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

Marius F. Niculescu, D. J. Wu, and Lizhen Xu *

Scheller College of Business, Georgia Institute of Technology, Atlanta, GA 30308

{marius.niculescu, dj.wu, lizhen.xu}@scheller.gatech.edu

September 2016
This Version: June 2017

Abstract

In this paper, we explore the strategic decision of an incumbent to open a proprietary technology platform in order 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 IP-sharing is not possible in equilibrium. When the network effects are of intermediate intensity, the incumbent opens the technology to the entrants who possess 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 vs. 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.

Keywords: platform economics; openness; intellectual property; network effects; competition; co-opetition; absorptive capacity; software

---

*All authors had equal contributions. Author names are listed in alphabetical order.

1 Introduction

The fact that 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 that 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) 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 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 altogether in the form of an open source project. It is important to highlight 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 look at 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 most likely impact competition but would not necessarily force the developer to offer the entire product (that uses some of those libraries) as an open source product. In fact, code opened under permissive licenses (e.g., Berkeley Software Distribution license or Apache license) allows both the originator and the adopters to still commercialize and close any derivative product.

Within the context of open innovation, in this paper we zoom in 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 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 come up with an alternative way to deliver similar functionality. If the IP owner opens the technology (in some limited way), competitors can jump in to offer (imperfect) substitutes of the original product. In that sense, the IP owner is engaging in a form of *second-sourcing*, voluntarily inviting competitors in the market by opening its technology/architecture (Farrell and Gallini 1988). Second-sourcing by opening the core technology does not translate into the imitations being perfect substitutes of the original product. The entrants' production function is affected by both the *degree* of IP openness (Boudreau 2010) and their own *absorptive capacity*, defined by Cohen and Levinthal (1990) 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 get access to the shared IP or not, 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: *in a software business ecosystem, (i) 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, and (ii) how would these strategies be impacted by the absorptive capacity of the entrant?*

To address this question, we propose a competitive model where an incumbent controls the platform technology and considers the option to freely share (open) some of its IP with an entrant.

Both the incumbent and the entrant are strategic and the product category (containing both 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 drive up 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 possess 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 when the incumbent is uncertain of the entrant's absorptive capacity or when the entrant incurs a generalized (non-linear 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 out on valuable co-opetition opportunities.

To the best of 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 where both the incumbent and the entrant are strategic. We also compare and contrast bounded vs. 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, quantity). However, these papers treat the intensity of network effects as an exogenous market parameter. Nevertheless, many software applications nowadays 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 do have the ability to directly control the strength of network effects. On top of the modeling contribution, this paper intends to provide actionable guidance for core technology owners in a software market with respect to strategic sharing of IP 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 the discussion of the explicit positioning with respect to the extant literature to §2.

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

2   Literature Review

Our study draws on several streams of information systems 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 consumer utility level has similarities to Conner's framework, our setup 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, also chooses quality level. Considering all these strategic decisions jointly in the model leads to differences in insights compared to Conner (1995) and Economides (1996) in that 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 developing independently a superior (potentially incompatible) product (e.g., Gallini 1984). We differ from this literature in that, in our model, the technology owner possesses key technology that cannot be substituted.

The literature on platform and innovation openness for most part considers openness as a binary decision (Barge-Gil 2010, Dahlander and Gann 2010). Some of the more recent literature started exploring how degrees of platform openness impact various market outcomes. Boudreau (2010) explores how two approaches to platform openness, granting of access vs. 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 output of developers 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 the best of our knowledge, our study represents the first foray into 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 decades-long 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 prior to the unfolding of the competitive game. As mentioned in the first paragraph of this section, that is where we directly focus our efforts and 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 - 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 the best of 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 come up with 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 $q_2(\rho, e; k) = \rho k e$. 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 $e(q_2; \rho, k) = \frac{q_2}{\rho k}$.

Considering that, in reality, IP oftentimes takes modular form (e.g., software modules, programming libraries, individual patents), 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, namely, $\rho \in \{0, 1, 2\}$.[2] The case of $\rho = 0$ corresponds to the incumbent closing all of its IP. In this case, the entrant's marginal development cost, $\frac{1}{\rho k}$, 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 manuscript, 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] We have also explored an extension of our model in which the entrant is able to 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.

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

$\{1, 2\}$), we denote the entrant's development cost as simply cq_2, where $c = c(\rho, k) = \frac{1}{\rho k}$ is the marginal development cost.[3] On the other hand, since we look at 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 negligible for both firms. The entrant will only join the market if it can make strictly positive profit (we consider a tie-breaker 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 will 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:

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

The coefficient γ captures the intensity of the network effects, and N is the total user base across all 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 enjoy 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

---

[3]General 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 §4, we utilize the linear cost function (i.e., $\alpha = 1$) for analytical tractability. We relax this assumption in §5.3 and discuss via a numerical analysis how our results remain qualitatively similar under more general non-linear cost functions.

[4]If 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.

[5]In these models, the network effects $\gamma N q_i$ 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 bi-directional, the actual value amounts derived by each side due to this

$0 < \gamma < 1$ 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 or not; (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, whereas firms' decision variables $\{p_1, p_2, q, \rho\}$ together with the market shares $\{N_1, N_2, N\}$ are all 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 §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 §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 employ 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 the (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).

---

communication may be different.

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 (proof in the Appendix) that its equilibrium price, demand, and profit are as follows:

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

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 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 $c = \frac{1}{\rho k}$. 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 the 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 the 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 have to 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 Appendix (Table A1).

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

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

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

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

The analysis is highly non-trivial with numerous cases in different parameter regions, as detailed in the Appendix (Tables A2 and A3).

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 Appendix. □

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 the lowest

Table 1: Equilibrium Outcomes of Price Competition

	Region (i)	Region (ii)	Region (iii)
	$0 < \gamma < \frac{2-\sqrt{2}}{2}$, $0 < q < \frac{2\gamma^2-4\gamma+1}{1-2\gamma}$	(ii.a) $0 < \gamma < \frac{2-\sqrt{2}}{2}$, $\frac{2\gamma^2-4\gamma+1}{1-2\gamma} \le q < \frac{1-\gamma}{1+\gamma}$ (ii.b) $\frac{2-\sqrt{2}}{2} \le \gamma < 1$, $0 < q < \frac{1-\gamma}{1+\gamma}$	$\frac{1-\gamma}{1+\gamma} \le q < 1$
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	$\pi_1^* = \frac{(1-q)(4-q-3\gamma)^2}{16(1-\gamma)^2(2-q-\gamma)^2}$ $\pi_2^* = \frac{q(1-q)}{8(1-\gamma)(2-q-\gamma)} - cq$	$\pi_1^* = \frac{(1+\gamma-q)^2}{4(1-q)}$ $\pi_2^* = \frac{(1-\gamma-q)q\gamma}{2(1-q)} - cq$	$\pi_1^* = \frac{1}{16}(1-q)(3+\gamma)^2$ $\pi_2^* = \frac{1}{8}(1-q)(1-\gamma)^2 - cq$

among all the 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 forgone. As γ and/or q further increase, the market turns moderately competitive in region (ii). The incumbent prices more aggressively to grab 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. In contrast, when γ or q are large, region (iii) corresponds to the hyper-competitive scenario. Facing intensified competition from the incumbent, the entrant has to lower its price below the lowest-type consumer's willingness-to-pay. As a consequence, the market is fully covered, and all consumers enjoy strictly positive surplus.

Before proceeding to the next step of the backward induction, we take this opportunity to 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
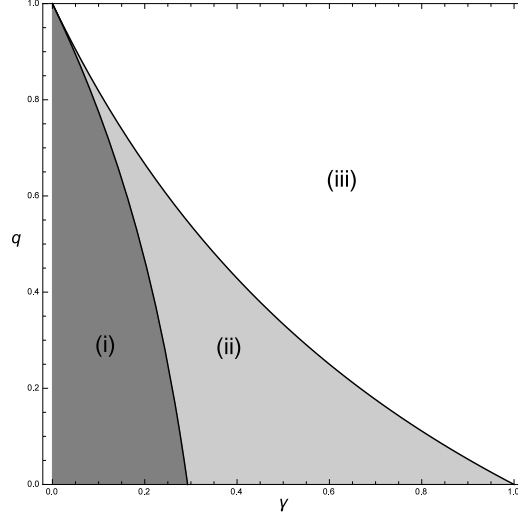
Figure 1: Pricing Equilibrium under IP Sharing

contradict the classical wisdom in the literature. To better elaborate on the connection and diffe-
rence, we plot how the equilibrium prices, demands, and profits change with γ and q in Figures 2
and 3, respectively, followed by detailed discussion below. In §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
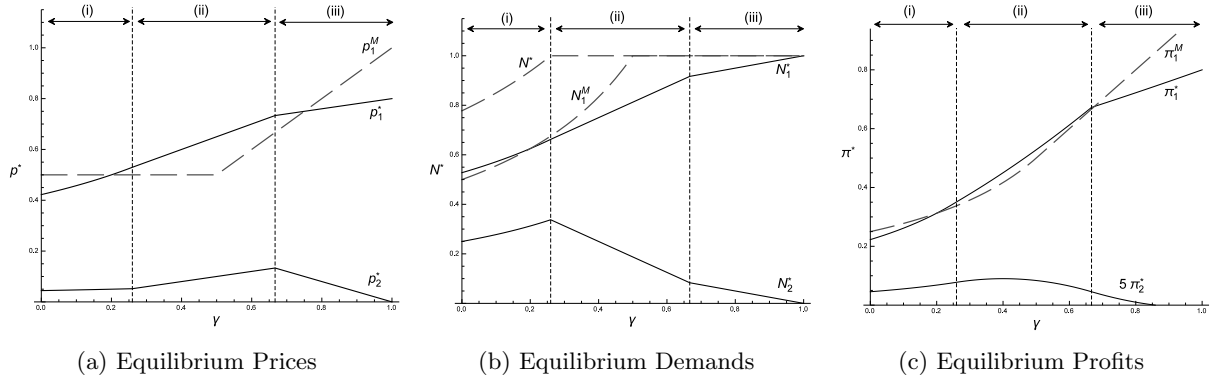of such an assumption on the strategic openness outcome.

