

Strategic Intellectual Property Sharing: Competition on an Open Technology Platform Under Network Effects

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Abstract. In this paper, we explore the strategic decision of an incumbent to open a proprietary technology platform to allow same-side co-opetition in a market characterized by network effects. We propose a game-theoretic model that analytically conceptualizes the interplay among the degree of same-side platform openness, the absorptive capacity of the entrant, and the intensity of network effects. Our analysis uncovers interesting new results. First, when entrant product quality is exogenous, under very strong network effects, the incumbent closes the technology. Moreover, we discuss various interesting open-platform co-opetition outcomes that arise under a fully covered market. When the entrant chooses the quality level and the incumbent is strategic in its platform opening decision, we find that intense network effects make new players shun the market, so intellectual property (IP) sharing is not possible in equilibrium. When the network effects are of intermediate intensity, the incumbent opens the technology to the entrants who have a sufficiently high absorptive capacity, calibrating the amount of sharing to the entrant's absorptive capacity level to ensure that the duopoly setting is mutually beneficial. Our key findings and insights are robust to several model extensions, including scenarios when the incumbent is uncertain of the entrant's absorptive capacity, or when the entrant incurs a general non-linear development cost structure. We also compare and contrast bounded versus unbounded market scenarios. We further explore the ability of the incumbent to engineer the strength of network effects in the market and uncover non-trivial alternating-monotonicity patterns for the optimal intensity of network effects with respect to the entrant's absorptive capacity. We also show that a model with exogenous network effects could drastically underestimate the range of entrants' absorptive capacity values for which the incumbent should open its platform, causing the latter to miss valuable co-opetition opportunities. We also discuss various managerial implications of our theoretical framework.

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1. Introduction

The fact that information technology (IT)-fueled platforms have been at the forefront of disruptions in many business sectors is yesterday's news. An increasing number of platform providers are adopting a business model whereby they are opening their product in one form or another (Eisenmann et al. 2009, Parker and Van Alstyne 2017). The platform opening strategy can manifest at many points of interaction in the business ecosystem. Platform owners can exchange intellectual property (IP) with other market players (i.e., support open innovation), sponsor other platform providers or open platform access to complementors and users.

In this study, we focus on providers who consider opening their IP (core technology) to other competitors on the same side of the ecosystem, effectively sponsoring interoperability and the development of substitutes on top of the same technology platform for the benefit of market expansion and accelerated adoption of standards (Garud and Kumaraswamy 1993, Conner 1995, Huang et al. 2016). This falls under the broad spectrum of *open innovation*, a term coined by Chesbrough (2006, p. 1) as “the use of purposive inflows and outflows of knowledge to accelerate internal innovation and to expand the markets for external use of innovation, respectively.” For example, IBM opened its

architecture for Personal Computers (PCs) in the early 1980s (Moore 1993). Tesla and Toyota also opened their patents related to alternative fuel vehicles (e.g., Ramsey 2014, Inagaki 2015). 3D Robotics (3DR) opened some of its non-core software and hardware innovations in the drone space (Kolodny 2017). On the other hand, developers of high end computer games and high frequency trading (HFT) algorithms do not usually open these platforms on the provider side for other firms to build competing substitutes on the same technology.

Open innovation and IP sharing can happen via direct inter-firm agreements and licensing or via opening a product or supporting technology to the general public in the form of an open source project. Note that there is a major difference between opening core technology and offering a finished product in an open source form: In many instances, open source products do not accompany open source technology or open IP. The fact that Tesla allows the general public to view their IP related to battery and charging technologies (Ramsey 2014) does not mean that consumers find it cost efficient to build their own electric cars (at least not in the near future). This IP sharing will only indirectly affect customers because other automakers could try to embed such innovation in their own product line (amortizing development costs over a large consumer base), which can lead to competition and more innovation. Similarly, for complex software applications and services, opening a code library to the general public would likely impact competition but would not necessarily force the developer to offer the entire product (that uses some of these libraries) as an open source product. In fact, code opened under permissive licenses (e.g., Berkeley Software Distribution license or Apache license) allows the originator and the adopters to still commercialize and close any derivative product.

Within the context of open innovation, in this paper we focus on the scenarios considering *same-side* (business-to-business) core IP sharing between the incumbent (owner) and potential entrants *without* an open source product (built on that IP) being released in the market. The products (from the entrant and the incumbent) are complex software application suites sold for profit and heavily reliant on the technology platform owned by the incumbent. Thus, with that core technology and the IP closed on the incumbent side, it is cost-prohibitive for other firms to enter the market and develop an alternative way to deliver similar functionality. If the IP owner opens the technology (in some limited way), competitors can immediately offer (imperfect) substitutes of the original product. In that sense, the IP owner is engaging in a form of *second-sourcing*, voluntarily inviting competitors into the market by opening its technology/architecture (Farrell and Gallini 1988). Second-sourcing by opening the core technology does not mean that the imitations

will be perfect substitutes of the original product. The entrants' production function is affected by the *degree* of IP openness (Boudreau 2010) and their own *absorptive capacity*, defined by Cohen and Levinthal (1990, p. 128) as "the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends." On the consumer side, in the absence of an open source product, whether end-users can access the shared IP, they will still find it cost effective to acquire one of the products on the market instead of attempting any individual development effort to build on top of the shared technology. In this context, we ask the following research questions: (i) *In a software business ecosystem, when and to what degree should a for-profit incumbent provider open its IP (core technology) to other potential competitors on the same side of the market?* (ii) *How would these strategies be impacted by the absorptive capacity of the entrant?*

To address these questions, we propose a competitive model wherein an incumbent controls the platform technology and considers the option to freely share (open) some of its IP with an entrant. The incumbent and the entrant are strategic and the product category (containing the entrant and the incumbent's products built on the incumbent's technology) exhibits network effects at the user utility level. The entrant's ability and cost to partially replicate the incumbent's product depend on the extent of IP sharing from the latter as well as the entrant's absorptive capacity. Moreover, the quality of the entrant's product is endogenized. We further explore the option to endogenize the intensity of the network effects.

Our analysis uncovers interesting and non-trivial results. First, when quality is exogenous for the entrant (which is one of the steps in solving our general equilibrium via backward induction), we find that if products are vertically differentiated and the intensity of network effects is very strong, then the incumbent prefers to close the technology. This finding departs from established results in the literature (Conner 1995, Economides 1996) that state the opposite. We further show that opening the technology can dominate a monopolistic strategy in some cases where the incumbent would have had the market fully covered under a monopolistic scenario. In such instances, the incumbent prefers co-opetition, focusing on the top-valuation consumers while willingly relinquishing the rest of the market to the entrant, thus sharing the efforts to *jointly* build the user network and increase consumer utility.

When the entrant chooses the quality level and the incumbent is strategic in its platform opening decision, we find that intense network effects make new players shun the market, so IP sharing is not possible in equilibrium. When the network effects are of intermediate intensity, the incumbent opens the technology to the entrants who have a sufficiently high

absorptive capacity, calibrating the amount of sharing to the entrant's absorptive capacity level to ensure that the duopoly setting is mutually beneficial. Our key findings and insights are qualitatively robust to several model extensions including scenarios wherein the incumbent is uncertain of the entrant's absorptive capacity or the entrant incurs a generalized (nonlinear in quality) development cost. We further explore the ability of the incumbent to engineer the strength of network effects in the market. When the incumbent finds it optimal to open its core technology, we observe non-trivial alternating-monotonicity patterns for the intensity of network effects with respect to the entrant's absorptive capacity, revealing complex interplay dynamics between the entrant's cost to join the market and the value of the network to the users. Moreover, we show that a model with exogenous network effects could drastically underestimate the range of entrants' absorptive capacity values for which the incumbent should open its platform. This may lead to sub-optimal blocking of certain firms from the market, causing the incumbent to miss valuable co-opetition opportunities.

To our knowledge, this is the first study on platform economics that combines strategic provider-side IP opening (whereby the incumbent owns and decides the degree of openness of the core technology), how the degree of IP sharing impacts the development costs and the quality of the entrant's product based on the absorptive capacity of the latter, network effects at the user level, and a competition model wherein the incumbent and the entrant are strategic. We also compare and contrast bounded versus unbounded market scenarios, further advancing the understanding of the role of this assumption in the equilibrium IP sharing outcomes for strong network effect scenarios. The extension that explores the endogenizing of the *intensity* of network effects further takes this paper in a novel direction. The literature on competition (including co-opetition) under network effects proposes models where the players optimize for other decision variables (such as price, quality, and quantity). However, these papers treat the intensity of network effects as an exogenous market parameter. Nevertheless, many software applications currently allow some form of interaction and/or collaboration among users via features built in by the developers (e.g., chat, editorial markups, multiplayer gaming, screen sharing, file syncing across multiple accounts, etc.). As such, software developers can directly control the strength of network effects. In addition to the modeling contribution, this paper provides actionable guidance for core technology owners in a software market with respect to strategic IP sharing as well as engineering of network effects. Such guidance is tailored to specifics of other potential competitors in the market (their absorptive capacities). For

brevity, we relegate discussion of explicit positioning with respect to the extant literature to Section 2.

The rest of the paper is structured as follows. Section 2 presents a review of the relevant literature. We introduce the model in Section 3 and present the analysis and a discussion of the results and various anecdotal cases in Section 4. We present several extensions and robustness checks of the model in Section 5. Concluding remarks are provided in Section 6. Proofs of the major results are included in the online appendix.

2. Literature Review

Our study draws on several streams of information systems (IS) literature. First, our paper is directly related to the literature on incentives for same-side (supply) opening of a core IP or platform by an owner with the intent to encourage competitor entry. Farrell and Gallini (1988) explicitly explore strategic timing of second-sourcing as a commitment mechanism. Conner (1995) and Economides (1996) consider price-based and quantity-based competition, respectively, to explore when the monopolist has incentives to invite/allow competition. While our model at the consumer utility level is similar to Conner's (1995) framework, our set-up takes a different approach. We consider a more complex core IP opening decision characterized by the degree of openness, entry costs (to develop the clone) that depend on the absorptive capacity of the imitator, and a more strategic entrant that makes the market entry decision rationally and, in addition to price, chooses quality level. Considering all these strategic decisions jointly in the model leads to differences in insights compared to Conner (1995) and Economides (1996): When the intensity of network effects is really high, in equilibrium, the monopolist does not open the technology for imitation. A different subset of research in this space considers technology licensing as a strategic incentive to prevent competitors from independently developing a superior (potentially incompatible) product (e.g., Gallini 1984). Our paper differs from this literature in that, in our model, the technology owner has key technology that cannot be substituted.

The literature on platform and innovation openness for the most part considers openness as a binary decision (Barge-Gil 2010, Dahlander and Gann 2010). Some of the more recent literature began exploring how degrees of platform openness impact various market outcomes. Boudreau (2010) explores how two approaches to platform openness, granting of access versus devolving control of the platform, impact the rate of innovation. Parker and Van Alstyne (2017) consider the case of a platform sponsor partially opening the platform to other developers. The sponsor initially foregoes revenue on the open portion of the platform

but can bundle the developers' output in later platform iterations (developers get only limited-time IP rights). It has been long recognized that firms differ in their ability to effectively internalize and act on outside open knowledge or IP (Roberts et al. 2012). To our knowledge, our study is the first to examine how the *absorptive capacity* of other same-side potential entrants in the market would affect the *strategic* choice of the *degree* of openness of a technology platform by a sponsor/owner.

Another research area directly related to our work is that on competition with network effects (which also covers some of the works mentioned above). In our setting, once the technology owner decided on the degree of openness of the core IP (the first stage of the game in the main model), the next stage becomes a competitive game where the entrant fully understands the costs to develop a clone for the primary product. There is a rich literature on modeling competition with network effects or externalities (e.g., Katz and Shapiro 1985, 1994; Conner 1995; Economides 1996; Baake and Boom 2001; Argenziano 2008; Cabral 2011; Chen and Chen 2011; Cheng et al. 2011; Griva and Vettas 2011). In this literature, once the competitive game starts, the firms resort to various controls such as price, quality, quantity or compatibility to shift the balance of the competition. Most of these models (with a few exceptions) do not consider any player in the market to have the ability to directly control the entry ability and the development cost of the competitor's product. Adding this dimension allows for another decision-making step that occurs before the competitive game unfolds. As mentioned in the first paragraph of this section, that is where we directly focus our efforts; thus our work is closer to Economides (1996), with important differences highlighted above.

