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User preferences and strategic interactions in platform ecosystems

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Abstract

Research summary: User demand affects the emergence and growth of platform ecosystems through indirect network effects. But how do these effects play out in the strategies of platform providers and complementors as the ecosystem evolves? We study how user preferences for ecosystem innovativeness (complement novelty and quality) and ecosystem size (number of complementors/complements), and demand-based economies of scale, shape the strategic interactions between the platform provider and the complementors in the ecosystem. Using an analytical model, we identify the conditions that give rise to a trade-off between ecosystem innovativeness and size; when (and why) this trade-off generates a tension between value co-creation and appropriation among ecosystem participants; and the strategic implications for ecosystem competitiveness and for the different stages of the ecosystem's evolution.

Managerial summary: Managing complementors' incentives is critical for the success of a platform ecosystem. Such incentives may be offered not only for joining the platform, but also for contributing high-quality, innovative complements throughout the ecosystem's evolution. In this article, we show that demand-side economies of scale are the driving force of complementors' incentives, and hence the key success

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factor for platform strategies. The strength of user preferences ultimately determines whether a larger ecosystem can also be more innovative, in which case all ecosystem participants can gain; or if instead there is a trade-off between size and innovativeness, which could also lead to a tension between value co-creation and appropriation among the platform provider and its complementors. The different stages of the evolution of a platform ecosystem call for different strategies that adapt to the evolution of user preferences.

KEYWORDS

ecosystem innovativeness, indirect network effects, platform ecosystems, platform evolution, user preferences

1 | INTRODUCTION

The digitization of many sectors creates opportunities for firms to capture major benefits from demand-based economies of scale. Increasingly, firms are shifting toward demand-driven strategies to better respond to customer needs and intercept their different preferences for multiple, connected products, and services. Platform technologies, and their ecosystems of complementors, are a manifestation of this shift in the way firms are organizing to create greater value for end users. Moreover, because of the central role they now play in the economy (Stigler Committee on Digital Platforms, 2019; The Economist, 2014; The Financial Times, 2019), platforms have received significant attention from different streams of literature, with many studies (e.g., Armstrong, 2006; Caillaud & Jullien, 2003; Parker & Van Alstyne, 2005; Rochet & Tirole, 2006) emphasizing the importance of indirect network effects for cultivating user demand, especially for the initial formation of the ecosystem. Accordingly, platform ecosystems create more value for their users as they grow larger, and complementors have greater incentives to join and provide innovative complements.

However, users are interested not in the sheer number of complements per se, but in the benefits, they enjoy from using them with the platform, which can vary according to user preferences for complement quality (Cennamo, 2018; Cennamo & Santaló, 2019; Markovich & Moenius, 2009; Seamans & Zhu, 2014). Thus, the innovativeness (quality and novelty) of complements is just as important as their quantity, if not more so, in determining users' demand (e.g., Binken & Stremersch, 2009; Kim, Prince, & Qiu, 2014). Accordingly, the combined effect of user preferences for complement quantity and innovativeness on users' demand is an important driver of the value co-creation and strategic dynamics in platform ecosystems; yet, this effect and its underlying mechanisms are poorly understood. We put this aspect at the center of our analysis.

We characterize, respectively, the case in which users enjoy increasing benefits from an expanding ecosystem's innovativeness and size (i.e., increasing returns to scale on the demand) or the case in which the marginal benefits users enjoy from an additional increase in an ecosystem's innovativeness and size decrease (i.e., decreasing returns to scale on the demand). For instance, in the videogame industry, gamers can enjoy increasing benefits from a larger variety and higher quality of games available for a game console in the early stage of the console technology's evolution. As the technology evolves and the ecosystem grows larger, gamers will gain lower marginal value from the provision of additional games or additional enhancement of game quality—increases in game quantity/quality will increase the gamer's utility less than proportionally (i.e., at a decreasing rate). We study these scenarios through an analytical model and simulations, going beyond the initial formation stage of the platform ecosystem, which has been the focus of most literature on platforms, to consider the case of users' preferences changing throughout the evolution of the ecosystem.

We identify the conditions in which the relative strength of user preferences can generate a trade-off between the innovativeness of complements and the size of the ecosystem, and in turn create a tension between value creation and appropriation among ecosystem participants. Specifically, a trade-off emerges if there are decreasing returns to scale on the demand size, such that complementors that are part of a larger ecosystem invest less in innovativeness. When this happens, a larger ecosystem can still generate greater value for the platform provider, but this may come at the expense of complementors, leading to a tension between value co-creation and value appropriation for ecosystem participants. We also study how these forces affect complementors' decisions to join the platform, and further tease out the implications of our equilibrium analysis with comparative statics and simulation exercises. Figure S1 depicts the main structure and variables of our model.

Our theory implies that there is no single, fixed ecosystem design or platform strategy that can maximize complementors' incentives and boost value creation. Instead, there is a constant need to align complementors' incentives to the stage of the ecosystem's evolution, which is largely driven by user preferences. We discuss these implications at the tail end of the paper. Next, we briefly situate our contribution within the received (theoretical and empirical) literature before we introduce our conceptualization (and the analytical model) of the role of user preferences in platform ecosystems.

2 | THEORETICAL BACKGROUND

Early economics literature on "two-sided" markets (Armstrong, 2006; Caillaud & Jullien, 2003; Parker & Van Alstyne, 2005; Rochet & Tirole, 2006), and the more recent literature on platform ecosystems (Jacobides, Cennamo, & Gawer, 2018; McIntyre & Srinivasan, 2017; Parker, Van Alstyne, & Jiang, 2017), has highlighted the key role of indirect network effects for competitive advantage. Formal models suggest value-creating platform strategies (pricing, in particular) that aim at growing the platform ecosystem and solving the "chicken-and-egg" problem of attracting members from both sides of the market.[1]

[1]The classical problem is how to initially attract consumers to the platform before sufficient complements are available on it, and how to entice complementors to produce complements before there are sufficient users. A typical approach in the economics literature is to start with a utility (or demand) function for members on both sides that accounts for indirect network effects, then derive the number of members (that play the simultaneous coordination game, or arrive in a defined order) as a function of the fees charged by the platform, and finally compute optimal fees (e.g., Armstrong, 2006; Caillaud & Jullien, 2003; Hagiu, 2006; Rochet & Tirole, 2003, 2006). This approach offers deep insights and provides a fair description of two-sided markets such as payment systems (e.g., credit cards, PayPal), matching platforms (e.g., Match.com, InnoCentive), or pure marketplaces (e.g., eBay), where the sheer number of transactions represents the main source of platform value. However, it fails to capture the innovation dynamics and coordination problems typical of platform ecosystem contexts (Cennamo & Santaló, 2013, 2019; Jacobides et al., 2018).

However, in contexts in which platforms are not just marketplaces but offer the technological infrastructure for other firms to build their complementary innovations, the strategic problem of how to nurture the ecosystem of complementors and align their incentives to the ecosystem's objectives becomes central (Cennamo & Santaló, 2019; Jacobides et al., 2018; Rietveld, Schilling, & Bellavitis, 2019). In platform-based ecosystems such as video-games consoles, mobile devices, or media platforms, the novelty and quality of complements are just as important as their quantity, if not more so (e.g., Binken & Stremersch, 2009; Cennamo, 2018; Kim et al., 2014; Markovich & Moenius, 2009; Seamans & Zhu, 2014, 2017). In these cases, how can the platform provider foster innovativeness of the ecosystem? Is there a trade-off between innovativeness and size? When might a tension between value co-creation and appropriation among ecosystem participants emerge? The extensive review by McIntyre and Srinivasan (2017) highlights two critical aspects that merit deeper analysis: first, the structure and relative strength of indirect network effects, rather than their mere existence; and, second, the perspective of complementors and how platform providers can strategically manage them to align the ecosystem and hence induce greater participation and innovativeness (Adner, 2017; Jacobides et al., 2018).