(a) Equilibrium Prices   (b) Equilibrium Demands   (c) Equilibrium Profits

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

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^*

14

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 one. Note that the incumbent would cover the whole market as a monopolist (i.e., $N_1^M = 1$) when $\gamma > \frac{1}{2}$, 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 is able to 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 cutoff $\gamma_0(q) \in (0,1)$ 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 both firms' profits. As a result, shortly after γ enters region (iii) from below, π_1^* turns inferior to π_1^M, and the incumbent would prefer remaining a monopolist. This result is in sharp contrast with 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. Noteworthily, 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 the entrant may not always be willing to enter the market even if the incumbent offers to share its IP, as we further probe in the next section.
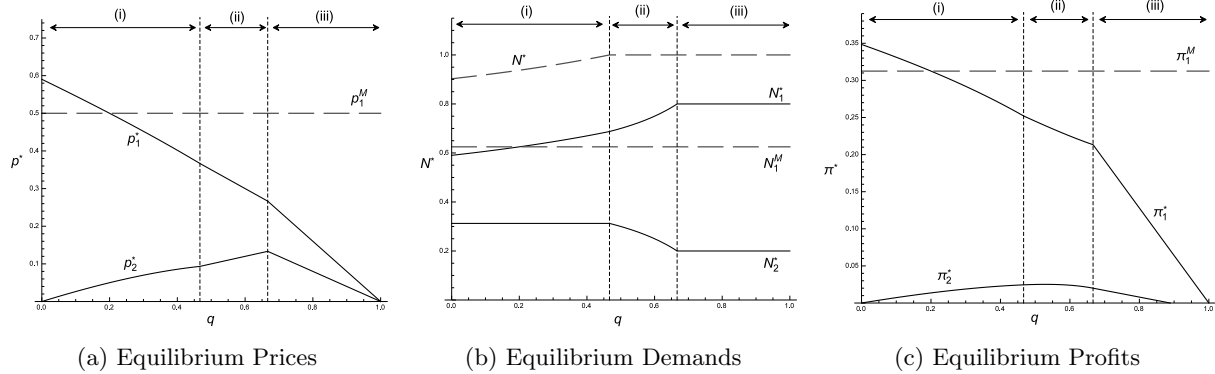

(a) Equilibrium Prices   (b) Equilibrium Demands   (c) Equilibrium Profits

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

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 turns more competitive on quality, it invites fierce competition from its stronger rival, indicated by the steep drop in both firms' prices in region (iii). In 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.

16

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 is entering the market (in stage iii of the game) as well as its entry decision (stage ii). For a given quality 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

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

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.*

Table 2: Optimal Quality Choice of the Entrant

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

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 $\gamma \in \left(0, \frac{2-\sqrt{2}}{2}\right)$.

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. We point out that $q^*(\gamma, c)$ never falls into the pricing equilibrium region (iii) because it would be suboptimal to engage in the hyper-competition 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
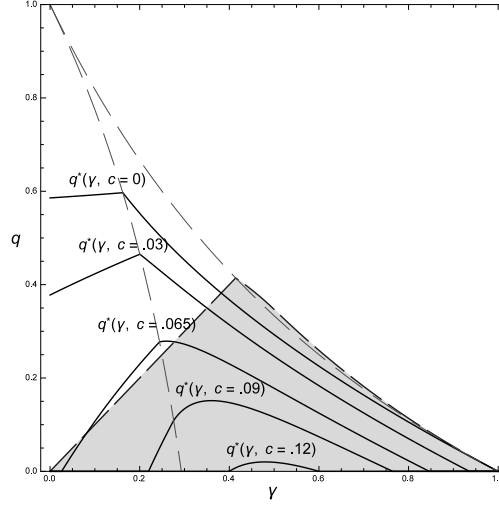
Figure 4: Entrant's Optimal Quality Choices

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. There is an interesting aspect especially worth mentioning: 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 head-on competition. While we discuss the optimal IP sharing decision at length in the next section, we just briefly mention here 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) $0 < c \leq \frac{1}{16}$ *and* $0 < \gamma < \frac{1+\sqrt{1-8c}}{2}$; *or*

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

(c) $\frac{\sqrt{2}-1}{4} < c < \frac{1}{8}$ *and* $\frac{1-\sqrt{1-8c}}{2} < \gamma < \frac{1+\sqrt{1-8c}}{2}$.

18

As Corollary 2 summarizes and Figure 4 illustrates, for any $c > 0$, if γ is too large (i.e., $\gamma > \frac{1+\sqrt{1-8c}}{2}$), the entrant will not enter the market; for moderate marginal development costs (i.e., $\frac{1}{16} < c < \frac{1}{8}$), the entrant is also unwilling to enter if γ is small (i.e., $\gamma < \frac{3}{2} - \sqrt{\frac{1+2c}{8c}}$ or $\frac{1-\sqrt{1-8c}}{2}$); 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) has to satisfy for IP sharing to be a dominating 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.*

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

As Figure 4 depicts, $\tilde{q}(\gamma)$ 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 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 cutoff $\tilde{q}(\gamma)$ 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. It thus gives us the conditions on (γ, c) for the incumbent to be willing to share. Furthermore, because $c = \frac{1}{\rho k}$, we can then derive the optimal

19

degree of sharing, ρ^*, as a function of the network effect intensity γ and the entrant's absorptive capacity k. The next proposition summarizes $\rho^*\left(\gamma,k\right)$ 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.*

Table 3: Optimal IP Sharing Strategy

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

Notes:

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

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

As can be seen from 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 at all 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 either larger γ or smaller k, basic sharing turns optimal for the incumbent, generating higher
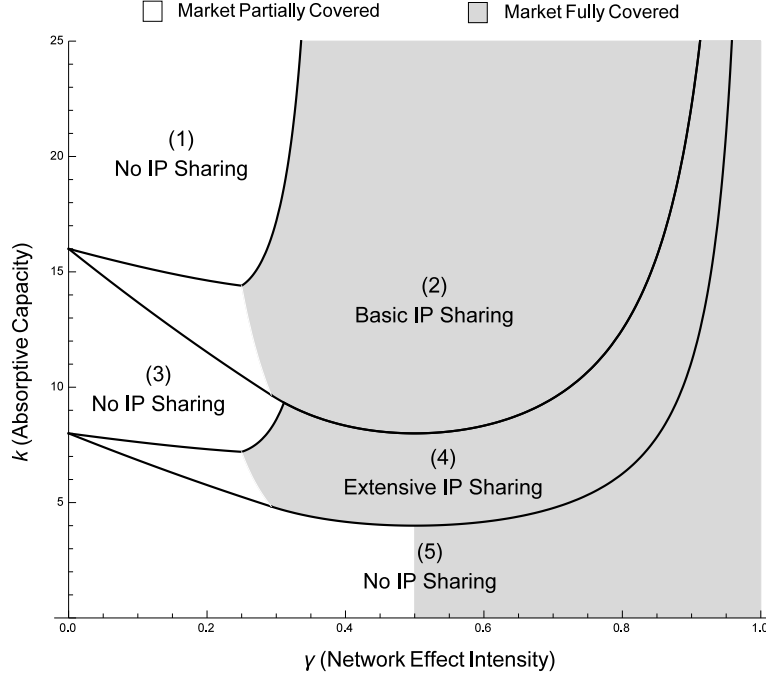
Figure 5: Full Equilibrium Outcome

profit exceeding 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, making its market entry feasible. As a result, $\rho^* = 1$ sustains as an equilibrium, and both firms' products co-exist 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, in 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 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 hence needs to 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 ends 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. Different from region (3), however, region (4) entails either larger γ or smaller k, which makes extensive sharing more profitable than monopoly thanks to the benefit from stronger network effect intensity or less competition threat. On the other hand, the entrant is able to 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 unshadowed (shadowed) 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. Our findings hence greatly enrich the existing understanding in the literature that greater network effect intensity tends to encourage openness monotonically. To further elaborate 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 interestingly, as γ grows, instead of transitioning from $\rho^* = 0$ to $\rho^* = 1$, the optimal sharing strategy jumps to extensive sharing directly. In this case, although basic sharing is still insufficient to motivate market entry, extensive sharing, under which market
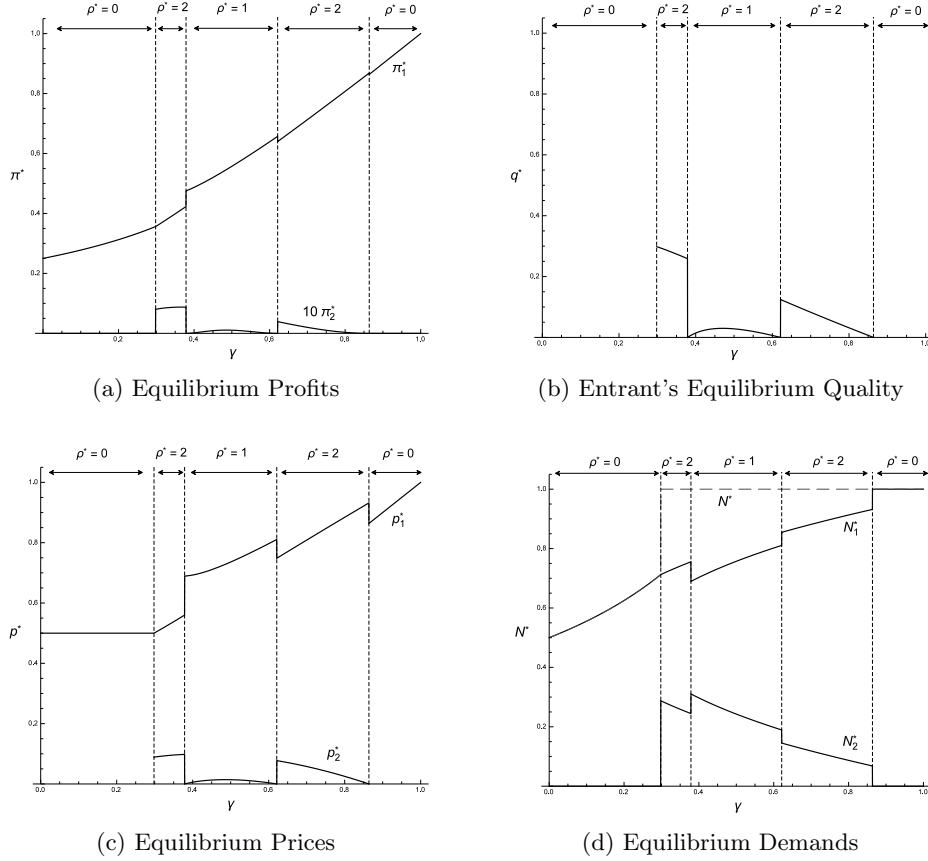
(a) Equilibrium Profits

(b) Entrant's Equilibrium Quality

(c) Equilibrium Prices

(d) Equilibrium Demands

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

entry is profitable for the entrant, starts to generate higher profit than monopoly for the incumbent as well. As a result, $\rho^* = 2$, and thanks to the extensive sharing of proprietary IP, the entrant is able to reduce its marginal development cost, resulting in the highest quality q^* and the highest profit π_2^* among all the 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 own profit. As a result, we can see a clear jump of π_1^* in the center segment of Figure 6a, 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 has to switch back to extensive sharing again in order 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

23

switching from extensive sharing to 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. It once 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. There is shown to be a nonmonotonic relationship between the degree of strategic IP sharing and either 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, evidenced by the largest area within the parameter space with $\rho^* > 0$ for intermediate γ's. In contrast, either too strong or too weak network effect intensity makes sharing less likely to happen. Along the line 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 a too weak absorptive capacity makes profiting from competition on an open platform impossible. On the other hand, a firm with intermediate absorptive capacity will be able to join the market and will be welcomed by the technology platform owner, resulting in a win-win situation for both competing firms, which is most prominent at moderate levels of network effect intensity.

