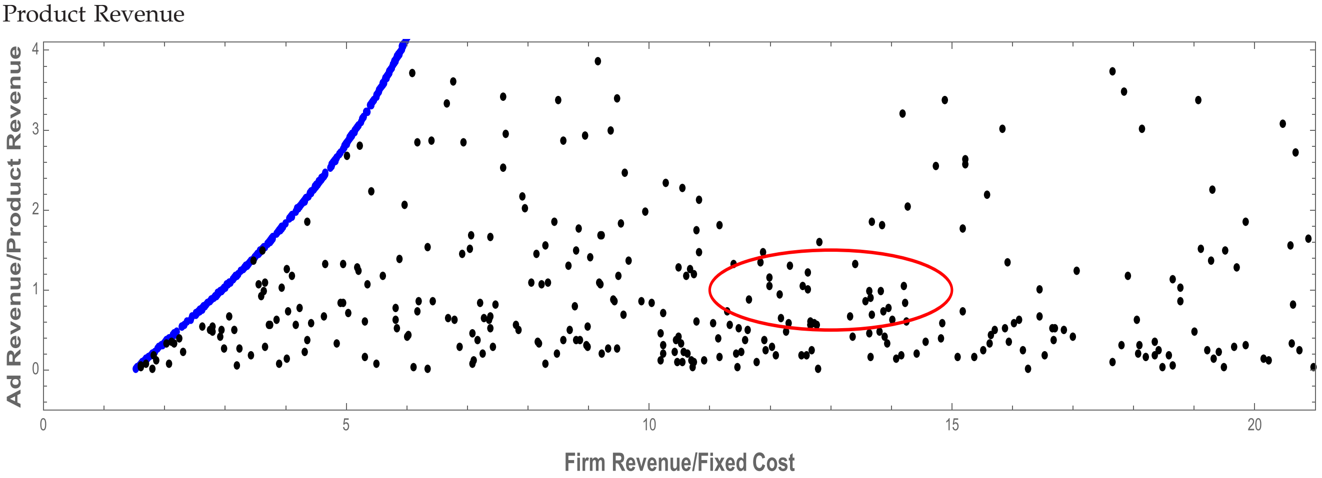
$q_P^{m*} - q^{b*} = \frac{\frac{4(a+1)(25c-(a+1)(a+4))}{25c-(a+1)(3a+4)}-5}{15c} < 0 \ \forall \ a < \frac{1}{4}$ and $c > \tilde{c} = \frac{(4-4a^3-9a^2-a)}{25(1-4a)}$. □

A.9. Proof of Corollary 3

Substituting $q_A = q_B = q_T$ in the second-stage prices we obtained in Section 4, we get $p_A^{b*} = p_B^{b*} = p^{b*} = 3$ and $p_A^{t*} = p_B^{t*} = p^{t*} = 1$. We then substitute the equilibrium qualities and prices into the demand functions to get $D_A^{b*} = D_B^{b*} = \frac{1}{2}$ and $D_A^{t*} = D_B^{t*} = D_T^{t*} = \frac{1}{3}$.

Substituting the equilibrium qualities and demands into the profit function of the firms in each case, we obtain equilibrium profits in the two cases: $\pi_i^{b*} = \frac{3}{2} - \frac{1}{18c}$ for $i \in \{A, B\}$ and $\pi_i^{t*} = \frac{1}{3} - \frac{8}{225c}$ for $i \in \{A, B, T\}$. An unusual feature of the equilibrium firm profits is that they increase with respect to c. This happens because the firms are unable to internalize any benefit of increasing quality in the first stage (as c decreases) because of symmetric price competition in the second stage.