There is another important way in which we contribute to the literature on competition with network effects. In general, the analytical modeling literature considers the *intensity* of network effects as exogenously given, i.e., a firm or industry level characteristic, but not a decision variable. In many of the papers, the overall magnitude of network effects ends up being endogenous but that is because of how network size is determined in equilibrium as a result of other parameters being optimized. In a novel direction, a couple of recent papers started examining the strategic engineering of network effects through the optimization of the strength parameter. Bakos and Katsamakas (2008) consider how a two-sided market designer can optimize cross-side network effects. Dou et al. (2013) consider how a monopolist optimizes in tandem the strength of network effects and the seeding ratio in the market. In our study, we incorporate the strength of network effects as a decision variable for the technology owner. To our knowledge, this is the first study of competition

with network effects where the intensity of these effects is endogenized.

3. Model

We consider an incumbent firm (referred to as firm 1) with a software product developed on its proprietary technology platform. The incumbent initially holds a monopoly position in the market, and the quality of its product is $q_1 (> 0)$. There is a potential entrant (referred to as firm 2) that considers entering the market by developing and selling a competing product. Nevertheless, it is prohibitively expensive for the entrant to identify alternative ways to develop and offer similar functionality without relying on the incumbent's IP. Thus, the entrant can join the market only if the incumbent is willing to open its platform by sharing some of its proprietary core IP.¹ The quality of the entrant's software product, q_2 , is determined by the co-production function $q_2(\rho, e; k) = \rho ke$. Here, ρ captures the *degree* of IP sharing chosen by the incumbent firm, k is the entrant's absorptive capacity, measuring its ability or efficiency in transforming the available knowledge into product, and e represents the entrant's development cost (or effort). The inverse of the production function leads to the development cost function $e(q_2; \rho, k) = q_2/(\rho k)$.

Considering that, in reality, IP often takes modular form (e.g., software modules, programming libraries, individual patents, etc.), it is reasonable and realistic to model the incumbent's degree of IP sharing as a discrete decision variable. For expositional simplicity, we consider three potential degrees of IP sharing, i.e., $\rho \in \{0, 1, 2\}$.² The case of $\rho = 0$ corresponds to the incumbent closing all of its IP. In this case, the entrant's marginal development cost, $1/(\rho k)$, goes to infinity, and the entrant stays out of the market. Consequently, the incumbent stays in monopoly mode with a closed platform. The case of $\rho = 1$ corresponds to the incumbent choosing to open its platform and freely sharing the basic subset of its IP with the entrant, making it possible for the latter to develop products with positive quality at a finite cost level. We refer to this case as *basic sharing*. Finally, $\rho = 2$ corresponds to the incumbent freely sharing an extensive portion of its IP. Such IP sharing further lowers the entrant's marginal development cost. We refer to this case as *extensive sharing*. Throughout the rest of the paper, we will refer to opening and sharing interchangeably.

To simplify notation during the analysis, when the incumbent opens the platform (i.e., $\rho \in \{1, 2\}$), we denote the entrant's development cost as simply cq_2 , where $c = c(\rho, k) = 1/(\rho k)$ is the marginal development cost.³ On the other hand, since we examine the incumbent's strategic decisions after it has developed its product, the incumbent's development cost is sunk. Because software products are digital goods, marginal

production costs are assumed to be negligible for both firms. The entrant will only join the market if it can make strictly positive profit (we consider a tiebreaker rule whereby an entrant would choose to stay out of the market if its profit is exactly zero). Without loss of generality, we normalize $q_1 = 1$ and let $q_2 = q$ with $0 \leq q \leq 1$; in other words, the entrant's product quality cannot exceed that of the incumbent.⁴

There is a continuum of consumers with total mass 1 in the market, and each consumer needs at most one unit of the product. Net of any network effects, consumers are heterogeneous in their valuation of the product functionality. We capture this valuation heterogeneity via parameter $\theta \sim U[0, 1]$, which we call the consumer *type*. A consumer of type θ derives the following utility from purchasing firm i 's product with quality q_i and price p_i :

$$u(q_i, p_i; \theta) = (\theta + \gamma N)q_i - p_i, \quad \forall i \in \{1, 2\}. \quad (1)$$

The coefficient γ captures the intensity of the network effects, and N is the total user base across all of the products in the market. If the incumbent opens its platform, we assume that the two firms' products are inherently compatible because the entrant builds on the incumbent's technology and hence enjoys shared network effects proportional to the sum of both firms' user bases (i.e., $N = N_1 + N_2$). If the incumbent chooses to keep its platform closed, then it maintains a monopoly market, and $N = N_1$. The above parameterization of network effects follows a common approach used in the literature (e.g., Conner 1995, Sun et al. 2004, Cheng and Liu 2012).⁵ We further assume $0 < \gamma < 1$ to ensure a downward sloping demand function.

The timeline of the game is as follows: (i) The incumbent decides the degree of openness ρ ; (ii) The entrant decides whether to enter the market; (iii) If entering, the entrant determines its quality level q and price p_2 ; (iv) The incumbent responds with price p_1 ; (v) Consumers observe the qualities and prices of both firms' products and purchase the one yielding higher (positive) utility according to (1). The model parameters of interest are the entrant's absorptive capacity k and the network effect strength γ ; firms' decision variables $\{p_1, p_2, q, \rho\}$ together with the market shares $\{N_1, N_2, N\}$ are endogenously determined by the strategic interplay in the game. We consider a complete information structure in which all model parameters and decision variables are known to all parties. In Section 5.2, we extend our model to allow the entrant's absorptive capacity k to be uncertain to the incumbent and show that our results remain robust. In Section 5.4, we further extend our main model to make γ a decision variable for the incumbent and add another stage during which γ is optimized at the very beginning of the game.

4. Analysis and Results

In this study, we use the concept of a *subgame perfect rational expectations equilibrium*. We solve the equilibrium via backward induction so that the full equilibrium solution is subgame perfect. When making purchase decisions, consumers form (common) expectations about the network size; such an expectation, in turn, is rational and consistent with the actual demands in equilibrium. Therefore, the demand functions are the results of a rational expectations equilibrium.

We start with the case in which the incumbent chooses not to open its platform and maintains a monopoly market. We next analyze the competition under an open platform. Following the backward induction, we first solve the equilibrium pricing $\{p_1^*(q, \gamma), p_2^*(q, \gamma)\}$ given any product quality of the entrant. Next, we derive the optimal quality choice $q^*(\gamma, c)$ of the entrant as a function of γ (the network effect strength) and c (the entrant's marginal development cost). Finally, we compare the profits under open and closed strategies to determine the incumbent's opening decision $\rho^*(\gamma, k)$, summarized over the entire space of γ and k (the entrant's absorptive capacity).

4.1. Monopoly Pricing

When the incumbent keeps its technology platform closed and remains a monopoly, it sets price p_1 to maximize its profit function $\pi_1(p_1) = p_1 N_1(p_1)$. It can be shown (see the proof in the online appendix) that its equilibrium price, demand, and profit are as follows:

$$(p_1^M, N_1^M, \pi_1^M) = \begin{cases} \left(\frac{1}{2}, \frac{1}{2(1-\gamma)}, \frac{1}{4(1-\gamma)} \right), & \text{if } \gamma < \frac{1}{2}, \\ (\gamma, 1, \gamma), & \text{if } \gamma \geq \frac{1}{2}. \end{cases} \quad (2)$$

As Equation (2) shows, when the intensity of the network effects is weak (i.e., $\gamma < \frac{1}{2}$), the market is partially covered (i.e., $N_1^M < 1$), and the optimal price is $\frac{1}{2}$. As the network effects grow in intensity (i.e., $\gamma \geq \frac{1}{2}$), the market becomes fully covered (i.e., $N_1^M = 1$), and the firm raises its price beyond the usual monopoly level (i.e., $p_1^M > \frac{1}{2}$) to exploit the network effects. This simple case of monopoly pricing indicates that, with network effects, strategic outcomes can be significantly different under fully and partially covered markets. Differences in strategies across such market-coverage regimes are even more intricate and interesting in the competition case, as discussed below.

4.2. Competitive Pricing Under IP Sharing

In this section, we derive the pricing equilibrium when the two firms sell competing products developed on the same open platform (given that the incumbent agrees to share its IP, i.e., $\rho \in \{1, 2\}$, and the entrant

Table 1. Equilibrium Outcomes of Price Competition

	Region (i)	Region (ii)	Region (iii)
	$0 < \gamma < \frac{2-\sqrt{2}}{2}, 0 < q \leq \frac{2\gamma^2-4\gamma+1}{1-2\gamma}$	(ii.a) $0 < \gamma < \frac{2-\sqrt{2}}{2}, \frac{2\gamma^2-4\gamma+1}{1-2\gamma} < q \leq \frac{1-\gamma}{1+\gamma}$ (ii.b) $\frac{2-\sqrt{2}}{2} \leq \gamma < 1, 0 < q \leq \frac{1-\gamma}{1+\gamma}$	$\frac{1-\gamma}{1+\gamma} < q < 1$
Price	$p_1^* = \frac{(1-q)(4-q-3\gamma)}{4(1-\gamma)(2-q-\gamma)}$ $p_2^* = \frac{q(1-q)}{2(2-q-\gamma)}$	$p_1^* = \frac{1+\gamma-q}{2}$ $p_2^* = q\gamma$	$p_1^* = \frac{1}{4}(1-q)(3+\gamma)$ $p_2^* = \frac{1}{2}(1-q)(1-\gamma)$
Demand	$N_1^* = \frac{4-q-3\gamma}{4(1-\gamma)(2-q-\gamma)}, N_2^* = \frac{1}{4(1-\gamma)}$ $N^* = \frac{3-q-2\gamma}{2(1-\gamma)(2-q-\gamma)} < 1$	$N_1^* = \frac{1+\gamma-q}{2(1-q)}, N_2^* = \frac{1-\gamma-q}{2(1-q)}$ $N^* = 1$	$N_1^* = \frac{3+\gamma}{4}, N_2^* = \frac{1-\gamma}{4}$ $N^* = 1$
Profit	$\pi_1^* = \frac{(1-q)(4-q-3\gamma)^2}{16(1-\gamma)^2(2-q-\gamma)^2}$ $\pi_2^* = \frac{q(1-q)}{8(1-\gamma)(2-q-\gamma)} - cq$	$\pi_1^* = \frac{(1+\gamma-q)^2}{4(1-q)}$ $\pi_2^* = \frac{(1-\gamma-q)q\gamma}{2(1-q)} - cq$	$\pi_1^* = \frac{1}{16}(1-q)(3+\gamma)^2$ $\pi_2^* = \frac{1}{8}(1-q)(1-\gamma)^2 - cq$

decides to join the market). At this stage of the backward induction analysis, we take the quality q of the entrant's product as given and derive the equilibrium demands, prices, and profits as functions of q , γ , and $c = 1/(\rho k)$. We first derive the demand functions $N_i(p_1, p_2)$ based on consumers' rational expectations (in stage v of the game), then the optimal pricing strategy of the incumbent in response to the entrant's $p_1^*(p_2)$ (stage iv), and finally the optimal price of the entrant p_2^* (stage iii).

The demand functions $N_i(p_1, p_2)$ ($i = 1, 2$) can be derived as the fixed-point solutions based on the concept of rational expectations equilibrium. Let $\tilde{\theta}_{12}$ denote the type of consumer who is indifferent between purchasing from the incumbent and the entrant. Also, for each firm i (with $i \in \{1, 2\}$), let $\tilde{\theta}_i$ denote the type of marginal consumer indifferent between buying from firm i and doing nothing. There are two possible ordering outcomes for these threshold values: (i) $\tilde{\theta}_2 \leq \tilde{\theta}_1 \leq \tilde{\theta}_{12}$ or (ii) $\tilde{\theta}_{12} < \tilde{\theta}_1 \leq \tilde{\theta}_2$. In addition, these threshold values must be compared with the boundaries of the domain $[0, 1]$ for the consumer type. Consequently, the analysis is quite involved with multiple cases under various parameter conditions. We present the full summary of the demand functions under different parameter regions in the online appendix (Table A1).

Anticipating the demands, both firms optimize their prices to maximize their own profit. Thus, the incumbent maximizes its profit $\pi_1(p_1, p_2) = p_1 N_1(p_1, p_2)$; its best response in pricing, given the entrant's price p_2 , can be determined as

$$p_1^*(p_2) = \arg \max_{p_1} \pi_1(p_1, p_2). \quad (3)$$

Anticipating the incumbent's best response in pricing, the entrant chooses the optimal price p_2^* to maximize its profit $\pi_2(p_1, p_2) = p_2 N_2(p_1, p_2) - cq$ such that

$$p_2^* = \arg \max_{p_2} \pi_2(p_1^*(p_2), p_2). \quad (4)$$

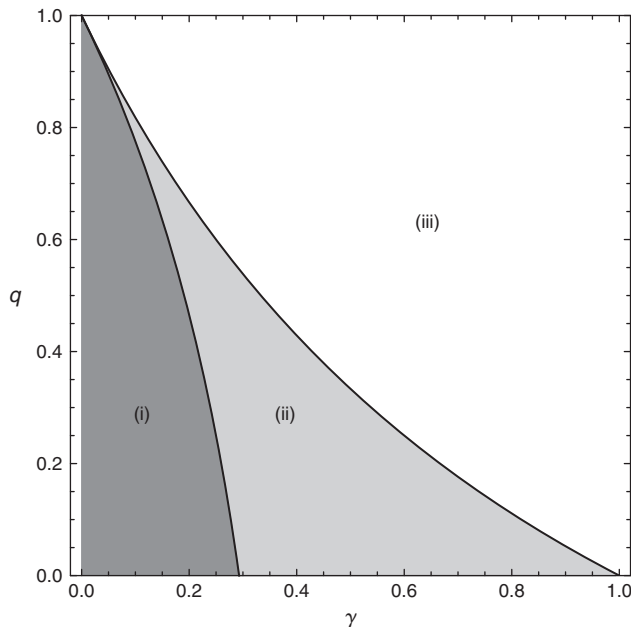
The analysis is highly nontrivial with numerous cases in different parameter regions (see Tables A2 and A3 in the online appendix for details).