4.5   Anecdotal Observations and Insights

In this section, we look at various anecdotal cases through the lens of our model. Let us first 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 of region (5) in Figure 5). At the other end of the spectrum, HFT algorithms represent an example of product components with reduced network effects. In the financial sector, many players have 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 early 1980s, IBM opened its PC architecture to

outside suppliers but did not impose non-exclusive relationships (Moore 1993). Initially, potential entrants had only moderate absorptive capacity and the early PCs exhibted only low to moderate network effects. This corresponds to the left hand side 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, 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 a lot of the innovation resided now 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 US-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 analysing aerial data, they opened up non-core software and hardware (including drone autopilot hardware design, flight code, and several apps for their Solo drone). 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 SDK and web 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 OS), the absorptive capacity of entrants while starting lower, was likely to get very fast to the high end. This would correspond to our region (1) or the left-hand side 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 of time. 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). Given that it was impossible to walk away from competition in the market for hardware, 3DR's retreat to focus on its portfolio of proprietary software seems logical in the context of our model.

Last, let us 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 utilized to improve the car performance (more on this in §5.4). Thus γ is moderate. At the same time, the absorptive capacity of other firms in the industry is intermediate. Obviously, other car manufacturers have some expertise in building cars and thus k is not very low. At the same time, even with access to IP, it takes a lot of effort and resources to build a new electric car (beyond integrating a few technology 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 players in the market 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, who 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 those 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 (non-linear in quality) 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 we point out in §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 both 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 θ's are not bounded below at zero, and hence the demand functions do not encounter the corner constraint, which eliminates many cases of different parameter conditions and thus largely simplifies the analysis and results.

Along this line, the monopoly pricing analyzed in §4.1 reduces to one case only, that is, $\pi_1^M = \frac{1}{4(1-\gamma)}$, 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 can 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 7a). As discussed in §4.2, this result is consistent with the finding 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

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

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

(a) Entrant's Optimal Quality Choices   (b) Optimal IP Sharing Strategies
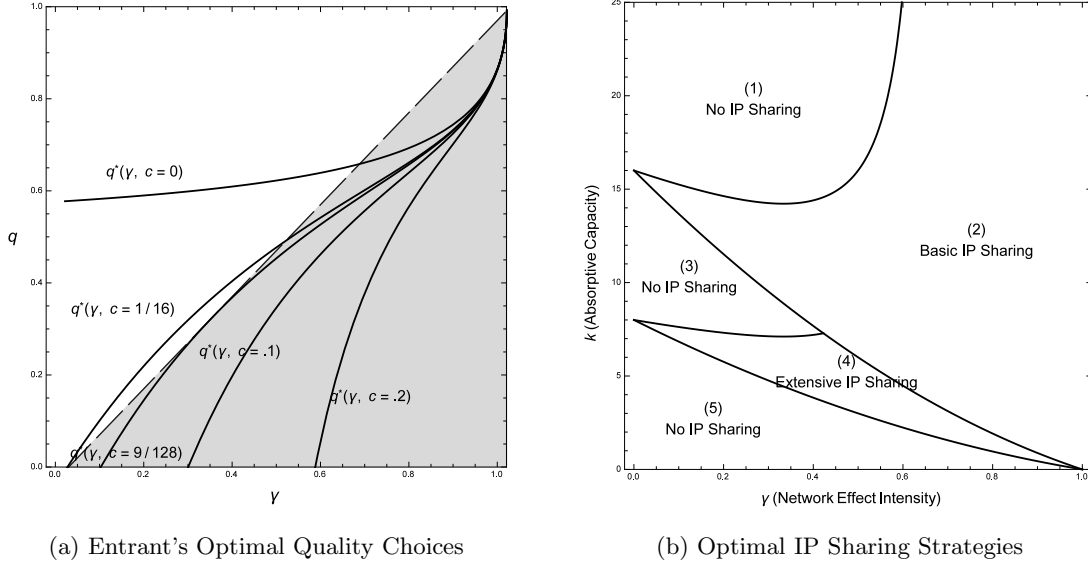
Figure 7: Full Equilibrium Outcomes under Unbounded Market

Comparing Figures 7b and 5, 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 the cases of different optimal IP sharing strategies continue to arise 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 misinterpretation of how platforms' optimal strategies depend on network effect intensity. For example, when the total market size is finite, too large network effect intensity, instead of inducing openness as suggested in Figure 7b, actually makes an open platform less appealing to both firms, and IP sharing may

not end up a viable equilibrium in consequence, as we discussed in §4 and illustrated in Figure 5.

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: (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:

$$\rho^*(\bar{k}, \gamma) = \underset{\rho \in \{0,1,2\}}{\arg \max} \, E_k \left[\, \pi_1^* \left(q^*(\gamma, \frac{1}{\rho k}), \gamma \right) \, \mid \, \bar{k} \, \right]. \tag{8}$$

Note that once the entrant chooses its quality q^*, the incumbent's profit π_1^* does not depend on k directly, 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 §4. To construct the expected profit under the two aforementioned distributions, we use a Monte Carlo approach with 7500 draws for each distribution. The IP sharing equilibria under uncertainty are depicted in panels (a) and (b) in Figure 8. Given that we are now considering a random variable k, the y-axis in each of the two panels captures the distribution mean $\bar{k}$. We confirm that the previous insights from §4.4 continue to hold.

5.3 Non-linear Entrant Cost Function

In this section, we explore numerically a generalization of our model considering a non-linear quality cost for the entrant in the form $e = \frac{q^\alpha}{\rho k} = cq^\alpha$, with $\alpha > 0$. The prior analysis in §4 corresponds to the linear cost model ($\alpha = 1$). Given our setup 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 code has been developed, adding another level is considerably easier. Here, content volume would
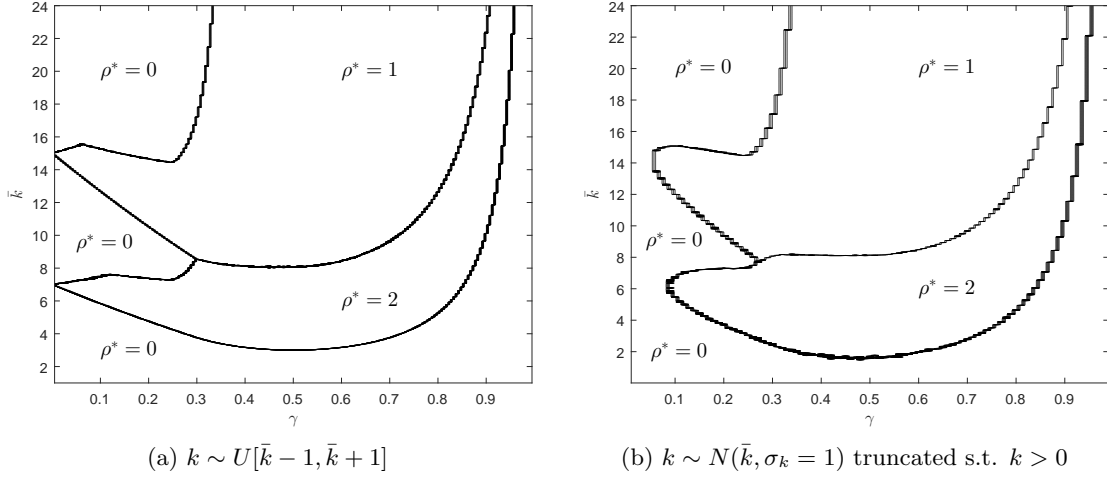
(a) $k \sim U[\bar{k} - 1, \bar{k} + 1]$ (b) $k \sim N(\bar{k}, \sigma_k = 1)$ truncated s.t. $k > 0$

Figure 8: Equilibrium IP Sharing with The Incumbent Being Uncertain about k.

be one dimension of quality. On the other hand, the case $\alpha > 1$ corresponds to a convex cost function with increasing marginal costs. This setup 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 functionality level.

It is important to highlight that in our setup 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 §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 the lower end consumers. For very low quality level, for a given c (i.e., fixed $k \cdot \rho$), the paths of cq^{α} start diverging very fast away from the linear level when α moves away from 1.

We depict in Figure 9 three scenarios for α: 0.9, 1, and 1.1. Panel (b) is our benchmark panel, representing the linear case (replicating the results in Figure 5). In panel (a) - the concave cost scenario - the entrant finds it considerably more expensive to develop its lower quality product. Hence we see the regions where the basic IP sharing is optimal pulling upwards - the entrant would need a higher absorptive capacity or more assistance (higher level of IP sharing) to be able to keep its development costs in balance. Also, when the network effects are weak, there is no IP sharing. Panel (c) - the convex cost scenario - on the other hand corresponds to significantly lower costs for
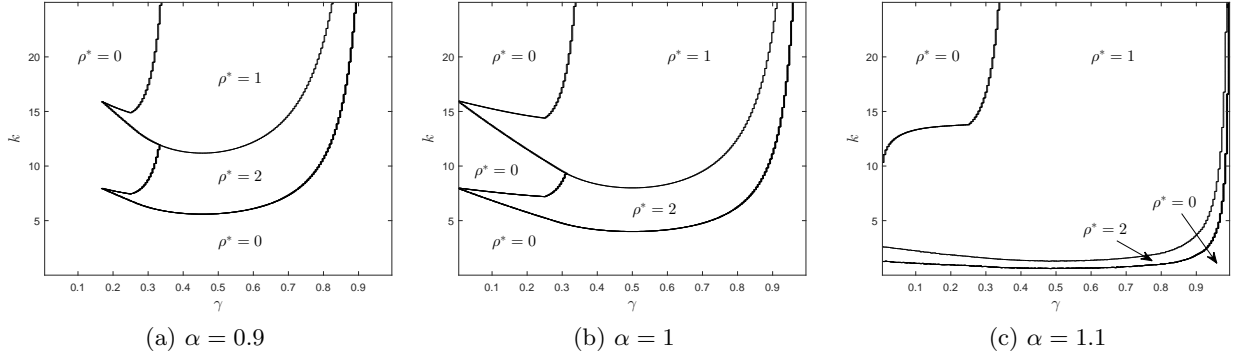
Figure 9: Equilibrium IP Sharing with Non-Linear Entrant Cost cq^α.