In relation to the first aspect, we incorporate end users' preferences for ecosystem innovativeness (complement novelty and quality) and ecosystem size (number of complementors) into our analysis, looking at the combined effect on the users' demand. Departing from mainstream platform literature, we start from the premise that user's preferences and demand can change over time because of the evolving composition of the user base, where consumers with strong preferences for innovativeness might be more likely to join the platform at first, while later adopters will take into consideration the size of the ecosystem. For instance, in the video game context, early adopters of next-generation console platforms may value the quality of the new games available much more that their quantity, while later adopters also weigh the quantity of games available when making their decisions (e.g., Cennamo, 2018; Rietveld & Eggers, 2018). Yet, mainstream platform literature does not account for these multifaceted user preferences nor for the fact that network effects can accelerate or decelerate depending on the evolutionary stage of the platform market. Markovich and Moenius (2009) propose that indirect network effects can increase when the quality of complements increases, while Cennamo, Ozalp, and Kretschmer (2018) shows that there could be diminishing returns from further expanding the size of the ecosystem, particularly at later stages of the platform evolution (due to possible degrading effects on complement quality). User preferences may also change from stage to stage, to due to changes in the composition of user types (e.g., Cennamo & Santaló, 2019; Zegners & Kretschmer, 2017). Here, we take a more holistic approach, considering users' preferences and cases in which innovativeness and size can be mutually *reinforcing* (growth in users' demand accelerates due to increasing returns) or *weakening* (growth in users' demand decelerates due to decreasing returns). These effects can change over time and relate to the capacity of the ecosystem to generate value for users; ultimately, this depends on complementors' incentives to invest in enhancing the quality of their complements.

It remains unclear how strategies designed by the platform provider to attract more users and complementors impact the incentives of complementors (to invest and boost innovativeness) depending on users' preferences and, ultimately, how they impact the total value co-created in the ecosystem (Boudreau, 2010, 2012; Cennamo & Santaló, 2013, 2019; Ozalp, Cennamo, & Gawer, 2018; Rietveld & Eggers, 2018). We address this knowledge gap and extend previous research through a parsimonious analytical model.

3 | MODEL OF PLATFORM-BASED ECOSYSTEM

Our model has a number of key features that we explain verbally before we show its formal characterization.

Feature 1. There is a monopoly platform with a given core technology and ecosystem size.

Feature 2. Users are more willing to join a platform with a greater ecosystem size, and with cheaper and more innovative core technology and complements.

Feature 3. Users are more willing to buy a complement that is cheaper and more innovative relatively to other complements.

Feature 1 clarifies the boundary conditions of our analysis. Working with a monopoly platform we are able to clearly identify the strategic interactions between the platform provider and its complementors within the given ecosystem, abstracting from external market forces. Also, because our focus is on how to nurture the ecosystem after its formation, we relate our analysis to the moment when the platform provider has already made the choice about the technological functionalities of the core technology, and when the ecosystem has already been created and is fixed. Thus, as explained, our focus is on the platform provider's problem of keeping complementors' incentives for providing more innovative complements once the initial chicken-end-egg problem is solved and a platform market has emerged. We relax this assumption and endogenize (numerically) ecosystem size after having provided the key equilibrium results.

On the users' side, buying behavior can be understood as a two-stage process where users first purchase a core technology and then purchase complements (Hagiu, 2006), but when deciding whether to buy the core technology, users take into account the consumption benefits they will derive from the complements available for the platform (Cennamo, 2018; Clements & Ohashi, 2005; Corts & Lederman, 2009). Feature 2 accounts for the attractiveness of the platform due to ecosystem innovativeness and size. Feature 3 relates users' purchasing behavior once they have joined the platform to the characteristics of the complements available for the platform. Formally, we will model complementors' market shares in relation to how attractive their complements are compared to rivals'.

Whereas the first three features relate to factors that (at first) we keep as exogenous, that is, the core technology, users' preferences, and ecosystem size, the next two features clarify which are the strategic decisions that ecosystem participants make.

Feature 4. The platform provider sets the price of the core technology to users and the royalty fee to complementors.

Feature 5. Following the platform provider's choices, the complementors set the price and the innovativeness of their complements.

Feature 4 is standard in the literature (e.g., Anderson, Parker, & Tan, 2014; Rochet & Tirole, 2006). Feature 5 is a variant of the standard characterization of complementors' strategies in the literature; beyond the pricing strategy, it accounts also for the strategic choice that complementors make about the innovativeness of their products (which is a function of their innovation effort investments), in response to the platform provider's pricing decision. Since we have assumed that there is a monopoly platform in the market, complementors will compete for users within that platform (within-platform competition), aiming to attract more users through their (strategic and simultaneous) choices of the innovative efforts and the pricing of the complements. So, to sum up, the timing of decisions is as follows: the platform provider chooses the pricing strategy; then, the complementors decide the price and innovativeness of their complements; finally, users purchase the core platform and complements.

3.1 | Main variables and profits

Consider an ecosystem made of a platform provider and $m \geq 2$ complementors. The platform provider produces a core technology with certain technological functionalities and performance $T > 0$ that reflects the platform innovativeness at a marginal cost $C > 0$, and sets the price P to the users and the royalty R to the complementors. Complementor $i = 1,..., m$ exerts an innovative effort (that corresponds to the innovativeness of its complement) $e_i \geq 0$, incurring a cost that is assumed to be quadratic and equal to $\frac{c}{2}(e_i)^2$, $c > 0$, and it sells its complement at a price $p_i > 0$.[2] Given the demand of end users, D, and the fraction of users that purchase complementor i's product, that is, i's market share s^i, the profits of the platform provider, Π, proceed from (the sum of) the revenues generated from the sales of the core technology to users and the royalties collected from the complementors, net of the cost of producing the core technology, and write as

$$\Pi = [P - C + R]D, \tag{1}$$

whereas complementor i's profits, π^i, generate from the revenues from selling its complement, net of the royalties paid and the cost of its innovative effort, and write as

$$\pi^i = (p_i - R)s^i D - \frac{c}{2}(e_i)^2. \tag{2}$$

The functions D and s^i, $i = 1,..., m$, admit first, second, and cross-order derivatives, and guarantee internal solutions for the formal problems studied below. Moving beyond these general properties, in order to solve our model, we make additional assumptions and specify the functions D and s^i, as explained next.

3.2 | Formulating the platform-based ecosystem

In reference to the main features described above, the platform demand D increases if users can buy a cheaper and better core technology, such that D increases with a lower price P and a greater innovativeness T. Also, D is greater if users can find cheaper, better, and more complements, such that D increases with lower prices p_i and greater innovativeness e_i, $i = 1,...,m$, and with greater size m. Finally, i's market share s^i increases when lowering the price p_i and increasing the innovativeness e_i relatively to the other complementors, in line with a share-attraction framework that we describe below. Intuitively, we simply assume here that a complementor's capacity to gain a larger market share within the platform ecosystem depends on the relative attractiveness of its complement.