Having obtained p_2^* , we can derive the equilibrium price $p_1^* = p_1^*(p_2^*)$, demands $N_i^* = N_i(p_1^*, p_2^*)$, and profits $\pi_i^* = \pi_i(p_1^*, p_2^*)$ accordingly, as summarized in the following proposition:

Proposition 1. *When the incumbent opens its platform and both firms compete via products built on the open platform, for a given parameter set $\{q, \gamma, c\}$, the pricing equilibrium is summarized in Table 1 and illustrated in Figure 1.*

Proof. All proofs are included in the online appendix. \square

Proposition 1 not only lays the foundation for the subsequent analysis but can also serve as a standalone analysis for the price competition of vertically differentiated products under network effects, with the product quality exogenously given. The equilibrium outcomes illustrated in Figure 1 reveal interesting strategic interplays. In region (i), where the network effect strength γ is small and the entrant's product quality q is not too high, the competition intensity turns out to be the lowest among all three cases. Both firms set their prices less competitively such that the lower price p_2 is greater than the lowest-type consumer's willingness-to-pay. As a result, the market is only partially covered, and the low-end customers are passed

Figure 1. Pricing Equilibrium Under IP Sharing

up. As γ and/or q further increase, the market turns moderately competitive in region (ii). The incumbent prices more aggressively to obtain a larger share of the market; in response, the entrant caters to all lower-type consumers. More precisely, it sets p_2 exactly equal to the lowest-type consumer's willingness-to-pay, $q\gamma$. As a result, the market is just fully covered with the lowest-type consumer being indifferent between purchasing and not purchasing. By contrast, when γ or q are large, region (iii) corresponds to the hypercompetitive scenario. Facing intensified competition from the incumbent, the entrant must lower its price below the lowest-type consumer's willingness-to-pay. As a consequence, the market is fully covered, and all consumers enjoy a strictly positive surplus.

Before proceeding to the next step of the backward induction, we highlight important differences between our results and some established results in the literature. Note that extant models of markets with network effects (e.g., Conner 1995) typically assume the market size can grow arbitrarily due to the sufficiently large adoption costs for the low-valuation end of the consumer population. Consequently, the market will never be saturated, which largely simplifies the analysis and results. Such a scenario hence corresponds to region (i) of our results in Proposition 1. As we show, removing this simplifying assumption and analyzing full market conditions for the price competition under network effects result in richer findings, some of which contradict the classical wisdom in the literature. To better elaborate on the connection and difference, we plot how the equilibrium prices, demands, and profits change with γ and q in Figures 2 and 3,

respectively, followed by a detailed discussion below. In Section 5.1, we further solve the full game under the scenario where the market is assumed to be never fully covered and illustrate the impacts of such an assumption on the strategic openness outcome.

As Figure 2 shows, the pricing equilibrium in region (i) is consistent with the findings in the classical literature on markets with network effects. In particular, the overall demand or the covered market size, N^* , grows as the strength of the network effects γ increases. As a result, both firms benefit from the growing size of the total "pie" and enjoy the increasing equilibrium profits π_1^* and π_2^* . Consistent with Conner (1995), in this region, when γ goes above a certain threshold, the incumbent's profit under competition, π_1^* , even exceeds its monopoly profit, π_1^M , resulting in the competitor being welcomed into the market.

Interesting findings, on the other hand, arise in the previously unexplored regions (ii) and (iii). Once the market is saturated (i.e., $N^* = 1$), the total network size cannot grow any further regardless of how low the firms set their prices. Interestingly, we show that even *without* the growth in the total network size, the incumbent can still achieve a higher profit in a competition market than a monopoly. Note that the incumbent would cover the whole market as a monopolist (i.e., $N_1^M = 1$) when $\gamma \geq \frac{1}{2}$, whereas its market share would be reduced under competition on the open platform (i.e., $N_1^* < 1$). In this sense, the incumbent is essentially willing to give away some of its own market to the competitor. In return, this otherwise monopolist can charge the higher-end market an elevated premium without losing the benefit of network effects. The incumbent prefers co-opetition and adopts a strategy to *split* the efforts with the entrant towards *jointly* building the user network and driving up consumer utility. The overall effects result in a higher profit level exceeding the monopoly profit. This result thus complements the existing knowledge in the literature that inviting competition under network effects could increase profit because of the growth in the total network size.

Another interesting aspect is that π_1^* can fall below π_1^M when γ is sufficiently large. We formalize this result in the corollary below, followed by further discussion.

Corollary 1. For any given $q < 1$, there exists a cut-off $\gamma_0(q) \in (0, 1)$ such that for $\gamma_0(q) < \gamma < 1$, the incumbent's profit under IP sharing is less than its monopoly profit, that is, $\pi_1^*(q, \gamma) < \pi_1^M(\gamma)$.

When the network effect intensity is sufficiently large, with the market being saturated and the total network size fixed, competition intensifies. The entrant prices so low (i.e., below the lowest-type consumer's willingness-to-pay) that it forces the incumbent to mark down as well. Without generating additional growth in the total network effects, such price competition heavily erodes

Figure 2. Equilibrium Prices, Demands, and Profits Changing in γ ($q = 0.2, c = 0.01$)

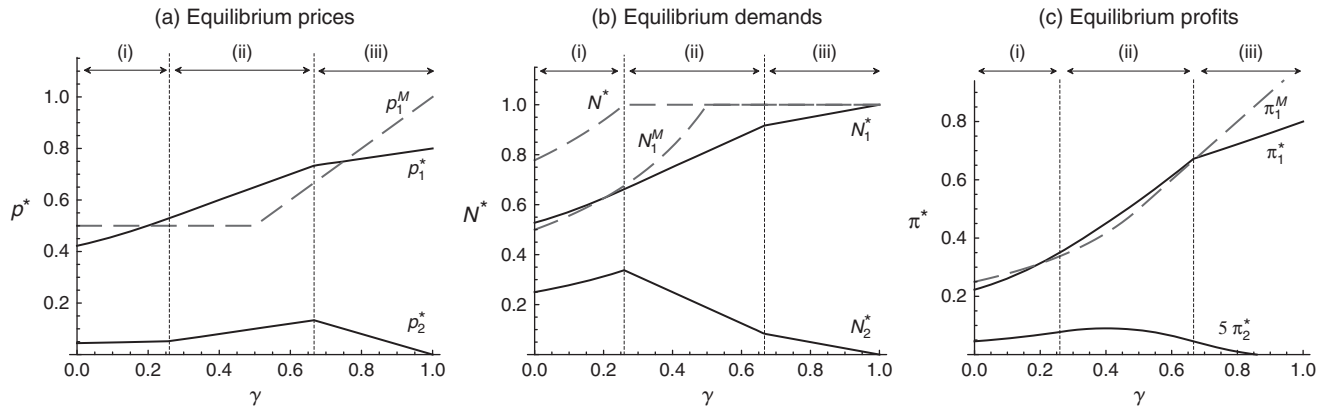
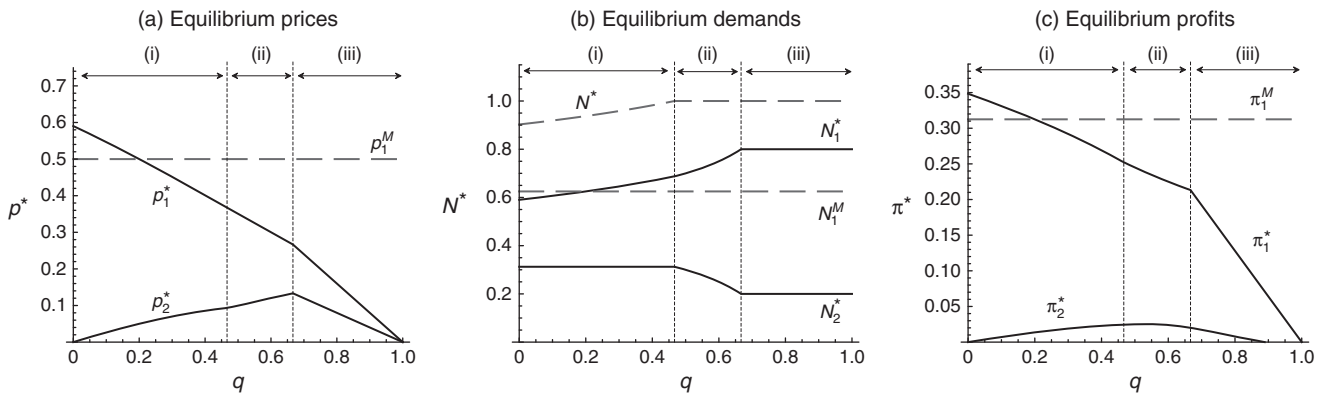


Figure 3. Equilibrium Prices, Demands, and Profits Changing in q ($\gamma = 0.2, c = 0.01$)



both firms' profits. As a result, shortly after γ enters region (iii) from below, π_1^* becomes inferior to π_1^M , and the incumbent would prefer remaining a monopolist. This result is in sharp contrast to the classical wisdom in the literature that inviting competition under network effects is always beneficial as long as the network effect strength is sufficiently large (e.g., Conner 1995, Economides 1996).

The entrant's profit in regions (ii) and (iii) is also worth discussing. Note that the entrant's profit changes nonmonotonically in γ . On one hand, the entrant sets its price equal to the lowest-type consumer's willingness-to-pay in region (ii), so $p_2 = q\gamma$, which increases in γ . On the other hand, because the market is saturated in region (ii), the entrant cannot further expand its market share toward the lower end even with increased network effects. As a result, facing intensified competition from the incumbent and the quality disadvantage enlarged by the increased network effects, the entrant's demand N_2^* starts to shrink with γ in region (ii). The combined effects lead to a first-increasing-then-decreasing pattern of π_2^* as γ grows. This result is also in contrast with the general notion in the literature that greater network effects always benefit the entrant and its profit is an increasing

function of the network effect strength (e.g., Conner 1995, p. 214). Note that π_2^* may drop to zero for large γ 's, which implies that the entrant may not always be willing to enter the market even if the incumbent offers to share its IP, as we further discuss in Section 4.3.

Figure 3 shows how the pricing competition outcomes change with the entrant's product quality q . As can be expected, when the competitor gets closer in quality, the incumbent's profit space becomes limited, so π_1^* is decreasing in q . Counterintuitively, however, the entrant's profit does not necessarily increase in its own product quality. As the entrant becomes more competitive on quality, it invites fierce competition from its stronger rival, as indicated by the steep drop in both firms' prices in region (iii). As a consequence, π_2^* changes nonmonotonically in q and decreases to zero as q gets close to 1. For this reason, the entrant will actually avoid region (iii) when it can endogenously choose its quality level, as we examine next.