the entrant. Two effects are immediately noticeable. First, compared to panel (b), the incumbent will share its IP for considerably lower k values. We remind the readers 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 - that is 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. Also, we observe similar shifting pattern for the optimal degree of IP sharing moving from 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

31

parameter and analyze the equilibrium outcomes as functions of γ. Nevertheless, the 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 both 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, increase the car performance, but also to train and calibrate its AI, 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 single driver. Collecting and utilizing real drive data for better performance calibration (together with allowing updates to be pushed over the air to cars) were explicit decisions that the company had made which 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 are leveraging 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 like Uber and Lyft became mainstream - one 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 are interested in examining 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 very beginning. Thus, the incumbent will first choose the strength of the network effects in the market and then the game unfolds according to the five-stage sequence described at the end of §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, $\Pi_1(\gamma, k; \rho^*) = \pi_1^*\left(q^*\left(\gamma, \frac{1}{\rho^* k}\right), \gamma\right)$, 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

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

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 up in a very complex way the profit and opening decisions of the incumbent. Adding the optimization of the intensity of the network effects along with the associated costs is bringing another layer of complexity to an already highly-nontrivial problem. This makes the problem analytically intractable in certain regions but this research question lends itself to numerical exploration.
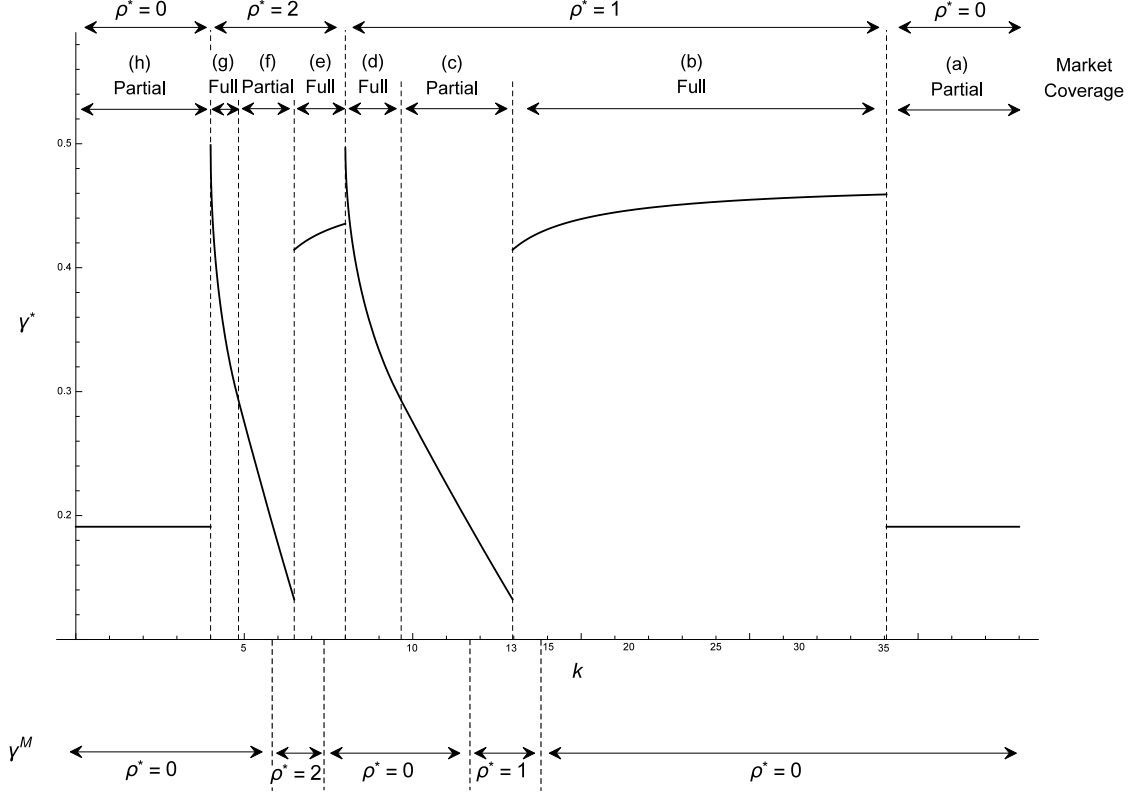
Figure 10: Optimal Network Effect Strength $\gamma^{*}(k)$

Hence, we numerically derive and present the full solution of $\gamma^{*}(k)$ in Figure 10. Before we discuss the solution, we point out that the right-half of the x-axis of Figure 7 is re-scaled because we wanted to showcase multiple regions while not compressing some of them to the point where patterns or labels are not visible. As it 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, $\gamma^{M} = \frac{3-\sqrt{5}}{4}$, 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 $\pi_1^* \left(q^* \left(\gamma, \frac{1}{k} \right), \gamma \right) - \gamma^2$ with $\pi_1^* \left(q, \gamma \right) = \frac{(1+\gamma-q)^2}{4(1-q)}$ and $q^* \left(\gamma, \frac{1}{k} \right) = 1 - \sqrt{\frac{\gamma^2}{\gamma-2/k}}$. 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 *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, $q^* \left(\gamma, \frac{1}{k} \right) = 1 - \sqrt{\frac{\gamma^2}{\gamma-2/k}}$ 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 $\frac{\delta \pi_1^*}{\delta q} < 0$ 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 translates immediately 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 price low. Taking these two effects on product differentiation in balance, 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 also generate 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. It is worth highlighting 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.

In 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 turns less profitable. In 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 $k \simeq 12.97$. 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 coverage (i.e., pricing equilibrium region (ii)) at $\gamma^* = \frac{2-\sqrt{2}}{2}$. It is also noteworthy that the optimal network effect intensity can vary over a wide range from as high as $\frac{1}{2}$ to as low as underneath 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) of 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 $\gamma^M = \frac{3-\sqrt{5}}{4}$.

As we show, endogenizing the network effect intensity equips the incumbent with an additional degree of freedom, allowing it to optimize its multi-dimensional 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 $\gamma^M = \frac{3-\sqrt{5}}{4}$ and plot $\rho^*\left(k; \gamma = \gamma^M\right)$. We append $\rho^*\left(k; \gamma = \gamma^M\right)$ to the bottom of Figure 10 in order to compare the optimal IP sharing strategies under the cases of endogenous and exogenous network effect intensity. As can be clearly seen, 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 (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 as 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 in order to allow co-opetition in a market characterized by network effects. In order to approach this research question, we propose a novel model that, to the best of 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 in the opposite direction compared to conclusions in Conner (1995) and Economides (1996). Moreover, we discuss various interesting open-platform co-opetition outcomes that arise in parallel with a 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 would 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 outcomes present actionable guidance for technology platform owners and the recommendation is customized by product class (different product classes may exhibit different strength of network effects) and entrant absorptive capacity. We also discuss several anecdotal

examples throughout the paper.

We further extend our analysis on multiple fronts. First, we compare and contrast our main setup with an alternative one 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, 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), highlighting the critical importance of the market boundedness assumption on the results. This comparative analysis offers guidance for both 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, namely that of optimizing the strength of network effects at consumer utility level. To the best of 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 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 do acknowledge several limitations of our model which 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 re-combinant innovation whereby players could generate additional innovation at subsequent periods of time and the incumbent can integrate that innovation in its platform at a later stage. Recent research already started considering this direction in the context of platform economics (e.g., Parker and Van Alstyne 2017).

Second, as mentioned at the beginning of §5.4, for tractability purposes, we use a reduced-form model where the impact of the complementors 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 along this line, 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 setup of IP openness which 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 development costs of the latter. Sixth, it would be interesting to extend the setup beyond duopoly to account for many heterogeneous potential entrants. Last but not least, it would be very interesting to explore empirically the connection between the degree of IP sharing and the absorptive capacity of potential entrants.

References

Anderson, Edward G, Geoffrey G Parker, Burcu Tan. 2014. Platform performance investment in the presence of network externalities. *Information Systems Research* **25**(1) 152–172.

Argenziano, R. 2008. Differentiated networks: Equilibrium and efficiency. *The RAND Journal of Economics* **39**(3) 747–769.

Baake, P., A. Boom. 2001. Vertical product differentiation, network externalities, and compatibility decisions. *International Journal of Industrial Organization* **19**(1) 267–284.

Bakos, Y., E. Katsamakas. 2008. Design and ownership of two-sided networks: Implications for Internet platforms. *Journal of Management Information Systems* **25**(2) 171–202.

Banker, R. D., C. F. Kemerer. 1989. Scale economies in new software development. *IEEE Transactions on Software Engineering* **15**(10) 1199.

Barge-Gil, A. 2010. Open, semi-open and closed innovators: towards an explanation of degree of openness. *Industry and Innovation* **17**(6) 577–607.

Boehm, B. W. 1981. *Software Engineering Economics*, vol. 197. Prentice-hall Englewood Cliffs (NJ).

Boehm, B. W., C. Abts, S. Chulani. 2000. Software development cost estimation approachesa survey. *Annals of Software Engineering* **10**(1-4) 177–205.

Boudreau, K. 2010. Open platform strategies and innovation: Granting access vs. devolving control. *Management Science* **56**(10) 1849–1872.

Cabral, L. 2011. Dynamic price competition with network effects. *The Review of Economic Studies* **78**(1) 83–111.

Chen, H. C., C. C. Chen. 2011. Compatibility under differentiated duopoly with network externalities. *Journal of Industry, Competition and Trade* **11**(1) 43–55.

Cheng, H. K., Y. Liu. 2012. Optimal software free trial strategy: The impact of network externalities and consumer uncertainty. *Information Systems Research* **23**(2) 488–504.

Cheng, H. K., Y. Liu, Q. Tang. 2011. The impact of network externalities on the competition between open source and proprietary software. *Journal of Management Information Systems* **27**(4) 201–230.

Chesbrough, H. 2006. Open innovation: A new paradigm for understanding industrial innovation. *Open innovation: Researching a New Paradigm* 1–12.

Cohen, W. M., D. A. Levinthal. 1990. Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly* **35** 128–152.

Conner, K. R. 1995. Obtaining strategic advantage from being imitated: When can encouraging "clones" pay? *Management Science* **41**(2) 209–225.

Dahlander, L., D. M. Gann. 2010. How open is innovation? *Research Policy* **39**(6) 699–709.

Dou, Y., M. F. Niculescu, D. J. Wu. 2013. Engineering optimal network effects via social media features and seeding in markets for digital goods and services. *Information Systems Research* **24**(1) 164–185.