To model explicitly these effects, we start by defining the notion of *attractiveness* in relation to the combination of price(s) and innovativeness of the platform, $A = TP^{-\sigma}$, of the individual complementor, $a_i = e_i p_i^{-\delta}$, and of the overall ecosystem, $a = \sum_{j=1}^{m} a_i$, where the parameters σ, $\delta > 1$ correspond to the price elasticities. As for the specification of demand D, if the core

[2]A fixed cost of production and a zero marginal cost of replication is a typical cost structure for information goods. Here the fixed cost is determined by the innovative effort. The quadratic form captures the idea that it becomes increasingly more costly to raise product quality.

technology is a stand-alone technology, one would expect the baseline demand to correspond to its technology's attractiveness, $D = A^{\omega} = (TP^{-\sigma})^{\omega}$, $\omega > 0$: the parameter ω captures the importance that users attribute to the attractiveness of the core technology. In a two-sided market, demand should reflect the indirect network effects. Thus, we augment the demand to account for users' greater willingness to join a platform with a larger ecosystem, such that $D = (TP^{-\sigma})^{\omega} m^{\rho}$, $\rho > 0$; the parameter ρ captures the strength of the effect of size m due to agglomeration around the core technology—that is, the marginal impact that one extra complement available for the platform has on the platform demand by users. This specification accounts for the size effect, but does not account for users' actual benefits from consuming the complements. Therefore, we augment further the demand function to account for the innovativeness effect, assuming that the users are more willing to join the platform if the overall ecosystem is more attractive, that is, if there are cheaper and better complements. Accordingly, following Bell, Keeney, and Little (1975), we relate D to the attraction a of the complements. We assume that the demand D corresponds to the attractiveness of the core platform technology augmented by the size of the ecosystem and its attractiveness; specifically:

$$D = A^{\omega} m^{\rho} a^{\theta}. \tag{3}$$

This function, which is a standard Cobb–Douglas specification, implies that there are complementarities among the attractiveness of the platform A, the attractiveness of the ecosystem a, and the ecosystem size m. Karnani (1985) argues that, because the marginal utility of the end users from more, cheaper, and better products is decreasing, D can be assumed to be increasing and concave in a, with $\theta \in (0, 1]$. The two parameters θ and ρ then capture the strength of the effect of innovativeness and size, and their sum has a specific economic meaning. The case $\theta + \rho < 1$ corresponds to the case of decreasing returns to scale, and we will refer to this case as weakening network effects. Following the same logic, we refer to the case $\theta + \rho > 1$ as reinforcing network effects. For completeness, the case when $\rho = 1 - \theta$, such that $\theta + \rho = 1$, corresponds to constant returns to scale.[3] We impose the conditions $\omega\sigma > 1$ and $\delta\theta > 1$, that is, that the price elasticities be greater than 1, in order to have internal solutions for our model.

Next, we define the complementors' market share. The attraction theorem first formulated in Bell et al. (1975) implies that a complementor's market share (within the platform market) will be defined by the attraction of its complement, a_i, relative to the overall attraction of all the complements available on the platform, such that

$$s^i = \frac{a_i}{\sum_{j=1}^{m} a_j} = \frac{e_i p_i^{-\delta}}{\sum_{j=1}^{m} e_j p_j^{-\delta}}. \tag{4}$$

This equation implies that (a) no user purchases a complement i whose attraction is zero, thus, users buy only complements that offer some level of consumption benefits (either because of lower price or greater innovativeness); (b) two complementors i and j selling equally attractive complements have the same market share, such that complementors do not hold sources of market power other than those related to their complement attractiveness; and (c) that equally

[3]We could also write $\rho = r + 1 - \theta$, such that $r \gtreqless 1$ would correspond to decreasing, constant, and increasing return to scale. In our specification, we maintain ρ and θ as independent as to identify more clearly the effect of innovativeness and size.

attractive complements i and j are affected in the same way by changes caused by a third complement k; if an increase in attractiveness of complement k will erode the market appeal of complement i by a certain factor, it will erode complement j's market appeal by the same factor. This share-attraction framework captures the local market power when, for instance, each complementor positions differently along the map of consumer preferences and becomes a leader in a given product niche. This specification is in line with the recent empirical findings showing that complements of very high-quality captures most of the sales within a platform (Binken & Stremersch, 2009; Clements & Ohashi, 2005), and that complements tend to be to greater extent substitutes within a product niche but less so across product niches (Boudreau, 2012; Venkatraman & Lee, 2004), such that complementors may capture at most some local (i.e., within the product niche) monopoly power.

4 | MAIN FINDINGS FROM THE MODEL

We solve for the optimal pricing strategy, P^* and R^*, chosen by the platform provider when taking into account the complementors' responses, and for the equilibrium values for the complementors. Since we assume all complementors are symmetric, we focus on symmetric equilibrium, that is, the situation where the complementors make equal pricing and investment choices, p^* and e^*.[4] For ease of exposition, the formal proofs and the complete formulas of the equilibrium values appear in Data S1.

Our first proposition characterizes the platform's pricing strategy for users and complementors respectively, where

$$P^* = \frac{\sigma\omega}{\sigma\omega + \delta\theta - 1} C, \tag{5}$$

and

$$R^* = \frac{2\delta\theta - 1}{2(\sigma\omega + \delta\theta - 1)} C. \tag{6}$$

Proposition 1 *In equilibrium, when the platform attraction (ω) increases and the ecosystem attraction (θ) decreases, the platform provider raises the price to the end users and decreases the royalty fee to the complementors.*

Proposition stresses the importance of users' preferences clarifying how the platform provider adjusts the pricing in relation to the importance of platform's and the complements' attraction (see Figure 1).[5] When users value more the attractiveness of the core technology,

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[4]Although there might be also asymmetric equilibria, it is virtually impossible to explicitly compute them due to the nonlinearity in the best-response functions, and to the fact that we allow for (a large number of) complementors that control two variables at once.

[5]In all figures of the paper, we represent the equilibrium values corresponding to the specifications $\sigma = \delta = 2$, $\omega = 1$, $c = 0, 1$, $C = 10$, $T = 1{,}000$.

such that ω increases, the platform provider charges more the end users by increasing the price P^*, while eliciting complementors' participation to the ecosystem through lower royalties R^*. Contrary, when users value more the attractiveness of the complements, such that θ increases, the platform provider stimulates users' platform adoption by lowering P^*, and then recovers profits by raising the royalty fees for complementors. Intuitively, because end users derive greater benefits from consuming the complements associated with the platform when θ increases, there is greater alignment between users' interests and complementors' incentives, and thus, all else equal, the platform provider does not need to offer extra inducements to stimulate their participation. While previous research has emphasized the role of pricing as coordination mechanism between users and complementors to solve the initial chicken-end-egg problem, the intuition here is that such inducement is important also once the market and