Figure A.1. (Color online) Sample Valid Range of the Ratio of (i) Firm's Revenue to Cost and (ii) Platform's Ad Revenue to Product Revenue



Substituting the equilibrium qualities and demands into the profit function of the platform in each case, we obtain its equilibrium profits in the two cases: $\pi_P^{b*} = \frac{a}{3c} > \pi_P^{t*} = \frac{4a}{15c}$. □

A.10. Proof of Proposition 3

Substituting equilibrium qualities into the price expressions given in Table 1, we get the equilibrium prices as $p_A^{m*} = p_B^{m*} = \frac{25c-4(1+a)^2}{25c-(1+a)(4+3a)}$ and $p_P^{m*} = 2 + \frac{9a+4-25c}{25c-(1+a)(4+3a)}$. We then substitute the equilibrium qualities and prices into the profit function of the platform to obtain its equilibrium profit π_P^{m*}.

The platform's gain from its own entry is given by

$$\pi_P^{m*} - \pi_P^{b*} = \frac{\dfrac{\begin{array}{c}46875c^3 + 625c^2(a-2)(a+16) - 25c(a+1)\\ (a+4)(a(86a+73)-28) + 4(a+1)^3\\ (a+4)(a(43a+50)-8)\end{array}}{(25c-(a+1)(3a+4))^2} - 75a}{225c}.$$

This is greater than 0 $\forall\ c > \bar{c}$ and $a > 0$, where $\bar{c}$ is derived in Appendix A.5. □

A.11. Proof of Corollary 4

We have $\pi_{Ps}^{m*} = p_P^{m*} D_P^{m*} - \frac{c q_P^{m*2}}{2} = \frac{(25c-(a+1)(a+4))(1875c^2-25c(a(26a+31)+20)+8(a+4)(a+1)^3)}{225c(25c-(a+1)(3a+4))^2} < 0$ when $c < \grave{c}$, where $\grave{c} = \frac{1}{150}(26a^2 + \sqrt{580a^4+940a^3+561a^2-8a+16} + 31a + 20)$. But $\grave{c} > \bar{c}$ only when $a > \frac{1}{4}$, where $\bar{c}$ is derived in Appendix A.5. Therefore, $\pi_{Ps}^{m*} \geq 0\ \forall\ c$ when $a \leq \frac{1}{4}$, and $c \geq \grave{c}$ when $a > \frac{1}{4}$, and $\pi_{Ps}^{m*} < 0\ \forall\ c < \grave{c}$ when $a > \frac{1}{4}$.

We have $\pi_{Pa}^{m*} = a(q_A^{m*} d_A^{m*} + q_B^{m*} d_B^{m*} + q_P^{m*} d_P^{m*})$. Then,

$$\pi_{Pa}^{m*} - \pi_P^{b*} = \frac{a\left(\frac{2\left(625c^2(a+2)-100c(a+4)(a+1)^2 \quad +2(a+4)(3a+4)(a+1)^3\right)}{((a+1)(3a+4)-25c)^2} - 5\right)}{15c}.$$

This is positive for $c < \acute{c} = \frac{4a^3+9a^2-\sqrt{2}\sqrt{-a^2(a+1)^2(4a^2+5a-4)}+a-4}{50a-25}$ when $a < \frac{1}{2}$, and $\forall\ c$ when $a \geq \frac{1}{2}$. Now, $\grave{c} < \acute{c}\ \forall\ 0 < a < \frac{1}{2}$. Therefore, we have (i) $\pi_{Ps}^{m*} < 0$ and $\pi_{Pa}^{m*} > \pi_P^{b*}$ for $c < \grave{c}$ and $a > \frac{1}{4}$, and (ii) $\pi_{Ps}^{m*} > 0$ and $\pi_{Pa}^{m*} < \pi_P^{b*}$ for $c > \acute{c}$ and $a < \frac{1}{2}$. □

A.12. Proof of Lemma 6

We have $q_P^{m*} - q^{t*} = \frac{4a((1+a)(2+a)-25c)}{15c(25c-(1+a)(4+3a))} > 0\ \forall\ c > \bar{c}$ and $a > 0$, and $q_A^{m*} - q^{t*} = \frac{a(25c-4(1+a)(2+a))}{15c(25c-(1+a)(4+3a))} < 0\ \forall\ c < \frac{4}{25}(1+a)(2+a)$, where $\bar{c}$ is derived in Appendix A.5. □