Economides, N. 1996. Network externalities, complementarities, and invitations to enter. *European Journal of Political Economy* **12**(2) 211–233.

Eisenmann, T. R., G. Parker, M. Van Alstyne. 2009. Opening platforms: How, when and why? *Platforms, Markets and Innovation* (Chapter 6). Edited by Annabelle Gawer. Edward Elgar Publishing.

Farrell, J., N. T. Gallini. 1988. Second-sourcing as a commitment: Monopoly incentives to attract competition. *The Quarterly Journal of Economics* **103**(4) 673–694.

Gallini, N. T. 1984. Deterrence by market sharing: A strategic incentive for licensing. *The American Economic Review* **74**(5) 931–941.

Garud, Raghu, Arun Kumaraswamy. 1993. Changing competitive dynamics in network industries: An exploration of Sun Microsystems' open systems strategy. *Strategic Management Journal* **14**(5) 351–369.

Gawer, A., M. A. Cusumano. 2002. *Platform leadership: How Intel, Microsoft, and Cisco Drive Industry Innovation*. Harvard Business School Press Boston.

Griva, K., N. Vettas. 2011. Price competition in a differentiated products duopoly under network effects. *Information Economics and Policy* **23**(1) 85–97.

Huang, H., G. Parker, Y. Tan, H. Xu. 2016. Altruism or shrewd business? Implications of technology openness on platform innovations and competition. Working paper. Available at http://ssrn.com/abstract=2778834 (accessed on Aug. 29, 2016).

Hull, D. 2016. The Tesla advantage: 1.3 billion miles of data. Bloomberg, Dec. 20. https://www.bloomberg.com/news/articles/2016-12-20/the-tesla-advantage-1-3-billion-miles-of-data (accessed on May 25, 2017).

Inagaki, K. 2015. Toyota to share fuel-cell vehicle patents free of charge. Financial Times, Jan. 6, https://www.ft.com/content/68e00992-9581-11e4-b3a6-00144feabdc0?mhq5j=e2 (accessed on May 28, 2017).

Jones, R., H. Mendelson. 2011. Information goods vs. industrial goods: Cost structure and competition. *Management Science* **57**(1) 164–176.

Katz, M. L., C. Shapiro. 1985. Network externalities, competition, and compatibility. *The American Economic Review* **75**(3) 424–440.

Katz, M. L., C. Shapiro. 1994. Systems competition and network effects. *The Journal of Economic Perspectives* **8**(2) 93–115.

Kolodny, L. 2017. Investors are betting 3DR can find life after solo as a drone data platform. TechCrunch, Apr. 27, https://techcrunch.com/2017/04/27/investors-are-betting-3dr-can-find-life-after-solo-as-a-drone-data-platform/ (accessed on May 24, 2017).

Mac, R. 2016. Behind the crash of 3D Robotics, North America's most promising drone company. Forbes, Oct. 5, https://www.forbes.com/sites/ryanmac/2016/10/05/3d-robotics-solo-crash-chris-anderson/#1ac520353ff5 (accessed on May 28, 2017).

Moore, J. F. 1993. Predators and prey: A new ecology of competition. *Harvard Business Review* **71**(3) 75–83.

Parker, G., M. Van Alstyne. 2017. Innovation, openness, and platform control. *Management Science*, Forthcoming.

Ramsey, M. 2014. Tesla motors offers open licenses to its patents. The Wall Street Journal. Jun. 12. http://www.wsj.com/articles/tesla-motors-says-it-will-allow-others-to-use-its-patents-1402594375 (accessed on Aug. 29, 2016).

Roberts, N., P. S. Galluch, M. Dinger, V. Grover. 2012. Absorptive capacity and information systems research: Review, synthesis, and directions for future research. *MIS Quarterly* **36**(2) 625–648.

Sun, B., J. Xie, H. H. Cao. 2004. Product strategy for innovators in markets with network effects. *Marketing Science* **23**(2) 243–254.

A Appendix - Proofs of Main Results

A.1 Proof of Monopolistic Pricing (§4.1)

Proof. When the incumbent is a monopoly in the market, the boundary consumer who is indifferent between purchasing from the incumbent and not purchasing at all, $\tilde{\theta}$, can be formulated as $\left(\tilde{\theta} + \gamma N\right) - p_1 = 0$. Therefore, $\tilde{\theta} = p_1 - \gamma N$. In a rational expectations equilibrium (REE), consumers rationally anticipate the network size, so N and $\tilde{\theta}$ need to be solved simultaneously. Suppose $0 < \tilde{\theta} < 1$, then $N = N_1 = 1 - \tilde{\theta}$. As a result, $\tilde{\theta}$ can be solved as $\tilde{\theta} = \frac{p_1 - \gamma}{1 - \gamma}$. As we can easily check, $\frac{p_1 - \gamma}{1 - \gamma} > 0$ if and only if $p_1 > \gamma$; $\frac{p_1 - \gamma}{1 - \gamma} < 1$ if and only if $p_1 < 1$. Therefore, we can summarize the demand function for the monopolistic incumbent as follows.

$$
N_1\left(p_1\right) = \begin{cases} 1, & p_1 \leq \gamma; \\ 1 - \frac{p_1 - \gamma}{1 - \gamma}, & \gamma < p_1 < 1; \\ 0, & 1 \leq p_1. \end{cases} \tag{A.1}
$$

The incumbent sets p_1 to maximize its profit function $\pi_1\left(p_1\right) = p_1 N_1\left(p_1\right)$. It is easy to show that the optimal p_1 must fall in $[\gamma, 1)$. The first order condition yields $\hat{p}_1 = \frac{1}{2}$. Therefore, if $\gamma < \frac{1}{2}$, $\hat{p}_1 > \gamma$, so $p_1^* = \hat{p}_1 = \frac{1}{2}$; if $\gamma \geq \frac{1}{2}$, $\hat{p}_1 \leq \gamma$, so p_1^* takes the corner solution, i.e., $p_1^* = \gamma$. $\square$

A.2 Proof of Proposition 1

Proof. To derive the pricing equilibrium, we need to examine three stages of strategic decisions (i.e., the last three stages of the whole model). Along the line of backward induction, we derive the pricing equilibrium in the following three steps: (1) first, determine the demands for both firms' products as functions of the prices, $N_i\left(p_1, p_2\right)$ $(i = 1, 2)$; (2) next, determine the incumbent's best response in pricing as a function of the entrant's price, $p_1^*\left(p_2\right)$; (3) finally, determine the optimal price of the entrant, p_2^*. Throughout the analysis for this proposition, we take the entrant's product quality q and the strength of network effects γ as given, and discuss the equilibrium outcomes when these parameters take different values.

(1) We first derive the demand functions $N_i\left(p_1, p_2\right)$ $(i = 1, 2)$ given p_1 and p_2.

Consumers choose among three options: purchasing from the incumbent, purchasing from the

entrant, and not purchasing at all. The boundary consumer who is indifferent between purchasing from the incumbent and purchasing from the entrant, $\tilde{\theta}_{12}$, can be derived by solving $\tilde{\theta}_{12} + \gamma N - p_1 = \left(\tilde{\theta}_{12} + \gamma N \right) q - p_2$, which yields $\tilde{\theta}_{12} = \frac{p_1 - p_2}{1-q} - \gamma N$, where $N = N_1 + N_2$. Similarly, the boundary consumer indifferent between purchasing from the entrant and not purchasing at all is $\tilde{\theta}_2 = \frac{p_2}{q} - \gamma N$; the boundary consumer indifferent between purchasing from the incumbent and not purchasing at all is $\tilde{\theta}_1 = p_1 - \gamma N$. As we can easily show, all consumers with $\theta > \tilde{\theta}_{12}$ prefer purchasing from the incumbent to purchasing from the entrant, and vice versa; likewise, all consumers with $\theta < \tilde{\theta}_2$ (or $\tilde{\theta}_1$) prefer purchasing nothing to purchasing from the entrant (or incumbent), and vice versa.

In REE, consumers form rational expectations about the total network size N when making purchase decisions. Therefore, $\left\{ \tilde{\theta}_{12}, \tilde{\theta}_2, \tilde{\theta}_1 \right\}$ need to be simultaneously solved with N. Note that $\{N_1, N_2\}$ and hence N all depend on the relative magnitude of $\tilde{\theta}_{12}, \tilde{\theta}_2, \tilde{\theta}_1$, and the bounds of θ's range $[0, 1]$. Comparing these relative magnitudes and solving $\left\{ \tilde{\theta}_{12}, \tilde{\theta}_2, \tilde{\theta}_1, N \right\}$ simultaneously lead to different demand cases under different parameter conditions. For example, suppose $0 < \tilde{\theta}_2 \left(< \tilde{\theta}_1 \right) < \tilde{\theta}_{12} < 1$, then $N_1 = 1 - \tilde{\theta}_{12}$, $N_2 = \tilde{\theta}_{12} - \tilde{\theta}_2$, and as a result, $N = N_1 + N_2 = 1 - \tilde{\theta}_2$. Substituting $N = 1 - \tilde{\theta}_2$ into $\tilde{\theta}_2 = \frac{p_2}{q} - \gamma N$, we can solve $\tilde{\theta}_2$ as $\tilde{\theta}_2 = \frac{p_2 - q\gamma}{q(1-\gamma)}$. Consequently, $N = \frac{q - p_2}{q(1-\gamma)}$, and $\tilde{\theta}_{12} = \frac{p_1 - p_2}{1-q} - \gamma \frac{q - p_2}{q(1-\gamma)}$, $\tilde{\theta}_1 = p_1 - \gamma \frac{q - p_2}{q(1-\gamma)}$. We then need to verify under what conditions $0 < \tilde{\theta}_2 \left(< \tilde{\theta}_1 \right) < \tilde{\theta}_{12} < 1$ holds. Solving the inequalities after substituting the solutions of $\left\{ \tilde{\theta}_{12}, \tilde{\theta}_2, \tilde{\theta}_1 \right\}$, we arrive at the conditions: $q\gamma < p_2 < q$, and $\frac{p_2}{q} < p_1 < \frac{(q-\gamma)p_2 + q(1-q)}{q(1-\gamma)}$.

In a similar way to the case of $0 < \tilde{\theta}_2 \left(< \tilde{\theta}_1 \right) < \tilde{\theta}_{12} < 1$ analyzed above, we can exhaust all cases of different relative magnitudes of $\tilde{\theta}_{12}, \tilde{\theta}_2, \tilde{\theta}_1$ and the bounds $[0, 1]$, which gives us the demands in different regions, as summarized in Table A1.

(2) We next derive the incumbent's best response function $p_1^* (p_2)$.