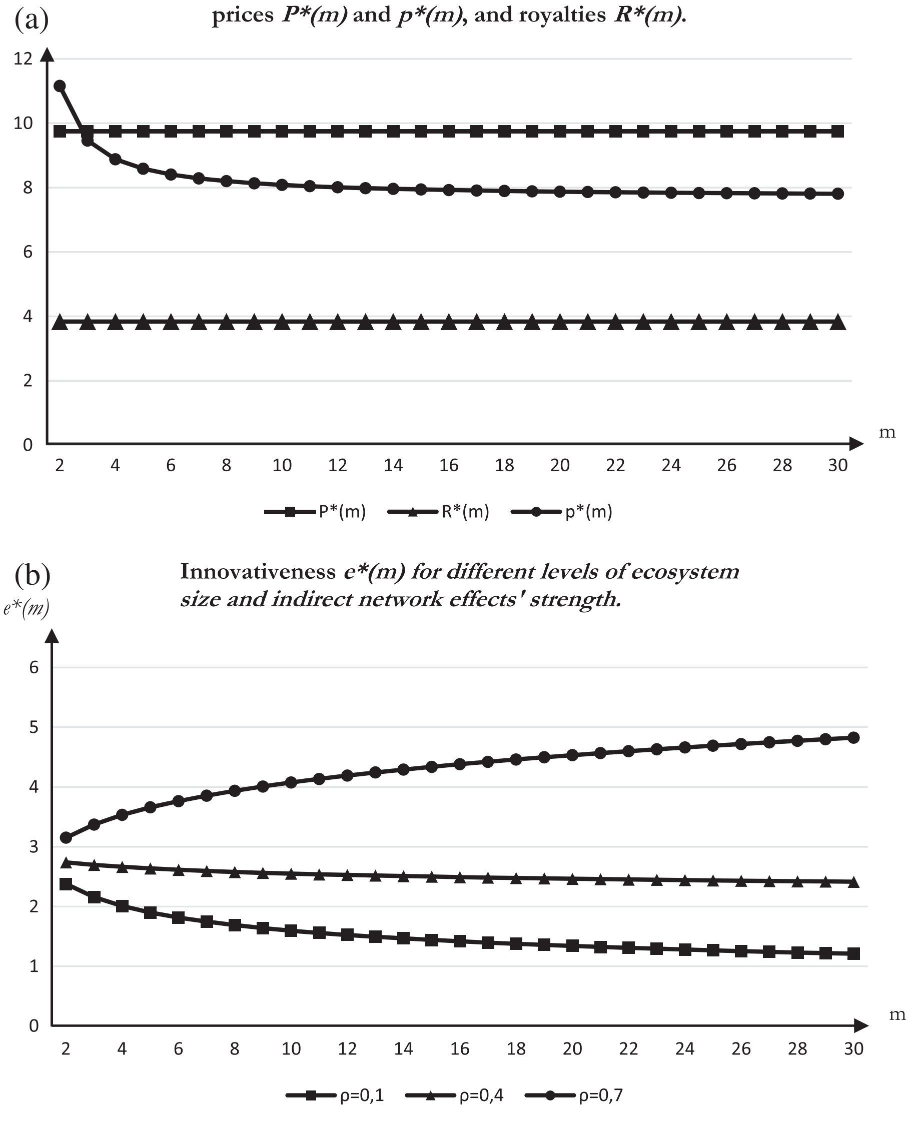


FIGURE 1 Platform provider's and complementors' equilibrium choices as a function of ecosystem size m

ecosystem are formed to stimulate further demand and thus transactions within the platform. In other words, once the platform is formed, these platform strategies are still important to align complementors' incentives.

Proposition 2 *In equilibrium, as the platform ecosystem (m) grows, the complementors lower the price of the complements, and, under reinforcing (weakening and modest) network effects, they invest more (less) in innovativeness.*

Proposition reveals that the impact of ecosystem size m on complement innovativeness depends on the strength of users' preferences for innovativeness and size (Figure 1). When the number of complements/complementors increases, there is greater competition for users, but also an increase in demand due to the agglomeration effects (m^{ρ}) and the greater attractiveness of the ecosystem (a^{θ}), and there are two different scenarios. With reinforcing network effects, $\rho + \theta > 1$, the competition effect is dominated by the greater demand. In this case, a larger number of complementors will stimulate higher levels of complement innovativeness. Since complement price always goes down with an increase in ecosystem size (more competition from complementors has always a negative effect on price), we observe a negative correlation between price (which goes down) and innovativeness (which goes up) when the platform ecosystem gets larger. However, with weakening and modest network effects,[6] complement price and innovativeness can correlate positively, and both decrease as the platform ecosystem gets larger. Intuitively, the additional available complements increase the demand of the platform less than proportionally; this low increase in demand might not sufficiently compensate for the greater competitive intensity associated with the larger ecosystem. Complementors will thus capture less and less value from their investment in innovativeness as the ecosystem gets larger, whereas the platform provider's profits increase with size (Figure 2). These aspects are investigated at length in the next section.

5 | ANALYZING THE COLLECTIVE CREATION OF VALUE

The comparative statics and simulation experiments of this section seek to reveal the role played by the users' preferences for innovativeness and size and the relationships among the equilibrium variables. The emphasis in this section is on how the key parameters of our analysis relate to the composition of users with different preferences, following, for example, the intuition in Zegners and Kretschmer (2017) in the context of the gaming industry.[7]

5.1 | Endogenous ecosystem size

As a first additional step in our analysis, we investigate how users' preferences determine the ecosystem size following complementors' optimal choices. So far, in deriving our results, we considered m, the size of the ecosystem, as given and exogenous, which enabled us to single out

[6]See the Data S1 for the exact threshold of the strenght of indirect network effects.

[7]In Zegners and Kretschmer (2017), low-valuation consumers are relatively more frequent in the Christmas season, which explains consoles and games bundling strategies.

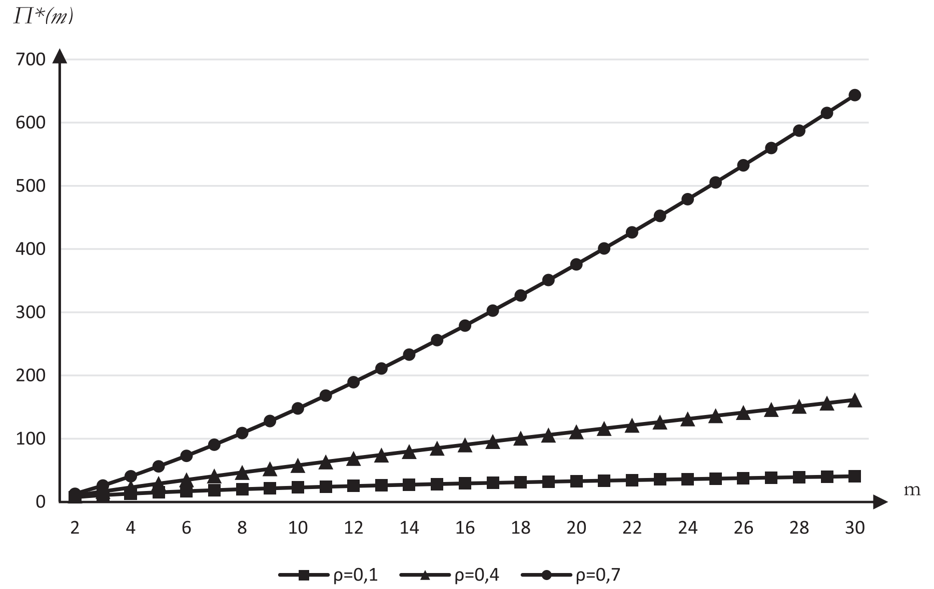


FIGURE 2 Platform provider's equilibrium profits *Π*(m)* for different levels of ecosystem size and indirect network effects' strength. *Note*: Figures 1 and 2 depict the equilibrium values corresponding to θ = 0.525

the optimal strategies of the different ecosystem participants and isolate the underlying mechanisms. We now relax this exogeneity assumption and (numerically) calculate the equilibrium size of the ecosystem for changing values of θ and ρ, assessing how complementors' profits change in different scenarios.

We endogenize the ecosystem size considering the case when a population of $M = 250$ complementors decide to join the platform ecosystem on the basis of the expected equilibrium profits.[8] Because of the interrelation of the key parameters of the model, we cannot always work out the equilibrium size, m^*, in a closed-form solution; therefore, we compute m^* numerically. Starting from the equilibrium strategy solutions in Propositions and , we relate m^* to a zero-profits condition in the presence of entry costs $\nu \geq 0$. For the effect of ecosystem size, we consider values $\rho \in [0.05; 0.15; 0.25; 0.35; 0.45; 0.55]$, whereas for the effect of ecosystem innovativeness we consider the two alternative cases when consumers value highly innovativeness ($\theta = 0.975$) and when consumers have more limited valuations of innovativeness ($\theta = 0.525$).

When θ and ρ are small enough, that is, when $\theta + \rho < 1$, there are weakening network effects; complementors' profits decrease (see the cases for $\rho \leq 0.45$ and $\theta = 0.525$ in Figure 3a) and therefore, there is a limit to entry and participation in the ecosystem. Depending on the entry cost, there is a unique equilibrium level m^*: $\pi^*(m^*) - \nu = 0$. Here, the strategic problem for the platform is one of ecosystem structure alignment (Adner, 2017; Jacobides et al., 2018); that is, aligning incentives of complementors such to induce them to keep investing in innovative complements and create value for the overall ecosystem despite the competitive pressure coming from a larger ecosystem. In fact, in this context, there will be a maximum ecosystem

[8]We set the population of complementors M to a maximum number for the sake of the computational exercise; the level one chooses is irrelevant for the results we obtain. Also, in this exercise, we do not actually account for timing of entry of the complementors. We do so in the next section when we simulate the platform evolution.