A.13. Proofs of Lemma 5 and Proposition 4

CS in the benchmark case and the two cases of entry are given by the following:

$$\begin{aligned} CS^{b*} = \alpha + \frac{1}{3}\Bigg(& \int_0^{\bar{x}_{AB}^{b*}} \left(q_A^{b*} - x - p_A^{b*}\right) dx \\ & + \int_{\bar{x}_{AB}^{b*}}^1 \left(q_B^{b*} - (1-x) - p_B^{b*}\right) dx + \int_0^{\frac{1}{2}} \left(q_A^{b*} - x - p_A^{b*}\right) dx \\ & + \int_0^{\frac{1}{2}} \left(q_B^{b*} - x - p_B^{b*}\right) dx + \int_0^{\frac{1}{2}} \left(q_A^{b*} - (1-x) - p_A^{b*}\right) dx \\ & + \int_0^{\frac{1}{2}} \left(q_B^{b*} - (1-x) - p_B^{b*}\right) dx \Bigg), \end{aligned}$$

where $\bar{x}_{ij}^{k*}$ denotes the equilibrium location of the consumer who is indifferent between products i and j in case $k \in \{b, t, m\}$. The first constant term comes from the base utility of all the consumers, and the other integral terms represent the sum of net surplus from quality across all consumers. Specifically, the first two integral terms are for consumers whose two preferred firms are A and B, the next two integral terms are for consumers who only have their first choice available, and the last two terms are for consumers who only have their second choice available. Similarly,

$$\begin{aligned} CS^{j*} = \alpha + \frac{1}{3}\Bigg(& \int_0^{\bar{x}_{AB}^{j*}} \left(q_A^{j*} - x - p_A^{j*}\right) dx + \int_{\bar{x}_{AB}^{j*}}^1 \left(q_B^{j*} - (1-x) - p_B^{j*}\right) dx \\ & + \int_0^{\bar{x}_{Ai}^{j*}} \left(q_A^{j*} - x - p_A^{j*}\right) dx + \int_{\bar{x}_{Ai}^{j*}}^1 \left(q_i^{j*} - (1-x) - p_i^{j*}\right) dx \\ & + \int_0^{\bar{x}_{Bi}^{j*}} \left(q_B^{j*} - x - p_B^{j*}\right) dx + \int_{\bar{x}_{Bi}^{j*}}^1 \left(q_i^{j*} - (1-x) - p_i^{j*}\right) dx \Bigg) \end{aligned}$$

for $(i, j) \in \{(T, t), (P, m)\}$. Note that, in this case, every consumer has both choices available.

$$CS^{b*} = \alpha + \frac{1}{3c} - \frac{41}{12}.$$
$$CS^{t*} = \alpha + \frac{4}{15c} - \frac{5}{4}.$$
$$CS^{m*} = \alpha + \frac{\begin{array}{c}1250c^2(g(11a+25)+20) - 5c(a+1)(a(a(187a+767)\\ +1400)+880) + 16(a+1)^3(a+4)(3a+4) - 46875c^3\end{array}}{60c(25c-(a+1)(3a+4))^2}.$$

Given these expressions, we have $CS^{m*} > CS^{t*} > CS^{b*}\ \forall\ c > \bar{c}$ and $a > 0$, where $\bar{c}$ is derived in Appendix A.5. □

A.14. Spokes Model with $N \geq 4$

As in Section 5.1, we assume $u(q) = q$ and $\phi(q; a) = aq$. For any firm, the demand comes from (i) consumers who have both their choices available and (ii) those who only have one of their choices available. With N spokes, there are $\frac{1}{N}$ consumers on each spoke, and the probability that the second preferred product of a consumer on spoke $i \in \{1, 2..N\}$ is $j \neq i \in \{1, 2..N\}$ equals $\frac{1}{N-1}$.