Based on the demands derived in Table A1, we can formulate the profit function of the incumbent given the entrant's price, $\pi_1 (p_1; p_2)$. For example, according to Case (A) in Table A1, when $0 < p_2 < q\gamma$, we have

$$\pi_1 (p_1; p_2) = \begin{cases} p_1, & 0 < p_1 < p_2 + (1-q)\gamma; \\ p_1 \left(1 + \gamma - \frac{p_1 - p_2}{1-q} \right), & p_2 + (1-q)\gamma < p_1 < p_2 + (1-q)(1+\gamma); \\ 0, & p_2 + (1-q)(1+\gamma) < p_1 \leq 1 + \gamma. \end{cases} \quad (A.2)$$

Table A1: Demands Given Both Firms' Prices p_1 and p_2

Cases	Conditions	$N_1(p_1,p_2)$	$N_2(p_1,p_2)$	$N(p_1,p_2)$
(A)	$0 < p_2 < q\gamma$:			
(A1)	$0 < p_1 < p_2 + (1-q)\gamma$;	1	0	1
(A2)	$p_2 + (1-q)\gamma < p_1 < p_2 + (1-q)(1+\gamma)$;	$1 + \gamma - \frac{p_1 - p_2}{1-q}$	$\frac{p_1 - p_2}{1-q} - \gamma$	1
(A3)	$p_2 + (1-q)(1+\gamma) < p_1 < 1 + \gamma$	0	1	1
(B)	$q\gamma < p_2 < q$:			
(B1)	$0 < p_1 < \gamma$;	1	0	1
(B2)	$\gamma < p_1 < \frac{p_2}{q}$;	$\frac{1-p_1}{1-\gamma}$	0	$\frac{1-p_1}{1-\gamma}\,(<1)$
(B3)	$\frac{p_2}{q} < p_1 < \frac{(q-\gamma)p_2 + q(1-q)}{q(1-\gamma)}$;	$1 - \frac{p_1-p_2}{1-q} + \gamma\frac{q-p_2}{q(1-\gamma)}$	$\frac{p_1-p_2}{1-q} - \frac{p_2}{q}$	$\frac{q-p_2}{q(1-\gamma)}\,(<1)$
(B4)	$\frac{(q-\gamma)p_2 + q(1-q)}{q(1-\gamma)} < p_1 < 1 + \gamma$	0	$\frac{q-p_2}{q(1-\gamma)}$	$\frac{q-p_2}{q(1-\gamma)}\,(<1)$
(C)	$q < p_2 < q(1+\gamma)$:			
(C1)	$0 < p_1 < \gamma$;	1	0	1
(C2)	$\gamma < p_1 < 1$;	$\frac{1-p_1}{1-\gamma}$	0	$\frac{1-p_1}{1-\gamma}\,(<1)$
(C3)	$1 < p_1 < 1 + \gamma$	0	0	0

It is easy to see that any $p_1 < p_2 + (1-q)\gamma$ or $p_1 > p_2 + (1-q)(1+\gamma)$ cannot be the optimal price for the incumbent. Therefore, we only need to focus on the second segment in (A.2). The first order condition yields the solution $\hat{p}_1 = \frac{1}{2}\left[(1-q)(1+\gamma) + p_2\right]$. We then need to compare $\hat{p}_1$ against the two bounds of that segment, $p_2 + (1-q)\gamma$ and $p_2 + (1-q)(1+\gamma)$. Note that $\hat{p}_1 < p_2 + (1-q)(1+\gamma)$ automatically holds, and $\hat{p}_1 > p_2 + (1-q)\gamma$ if and only if $p_2 < (1-q)(1-\gamma)$. Because $0 < p_2 < q\gamma$ under Case (A), we also need to compare $(1-q)(1-\gamma)$ with $q\gamma$: $(1-q)(1-\gamma) < q\gamma$ if and only if $q > 1 - \gamma$. Altogether, we have the following three subcases: (a) if $q > 1 - \gamma$ and $0 < p_2 < (1-q)(1-\gamma)\,(<q\gamma)$, then $p_1^*(p_2) = \frac{1}{2}\left[(1-q)(1+\gamma) + p_2\right]$, and the demands fall into Case (A2) as in Table A1; (b) if $q > 1 - \gamma$ and $(1-q)(1-\gamma) < p_2 < q\gamma$, then $p_1^*(p_2) = p_2 + (1-q)\gamma$, and the demands fall into Case (A1) as in Table A1 (in fact, the intersecting bound between Cases (A1) and (A2)); (c) if $q < 1 - \gamma$ and $0 < p_2 < q\gamma\,(<(1-q)(1-\gamma))$, then $p_1^*(p_2) = \frac{1}{2}\left[(1-q)(1+\gamma) + p_2\right]$, and the demands fall into Case (A2) as in Table A1.

Following a similar manner, we can analyze the incumbent's best response corresponding to the demand case (B) in Table A1. Note that demand case (C) is irrelevant because $N_2 \equiv 0$ in this case, which means the entrant will not be able to make any profit if it prices within these regions. As a result, p_1 will not fall into this region in equilibrium, and hence the demand case (C) will not appear in equilibrium. Altogether, we summarize the incumbent's best response $p_1^*(p_2)$ in Table

Cases	Conditions	$p_1^*(p_2)$	Demand Cases (as in Table A1)
(1)	$0 < \gamma < \frac{1}{2},\, 0 < q < \gamma\,(< 1-\gamma):$		
(1a)	$0 < p_2 < q\gamma;$	$\frac{(1-q)(1+\gamma)+p_2}{2}$	(A2)
(1b)	$q\gamma < p_2 < q\frac{(1-q)-\sqrt{(1-q)(1-\gamma)}}{\gamma-q};$	$\frac{(q-\gamma)p_2+q(1-q)}{2q(1-\gamma)}$	(B3)
(1c)	$q\frac{(1-q)-\sqrt{(1-q)(1-\gamma)}}{\gamma-q} < p_2 < q$	$\frac{1}{2}$	(B2)
(2)	$0 < \gamma < \frac{1}{2},\, \gamma < q < 1-\gamma:$		
(2a)	$0 < p_2 < q\gamma;$	$\frac{(1-q)(1+\gamma)+p_2}{2}$	(A2)
(2b)	$q\gamma < p_2 < q\frac{(1-q)}{2-q-\gamma};$	$\frac{(q-\gamma)p_2+q(1-q)}{2q(1-\gamma)}$	(B3)
(2c)	$q\frac{(1-q)}{2-q-\gamma} < p_2 < q$	$\min\left\{\frac{p_2}{q},\frac{1}{2}\right\}$	(B2) / (B3)
(3)	$0 < \gamma < \frac{1}{2},\, (\gamma <)\, 1-\gamma < q < 1:$		
(3a)	$0 < p_2 < (1-q)(1-\gamma);$	$\frac{(1-q)(1+\gamma)+p_2}{2}$	(A2)
(3b)	$(1-q)(1-\gamma) < p_2 < q\gamma;$	$p_2 + (1-q)\gamma$	(A1) / (A2)
(3c)	$q\gamma < p_2 < q$	$\min\left\{\frac{p_2}{q},\frac{1}{2}\right\}$	(B2) / (B3)
(4)	$\frac{1}{2} < \gamma < 1,\, 0 < q < 1-\gamma\,(< \gamma):$		
(4a)	$0 < p_2 < q\gamma;$	$\frac{(1-q)(1+\gamma)+p_2}{2}$	(A2)
(4b)	$q\gamma < p_2 < q\frac{(1-q)-2(1-\gamma)\sqrt{(1-q)\gamma}}{(\gamma-q)};$	$\frac{(q-\gamma)p_2+q(1-q)}{2q(1-\gamma)}$	(B3)
(4c)	$q\frac{(1-q)-2(1-\gamma)\sqrt{(1-q)\gamma}}{(\gamma-q)} < p_2 < q$	γ	(B1) / (B2)
(5)	$\frac{1}{2} < \gamma < 1,\, 1-\gamma < q < 1:$		
(5a)	$0 < p_2 < (1-q)(1-\gamma);$	$\frac{(1-q)(1+\gamma)+p_2}{2}$	(A2)
(5b)	$(1-q)(1-\gamma) < p_2 < q\gamma;$	$p_2 + (1-q)\gamma$	(A1) / (A2)
(5c)	$q\gamma < p_2 < q$	γ	(B1) / (B2)

A2.

(3) We finally solve the entrant's optimal price p_2^*.

Based on the incumbent's best response functions in Table A2, we can formulate the entrant's profit function when anticipating the incumbent's best response in pricing, $\pi_2(p_2; p_1^*(p_2))$. For example, consider Case (1) in Table A2, that is, when $0 < \gamma < \frac{1}{2}$ and $0 < q < \gamma$.

$$\pi_2(p_2; p_1^*(p_2)) = \begin{cases} p_2\left(\frac{p_1^*(p_2)-p_2}{1-q} - \gamma\right) = p_2\frac{(1-q)(1-\gamma)-p_2}{2(1-q)}, & 0 < p_2 < q\gamma; \\ p_2\left(\frac{p_1^*(p_2)-p_2}{1-q} - \frac{p_2}{q}\right) = p_2\frac{q(1-q)-(2-q-\gamma)p_2}{2q(1-q)(1-\gamma)}, & q\gamma < p_2 < q\frac{(1-q)-\sqrt{(1-q)(1-\gamma)}}{\gamma-q}; \quad \text{(A.3)} \\ 0, & q\frac{(1-q)-\sqrt{(1-q)(1-\gamma)}}{\gamma-q} < p_2 < q. \end{cases}$$

It is easy to see that any $p_2 > q\frac{(1-q)-\sqrt{(1-q)(1-\gamma)}}{\gamma-q}$ cannot be optimal for the entrant. Therefore, we only need to focus on the first two segments of (A.3). The first order conditions for the first and the second segments yield $\hat{p}_2 = \frac{1}{2}(1-q)(1-\gamma)$ and $\hat{p}_2' = \frac{q(1-q)}{2(2-q-\gamma)}$, respectively. In order to determine the optimal p_2^*, we need to compare $\hat{p}_2$ and $\hat{p}_2'$ against the bounds 0, $q\gamma$, and $q\frac{(1-q)-\sqrt{(1-q)(1-\gamma)}}{\gamma-q}$. For example, if $0 < \gamma < \frac{1}{4}$, then $\hat{p}_2 > q\gamma$ and $q\gamma < \hat{p}_2' < q\frac{(1-q)-\sqrt{(1-q)(1-\gamma)}}{\gamma-q}$. As a result, $p_2^* = \hat{p}_2'$. In total, there are 6 subcases under Case (1). Table A3 shows the detailed parameter conditions with their respective equilibrium prices.