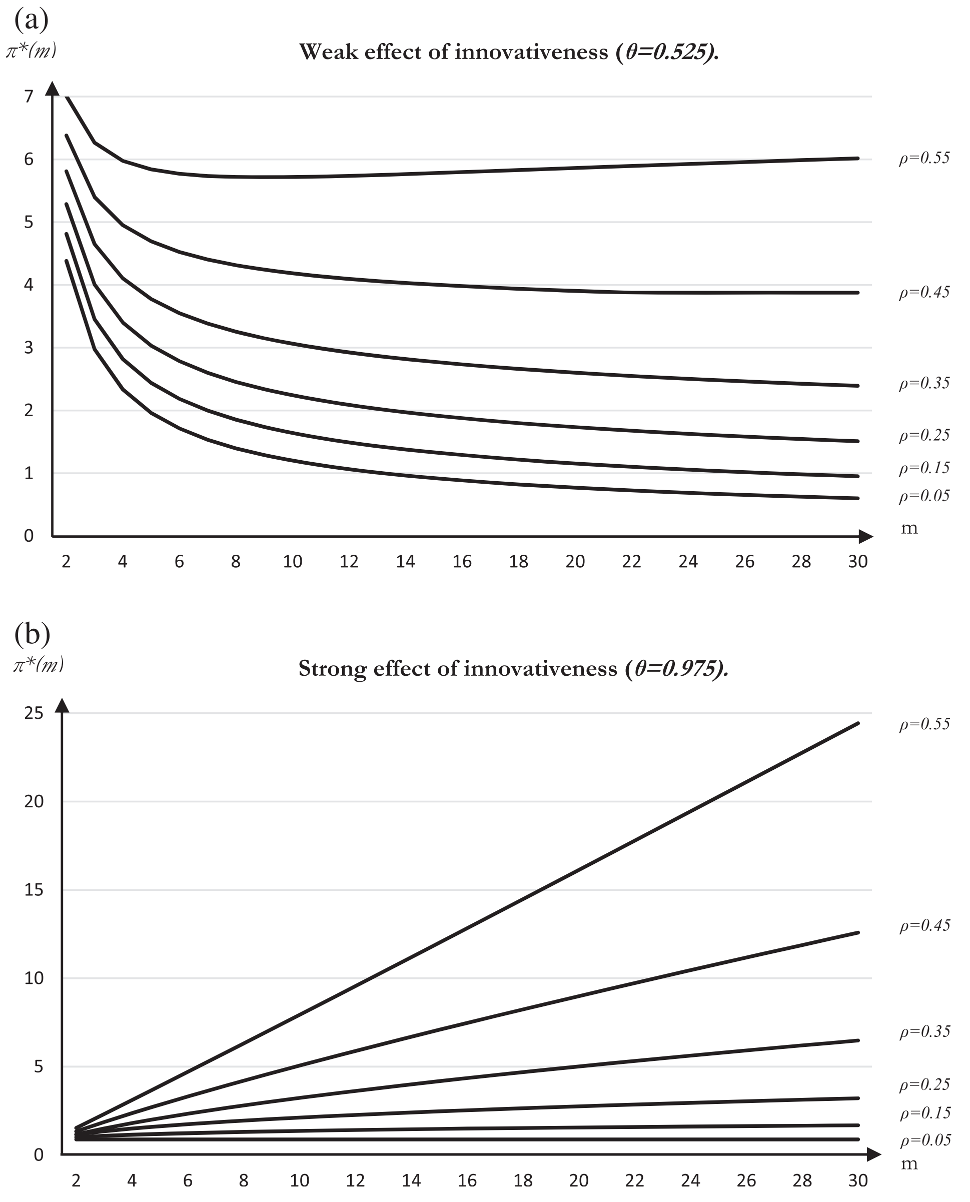
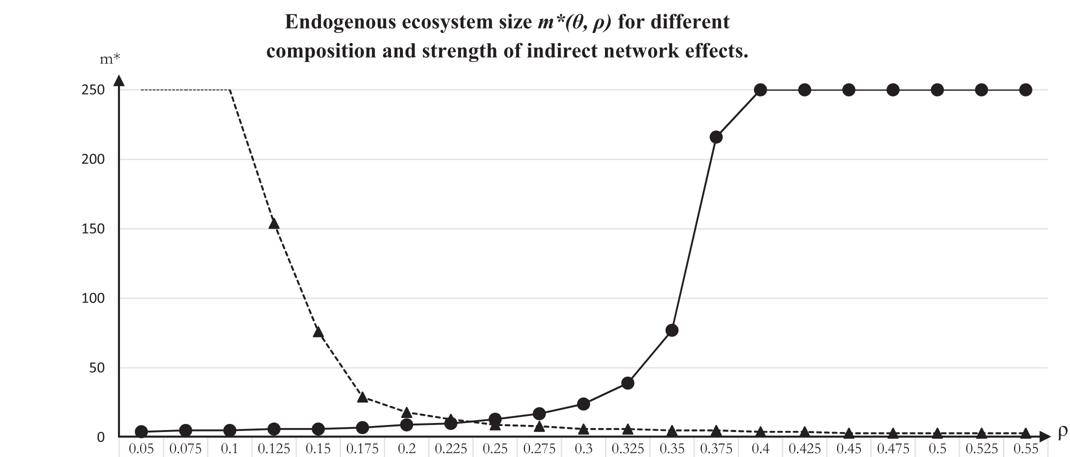


FIGURE 3 Complementors' equilibrium profits as a function of ecosystem size m, for different levels of indirect network effects

size past which developers would no longer make profits and have no incentives to participate in the ecosystem. Since the platform is still benefiting in terms of profits from a larger ecosystem, and might be interested to grow it, the key strategic problem becomes how to grow the ecosystem while keeping complementors' incentives aligned.[9]

[9]Platform providers can resort to different mechanisms such as lowering the cost of entry and of innovation for complementors through innovation on the platform technological architecture and technological support (e.g., Anderson et al., 2014; Ozalp et al., 2018), through direct marketing support (e.g., Rietveld et al., 2019) or through sweat-deal arrangements with select complementors such as exclusivity membership (Cennamo & Santaló, 2013).



	0.05	0.075	0.1	0.125	0.15	0.175	0.2	0.225	0.25	0.275	0.3	0.325	0.35	0.375	0.4	0.425	0.45	0.475	0.5	0.525	0.55
θ=0,525	4	5	5	6	6	7	9	10	13	17	24	39	77	216	250	250	250	250	250	250	250
θ=0,925	---	---	---	154	76	29	18	13	9	8	6	6	5	5	4	4	3	3	3	3	3

FIGURE 4 Endogenous ecosystem size $m^*(\theta, \rho)$ for different composition and strength of indirect network effects

When θ and ρ are large enough, that is, when $\theta + \rho > 1$, there are reinforcing network effects; complementors' profits increase (Figure 3b). This has two implications. First, the nature of the (symmetric) equilibrium changes. That is, now instead of trying to induce entry by the maximum number of complementors possible for a given entry cost, a minimum (expected) ecosystem size is needed to trigger increasing complementors' participation in the platform ecosystem, resulting in positive (and increasing) profits. Second, there are multiple equilibria, with possibly one (symmetric) equilibrium where nobody participates into the platform ecosystem; that is, a failure of coordination due to complementors' negative expectations about the growth of the platform ecosystem. Thus, the major problem for the platform provider is to coordinate adoption by users and investment/participation by the minimum threshold that is needed to induce entry by the complementors, such that the platform can take off (e.g., Caillaud & Jullien, 2003). Once this process starts, that is, when the complementors have the right expectations about the growth of the ecosystem, reinforcing network effects will lead to the winner-take-all scenario discussed in the early literature on platforms.