In the benchmark case, there are two occupied spokes and $N-2$ empty spokes, leading to $\frac{2}{N(N-1)}$ consumers who have both their choices available. There are also $\frac{N-2}{N(N-1)}$ mass of consumers for whom A or B is their second choice and their first choice is not available. Similarly, $\frac{N-2}{N(N-1)}$ mass of consumers on spoke A or B only have their first choice available. Therefore, we can write the demand function for firm $i \in \{A, B\}$ in the benchmark case as follows:

$$\begin{aligned} D_i &= \frac{2}{N(N-1)}(\bar{x}_{ij} + (N-2)) \\ &= \frac{q_i - q_j - p_i + p_j}{N(N-1)} - \frac{3-2N}{N(N-1)} \text{ for } i \neq j \in \{A, B\}, \end{aligned}$$

where $\bar{x}_{ij}$ represents the consumer who is indifferent between firms i and j, which is still given by the solution to $\alpha + q_i - x - p_i = \alpha + q_j - (1-x) - p_j$. With the entry of a new product at one of the empty spokes, a fraction of those who had no choice available in the benchmark case now have one choice available. This set of consumers leads to market expansion with new entry. As previously in the benchmark case, the demand function in the third-party entry and the platform entry cases (with three occupied spokes) can be written as follows:

$$D_i = \frac{2}{N(N-1)}(\bar{x}_{ij} + \bar{x}_{ik} + (N-3)) = \frac{2q_i - q_j - q_k - 2p_i + p_j + p_k}{N(N-1)} + \frac{2(N-2)}{N(N-1)} \quad \forall\ i,j,k \in \{A,B,T/P\} \text{ and } i \neq j \neq k.$$

We use the demand functions to write the profit functions of the firms and the platform and then solve for prices in terms of qualities. We finally substitute these prices into the profit functions to solve for the optimal qualities. We get the equilibrium qualities, prices, and platform's profits as follows:

Two-firm benchmark case: $q_A^{b*} = q_B^{b*} = q^{b*} = \frac{4N-6}{3cN(N-1)}$, $p_A^{b*} = p_B^{b*} = p^{b*} = 2N-3$, $\pi_P^{b*} = \frac{4a(3-2N)^2}{3c(N-1)^2N^2}$.

Third-party firm entry case: $q_A^{t*} = q_B^{t*} = q_T^{t*} = q^{t*} = \frac{8N-16}{5cN(N-1)}$, $p_A^{t*} = p_B^{t*} = p_T^{t*} = p^{t*} = N-2$, $\pi_P^{t*} = \frac{48a(N-2)^2}{5c(N-1)^2N^2}$.

Platform entry case: We report the equilibrium qualities and prices in Table A.1. Substituting the equilibrium qualities and prices into the profit function, we get the equilibrium profit of the platform in the platform entry case.

$$\begin{aligned}\pi_P^{m*} = &\frac{1}{25c(N-1)^2N^2(6a(3a+7)-25c(N-1)N+24)^2}\\ &\big(2(N-2)^2\big(12384a^6 + 101088a^5\\ &+ 24a^4(11844 - 1075c(N-1)N)\\ &+ 12a^3(30072 - 12575c(N-1)N)\\ &+ 2a^2(25c(N-1)N(25c(N-1)N - 4086)\\ &+ 101088) + 4a(25c(N-1)N - 24)\\ &\times (175c(N-1)N - 288)\\ &+ (24 - 25c(N-1)N)^2(25c(N-1)N - 16)\big).\end{aligned}$$

We require $c > \overline{c_N} = \text{Max}\{\frac{6(1+a)(4+5a)}{25(N-1)N}, \frac{6(a(6a+5)+4)}{25(N-1)N}\}$ for the equilibria to exist and be stable. Hereinafter, we assume $c > \overline{c_N}$.

Proposition A.1. We have $q_P^{m*} - q_A^{m*} = \frac{30a(N-2)}{25c(N-1)N-6a(3a+7)-24} > 0$ $\forall a > 0$, and $p_P^{m*} - p_A^{m*} = \frac{6a(3-2a)(N-2)}{25c(N-1)N-6a(3a+7)-24} < 0$ when $a > \frac{3}{2}$. Therefore, the platform's quality is higher than that of the firms, but its price is lower when $a > \frac{3}{2}$. □

Proposition A.2. We have $q^{t*} - q^{b*} = \frac{4N-18}{15cN(N-1)}$. $q^{t*} > q^{b*}\ \forall\ N \geq 5$ and $q^{t*} < q^{b*}$ for $N = 4$. Therefore, we compare q_A^{m*} with q^{b*} when $N = 4$ and with q^{t*} when $N \geq 5$.