4.3. Endogenous Quality Under IP Sharing

Continuing with the backward induction, we next derive the entrant's optimal choice of its product quality once it enters the market (in stage iii of the game) as well as its entry decision (stage ii). For a given quality

Table 2. Optimal Quality Choice of the Entrant

(a) $0 < c \leq \frac{1}{16}$	(b) $\frac{1}{16} < c \leq \frac{\sqrt{2}-1}{4}$
$q^*(\gamma, c) = \begin{cases} 2 - \gamma - \sqrt{\frac{(2-\gamma)(1-\gamma)}{1-8c(1-\gamma)}}, & 0 < \gamma \leq \hat{\gamma}(c) \\ 1 - \sqrt{\frac{\gamma^2}{\gamma-2c}}, & \hat{\gamma}(c) < \gamma < \frac{1+\sqrt{1-8c}}{2} \\ 0, & \frac{1+\sqrt{1-8c}}{2} \leq \gamma < 1 \end{cases}$	$q^*(\gamma, c) = \begin{cases} 0, & 0 < \gamma \leq \frac{3}{2} - \sqrt{\frac{1+2c}{8c}} \\ 2 - \gamma - \sqrt{\frac{(2-\gamma)(1-\gamma)}{1-8c(1-\gamma)}}, & \frac{3}{2} - \sqrt{\frac{1+2c}{8c}} < \gamma \leq \hat{\gamma}(c) \\ 1 - \sqrt{\frac{\gamma^2}{\gamma-2c}}, & \hat{\gamma}(c) < \gamma < \frac{1+\sqrt{1-8c}}{2} \\ 0, & \frac{1+\sqrt{1-8c}}{2} \leq \gamma < 1 \end{cases}$
(c) $\frac{\sqrt{2}-1}{4} < c \leq \frac{1}{8}$	(d) $\frac{1}{8} < c$
$q^*(\gamma, c) = \begin{cases} 0, & 0 < \gamma \leq \frac{1-\sqrt{1-8c}}{2} \\ 1 - \sqrt{\frac{\gamma^2}{\gamma-2c}}, & \frac{1-\sqrt{1-8c}}{2} < \gamma < \frac{1+\sqrt{1-8c}}{2} \\ 0, & \frac{1+\sqrt{1-8c}}{2} \leq \gamma < 1 \end{cases}$	$q^*(\gamma, c) \equiv 0, \quad \forall \gamma \in (0, 1)$

Note. $\hat{\gamma}(c)$ is the unique solution to $-4\gamma^3 + 4(2c+3)\gamma^2 - 8(2c+1)\gamma + 8c + 1 = 0$ for $\gamma \in (0, (2-\sqrt{2})/2)$.

level q , we have already obtained the entrant’s equilibrium profit function $\pi_2^*(q, \gamma; c)$ in Proposition 1. The optimal quality choice can thus be solved as

$$q^*(\gamma, c) = \arg \max_q \pi_2^*(q, \gamma; c), \quad (5)$$

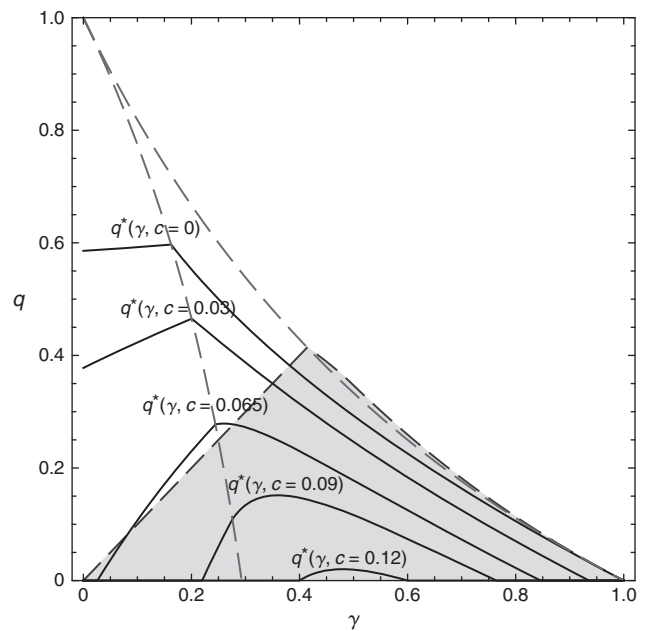
under various parameter conditions, as summarized in the following proposition.

Proposition 2. *If the incumbent opens its platform, for a given parameter set $\{\gamma, c\}$, the entrant’s optimal quality choice $q^*(\gamma, c)$ is summarized in Table 2 and illustrated in Figure 4.*

When the intensity of network effects is small (i.e., $\gamma < \hat{\gamma}(c)$), the entrant’s optimal quality choice $q^*(\gamma, c)$, if positive, falls in the pricing equilibrium region (i), where the market is partially covered. When $\gamma > \hat{\gamma}(c)$, $q^*(\gamma, c)$, if positive, falls in the pricing equilibrium region (ii) with full market coverage. Note that $q^*(\gamma, c)$ never falls into the pricing equilibrium region (iii) because it would be suboptimal to engage in the hypercompetition occurring in that region. From Table 2 we can see that $q^*(\gamma, c)$ is decreasing in the entrant’s marginal development cost c . In other words, given the same γ , the higher the cost, the lower the quality the entrant chooses. On the other hand, $q^*(\gamma, c)$ changes nonmonotonically in γ , first increasing and then decreasing, which causes the highest endogenous quality (for any given c) to appear in the moderate

range of the network effect intensity. Note especially that, even when the entrant can freely choose its quality level at no cost, that is, $c = 0$, the maximum quality level chosen by the entrant is far lower than the highest possible level, 1. In this sense, the entrant has incentives to distance itself from the incumbent to avoid the

Figure 4. Entrant’s Optimal Quality Choices



head-on competition. While we discuss the optimal IP sharing decision at length in Section 4.4, here we briefly note that the shaded area in Figure 4 represents the area where the incumbent is willing to share its IP.

The entrant is willing to enter the market if and only if $q^*(\gamma, c)$ is strictly positive. If $q^*(\gamma, c) = 0$, then $\pi_2^* = 0$, indicating that the entrant is unable to achieve any positive profit level. Consequently, it will not enter the market even when the incumbent is willing to share its IP. An immediate result from Proposition 2 leads to the market entry decision summarized in the following corollary.

Corollary 2. *The entrant is willing to enter the market if and only if one of the following condition pairs occurs:*

- (a) $0 < c \leq 1/16$ and $0 < \gamma < (1 + \sqrt{1 - 8c})/2$; or
- (b) $1/16 < c \leq (\sqrt{2} - 1)/4$ and $\frac{3}{2} - \sqrt{(1 + 2c)/(8c)} < \gamma < (1 + \sqrt{1 - 8c})/2$; or
- (c) $(\sqrt{2} - 1)/4 < c < \frac{1}{8}$ and $(1 - \sqrt{1 - 8c})/2 < \gamma < (1 + \sqrt{1 - 8c})/2$.

As Corollary 2 summarizes and Figure 4 illustrates, for any $c > 0$, if γ is too large (i.e., $\gamma > (1 + \sqrt{1 - 8c})/2$), the entrant will not enter the market; for moderate marginal development costs (i.e., $1/16 < c < \frac{1}{8}$), the entrant is also unwilling to enter if γ is small (i.e., $\gamma < \frac{3}{2} - \sqrt{(1 + 2c)/(8c)}$ or $(1 - \sqrt{1 - 8c})/2$); moreover, when the marginal development cost is too high (i.e., $c \geq \frac{1}{8}$), entry is not possible at all for any γ . The entrant's possible lack of interest in joining the market in various parameter regions highlights the importance of endogenizing quality and entry decision making in deriving reliable implications for strategic IP sharing.

4.4. Optimal IP Sharing Strategies

In this section, we complete the solution of the entire game by solving the first stage, that is, the incumbent's IP sharing decision. We first present an intermediate result that is critical in deriving the optimal sharing strategy. Specifically, we compare $\pi_1^*(q, \gamma)$ from Proposition 1 with the monopoly profit $\pi_1^M(\gamma)$ and derive the necessary conditions that the pair (q, γ) must satisfy for IP sharing to be a dominant strategy (i.e., $\pi_1^*(q, \gamma) > \pi_1^M(\gamma)$).

Lemma 1. *For any given q , the incumbent prefers sharing its IP if and only if $q < \tilde{q}(\gamma)$, which is defined as follows.*

$$\tilde{q}(\gamma) = \begin{cases} \gamma, & 0 < \gamma \leq \sqrt{2} - 1; \\ 1 - \frac{4}{(1 - \gamma)(3 + \gamma)^2}, & \sqrt{2} - 1 < \gamma < \frac{1}{2}; \\ 1 - \frac{16\gamma}{(3 + \gamma)^2}, & \frac{1}{2} \leq \gamma < 1. \end{cases} \quad (6)$$

As Figure 4 shows, $\tilde{q}(\gamma)$ in (6) defines the upper boundary of the shadowed region in the plane of γ and q , in which the incumbent prefers sharing to staying

a monopoly. As we can see, IP sharing is more profitable for the incumbent only when q is not too large and γ is neither too small nor too large. This is consistent with Corollary 1: When the total market size cannot grow arbitrarily, high network effect intensity would intensify price competition, which eventually erodes duopoly profit enough to make the incumbent shy away from opening to invite competition.

Comparing the endogenous quality $q^*(\gamma, c)$ in Proposition 2 and the cut-off $\tilde{q}(\gamma)$ in Lemma 1, we can conclude that IP sharing is optimal if and only if $q^*(\gamma, c) < \tilde{q}(\gamma)$, that is, when the curves of $q^*(\gamma, c)$ in Figure 4 enter the shadowed region. This gives us the conditions on (γ, c) for the incumbent to be willing to share. Furthermore, because $c = 1/(\rho k)$, we can then derive the optimal degree of sharing, ρ^* , as a function of the network effect intensity γ and the entrant's absorptive capacity k . The next proposition summarizes $\rho^*(\gamma, k)$ over various parameter regions.

Proposition 3. *The optimal IP sharing strategy for the incumbent, ρ^* , as a function of the strength of network effects, γ , and the entrant's absorptive capacity, k , is summarized by Table 3 and illustrated by Figure 5.*

As shown in Table 3 and Figure 5, there are five different regions in terms of optimal IP sharing strategy in the $\{k, \gamma\}$ parameter space. In region (1), where γ is small and k is large, the incumbent prefers not sharing and keeps the market in monopoly mode. This is because the competent opponent could pose a threat to the incumbent's profit by producing a close substitute and forcing an intense price competition, and the relatively weak network effect intensity cannot compensate for the revenue loss due to competition. Consequently, the incumbent prices as a monopolist and only partially covers the market. In region (2), the largest among the five regions, with larger γ or smaller k , basic sharing becomes optimal for the incumbent, generating higher profit compared to the monopoly case. Meanwhile, the entrant is competent enough (i.e., k is not too low) to obtain positive net profit in product market competition, which makes its market entry feasible. As a result, $\rho^* = 1$ sustains as an equilibrium, and both firms' products coexist and compete in the market. As Figure 5 depicts, the unshadowed region (i.e., γ is small) corresponds to the pricing equilibrium region (i) as in Proposition 1, where the market is partially covered; the shadowed region, by contrast, corresponds to the pricing equilibrium region (ii), where the market is fully covered.

Recall that the incumbent's profit $\pi_1^*(q, \gamma)$ is decreasing in q , whereas the entrant's quality choice $q^*(\gamma, c)$ is decreasing in c . For this reason, given any k , increasing ρ (i.e., sharing more) reduces c , which in turn helps the entrant to increase q^* and eventually hurts the incumbent's own profit. Therefore, the incumbent

Table 3. Optimal IP Sharing Strategy

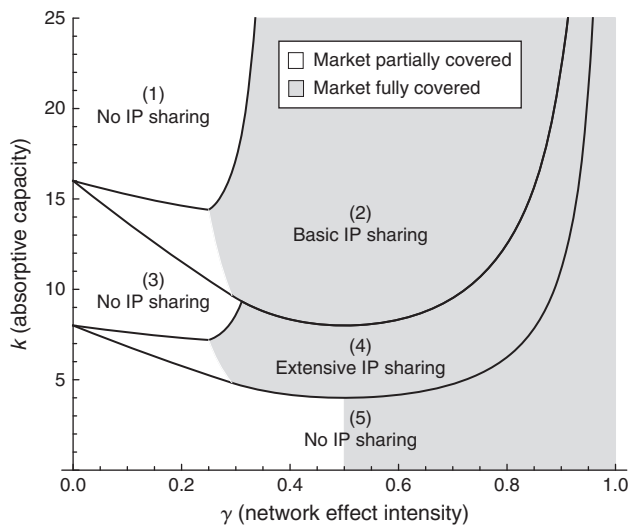
	Parameter region	IP sharing	Remark
(1)	$0 < \gamma < \frac{3-\sqrt{5}}{2}, \tilde{k}_1(\gamma) \leq k$	$\rho^* = 0$	Incumbent prefers not sharing
(2)	(2.a) $0 < \gamma < \frac{3-\sqrt{5}}{2}, \tilde{k}_2(\gamma) < k < \tilde{k}_1(\gamma)$ (2.b) $\frac{3-\sqrt{5}}{2} \leq \gamma < 1, \tilde{k}_2(\gamma) < k$	$\rho^* = 1$	Basic sharing optimal for incumbent
(3)	$0 < \gamma \leq \tilde{\gamma}, \frac{1}{2}\tilde{k}_1(\gamma) \leq k \leq \tilde{k}_2(\gamma)$	$\rho^* = 0$	Entrant unwilling to enter under basic sharing; incumbent prefers monopoly to extensive sharing
(4)	(4.a) $0 < \gamma \leq \tilde{\gamma}, \frac{1}{2}\tilde{k}_2(\gamma) < k < \frac{1}{2}\tilde{k}_1(\gamma)$ (4.b) $\tilde{\gamma} < \gamma < 1, \frac{1}{2}\tilde{k}_2(\gamma) < k \leq \tilde{k}_2(\gamma)$	$\rho^* = 2$	Incumbent prefers extensive sharing to monopoly; entrant willing to enter only under extensive sharing
(5)	$0 < \gamma < 1, k \leq \frac{1}{2}\tilde{k}_2(\gamma)$	$\rho^* = 0$	Entrant unwilling to enter even under extensive sharing

Note.

$$\tilde{k}_1(\gamma) = \begin{cases} \frac{32(1-\gamma)^2}{2-3\gamma}, & 0 < \gamma \leq \frac{1}{4}, \\ \frac{2(1-\gamma)^2}{\gamma[1-(3-\gamma)\gamma]}, & \frac{1}{4} < \gamma < \frac{3-\sqrt{5}}{2}, \end{cases} \quad \tilde{k}_2(\gamma) = \begin{cases} 8(2-\gamma)(1-\gamma), & 0 < \gamma \leq \frac{2-\sqrt{2}}{2}, \\ \frac{2}{\gamma(1-\gamma)}, & \frac{2-\sqrt{2}}{2} < \gamma < 1. \end{cases}$$

$\tilde{\gamma}$ is the unique solution to $(1-\gamma)^2/(\gamma[1-(3-\gamma)\gamma]) = 2/(\gamma(1-\gamma))$ for $\gamma \in ((2-\sqrt{2})/2, (3-\sqrt{5})/2)$.