Table A3: Optimal Pricing for the Entrant, p_2^*

Cases	Conditions	p_2^*	p_1^* (p_2) Cases (as in Table A2)	Demand Cases (as in Table A1)	Equilibrium Cases (as in Table 1)
(1)	$0 < \gamma < \frac{1}{2}$, $0 < q < \gamma$:				
	$0 < \gamma < \frac{1}{4}$, $0 < q < \gamma$;	$\frac{q(1-q)}{2(2-q-\gamma)}$	(1b)	(B3)	(i)
	$\frac{1}{4} < \gamma < \frac{2-\sqrt{2}}{2}$, $0 < q < \frac{2\gamma^2-4\gamma+1}{1-2\gamma}$;	$\frac{q(1-q)}{2(2-q-\gamma)}$	(1b)	(B3)	(i)
	$\frac{1}{4} < \gamma < \frac{2-\sqrt{2}}{2}$, $\frac{2\gamma^2-4\gamma+1}{1-2\gamma} < q < \gamma$;	$q\gamma$	(1a) / (1b)	(A2) / (B3)	(ii)
	$\frac{2-\sqrt{2}}{2} < \gamma < \sqrt{2}-1$, $0 < q < \gamma$;	$q\gamma$	(1a) / (1b)	(A2) / (B3)	(ii)
	$\sqrt{2}-1 < \gamma < \frac{1}{2}$, $0 < q < \frac{1-\gamma}{1+\gamma}$;	$q\gamma$	(1a) / (1b)	(A2) / (B3)	(ii)
	$\sqrt{2}-1 < \gamma < \frac{1}{2}$, $\frac{1-\gamma}{1+\gamma} < q < \gamma$	$\frac{1}{2}(1-q)(1-\gamma)$	(1a)	(A2)	(iii)
(2)	$0 < \gamma < \frac{1}{2}$, $\gamma < q < 1-\gamma$:				
	$0 < \gamma < \frac{1}{4}$, $\gamma < q < \frac{2\gamma^2-4\gamma+1}{1-2\gamma}$;	$\frac{q(1-q)}{2(2-q-\gamma)}$	(2b)	(B3)	(i)
	$0 < \gamma < \frac{1}{4}$, $\frac{2\gamma^2-4\gamma+1}{1-2\gamma} < q < \frac{1-\gamma}{1+\gamma}$;	$q\gamma$	(2a) / (2b)	(B3) / (A2)	(ii)
	$0 < \gamma < \frac{1}{4}$, $\frac{1-\gamma}{1+\gamma} < q < 1-\gamma$;	$\frac{1}{2}(1-q)(1-\gamma)$	(2a)	(A2)	(iii)
	$\frac{1}{4} < \gamma < \sqrt{2}-1$, $\gamma < q < \frac{1-\gamma}{1+\gamma}$;	$q\gamma$	(2a) / (2b)	(B3) / (A2)	(ii)
	$\frac{1}{4} < \gamma < \sqrt{2}-1$, $\frac{1-\gamma}{1+\gamma} < q < 1-\gamma$;	$\frac{1}{2}(1-q)(1-\gamma)$	(2a)	(A2)	(iii)
	$\sqrt{2}-1 < \gamma < \frac{1}{2}$, $\gamma < q < 1-\gamma$	$\frac{1}{2}(1-q)(1-\gamma)$	(2a)	(A2)	(iii)
(3)	$0 < \gamma < \frac{1}{2}$, $1-\gamma < q < 1$	$\frac{1}{2}(1-q)(1-\gamma)$	(3a)	(A2)	(iii)
(4)	$\frac{1}{2} < \gamma < 1$, $0 < q < 1-\gamma$:				
	$\frac{1}{2} < \gamma < 1$, $0 < q < \frac{1-\gamma}{1+\gamma}$;	$q\gamma$	(4a) / (4b)	(A2) / (B3)	(ii)
	$\frac{1}{2} < \gamma < 1$, $\frac{1-\gamma}{1+\gamma} < q < 1-\gamma$;	$\frac{1}{2}(1-q)(1-\gamma)$	(4a)	(A2)	(iii)
(5)	$\frac{1}{2} < \gamma < 1$, $1-\gamma < q < 1$	$\frac{1}{2}(1-q)(1-\gamma)$	(5a)	(A2)	(iii)

Following the same approach, we examine Cases (2) through (5) in Table A2 and derive the equilibrium prices within various sub-regions of parameter values, as we summarize in Table A3. Combining the cases with the same equilibrium outcome, we arrive at the equilibrium outcomes described in Proposition 1 and Table 1 (as we indicate in the rightmost column in Table A3). $\square$

A.3   Proof of Corollary 1

Proof. Given that $\lim_{\gamma\uparrow 1}\frac{1-\gamma}{1+\gamma} = 0$, we can see that for any fixed $q < 1$, there exists a threshold $\gamma_1(q) \in (0,1)$ such that when $\gamma > \gamma_1(q)$, we enter region (iii). Then, it immediately follows that $\lim_{\gamma\uparrow 1} \pi_1^*(q,\gamma) = 1 - q < \lim_{\gamma\uparrow 1} \pi_1^M(\gamma) = 1$. Consequently, there exists $\gamma_0(q) \in (\gamma_1(q),1)$ such that for all $\gamma \in (\gamma_0(q),1)$ we have $\pi_1^*(q,\gamma) < \pi_1^M(\gamma)$. $\qquad\square$

A.4   Proof of Proposition 2

Proof. According to Proposition 1, the entrant's equilibrium profit by choosing quality q can be written as

$$\pi_2(q) = \begin{cases} \frac{q(1-q)}{8(1-\gamma)(2-q-\gamma)} - cq, & 0 < q < \max\left\{\frac{2\gamma^2-4\gamma+1}{1-2\gamma}, 0\right\}; \\[2mm] \frac{(1-\gamma-q)q\gamma}{2(1-q)} - cq, & \max\left\{\frac{2\gamma^2-4\gamma+1}{1-2\gamma}, 0\right\} \leq q < \frac{1-\gamma}{1+\gamma}; \\[2mm] \frac{1}{8}(1-q)(1-\gamma)^2 - cq, & \frac{1-\gamma}{1+\gamma} \leq q < 1. \end{cases} \qquad (A.4)$$

Solving the first-order condition for the first segment of (A.4), we have $q_1^* = 2 - \gamma - \sqrt{\frac{(2-\gamma)(1-\gamma)}{1-8c(1-\gamma)}}$; the solution to the first-order condition for the second segment of (A.4) yields $q_2^* = 1 - \sqrt{\frac{\gamma^2}{\gamma-2c}}$. For the third segment of (A.4), because $\frac{d}{dq}\pi_2(q) = -\frac{1}{8}(1-\gamma)^2 - c < 0$, any $q > \frac{1-\gamma}{1+\gamma}$ cannot be optimal.

Define $\hat{\gamma}(c)$ as the unique solution to $-4\gamma^3 + 4(2c+3)\gamma^2 - 8(2c+1)\gamma + 8c + 1 = 0$ for $\gamma \in \left(0, \frac{2-\sqrt{2}}{2}\right)$. As we can verify, $\hat{\gamma}(c)$ is well defined for $c \in \left(0, \frac{\sqrt{2}-1}{4}\right)$. Note that $q_1^*(\hat{\gamma}) = q_2^*(\hat{\gamma}) = \frac{2\hat{\gamma}^2-4\hat{\gamma}+1}{1-2\hat{\gamma}}$.

Consider Case (a) when $0 < c \leq \frac{1}{16}$. We examine it in the following subcases.

(i) When $0 < \gamma < \hat{\gamma}(c)$, as we can show, $\frac{2\gamma^2-4\gamma+1}{1-2\gamma} > 0$, $0 < q_1^* < \frac{2\gamma^2-4\gamma+1}{1-2\gamma}$, and $q_2^* < \frac{2\gamma^2-4\gamma+1}{1-2\gamma}$. Therefore, $\pi_2(q)$ reaches its peak within the first segment of (A.4) at $q = q_1^*$, and any $q > \frac{2\gamma^2-4\gamma+1}{1-2\gamma}$ is suboptimal. As a result, the entrant's optimal quality choice is $q^* = q_1^* = 2 - \gamma - \sqrt{\frac{(2-\gamma)(1-\gamma)}{1-8c(1-\gamma)}}$.

(ii1) When $\hat{\gamma}(c) < \gamma < \frac{2-\sqrt{2}}{2}$, as we can show, $0 < \frac{2\gamma^2-4\gamma+1}{1-2\gamma} < q_1^*$ and $\frac{2\gamma^2-4\gamma+1}{1-2\gamma} < q_2^* < \frac{1-\gamma}{1+\gamma}$. Therefore, $\pi_2(q)$ reaches its peak within the second segment of (A.4) at $q = q_2^*$, and any $q < \frac{2\gamma^2-4\gamma+1}{1-2\gamma}$ or $q > \frac{1-\gamma}{1+\gamma}$ is suboptimal. As a result, $q^* = q_2^* = 1 - \sqrt{\frac{\gamma^2}{\gamma-2c}}$.

(ii2) When $\frac{2-\sqrt{2}}{2} < \gamma < \frac{1+\sqrt{1-8c}}{2}$, because $\frac{2\gamma^2-4\gamma+1}{1-2\gamma} < 0$, the first segment of A.4 no longer applies. As we can show, $0 < q_2^* < \frac{1-\gamma}{1+\gamma}$ within this region. Therefore, $\pi_2(q)$ reaches its peak

6

within the second segment of (A.4) at $q = q_2^*$, and any $q > \frac{1-\gamma}{1+\gamma}$ is suboptimal. As a result, $q^* = q_2^* = 1 - \sqrt{\frac{\gamma^2}{\gamma - 2c}}$.

(iii) When $\frac{1+\sqrt{1-8c}}{2} < \gamma < 1$, $q_2^* < 0$. Therefore, $\pi_2(q)$ is decreasing in q for $q \in [0, 1]$, and the optimal quality choice $q^* = 0$.

Combining (i) through (iii), we have the optimal quality choice of the entrant for Case (a) when $0 < c \le \frac{1}{16}$. The other cases can be proven in a similar fashion. $\qquad\square$

A.5 Proof of Corollary 2

Proof. Follows immediately from Proposition 2 by setting $q^*(\gamma, c) > 0$. $\qquad\square$

A.6 Proof of Lemma 1

Proof. Comparing the equilibrium profits of the incumbent, π_1^*, in Proposition 1 and equation (2) over various parameter regions, we have:

(1) If $\gamma < \frac{1}{2}$, according to equation(2), the incumbent's monopoly profit $\pi_1^* = \frac{1}{4(1-\gamma)}$.