At $N = 4$, $q_A^{m*} - q^{b*} = \frac{\frac{12(a+4)(2(+1)^2-25c)}{(a+1)(3a+4)-50c} - 25}{90c} > 0$ when $c > \frac{(a+1)(3a(8a+15)-4)}{50(6a-1)}$ and $a > \frac{1}{6}$.

For $N \geq 5$, $q_A^{m*} - q^{t*} = \frac{2a(N-2)(-25c(N-1)N+24a(a+3)+48)}{5c(N-1)N(-25c(N-1)N+6a(3a+7)+24)} > 0$ when $c > \text{Max}\{\frac{24(a+1)(2+a)}{25(N-1)N}, \frac{6(a(6a+5)+4)}{25(N-1)N}\}$. □

Proposition A.3. We have $\pi_P^{t*} - \pi_P^{b*} = \frac{4a(4N(4N-21)+99)}{15c(N-1)^2N^2} > 0$ $\forall N \geq 4$. Therefore, we compare π_P^{m*} with π_P^{t*}.

$$\begin{aligned}\pi_P^{m*} - \pi_P^{t*} = &\frac{1}{25c(N-1)^2N^2(-25c(N-1)N+6a(3a+7)+24)^2}\\ &\times \big(2(N-2)^2\big(24a^4(4284-1075c(N-1)N)\\ &+ 12a^3(3792 - 3575c(N-1)N)\\ &+ 2a^2(25c(N-1)N(25c(N-1)N + 954) - 19872)\\ &- 4a(25c(N-1)N - 24)(575c(N-1)N - 432)\\ &+ (24 - 25c(N-1)N)^2(25c(N-1)N - 16) + 12384a^6\\ &+ 62208a^5\big)\big).\end{aligned}$$

This expression is greater than zero for the entire parameter range of interest, leading the platform to always earn higher profits with its own entry. □

Proposition A.4. We can write the CS in the benchmark case and in the two cases of entry as follows:

$$\begin{aligned}CS^{b*} = &\,\alpha\left(\frac{2}{N} + \frac{2(N-2)}{N(N-1)}\right) + \frac{2}{N(N-1)}\left(\int_0^{\bar{x}_{AB}^{b*}}(q_A^{b*} - x - p_A^{b*})\,dx\right.\\ &\left.+ \int_{\bar{x}_{AB}^{b*}}^1 (q_B^{b*} - (1-x) - p_B^{b*})\,dx\right)\\ &+ \frac{2(N-2)}{N(N-1)}\left(\int_0^{\frac{1}{2}}(q_A^{b*} - x - p_A^{b*})\,dx\right.\\ &+ \int_0^{\frac{1}{2}}(q_B^{b*} - x - p_B^{b*})\,dx + \int_0^{\frac{1}{2}}(q_A^{b*} - (1-x) - p_A^{b*})\,dx\\ &\left.+ \int_0^{\frac{1}{2}}(q_B^{b*} - (1-x) - p_B^{b*})\,dx\right).\end{aligned}$$

All consumers on spokes A and B buy, which leads to a demand of $\frac{2}{N}$. Also, $\frac{2}{N(N-1)}$ mass of consumers buy from each of the $N-2$ empty spokes as they have either A or B as their second choice. The first constant term comes from the base