Figure 5. Full Equilibrium Outcome



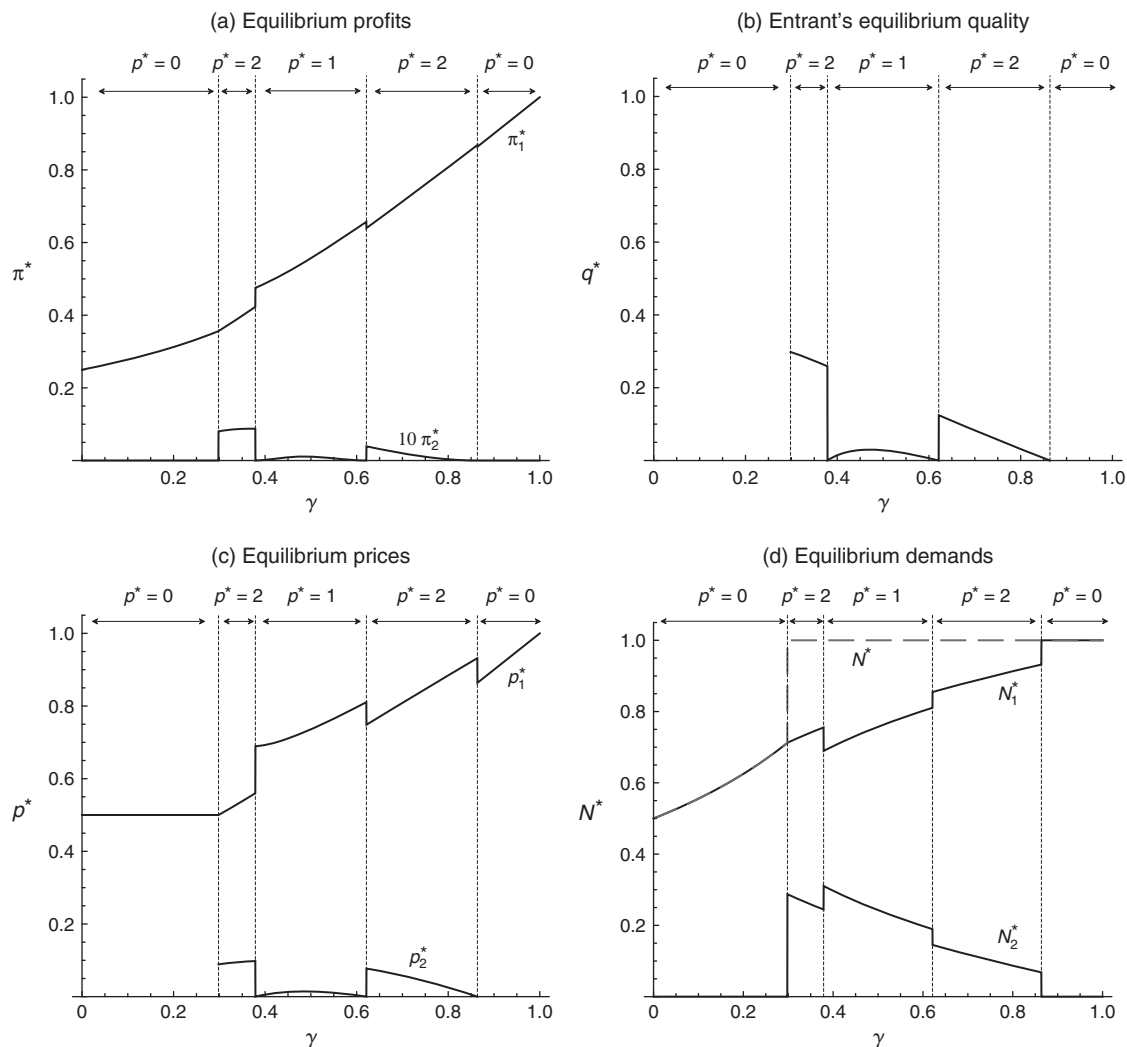
will not consider extensive sharing (i.e., $\rho^* = 2$) as long as the entrant is willing to enter the market under basic sharing (i.e., $\rho^* = 1$). However, once k falls below $\tilde{k}_2(\gamma)$ defined in Table 3 (i.e., the lower boundary of region 2), the entrant is too weak in absorptive capacity to develop a reasonably competitive product and obtain positive net profit under basic sharing. As a result, basic sharing is not sufficient to facilitate market entry, and the incumbent must consider extensive sharing if possible.

In region (3), the incumbent would prefer basic sharing, but basic sharing is not enough to encourage

market entry; nonetheless, extensive sharing would make the entrant too competitive (because k is not very low). Given the relatively weak network effect intensity, extensive sharing is inferior to staying in monopoly mode. As a result, the incumbent does not share in equilibrium and simply maintains a partially covered monopoly market as in region (1). Region (4) also corresponds to the case when the incumbent would prefer basic sharing, but market entry is not feasible under basic sharing. Unlike region (3), however, region (4) entails larger γ or smaller k , which makes extensive sharing more profitable than a monopoly thanks to the benefit from stronger network effect intensity or less competition threat. On the other hand, the entrant can achieve positive profit under extensive sharing and therefore is willing to enter the market. Consequently, $\rho^* = 2$ sustains as an equilibrium, and the pricing competition outcome resembles that of region (2), with the market partially (fully) covered in the unshaded (shaded) region. Finally, region (5) accounts for the case when the entrant is so weak (i.e., $k < \frac{1}{2}\tilde{k}_2(\gamma)$) that even extensive sharing cannot make its market entry possible. The resulting equilibrium hence retreats to the monopoly case, with partial (full) market coverage for $\gamma < \frac{1}{2}$ ($\gamma \geq \frac{1}{2}$).

A notable pattern in Figure 5 is the alternating switches among different IP sharing strategies as γ increases (for a given k). Such interesting patterns reflect the complexity of multi-level decision making over different market conditions. Thus our findings enrich the existing understanding in the literature that

Figure 6. Equilibrium Profits, Quality, Prices, and Demands Changing in γ ($k = 8.5$)



greater network effect intensity tends to encourage openness monotonically. To elaborate on how different aspects of the equilibrium outcome vary under the back-and-forth switches of optimal IP sharing strategies, we plot the equilibrium profits, quality, prices, and demands given a certain value of the entrant's absorptive capacity (i.e., $k = 8.5$) in Figure 6.

As Figure 6 illustrates, at a moderately low level of absorptive capacity of the entrant ($k = 8.5$), as network effect intensity γ increases from 0 to 1, the incumbent's optimal IP sharing strategy switches back and forth among all three levels, totaling five different cases. When γ is small, $\rho^* = 0$ because basic sharing cannot motivate the entrant to enter the market, whereas extensive sharing is dominated by monopoly. Most interesting, as γ grows, instead of transitioning from $\rho^* = 0$ to $\rho^* = 1$, the optimal sharing strategy directly jumps to extensive sharing. In this case, although basic sharing is still insufficient to motivate market entry, extensive sharing, under which market

entry is profitable for the entrant, starts to generate a higher profit than a monopoly for the incumbent as well. As a result, $\rho^* = 2$, and thanks to the extensive sharing of proprietary IP, the entrant can reduce its marginal development cost, resulting in the highest quality q^* and the highest profit π_2^* among all five cases. As γ further increases, once it reaches the level where basic sharing is enough to attract the entrant, the incumbent immediately switches to basic sharing, simply because a lower level of sharing limits the competitive strength of the rival and thus benefits the incumbent's profit. As a result, we can see a clear jump of π_1^* in the center segment of Figure 6(a), which corresponds to region (2) in Figure 5. Meanwhile, with ρ^* halved, the entrant's marginal development cost doubles, resulting in a significant drop in quality q^* and profit π_2^* . Once π_2^* drops down to zero under basic sharing, the incumbent must switch back to extensive sharing again to keep the entrant in the market, which incurs a bounce-up of the entrant's profit π_2^* but a drop in its own profit π_1^* .

When γ is too large, market entry is not feasible even under extensive sharing, and hence $\rho^* = 0$. Note that the incumbent's profit π_1^* drops minimally when switching from extensive sharing to a monopoly at a large γ . In this sense, with strong network effect intensity, not only does the entrant lack motivation to enter the market, the incumbent's incentive to open and share its IP is also marginal at best. This again underscores the counterintuitive aspect of our findings that strong network effects could surprisingly be detrimental to strategic IP sharing and platform openness.

The results summarized in Proposition 3 and Figure 5 provide general implications deepening our understanding of strategic IP sharing. We uncover a nonmonotonic relationship between the degree of strategic IP sharing and the network effect intensity or the entrant's absorptive capacity. As we find, the moderate range of network effect intensity is the most prone to IP sharing and platform openness, as evidenced by the largest area within the parameter space with $\rho^* > 0$ for intermediate γ 's. By contrast, too strong or too weak network effect intensity makes sharing less likely. Along the lines of absorptive capacity, a potential entrant too strong in its capacity may find itself shunned by the technology owner and kept out of the market, whereas an entrant with too weak an absorptive capacity finds it impossible to profit under competition on an open platform. On the other hand, a firm with an intermediate absorptive capacity can join the market and will be welcomed by the technology platform owner, resulting in a win-win situation for both competing firms. This outcome is most prominent at moderate levels of network effect intensity.

4.5. Anecdotal Observations and Insights

In this section, we examine various anecdotal cases through the lens of our model. First, we consider developers of high quality games with multiplayer modes. For example, Activision Blizzard belongs to this category with World of Warcraft MMORPG or even more traditional franchises with multiplayer modes such as Starcraft, Warcraft, Diablo or Call of Duty. These products arguably exhibit very strong network effects and their source code is proprietary. Our model supports the market outcome of not opening in this range (right-hand side (RHS) of region (5) in Figure 5). At the other end of the spectrum, HFT algorithms are an example of product components with reduced network effects. In the financial sector, many players have a strong absorptive capacity to incorporate new algorithms into their platforms. This would be our region (1): In general, firms in this sector do not open their proprietary HFT code to competitors.

IBM provides another interesting example. In the early 1980s, IBM opened its PC architecture to outside suppliers but did not impose nonexclusive relationships (Moore 1993). Initially, potential entrants had

only moderate absorptive capacity and the early PCs exhibited only low to moderate network effects. This corresponds to the left-hand side (LHS) of region (4) in Figure 5 in which our model prescribes extensive sharing, matching IBM's strategy. This greatly expanded the ecosystem and allowed IBM PC clone makers such as Compaq to enter. Over time, the absorptive capacity moved higher in this industry. This corresponds to regions (1) or (2) in our model. IBM's reliance on outside vendors (e.g., Intel and Microsoft) for hardware and software components prevented it from regaining control over the market: It could not switch to basic or no sharing because much of the innovation now resided with the component manufacturers. Eventually IBM engaged in heavy price competition and exited the consumer PC market (selling its division to Lenovo).