(i) In region (i) of Proposition 1, $\frac{(1-q)(4-q-3\gamma)^2}{16(1-\gamma)^2(2-q-\gamma)^2} > \frac{1}{4(1-\gamma)}$ if and only if $\frac{(\gamma-q)\left(4\gamma^2 - (11-3q)\gamma + \left(q^2 - 5q + 8\right)\right)}{16(1-\gamma)^2(2-q-\gamma)^2} > 0$. Note that $4\gamma^2 - (11 - 3q)\gamma + \left(q^2 - 5q + 8\right) > 0$ always holds because $(11 - 3q)^2 - 16\left(q^2 - 5q + 8\right) = -7(1-q)^2 < 0$. Therefore, $\frac{(1-q)(4-q-3\gamma)^2}{16(1-\gamma)^2(2-q-\gamma)^2} > \frac{1}{4(1-\gamma)}$ if and only if $q < \gamma$.

(ii) In region (ii) of Proposition 1, $\frac{(1+\gamma-q)^2}{4(1-q)} > \frac{1}{4(1-\gamma)}$ if and only if $\frac{(\gamma-q)\left(-(1-\gamma)q + 1 - \gamma - \gamma^2\right)}{4(1-q)(1-\gamma)} > 0$. As we can show, because $q < \frac{1-\gamma}{1+\gamma}$ in this region, $\frac{(1+\gamma-q)^2}{4(1-q)} > \frac{1}{4(1-\gamma)}$ if and only if $q < \gamma$.

(iii) In region (iii) of Proposition 1, $\frac{1}{16}(1-q)(3+\gamma)^2 > \frac{1}{4(1-\gamma)}$ if and only if $q < 1 - \frac{4}{(1-\gamma)(3+\gamma)^2}$. Note that $\gamma = \frac{1-\gamma}{1+\gamma} = 1 - \frac{4}{(1-\gamma)(3+\gamma)^2}$ when $\gamma = \sqrt{2} - 1$.

(2) If $\gamma > \frac{1}{2}$, according to equation (2), the incumbent's monopoly profit $\pi_1^* = \gamma$.

(i) Region (i) of Proposition 1 does not apply when $\gamma > \frac{1}{2}$.

(ii) In region (ii) of Proposition 1, $\frac{(1+\gamma-q)^2}{4(1-q)} > \gamma$ if and only if $\frac{(1-q-\gamma)^2}{4(1-q)} > 0$, which always holds.

(iii) In region (iii) of Proposition 1, $\frac{1}{16}(1-q)(3+\gamma)^2 > \gamma$ if and only if $q < 1 - \frac{16\gamma}{(3+\gamma)^2}$. Note that $1 - \frac{16\gamma}{(3+\gamma)^2} = 1 - \frac{4}{(1-\gamma)(3+\gamma)^2}$ when $\gamma = \frac{1}{2}$.

Altogether, we can conclude that sharing its IP leads to higher equilibrium profit than remaining a monopoly when $q < \tilde{q}(\gamma)$, where $\tilde{q}(\gamma)$ is defined in (6) $\qquad\square$

A.7 Proof of Proposition 3

Proof. First note that the equilibrium profit of the incumbent in a duopoly market, $\pi_1^*(q,\gamma)$ as derived in Proposition 1, is decreasing in the entrant's product quality q. To see this, we take the first derivative with respect to q. In region (i) of Table 1, $\frac{d}{dq}\pi_1^*(q,\gamma) = \frac{-(4-3\gamma-q)[(1-q)^2+3(1-\gamma)^2]}{16(1-\gamma)^2(2-q-\gamma)^3} < 0$; in region (ii), $\frac{d}{dq}\pi_1^*(q,\gamma) = -\frac{1}{4}\left[1 - \frac{\gamma^2}{(1-q)^2}\right] < 0$ because $q < \frac{1-\gamma}{1+\gamma} < 1-\gamma$ in this region; in region (iii), $\frac{d}{dq}\pi_1^*(q,\gamma) = -\frac{1}{16}(3+\gamma)^2 < 0$.

We prove the results summarized in Table 3 by dividing the value range of γ into five cases: (a) $0 < \gamma \leq \frac{1}{4}$; (b) $\frac{1}{4} < \gamma \leq \frac{2-\sqrt{2}}{2}$; (c) $\frac{2-\sqrt{2}}{2} < \gamma \leq \tilde{\gamma}$; (d) $\tilde{\gamma} < \gamma \leq \frac{3-\sqrt{5}}{2}$; (e) $\frac{3-\sqrt{5}}{2} < \gamma < 1$. We analyze case (a) ($0 < \gamma \leq \frac{1}{4}$) in detail below. The other cases can be analyzed in a similar fashion.

(1) Recall the analysis and results for Proposition 2 and Lemma 1. For $0 < \gamma \leq \frac{1}{4}$, $q^*(\gamma,c) = 2-\gamma-\sqrt{\frac{(2-\gamma)(1-\gamma)}{1-8c(1-\gamma)}}$, and $\tilde{q}(\gamma) = \gamma$. Solving $q^*(\gamma,c) = \tilde{q}(\gamma)$ for c, we have $c = \frac{2-3\gamma}{32(1-\gamma)^2}$. Recall that $q^*(\gamma,c)$ is decreasing in c. Therefore, if $c < \frac{2-3\gamma}{32(1-\gamma)^2}$, $q^*(\gamma,c) > \tilde{q}(\gamma)$, so sharing its IP would lead to less profit for the incumbent than not sharing and remaining a monopoly. If $k > \frac{32(1-\gamma)^2}{2-3\gamma}$, with either basic sharing (i.e., $\rho = 1$) or advanced sharing (i.e., $\rho = 2$), $c = \frac{1}{\rho k} < \frac{2-3\gamma}{32(1-\gamma)^2}$. As a result, either basic or advanced sharing is dominated by remaining a monopoly, so the optimal strategy for the incumbent is no sharing (i.e., $\rho^* = 0$). Thus, this case constitutes a part of region (1) in Table 3.

(2) Solving $q^*(\gamma,c) = 2-\gamma-\sqrt{\frac{(2-\gamma)(1-\gamma)}{1-8c(1-\gamma)}} = 0$ for c, we have $c = \frac{1}{8(2-\gamma)(1-\gamma)}$. Therefore, if $\frac{2-3\gamma}{32(1-\gamma)^2} < c < \frac{1}{8(2-\gamma)(1-\gamma)}$ (note that $\frac{2-3\gamma}{32(1-\gamma)^2} < \frac{1}{8(2-\gamma)(1-\gamma)}$ for $\forall \gamma \in \left(0,\frac{1}{4}\right)$), $0 < q^*(\gamma,c) < \tilde{q}(\gamma)$, so sharing its IP leads to more profit for the incumbent than not sharing, and meanwhile, the entrant is willing to enter the market by achieving a strictly positive level of net profit with $q^* > 0$. For this reason, if $8(2-\gamma)(1-\gamma) < k < \frac{32(1-\gamma)^2}{2-3\gamma}$, the optimal strategy for the incumbent is basic sharing (i.e., $\rho^* = 1$ so that $c = \frac{1}{k}$). Note that advanced sharing (i.e., $\rho = 2$ so that $c = \frac{1}{2k}$) cannot be optimal in this case because as we have shown, $\pi_1^*(q,\gamma)$ (as in Proposition 1) is decreasing in q, so helping the entrant reduce development cost (which would increase $q^*(\gamma,c)$) would hurt the incumbent's equilibrium profit. Altogether, this case constitutes a part of region (2) in Table 3.

(3) When $\frac{16(1-\gamma)^2}{2-3\gamma} < k < 8(2-\gamma)(1-\gamma)$ (note that $\frac{16(1-\gamma)^2}{2-3\gamma} < 8(2-\gamma)(1-\gamma)$ for $\forall \gamma \in \left(0,\frac{1}{4}\right)$), if the incumbent chooses basic sharing (i.e., $\rho = 1$), then $c = \frac{1}{k} > \frac{1}{8(2-\gamma)(1-\gamma)}$. By the above analysis in (2), $q^*(\gamma,c) = 0$. In other words, with basic sharing, the entrant would be unable

to achieve a positive level of net profit, and hence $q^* = 0$ would be its optimal quality choice; as a result, the entrant would not enter the market in the first place. If the incumbent chooses advanced sharing (i.e., $\rho = 2$), then $c = \frac{1}{2k} < \frac{2-3\gamma}{32(1-\gamma)^2} \left(< \frac{1}{8(2-\gamma)(1-\gamma)} \right)$. By the above analysis in (1), $q^*(\gamma, c) > \tilde{q}(\gamma) (> 0)$, indicating that the incumbent could achieve more profit by remaining a monopoly than advanced sharing. Altogether, neither basic nor advanced sharing can outperform the monopoly profit. Therefore, the optimal strategy for the incumbent is no sharing (i.e., $\rho^* = 0$). This case hence constitutes a part of region (3) in Table 3.

(4) When $4(2-\gamma)(1-\gamma) < k < \frac{16(1-\gamma)^2}{2-3\gamma} (< 8(2-\gamma)(1-\gamma))$, if the incumbent chooses basic sharing (i.e., $\rho = 1$), then $c = \frac{1}{k} > \frac{1}{8(2-\gamma)(1-\gamma)}$. By the above analysis in (2), $q^*(\gamma, c) = 0$. As a result, the entrant would not enter the market in the first place, and the incumbent would maintain the monopoly profit. If the incumbent chooses advanced sharing (i.e., $\rho = 2$), then $c = \frac{1}{2k}$, so $\frac{2-3\gamma}{32(1-\gamma)^2} < c < \frac{1}{8(2-\gamma)(1-\gamma)}$. By the above analysis in (1) and (2), $0 < q^*(\gamma, c) < \tilde{q}(\gamma)$. As a result, the entrant is willing to enter the market by achieving a strictly positive level of net profit with $q^* > 0$, and meanwhile, the incumbent can achieve more profit than remaining a monopoly. Therefore, the optimal strategy for the incumbent is advanced sharing (i.e., $\rho^* = 2$). This case hence constitutes a part of region (4) in Table 3.

(5) When $k < 4(2-\gamma)(1-\gamma)$, even with advanced sharing (i.e., $\rho = 2$), $c = \frac{1}{2k} > \frac{1}{8(2-\gamma)(1-\gamma)}$, so $q^*(\gamma, c) = 0$. In other words, even with advanced sharing, the entrant would still be unable to achieve a positive level of net profit, and hence would not enter the market in the first place. As a result, the incumbent remains a monopoly in equilibrium. This case hence constitutes a part of region (5) in Table 3. $\qquad\square$