Table A.1. Equilibrium Qualities and Prices with Platform's Entry

Firm	Quality	Price
A, B	$q_i^{m*} = \frac{2(a+4)(N-2)(24a(a+2)+24-25c(N-1)N)}{5c(N-1)N(6a(3a+7)+24-25c(N-1)N)}$	$p_i^{m*} = \frac{(N-2)(25c(N-1)N-24a(a+2)-24)}{25c(N-1)N-6a(3a+7)-24}$
P	$q_P^{m*} = \frac{8(a+1)(N-2)(6a(a+5)+24-25c(N-1)N)}{5c(N-1)N(6a(3a+7)+24-25c(N-1)N)}$	$p_P^{m*} = \frac{(N-2)(25c(N-1)N-6a(6a+5)-24)}{25c(N-1)N-6a(3a+7)-24}$

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utility, and the rest of the terms represent the sum of the net surplus from quality across all consumers. Similarly,

$$
\begin{aligned}
CS^{j*} = {} & \alpha\left(\frac{3}{N}+\frac{3(N-3)}{N(N-1)}\right)+\frac{2}{N(N-1)}\left(\int_0^{\bar{x}^{j*}_{AB}}\left(q^{j*}_A-x-p^{j*}_A\right)dx\right.\\
& +\int_{\bar{x}^{j*}_{AB}}^1\left(q^{j*}_B-(1-x)-p^{j*}_B\right)dx+\int_0^{\bar{x}^{j*}_{Ai}}\left(q^{j*}_A-x-p^{j*}_A\right)dx\\
& +\int_{\bar{x}^{j*}_{Ai}}^1\left(q^{j*}_i-(1-x)-p^{j*}_i\right)dx+\int_0^{\bar{x}^{j*}_{Bi}}\left(q^{j*}_B-x-p^{j*}_B\right)dx\\
& \left.+\int_{\bar{x}^{j*}_{Bi}}^1\left(q^{j*}_i-(1-x)-p^{j*}_i\right)dx\right)\\
& +\frac{2(N-3)}{N(N-1)}\left(\int_0^{\frac{1}{2}}\left(q^{j*}_A-x-p^{j*}_A\right)dx\right.\\
& +\int_0^{\frac{1}{2}}\left(q^{j*}_B-x-p^{j*}_B\right)dx+\int_0^{\frac{1}{2}}\left(q^{j*}_i-x-p^{j*}_i\right)dx\\
& +\int_0^{\frac{1}{2}}\left(q^{j*}_A-(1-x)-p^{j*}_A\right)dx+\int_0^{\frac{1}{2}}\left(q^{j*}_B-(1-x)-p^{j*}_B\right)dx.\\
& \left.+\int_0^{\frac{1}{2}}\left(q^{j*}_i-(1-x)-p^{j*}_i\right)dx\right)
\end{aligned}
$$

for $(i,j) \in \{(T,t),(P,m)\}$.

$$
\begin{aligned}
CS^{b*} = {} & \alpha\left(\frac{2}{N}+\frac{2(N-2)}{N(N-1)}\right)\\
& +\frac{N(32(N-3)-3c(N-1)(4N(4N-11)+29))+72}{6c(N-1)^2N^2},\\
CS^{t*} = {} & \alpha\left(\frac{3}{N}+\frac{3(N-3)}{N(N-1)}\right)\\
& +\frac{3N(32(N-4)-5c(N-1)(2N(2N-7)+11))+384}{10c(N-1)^2N^2}, \text{ and}
\end{aligned}
$$

$$
\begin{aligned}
CS^{m*} = {} & \alpha\left(\frac{3}{N}+\frac{3(N-3)}{N(N-1)}\right)+\\
& \frac{1}{10c(N-1)^2N^2(6a(3a+7)-25c(N-1)N+24)^2}\\
& \big(3\big(3456a^5(N-2)^2-\\
& 60a^4(N(c(N-1)(2N(80N-293)+505)\\
& -480(N-4))-1920)-72a^3(N(15c(N-1)\\
& (2N(23N-85)+\\
& 149)-1168(N-4))-4672)+4a^2(N(5c(N-1)\\
& (N(25c(N-1)(2N(23N-83)+139)\\
& -5844N+22062)-\\
& 20091)+28512(N-4))+114048)+4a(25c(N\\
& -1)N-24)(N(5c(N-1)(2N(52N-187)+311)\\
& -768(N-4))-3072)-(24-25c(N-1)N)^2\\
& (N(5c(N-1)(2N(2N-7)+11)\\
& -32(N-4))-128))).
\end{aligned}
$$