A somewhat similar case is that of 3DR, a U.S.-based drone hardware and software solutions developer. Initially, 3DR adopted a basic IP sharing strategy. While keeping closed some of their core tools such as Site Scan enterprise-grade software for capturing and analyzing aerial data, they opened non-core software and hardware including drone autopilot hardware design, flight code, and several apps for their Solo drone (Kolodny 2017). This allowed users to tinker with the product and contribute to its evolution. 3DR further attempted to strengthen network effects by releasing DroneKit app platform, their free software development kit (SDK) and web application programming interface (API) for Solo drone, inviting developers to contribute complementary apps and grow the ecosystem of compatible solutions. More users would attract more developers, which in turn would indirectly benefit the users. Hence, 3DR built some limited network effects around their products. Given the widespread dissemination of knowledge on how to build drone hardware and software (in particular through open source designs) and the relatively contained complexity of producing drone hardware and software (compared, for example, with writing an entire operating system (OS)), the absorptive capacity of entrants, while starting lower, was likely to grow very fast. This would correspond to our region (1) or the LHS of region (2). This is also consistent with the fact that the drone market is currently not fully covered. 3DR's aforementioned basic sharing strategy would have been justified under our model had the market remained in region (2) for a prolonged period. However, within a few years, the absorptive capacity and the resources of the competitors grew significantly and a race-to-the-bottom on price was unavoidable. The overall market landscape rapidly shifted to region (1). By 2016, 3DR exited the drone-making business and refocused solely on enterprise software due to brutal competition on the hardware market (Mac 2016).

Last, we consider the example of Tesla. We assess it to be in the range of intermediate k and γ . More users encourage the expansion of the supercharger infrastructure, which in turn benefits all users. Users also provide a lot of real drive data that can be used to improve the car performance (see Section 5.4). Thus γ is moderate. At the same time, the absorptive capacity of other firms in the industry is intermediate. Obviously, other manufacturers have some expertise in building cars and thus k is not very low. At the same time, even with access to IP, a great deal of effort and resources are needed to build a new electric car (beyond integrating a few technological innovations). Hence, k is not extremely high either: Development costs are not dropping very low just by accessing the incumbent's IP. This places Tesla in region (4) for the time being, corresponding to an optimal strategy of extensive sharing. Indeed, in 2014, Tesla chose to share all its patents with the community (Ramsey 2014). Nevertheless, if in the future the absorptive capacity of the other potential market players increases substantially around electric vehicle (EV) design and manufacturing, then it might become optimal for Tesla to only partially share its IP or close it altogether. Toyota, which followed in Tesla's footsteps to open its patents around hydrogen fuel-cell cars, did impose a 2020 deadline on the royalty-free sharing on most of these patents (Inagaki 2015). Thus, when/if the standard catches on, Toyota will have some protection from intense competition (a switch from region (4) to regions (1) or (2)). While Tesla did not announce an expiration on the sharing of its current patents, it can gradually transition to basic sharing on future iterations of its product simply by not sharing any of the next innovations integrated in those iterations (assuming Tesla can stay ahead of the curve and keep innovating in the EV space).

5. Extensions

In this section, we consider four extensions of our prior analysis. First, we explore an alternative scenario where the market is unbounded and can grow indefinitely. Second, we explore the robustness of our results when the incumbent is uncertain of the entrant's absorptive capacity. Third, we discuss our results under a generalized (nonlinear) development cost structure for the entrant. Last, we expand our analysis and explore the more complex problem of how the incumbent should optimally engineer network effects.

5.1. Unbounded Market

As noted in Section 4.2, an important distinction between our study and the previous literature on competitive analysis with network effects is that we consider complete market conditions including partial and full market coverage. As already shown, such full market conditions lead to new and richer results in market

competition outcomes. To further illustrate the impact on the full equilibrium (including the endogenous quality choice and the optimal IP sharing strategies), in contrast to our original model and results, in this section, we explicitly solve the whole game under the scenario that the market can grow indefinitely and is hence never fully covered.

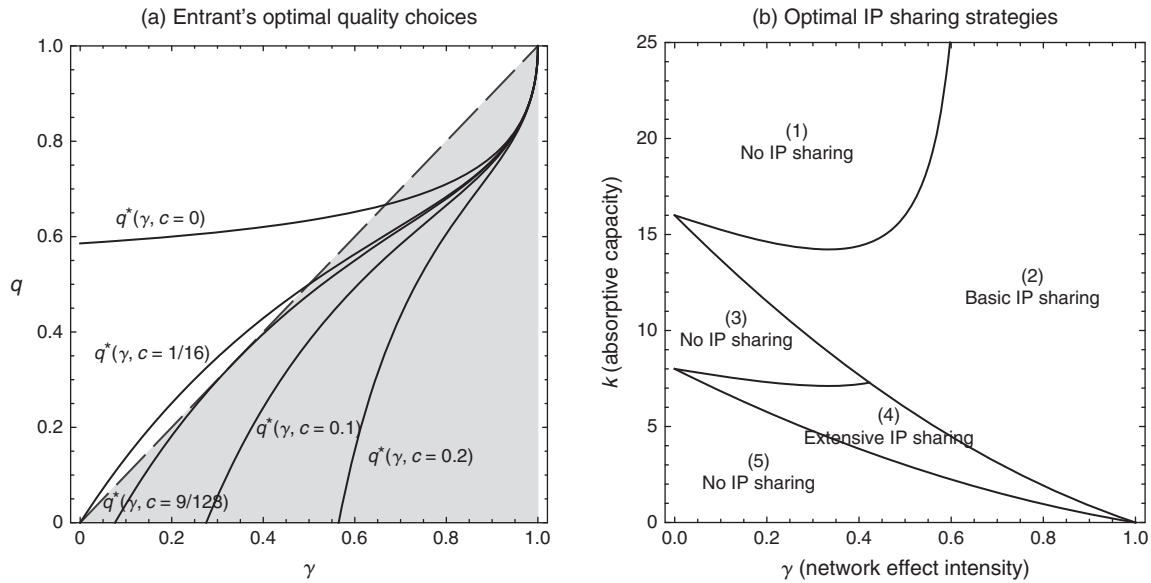
In particular, we now apply the simplifying assumption commonly adopted in the previous literature (e.g., Conner 1995, Sun et al. 2004) that there is a sufficiently large potential market consisting of consumers with adoption costs (characterized by negative θ 's uniformly distributed below zero with the same density as that of the existing market). As the product's user base and the associated network effects grow, the increased utility overcomes higher adoption costs and keeps attracting new consumers to enter the market, so the market never saturates. Under such an assumption, consumer types are not bounded below at zero, and hence the demand functions do not encounter the corner constraint. This eliminates many cases of different parameter conditions and thus largely simplifies the analysis and results.

Along these lines, the monopoly pricing analyzed in Section 4.1 reduces to one case only, that is, $\pi_1^M = 1/(4(1-\gamma))$, regardless of the value of γ . Likewise, the pricing equilibrium under IP sharing in Proposition 1 reduces to one case as well: The equilibrium prices, demands, and profits for region (i) now hold over the entire parameter space. Comparing the incumbent's profits under monopoly pricing and competitive pricing, we derive that the incumbent is willing to share its IP as long as the network effect intensity is large enough, that is, $\gamma > q$ (as illustrated in the shadowed region in Figure 7(a)). As discussed in Section 4.2, this result is consistent with the findings in the previous literature and contrasts with our findings under the bounded market, as highlighted in Corollary 1 and Figure 4. Consequently, the entrant's optimal quality choices in Proposition 2 are simplified to

$$q^*(\gamma, c) = \max \left\{ 2 - \gamma - \sqrt{\frac{(2-\gamma)(1-\gamma)}{1-8c(1-\gamma)}}, 0 \right\}, \quad \forall \gamma \in (0, 1). \quad (7)$$

Figure 7(a) depicts $q^*(\gamma, c)$ under different development cost c . Finally, we derive and summarize the incumbent's optimal IP sharing strategies (i.e., ρ^*) in Figure 7(b).

Comparing Figures 5 and 7(b), the equilibrium outcome under the scenario of unbounded market is simply an expansion of our original results and analysis for the partially covered market to the entire parameter space. Two aspects of the implications here are worth noting. On one hand, all of the cases of different optimal IP sharing strategies continue to arise

Figure 7. Full Equilibrium Outcomes Under Unbounded Market

in equilibrium when the market is assumed to be unbounded. In this sense, an essential part of our main results (e.g., how the optimal IP sharing strategy should change with the entrant's absorptive capacity), which are rooted in the competitive setting and multi-level decision analysis, are robust and do not depend on the assumptions of market formation. On the other hand, assuming away the possible market saturation could leave out important implications on strategic openness and might lead to a misinterpretation of how platforms' optimal strategies depend on network effect intensity. For example, when the total market size is finite, strong network effects, instead of inducing openness as suggested in Figure 7(b), actually make an open platform less appealing to both firms, and IP sharing may not consequently become a viable equilibrium, as discussed in Section 4 and illustrated in Figure 5. However, when the market is unbounded, strong network effects do not lead to market saturation and, thus, the price competition is less intense and at the same time each firm can see an increase in market share, allowing the entrant to capture surplus even when it has a low absorptive capacity. This leads to overinflated regions of IP sharing that do not exist when the market is bounded.

5.2. Uncertain Absorptive Capacity

In this section, we relax the assumption that the incumbent knows the entrant's absorptive capacity. Instead, we assume that the incumbent is uncertain of the actual k value but knows its distribution. We show numerically that our results are robust to such a scenario under several commonly used distributions with moderate variance. In particular, we consider two cases, i.e., (a) $k \sim U[\bar{k} - 1, \bar{k} + 1]$, a uniform distribution

with mean \bar{k} , and (b) $k \sim N(\bar{k}, \sigma_k = 1)$, a truncated normal distribution (bounded below at zero) with mean \bar{k} and variance 1. For every parameter pair $\{\bar{k}, \gamma\}$, the incumbent chooses the IP sharing strategy that maximizes its expected equilibrium profit over the potential absorptive capacity of the entrant

$$\rho^*(\bar{k}, \gamma) = \arg \max_{\rho \in \{0, 1, 2\}} E_k[\pi_1^*(q^*(\gamma, (\rho k)^{-1}), \gamma) | \bar{k}]. \quad (8)$$

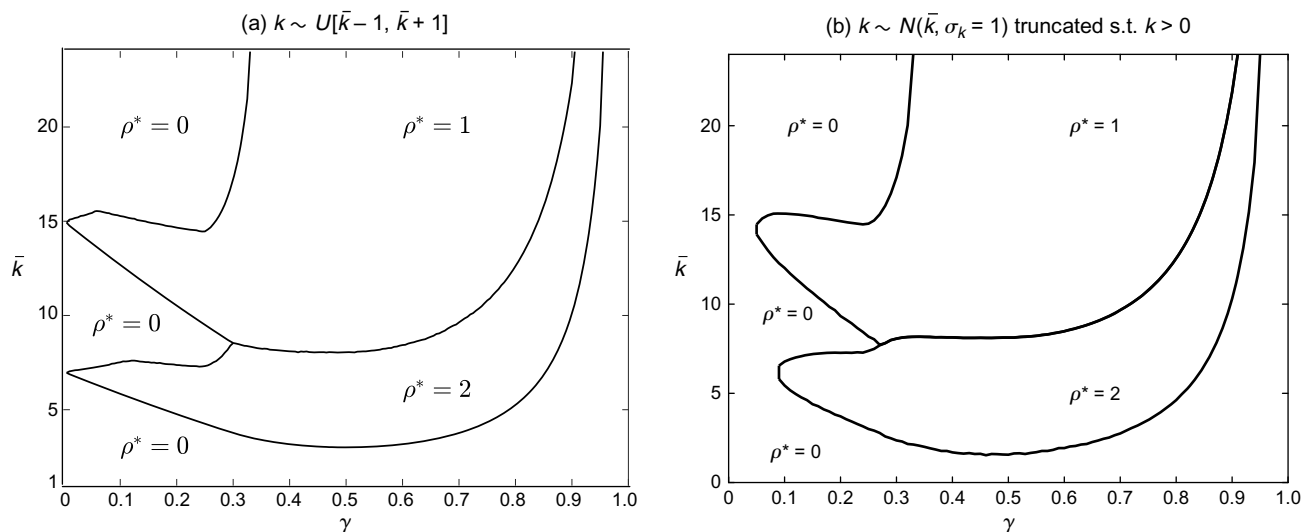
Note that once the entrant chooses its quality q^* , the incumbent's profit π_1^* does not directly depend on k , so the uncertain k here does not involve any signaling interplay or belief updating.

For a given sharing level ρ , for each potential realization of k , we fully solved the equilibrium in Section 4. To construct the expected profit under the two aforementioned distributions, we use a Monte Carlo (MC) approach with 7,500 draws for each distribution. The IP sharing equilibria under uncertainty are depicted in Figure 8(a) and 8(b). Given that we are now considering a random variable k , the y -axis in each panel captures the distribution mean \bar{k} . We confirm that the previous insights from Section 4.4 continue to hold.