Figure 4 shows graphically these results (for the sake of the numerical exercise, we have set the entry cost $v = 2$); specifically, the maximum m for the scenario of weakening network effects for different values of ρ and for $\theta = 0.525$, and the minimum m that is needed in the scenario with reinforcing effects for different values of ρ and for $\theta = 0.975$. For example, when $\rho = 0.3$, from the table in Figure 4 we can see that if $\theta = 0.525$, then $m^* = 24$ is the maximum size such that complementors make non-negative equilibrium profits; instead, if $\theta = 0.975$, $m^* = 6$ is the minimum size that is needed such that complementors make non-negative equilibrium profits. Figure 5a,b show instead the equilibrium values of the price p^* and innovativeness e^* that correspond, respectively, to the values of m^* for the case of weakening effects, and to $m = M = 250$ for the case of reinforcing effects (in the equilibrium when all complementors join the platform).

It is interesting to note that in both scenarios, an increase of the effect of size generates a win–win–win situation for the users, the complementors, and the platform provider. Thus, with reinforcing effects, both the complementors and the platform provider obtain greater profits as

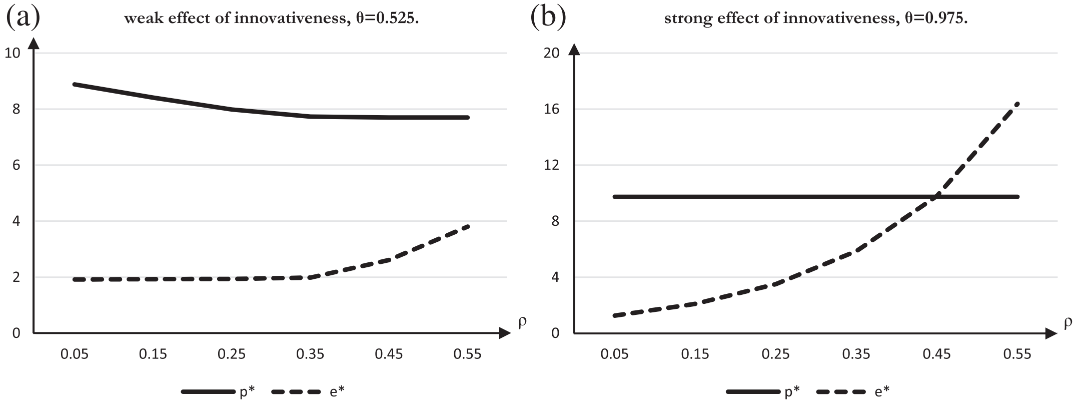


FIGURE 5 Complementors' equilibrium choices *p** and *e** corresponding to the endogenous size m*, for different composition and strength of indirect network effects

ρ (and therefore m^*) increases (Figures 2 and 3b). At the same time, users benefit from greater innovativeness that correspond to constant prices (Figure 5b). With weakening effects, complementors always obtain zero profits in an equilibrium of free entry, whereas the platform provider obtains greater profits as ρ increases; as for the users, they obtain again more benefits stemming from a combination of lower prices and greater innovativeness (Figure 5a).

5.2 | Platform evolution

The analysis above shows that depending on the strength of users' preferences for size and innovativeness of the ecosystem, and whether there are reinforcing or weakening network effects, the platform provider may face distinct scenarios. This also has distinct implications for the nature of the strategic ecosystem orchestration process (coordination of adoption vs. alignment of incentives). User preferences can vary across sectors (McIntyre & Srinivasan, 2017) and across platforms in the same sector due to market segmentation and differentiation among platforms (e.g., Bresnahan, Orsini, & Yin, 2015; Cennamo & Santaló, 2013). Moreover, as mentioned before (see Zegners & Kretschmer, 2017), the composition of user preferences can also change over time due to a seasonal demand. Here we emphasize that the strength of users' preferences can vary indeed also along the stages of platform evolution, for different reasons. Cennamo et al. (2018) and Rietveld and Eggers (2018) advance that, in fact, platform user preferences can change along the platform life cycle because of the different composition of users. In the early stages, consumers with strong preferences for innovativeness will be more likely to join the platform whereas later platform adopters will tend to weigh more the size of the ecosystem in their consumption decision (Rietveld & Eggers, 2018). Thus, complement innovativeness relative to variety might be more important in the early stages to grow the platform and the volume of business done in the platform ecosystem (e.g., Cennamo, 2018). Binken and Stremersch (2009), studying adoption rate of videogaming platforms as a function of high-quality, innovative games, referred to as "superstars", find that these superstars are what drives most of platform adoption decisions by customers. This suggests that gamers have strong preferences for innovative games; that is, θ is high in this case. Thus, depending on the composition of users at a given point in time and their preferences for innovativeness and size, the strength of network effects at the ecosystem aggregate level will change. Results from these studies delineate one specific evolutionary path, with reinforcing network effects in the early stages of the platform ecosystem, and weakening network effects later on, in the mature stage, as the ecosystem grows larger.

Following, we simulate this specific evolutionary path to analyze how changes in user preferences over ecosystem innovativeness and size might affect the strategic choices of the platform and complement providers along the platform evolution, and the overall value co-created in the platform ecosystem. Whereas in our analysis of the equilibrium size we have implicitly assumed that complementors make simultaneous entry decisions, we now make the more realistic assumption that entry happens over time, under the condition that the equilibrium profits remain positive, following changes in users' preferences. Specifically, we simulate patterns $\theta(t)$, $\rho(t)$, and $m(t)$ such to reflect the specific evolutionary path suggested in the literature, while assuming that entry costs remain negligible.[10]

To simulate the evolution of users' preferences, that is, the changing nature and strength of the indirect network effects, we basically extend the comparative statics exercise by means of the ad-hoc specifications $\theta(t)=\frac{1}{1+\alpha t}$, $\alpha>0$, and $\rho(t)=\frac{1}{2}(1+0.1t)$. Additionally, we account for how quickly the switch in preferences following the changes in the composition of users happens over time, considering the case when θ decreases more slowly ($\alpha = 0.1$) or more quickly ($\alpha = 0.2$) over time.

With these experiments, we obtain the (equilibrium) strategic choices of the complementors, $p^*(t)$ and $e^*(t)$, and the resulting (equilibrium) profits for the complementors and the platform provider, depicted in Figures 6 and 7.

From Figure 6a, we can note that complements' price decreases over time and tends to stabilize; a finding in line with recent studies' results (e.g., Clements & Ohashi, 2005; Rietveld & Eggers, 2018). However, and more interesting, we can also observe in Figure 6b that complementors' innovative efforts increase in the initial stages, but then decrease as the network effects diminish, passing from reinforcing to weakening. Thus, the trade-off between ecosystem size and ecosystem innovativeness is most prominent in the later stages of platform evolution.

This is somewhat in contrast to the implications of mainstream platform literature in economics. Because these studies do not account for consumers' preferences for innovativeness, the strength of network effects are somehow implicitly related to the stage and size of the platform market evolution. Thus, complementors' incentives to enter and invest in complements are assumed to grow over time with the growth of the platform market, while they are constrained in the early stages. However, this fails short in explaining why, in fact, complementors do invest in high-quality, innovative complements for the platform in the early stages when there is only a limited user base (e.g., Binken & Stremersch, 2009; Cennamo, 2018; Rietveld & Eggers, 2018). Our simulation analysis indicates that this is due to reinforcing network effects being present at this stage because of early user adopters' high preferences for innovativeness, which will make it profitable to participate in the ecosystem. We can observe, in fact, that prices and efforts are greater along the whole stages of platform evolution when, over time, users

[10]We replicate our analysis over $T = 50$ periods, with complementors entering gradually over time because of expected positive profits (in equilibrium); we use the ad-hoc specification $m(t) = 10 + 5\,t$. Following our discussion, we impose that there are reinforcing effects in the initial stages, followed by weakening effects, such that $\theta(t) + \rho(t) > 1$ for $t<\bar{t}$ for $t>\bar{t}$ the patterns $\theta(t)$, $\rho(t)$, and $m(t)$, we can simulate the changes in the platform's and complementors' strategies along the different stages of this specific platform evolution, simply plugging $\theta(t)$, $\rho(t)$, and $m(t)$ into the equilibrium values of our model in Propositions 3 and 4.