We have $CS^{m*} > CS^{t*} > CS^{b*}\ \forall\ a > 0$ and $N \geq 4$. □

Appendix B

Table B.1. List of Symbols

Symbol	Description
q^b_i	Quality of firm i in the benchmark case $\forall\ i \in \{A,B\}$
p^b_i	Price of firm i in the benchmark case $\forall\ i \in \{A,B\}$
π^b_i	Profit of firm i in the benchmark case $\forall\ i \in \{A,B\}$
π^b_P	Profit of the platform in the benchmark case
q^t_i	Quality of firm i in the third-party firm entry case $\forall\ i \in \{A,B,T\}$
p^t_i	Price of firm i in the third-party firm entry case $\forall\ i \in \{A,B,T\}$
π^t_i	Profit of firm i in the third-party firm entry case $\forall\ i \in \{A,B,T\}$
π^t_P	Profit of the platform in the third-party firm entry case
q^m_i	Quality of firm i with platform's entry $\forall\ i \in \{A,B,P\}$
p^m_i	Price of firm i with platform's entry $\forall\ i \in \{A,B,P\}$
π^m_i	Profit of firm i with platform's entry $\forall\ i \in \{A,B,P\}$

Endnotes

[1] For more information, please see the following: Atlanta: https://tinyurl.com/y3terwnp, Austin: https://tinyurl.com/y37mzgr8.

[2] As smartphone prices significantly vary (decline) over a product's life cycle and there may be many exogenous reasons why prices of different phones may decline at different rates, we find it better to focus on the price at the time of release for comparing prices.

[3] This article, https://tinyurl.com/u4339tx, compares between the two phones on two dimensions: quality (shown in blue) and cost effectiveness based on the current price (shown in red). Because we do not want to compare pricing after phone launch, we ignore the cost effectiveness metric and focus on the quality comparison in which Pixel's overall score is 67 and Moto Z's overall score is 65.

[4] For more information, see https://tinyurl.com/zx8fda7.

[5] We model entry by considering multiple exogenous market structures with different numbers of firms. A similar approach has been used previously in literature (see Banker et al. 1998, Vives 2008, Arkolakis et al. 2012).

[6] In Section 6.1, we extend our model to allow for market expansion.

[7] This assumption seems reasonable in our context. For example, we expect that typically not many ISPs are available in a locality because of the high costs of infrastructure to provide their services. In the United States, most cities tend to have four or fewer ISP service providers, and it is, therefore, reasonable to expect consumers who want to buy ISP services can choose from only a few options rather than having a plethora of choices.

[8] Although the quality of access products (q) is endogenous, we consider the quality of the platform's core service to be exogenous and fixed for the purpose of our analysis.

[9] We focus on interior solutions because we are only interested in those equilibria in which all firms compete with each other and have a positive market share in each consumer segment.

[10] A list of all the symbols is provided in Table B.1.

[11] Note that the second-stage price expressions in Table 1 boil down to second-stage prices in the Third-party firm entry case ($p^t_i(q^t)$ for $i \in \{A,B,T\}$) if $\phi'(q) = 0$.

[12] For more information, see https://tinyurl.com/y3terwnp.

[13] Thus, the marginal value of quality for a consumer is one, and the marginal value of quality for the platform is a. Depending upon the ability of the platform to create value for advertisers and extract the surplus from them, a can be relatively high or low.

[14] Later, in Section 6.2, we also consider $u(q) = q^{\kappa}$ and $\phi(q) = aq^{\kappa}$, where $0 < \kappa < 1$. We numerically verify the results we obtain with linear $u(q)$ and $\phi(q)$.

[15] q_A^{m*} and q_B^{m*} are also lower because, from Lemma 1, we know that $q_P^{m*} > q_A^{m*} = q_B^{m*}$.

[16] For more information, see https://tinyurl.com/yx3mw3nq.

[17] For more information, see https://broadbandnow.com/All-Providers.

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