5.3. Non-Linear Entrant Cost Function

In this section, we numerically explore a generalization of our model considering a non-linear quality cost for the entrant in the form $e = q^\alpha / (\rho k) = cq^\alpha$, with $\alpha > 0$. The prior analysis in Section 4 corresponds to the linear cost model ($\alpha = 1$). Given our set-up of $q < 1$, the case $\alpha < 1$ corresponds to a concave cost function with diminishing marginal costs. For example, this would be the case of a game such as Rovio's Angry Birds with multiple similar levels. Once the game framework

Figure 8. Equilibrium IP Sharing with the Incumbent Being Uncertain About k



code has been developed, adding another level is considerably easier. Here, content volume would be one dimension of quality. On the other hand, the case $\alpha > 1$ corresponds to a convex cost function with increasing marginal costs. This set-up is aligned, for example, with the development of new productivity application software where each function has a different role and where it is increasingly expensive to identify and develop novel features that bring additional value to the consumers. In this case, quality would be measured by the functionality level.

Note that in our set-up we have $0 \leq q < 1$. Thus, for any $\alpha_1 > 1 > \alpha_2$, we have $cq^{\alpha_1} < cq < cq^{\alpha_2}$. Hence, concave costs are higher than linear costs, which in turn are higher than convex costs. The reverse would be true if quality q were greater than 1. As shown in the linear case in Section 4, the entrant will attempt to differentiate its product from the incumbent to avoid price competition. Hence, the entrant will choose a significantly lower quality level, positioning its product for lower end consumers. For a very low quality level, for a given c (i.e., fixed $k \cdot \rho$), the paths of cq^α quickly diverge away from the linear level when α moves away from 1.

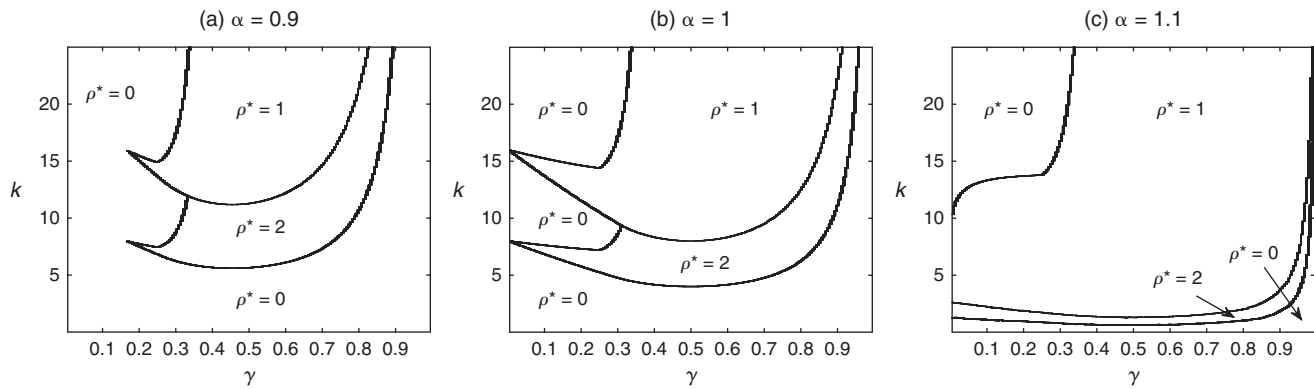
In Figure 9 we show three scenarios for α : 0.9, 1, and 1.1.⁶ Figure 9(b) is our benchmark panel, representing the linear case (replicating the results in Figure 5). In Figure 9(a), the concave cost scenario, the entrant finds it considerably more expensive to develop its lower quality product. Hence, we see the regions where basic IP sharing is optimal pulling upwards, i.e., the entrant would need a higher absorptive capacity or more assistance (higher level of IP sharing) to keep its development costs in balance. When the network effects are weak, there is no IP sharing. On the other hand, Figure 9(c), the convex cost scenario, corresponds to significantly lower costs for the entrant. Two

effects are immediately noticeable. First, compared to Figure 9(b), the incumbent will share its IP for considerably lower k values. Note that in the linear case, region (5) in Figure 5 corresponds to an area where it is too expensive for the entrant to enter even under extensive IP sharing, i.e., because of the low absorptive capacity. However, once we switch to convex costs, given that $q < 1$, it becomes significantly cheaper for the entrant to join the market even under low k values. As such, it makes sense for the incumbent to assist the entrant. Second, we note that the area of extensive sharing shrinks significantly while the area of basic sharing increases. Because of reduced development costs for the entrant, the incumbent will be much more reserved in extensively sharing its IP.

Overall, qualitatively, previous results remain robust even under the generalized cost structure. Under low γ and high k , the entrant is too competitive and the benefits from market expansion are limited; hence, the incumbent does not open. When k is very low, the entrant cannot compete. We also observe a similar shifting pattern for the optimal degree of IP sharing moving from the upper left towards the lower right part of the parameter space. While changes in the cost function lead to actual changes in cost magnitude for low quality levels, in turn affecting the size of each region, the dynamics remain the same in essence.

5.4. Engineering of Network Effects

The main driver for the incumbent to share its IP is to capitalize on the additional network effects created when the entrant joins the market. The overall network effects are captured by γN and $q\gamma N$ quantities. In the main model, we take the network effect intensity γ as an exogenous model parameter and analyze the equilibrium outcomes as functions of γ . Nevertheless, the

Figure 9. Equilibrium IP Sharing with Non-Linear Entrant Cost cq^α 

incumbent can do more in terms of influencing network effects. In this section, we extend our main model to consider the possibility that the technology platform owner can invest to “engineer” the *strength* of the network effects *in tandem* with sharing its IP to expand the market.

There are several ways in which the incumbent can engineer γ . The technology owner can directly create tools (function libraries) that can help with building functionality for user collaboration (messenger, video chat, knowledge management, shared screen, etc.), which the incumbent and the entrant can introduce in their products. Moreover, the technology owner can use residual output from the users to further improve the product and then release updates back to the users. For example, Tesla engineered its cars to collect real drive data, which in turn it uses to troubleshoot problems and increase car performance, but also to train and calibrate its artificial intelligence (AI) components, subsequently sending updates back to all cars. As of 2016, Tesla has accumulated over 1.3 billion miles of real driving, of which over 200 million were Autopilot-on miles (Hull 2016). Even when Autopilot is not switched on, it operates in “shadow mode,” continuously collecting real-world data. The more Tesla drivers there are on the road, the better the car performance (including Autopilot AI) becomes, which in turn benefits every driver. Collecting and using real drive data for better performance calibration (together with allowing updates to be pushed over the air to cars) were explicit company decisions that increased the strength of network effects (each driver benefits a little more from other drivers on the road). Last, but not least, if the software products of the incumbent and the entrant operate as platforms in their own way (in addition to being built on the same core technology platform), their value to the users is directly related to the available complementary value-adding services offered in many cases by third-party developers (Gawer and Cusumano 2002). The more the incumbent (the technology platform owner) extends

the API capability for complementors to develop applications that leverage inter-user communication and are compatible with the technology (and hence with the incumbent and entrant’s products), the higher the benefit to the users from the network itself. For example, once Apple and Google allowed apps (and app developers) via APIs to read in real time (with permission) the geo-location of the iOS or Android smartphones, services such as Uber and Lyft became mainstream: A critical factor was that drivers and passengers needed a way to instantaneously share their location data. Thus, users in general get more value out of the user network as a result of platform owners granting more access to the developers. In our model we do not explicitly model the developers but we can conceptualize in reduced form the efforts on the side of the technology owner to increase the value of the user network.

We examine the incumbent’s optimal choice of the network effect intensity, γ^* , as a function of the entrant’s absorptive capacity k . We further investigate how the endogenous choice of network effect intensity interplays with the optimal IP sharing strategy as well as the pricing equilibrium outcomes.

This strategic decision on the strength of the network effects, γ , represents an additional stage in the game sequence, added at the beginning. Thus, the incumbent will first choose the strength of the network effects in the market. Then the game unfolds according to the five-stage sequence described at the end of Section 3. Efforts towards engineering γ come with an associated cost $C(\gamma)$ that is increasing and convex in γ , where the convexity captures the increasing marginal cost of generating higher intensity of network effects. For simplicity, we let $C(\gamma) = \gamma^2$. For a given γ , net of any investment in engineering γ , we denote the incumbent’s equilibrium profit given its optimal IP sharing strategy (as summarized in Proposition 3) as $\Pi_1(\gamma, k; \rho^*(\gamma, k))$. When $\rho^*(\gamma, k) \in \{1, 2\}$, according to Propositions 1 and 2, $\Pi_1(\gamma, k; \rho^*) = \pi_1^*(q^*(\gamma, 1/(\rho^*k)), \gamma)$, which is the incumbent’s equilibrium sales profit

under competition on the open platform, $\pi_1^*(q, \gamma)$, with the entrant's endogenous quality choice $q^*(\gamma, c)$ substituted in; when $\rho^*(\gamma, k) = 0$, $\Pi_1(\gamma, k; \rho^*) = \pi_1^M(\gamma)$, which is the incumbent's monopoly sales profit according to Equation (2). Let $\Pi_1^\gamma(\gamma, k) = \Pi_1(\gamma, k; \rho^*(\gamma, k)) - \gamma^2$ denote the profit of the incumbent when considering the costs to engineer network effects. Thus, the incumbent's optimal choice of the network effect intensity, $\gamma^*(k)$, can be derived as

$$\gamma^*(k) = \arg \max_{\gamma} \Pi_1^\gamma(\gamma, k). \quad (9)$$

From Figure 5, one can immediately see, in the absence of engineering costs for network effects and without overlaying the profit values, that the interaction between γ and k shapes the incumbent's profit and opening decisions in a very complex way. Adding the optimization of the intensity of the network effects along with the associated costs brings another layer of complexity to an already highly nontrivial problem. Although this makes the problem analytically intractable in certain regions, the research question lends itself to numerical exploration.

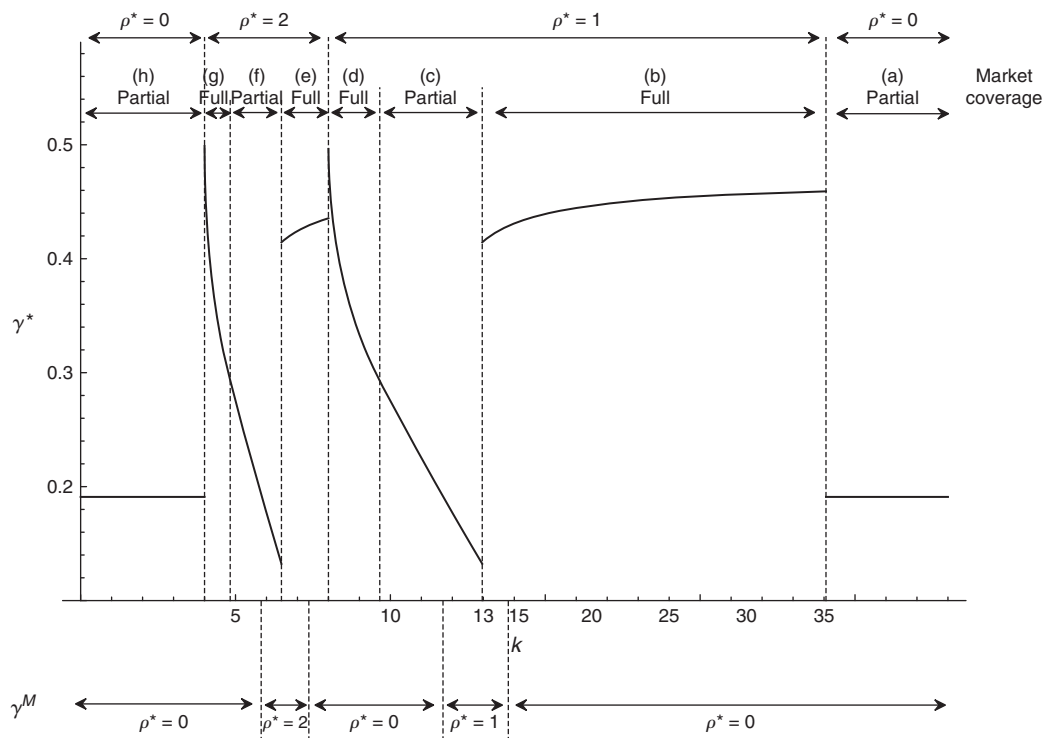
Hence, we numerically derive and present the full solution of $\gamma^*(k)$ in Figure 10. Before discussing the solution, we point out that the right-half of the x-axis of Figure 7 is rescaled to showcase multiple regions while not compressing some of them to the point where patterns or labels are not visible. As can be seen, $\gamma^*(k)$ exhibits non-trivial alternating-monotonicity patterns with discontinuous jumps. Starting from the rightmost case (a) in Figure 10, when the entrant's absorptive capacity is very large, IP sharing is optimal only with sufficiently large γ , according to Proposition 3. Nevertheless, the revenue improvement for the incumbent by sharing its IP is largely limited by the high competitiveness of the opponent and therefore cannot justify the cost of creating a high level of network effect intensity. As a result, the incumbent opts to keep its platform closed and operate the market as a monopoly. It thus sets the network effect intensity at the optimal monopoly level, $\gamma^M = (3 - \sqrt{5})/4$, a low level that results in a partially covered market.