(a)

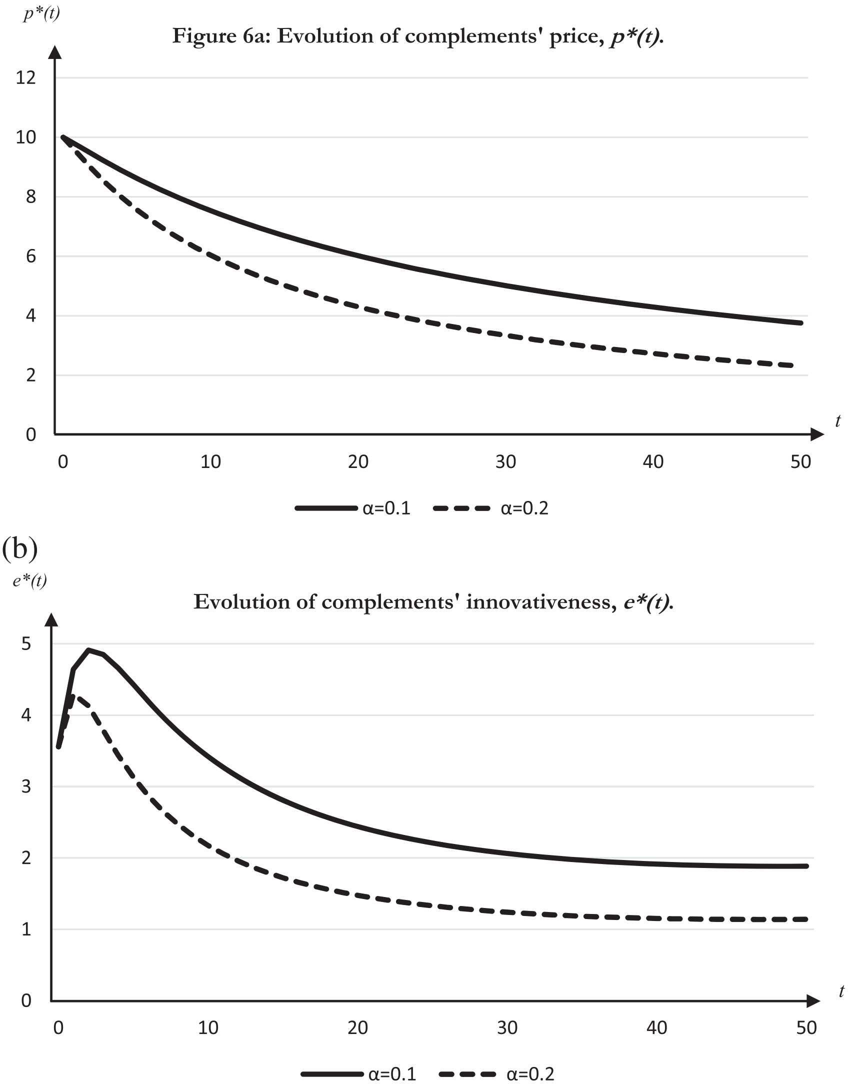


FIGURE 6 Evolution of ecosystem's characteristics for a pattern with high ($\alpha = 0.1$) and low ($\alpha = 0.2$) preferences for innovativeness

value more innovativeness ($\alpha = 0.1$). This also implies that the trade-off between innovativeness and size is more severe when users value innovativeness less.[11]

Figure 7 shows the changes in the total value jointly created in the ecosystem following changes in consumer preferences, and how this value is split between the platform

[11]This, for instance, might support the finding in Zegners and Kretschmer (2017) that console makers offer more console-game bundles when low-valuation users are more frequent. Although the problem and the mechanism studied by Zegners and Kretschmer (2017) is different from what is studied here, our intuition is that bundling might be a way to contrast the more limited incentives of complementors to invest in complements and participate in the ecosystem (absent any intervention of the platform provider) because of the lower profitability.

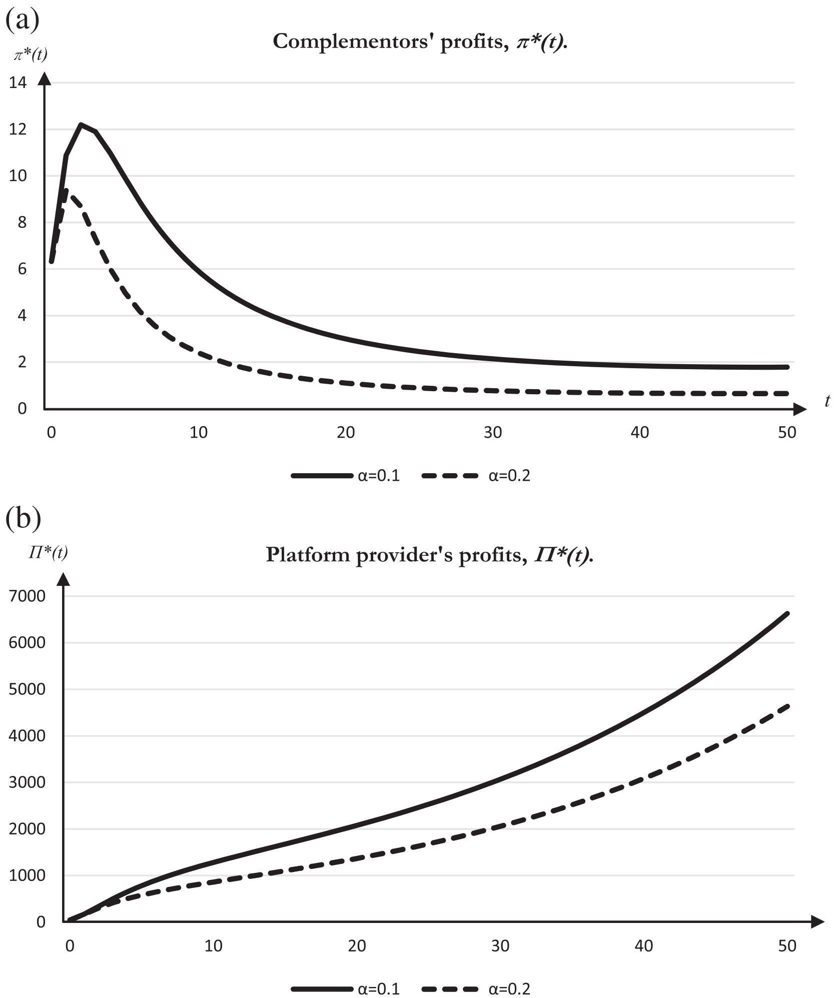


FIGURE 7 Evolution of ecosystem's participants profits for a pattern with high ($\alpha = 0.1$) and low ($\alpha = 0.2$) preferences for innovativeness

provider and the complementors. Complementors' profits follow the classical bell-shaped pattern over the life-cycle (see Figure 7a); they increase quickly when there are reinforcing network effects, and then decrease as the overall network effects diminish (which in this particular evolutionary path happens at later stages of platform evolution). In contrast, Figure 7b shows how the platform provider's profits increase steadily over time. This reveals the emergence of the tension between value co-creation in the ecosystem and its appropriation for the intermediate stages of the platform evolution; complementors' profits grow for the first few periods but then decrease, whereas the platform's profits keep on growing and if anything, they accelerate. Finally, also note that profits for all the participants are greater when the users maintain a stronger preference for innovativeness. This also implies that the tension between value co-creation and value appropriation between the platform provider and complementors is more severe when users value innovativeness less.