Case (b) as illustrated in Figure 10 is especially interesting. When the entrant's absorptive capacity is reasonably large but not too extreme, the incumbent's net profit of opening the platform (net of the cost of engineering network effects) can exceed the monopoly level. Therefore, the incumbent switches to the basic sharing strategy (i.e., $\rho^* = 1$) and sets γ^* at a relatively high level, which maximizes $\pi_1^*(q^*(\gamma, 1/k), \gamma) - \gamma^2$ with $\pi_1^*(q, \gamma) = (1 + \gamma - q)^2 / (4(1 - q))$ and $q^*(\gamma, 1/k) = 1 - \sqrt{\gamma^2 / (\gamma - 2/k)}$. The resulting pricing equilibrium falls in region (ii) of Proposition 1 with the market just fully covered. The most surprising result for this region is that γ^* turns out to be *increasing* in k . In other words, as

the competitor gets better at absorbing and transforming outside knowledge (which in turn lowers its development costs under IP sharing), the incumbent, surprisingly, is willing to bear a higher investment cost to create more intense network effects. Apart from costs, two opposing forces are at play here. First, it can be seen that in this region, $q^*(\gamma, 1/k) = 1 - \sqrt{\gamma^2 / (\gamma - 2/k)}$ is increasing in k for any given feasible γ . In isolation, a more competitive product from the entrant (i.e., with a higher q) has a negative impact on the incumbent's profit. Based on the formula for π_1^* from Proposition 1, it can be shown that $\delta\pi_1^* / \delta q < 0$ for any given γ and q in this region. On the other hand, in region (ii), for a fixed q and a given set of prices, due to full market coverage ($N = 1$), a stronger intensity of network effects immediately translates into greater product differentiation. The impact of this increased differentiation, as seen from Proposition 1 and Figure 2(c), even after optimizing prices, helps the incumbent in region (ii). Moreover, an increase in γ also increases the value that the users get from the network and reduces the pressure on the incumbent to keep prices low. Taking these two effects on product differentiation together, it turns out that in this particular range, the benefits from optimally engineering stronger network effects to further differentiate the products (and in the process generating more value for the consumers) substantially offset the associated increased quality-competition effect and, thus, fully justify the costs associated with such engineering action. In this sense, this case portrays an ideal "co-opetition" scenario: The IP owner welcomes a strong competitor by sharing its IP and willingly investing to create a high degree of network effect intensity. Note that such an interesting result arises only under the fully covered market and with the endogenous choice of γ , which once again underscores the necessity of analyzing full market coverage conditions and endogenizing all decision making associated with the competitive analysis of strategic IP sharing.

By sharp contrast, cases (c) and (d) in Figure 10 depict the situation when γ^* is decreasing in k . As the entrant's absorptive capacity falls in the moderate range, co-opetition in the large- γ domain becomes less profitable. By comparison, a relatively low γ that barely facilitates the competitor's market entry proves optimal for the incumbent, which results in the discontinuous paradigm shift at $k \approx 12.97$. In this sense, cases (c) and (d) represent the "entry facilitation" scenario: The weaker the entrant (i.e., a lower k), the more the incumbent needs to invest in network effect intensity to facilitate the entry (i.e., a higher γ^*), which explains the decreasing relationship between γ^* and k . Note that the transition from case (c) to case (d) is continuous, as the entry-facilitating γ^* smoothly transitions from a partial market coverage (i.e., pricing equilibrium region (i) of Proposition 1) to a full market

Figure 10. Optimal Network Effect Strength $\gamma^*(k)$



coverage (i.e., pricing equilibrium region (ii)) at $\gamma^* = (2 - \sqrt{2})/2$. Note also that the optimal network effect intensity can vary over a wide range from as high as $\frac{1}{2}$ to below the monopoly level.

As k further decreases, entry facilitation is no longer possible with basic sharing. As a result, the incumbent upgrades to full sharing (i.e., $\rho^* = 2$), and $\gamma^*(k)$ in cases (e)–(g) in Figure 10 mostly replicates the patterns of cases (b)–(d) with some distortion in scale. In case (h), when the entrant is too weak in its absorptive capacity (i.e., k falls below 4), basic or extensive opening strategies are ineffective, and the incumbent assumes a monopolistic position with $\gamma^M = (3 - \sqrt{5})/4$.

As we show, endogenizing the network effect intensity equips the incumbent with an additional degree of freedom, allowing it to optimize its multidimensional market strategy in one way or another, sometimes in unexpected patterns. To further illustrate how the endogenous choice of network effect intensity is connected with the IP sharing decision, we fix γ at the optimal monopoly level $\gamma^M = (3 - \sqrt{5})/4$ and plot $\rho^*(k; \gamma = \gamma^M)$. We append $\rho^*(k; \gamma = \gamma^M)$ to the bottom of Figure 10 to compare the optimal IP sharing strategies under the cases of endogenous and exogenous network effect intensity. Clearly, compared to the setting of exogenous intensity of network effects, endogenously optimizing network effect intensity leads to IP sharing for a considerably wider range of entrant absorptive capacity levels (as evidenced by the wider range of possible values of k over which $\rho^* > 0$). This argument

highlights the importance of optimizing the intensity of network effects: Without considering this a decision variable, the incumbent could significantly underestimate the range of competitor capabilities for which IP sharing is desirable.

6. Conclusion

In this paper, we explore the strategic decision of an incumbent to open a proprietary technology platform to allow co-opetition in a market characterized by network effects. To approach this research question, we propose a novel model which, to our knowledge, is the first attempt to analytically conceptualize in the context of this topic the interplay among the degree of same-side platform openness, the absorptive capacity of the entrant, and the intensity of network effects.

Using this framework, we uncover a host of interesting results. When quality is exogenously given, we show that under very intense network effects the incumbent does not have an incentive to open the market, an argument that is opposite to the conclusions in Conner (1995) and Economides (1996). Moreover, we discuss various interesting open-platform co-opetition outcomes that arise in parallel with full market coverage. When the incumbent is strategic about IP sharing and the potential competitor is strategic about entry and quality, we map out the regions where the incumbent opens its IP. The transition between regions can be governed by multiple forces, which in turn can lead to

interesting outcomes. For example, we illustrate how for a given absorptive capacity, as the intensity of network effects changes, the incumbent could go from not sharing, to extensive sharing, to basic sharing, and then back to extensive sharing, and eventually to no sharing.

Extremely weak or strong network effects in general lead to monopoly scenarios. Under moderate network effects, the incumbent's IP sharing strategy depends on the entrant's absorptive capacity. Low absorptive capacity firms cannot enter the market even with extensive help from the IP owner due to prohibitively high development costs. However, beyond a certain absorptive capacity threshold for the entrant, intermediate network effects lead to fruitful co-opetition opportunities. Intermediate absorptive capacity firms can boost the incumbent's profit provided they get extensive access to IP. When the entrant's expertise is high, the incumbent will prefer to engage only in basic sharing, ensuring that the entrant cannot easily clone the product at a high quality. This equilibrium outcome presents actionable guidance for technology platform owners: Note that the recommendation is customized by product class (different product classes may exhibit different strengths of network effects) and entrant absorptive capacity. We also discuss several anecdotal examples throughout the paper.

We extend our analysis on multiple fronts. First, we compare and contrast our main set-up with an alternative where the market is unbounded and never fully covered. We show that in general our results are robust for network effects of low or moderate strength. However, the results are different under strong network effects. In contrast to our main result, when the market is unbounded, the incumbent will open under strong network effects. This highlights the critical importance of the market boundedness assumption to the results. This comparative analysis offers guidance for managers and researchers who model phenomena in this space. We further show that our main results are qualitatively robust under more relaxed assumptions such as uncertain entrant absorptive capacity and generalized non-linear development cost functions. Finally, we extend our analysis into a scarcely charted area for analytical models of information system economics, i.e., that of optimizing the strength of network effects at the consumer utility level. To our knowledge, this is the first study that explores how the intensity of network effects should be optimally engineered by a provider in a competitive setting under network effects. Under optimal intensity of network effects, we find that the equilibrium strategy is to close the IP when the entrant has a weak or strong absorptive capacity. Compared to a setting with exogenous intensity of network effects, when the incumbent can engineer this market parameter the equilibrium outcome may lead to an open platform competition scenario for a much wider spectrum

of entrant absorptive capacities. For example, for a given network effect level, the incumbent might prefer to close the platform and function in monopoly mode. Nevertheless, if it can adjust network effects to a different level, it may actually find it beneficial to share the IP and invite co-opetition. Moreover, even if the openness outcome is the same, optimizing the intensity of network effects may boost profits. Thus, the immediate guidance to platform owners is that in many scenarios, it is preferable to consider adjustments to network effects in parallel with the platform openness decision.

We acknowledge several model limitations that present exciting opportunities for future research. First, our model examines a single-period game. Future work can be done to extend this framework to multi-period dynamics and explore sequential and/or recombinant innovation whereby players could generate additional innovation at subsequent periods and the incumbent can integrate that innovation in its platform at a later stage. Recent research is already considering this direction in the context of platform economics (e.g., Parker and Van Alstyne 2017). Second, as mentioned at the beginning of Section 5.4, for tractability purposes, we use a reduced-form model where the impact of the complementers is in some sense folded into the intensity parameter γ for network effects and intrinsic functionality valuation θ . Thus, another direction for future research would be to focus on cases when the products sold by the incumbent and the entrant are platforms on their own and explicitly model additional ecosystem participants such as third-party developers of complementary apps and additional interactions such as cross-side network externalities and cross-side strategic platform access granting (Anderson et al. 2014). Third, motivated by a class of industry examples of free IP sharing and the related literature, we focus on royalty-free IP sharing in our model. In the context of open innovation and platform economics, it is suggested that when the incumbent is incentivized to invite competition via paid licensing, the license fees, if any, are often minimal (e.g., Farrell and Gallini 1988). In future research, however, one could explore a more general set-up of IP openness that includes royalty-based IP licensing. Fourth, the analysis can be further extended to account for the incumbent exploring self-cloning (versioning) as an alternative to IP sharing. Some preliminary work on this problem under exogenous quality assumptions has been done by Sun et al. (2004). Fifth, a more complex model could allow the incumbent to also invest in training the entrant, thus boosting the absorptive capacity and further lowering the entrant's development costs. Sixth, it would be interesting to extend the set-up beyond duopoly to account for many heterogeneous potential entrants. Last, but not least, it would be very interesting to empirically explore the connection between the degree of IP sharing and the absorptive capacity of potential entrants.

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Endnotes

¹We have also explored an extension of our model in which the entrant can develop its own product without the help of the incumbent. Under reasonable assumptions, we find similar results to those in this paper. The detailed analysis and results are omitted due to their complexity and are available upon request from the authors.

²Our model and analysis can be naturally extended to a larger number or a continuum of degrees of openness with insights remaining qualitatively similar.

³General cost functions of the form cq^α ($\alpha > 0$) have been widely used in the literature on information goods development (Boehm 1981, Banker and Kemerer 1989, Boehm et al. 2000, Jones and Mendelson 2011). In particular, Banker and Kemerer (1989) empirically measure values of α between 0.72 and 1.49 (including several values close to 1 such as 0.95 and 1.06) for various projects. In the main analysis in Section 4, we use the linear cost function (i.e., $\alpha = 1$) for analytical tractability. We relax this assumption in Section 5.3 and discuss via a numerical analysis how our results remain qualitatively similar under more general non-linear cost functions.

⁴If the entrant’s product quality can exceed that of the incumbent (i.e., $q > 1$), it can be shown that the incumbent will not open its platform. This trivial case is omitted for brevity.

⁵In these models, the network effects γNq_i capture the fact that the exchange of value between consumers in the context of using these products is intermediated by the very product each of them is using. For example, suppose two users have different PDF editors. While these users can exchange PDF files and see the entire content, for each of them the ability to further edit (and the ease with which they can edit) those exchanged files depends on the interface and functionality pertaining to the specific editor they are using. Hence, while the exchanges of value based on communication between users are bidirectional, the actual value amounts derived by each side due to this communication may be different.

⁶We point out that the x -axes in all panels of Figure 9 start at $\gamma = 0.05$. In Figure 9(c), while not visible in the plot, for very small γ values (close to 0), the regions where basic and extensive sharing are optimal move away from each other, shrink, and eventually disappear (when $\gamma = 0$, IP sharing is not optimal). Given the very small scale of γ where this behavior is observed, this pattern was left out of this particular plot.

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