5.3 | Coordination versus alignment problem and the basis for platform competition

The different results of the simulations analyzed above can allow us to derive also some implications for platform competition; specifically, when we would expect one large, dominant platform to emerge and when we can have multiple competing platforms coexisting in the market, and how users' preferences can affect platform competition.

Consider first the case of reinforcing network effects. According to the findings above, both the platform provider and the complementors enjoy increasing profits as the ecosystem grows. There is alignment among ecosystem participants, and complementors have incentives to participate in a platform with a larger ecosystem, suggesting a winner-take-all outcome: Eventually the platform with the largest ecosystem will win the market and become monopolist, attracting all the complementors. In this case, the results from our analysis of the monopoly platform (with a given size) presented above would apply. The main strategic problem for the platform provider in this case is attracting enough complementors, and in a short time, such to reach the minimum threshold of ecosystem size to start the increasing returns process of the indirect network effects and thus be able to attract more and more complementors, up to the maximum available number. This is in line with the standard chicken-and-egg coordination problem between the two sides of the market largely discussed in the literature (e.g., Caillaud & Jullien, 2003; Hagiu, 2006; Parker & Van Alstyne, 2005; Rochet & Tirole, 2003, 2006). From Figures 3 and 4, we can notice how this problem is particularly acute for small values of ρ (despite θ being high). This might be the case of the early stage platform life cycle discussed in the literature (e.g., Binken & Stremersch, 2009; Cennamo, 2018; Rietveld & Eggers, 2018) where early user adopters tend to have strong preferences for innovative, high-quality complements (i.e., high θ valuation) but limited preferences for size and variety. In such case, the platform would need to attract to its ecosystem all of the complementors available in the market to jump-start the increasing returns process and tip the market toward its platform. This might prove a particular severe coordination problem; one of the possible outcomes can be that no complementor will join the platform at this stage (as per one of the equilibria we identified). However, when the composition of users changes and ρ increases, the minimum threshold of complementors needed to tip the market toward the platform will lower quickly.

In the case of weakening network effects, complementors' profits will decrease with a growing ecosystem size. In fact, it appears that most studies have implicitly restricted their analysis of platform competition to the cases of constant or reinforcing network effects, leaving out the case of competition under weakening effects. But this is also the most interesting case from a strategic point of view, given the value co-creation and appropriation tension. Accordingly, there could be an ecosystem size past which complementors would incur in losses, and have no incentives to participate in the ecosystem, thus leaving room for other platforms. With more platform ecosystems available for complementors, some of them might join ex novo or even migrate from the larger platform where they make low profits to a platform with a smaller ecosystem, where they can possibly make positive profits.

Understanding how the insights from our model can be extended to the case of competition across platforms is a challenging exercise because, in addition to the vertical and horizontal interactions analyzed before, a comprehensive analysis should account also for the strategic interactions among platforms who compete for the end users as well as for the complementors, and among the populations of complementors on each platform, because they collectively determine the overall attractiveness of the platform through their choices of the price and innovativeness of the complements. We discuss here our intuition in contrast to our monopoly platform model's results.

Consider first the platforms' pricing decisions. When competing to attract the complementors, who can now choose among different platforms, platform providers are pressured to lower royalties to guarantee greater profits for their complementors; in turn, platform providers might raise the price of the core technologies for end users. To better understand these effects, we can make the comparison with the case of monopoly platform in our formal model. The value of the platform under monopoly depends exclusively on its core technology functionalities and the (absolute) level of attractiveness of its ecosystem (which depends on its innovativeness and size). The platform provider can thus induce complementors to produce complements for the platform by lowering the price of the core technology for final users, as to attract a large, increasing numbers of users. However, in the case of platform competition, platform providers should also maintain a higher level of attractiveness (for end users and complementors) vis-à-vis competing platforms. They should then offer stronger incentives to attract complementors, who decide which platform to join, and enhance the attractiveness of the platform ecosystem relative to competitors. They can accomplish this by charging lower royalties as competition across platforms intensifies, and might charge end users more (compared to the case of platform monopoly).

This change in pricing in the presence of platform competition might be needed also to compensate complementors from intensified cross-platform competition that can lead to lower complement prices (and profits). Again, a contrast with the monopoly case helps to understand the intuition. While with a monopoly platform complementors only face competition from other complement providers within the ecosystem, now they also face competition from offerings of competing platform ecosystems. As a collective, complementors must compete also with rival platform ecosystems to increase the platform ecosystem's attractiveness for end users relative to rivals. In this regard, platform competition creates greater alignment between the platform and its complementors. However, complementors' innovative effort might also reduce due to platform competition. Because of the lower complement prices, their profits under enhanced cross-platform competition will be lower, also because of the lower marginal effect that increasing innovativeness has on attracting end users. Thus, complementors have lower incentives to invest in complement innovativeness. Therefore, on one hand, compared to the case of monopoly platform, increasing cross-platform competition can induce greater alignment between the platform provider and complementors and lessen the value co-creation and appropriation tension. On the other hand, given its negative impact on complementors' incentives to invest in more innovativeness, greater cross-platform competition can pose a more acute trade-off between ecosystem size and innovativeness. Thus, whereas with a monopoly platform the trade-off between size and innovativeness also leads to a tension between value co-creation and appropriation between ecosystem participants, with platform competition the trade-off and the tension we identified might be decoupled from each other. These considerations reveal the intricacy of the relationship between (within- and cross-platform) competition and the value co-creation and appropriation tension among ecosystem participants.

6 | DISCUSSION AND CONCLUSION

Mainstream theory about two-sided platforms has abstracted away from consumers' preferences about complements' attributes other than their sheer number. Thus, it has mainly focused on the link between platform value and the number of users and complementors joining the platform on each side. As a result, the nature of the indirect network effects, and the possibility that their strength may vary throughout the different stages of the platform evolution, have gone largely unexplored (McIntyre & Srinivasan, 2017). Our model accounts for the strength of users' preferences for ecosystem innovativeness and size, and incorporates this distinction into the (vertical and horizontal) strategic interactions among the participants of a platform's ecosystem. The comparative statics and simulation exercises of platform evolution (incorporated in the equilibrium analysis) provide further insights into effective platform strategies. From a theoretical point of view, a key learning point of our model is that platforms' and complementors' strategies, the potential trade-off between ecosystem size and innovativeness, and the potential tension between value co-creation and value appropriation, all largely depend, both qualitatively and quantitatively, on users' preferences for ecosystem innovativeness and size.

Our propositions and findings highlight the importance of digging deeper into the different sources of indirect network effects, identifying and contrasting contexts in which complements' innovativeness can be relatively more important than size for users (e.g., video games, smartphones, newspapers, shopping malls) compared with opposite cases (e.g., matching web sites, payment systems, auction platforms) and also in relation to the different stages of platform evolution. Empirical studies have started to document these aspects, but additional research is needed to introduce more granularity about the functioning of platform ecosystems, their dynamics, and the sources of strategic advantage. Surprisingly, there is only scant research that takes consumers' preferences into account (but see Cennamo & Santaló, 2019; Rietveld & Eggers, 2018; Schilling, 2002, 2003; Seamans & Zhu, 2014; Zegners & Kretschmer, 2017). One interesting additional implication of our simulation analysis relates to the potential change in the strength of network effects during the evolution of the ecosystem, which could be due to different types of consumers (i.e., with different preferences) entering at different stages of the platform life cycle. Is there a relationship between the strength of network effects at a given point in a platform's life and the type of users who populate it? Such analysis would be challenging—not just because of the multiple endogeneity problems, but also because of the difficulty in measuring consumers' preferences. Yet, this research could be very fruitful: if a relationship is established, it would imply that platform providers can act on the strength of network effects—for instance, by designing strategies for selecting the "right" type of consumers.

This also has significant implications for competition between rival platform ecosystems. Do we observe different pricing dynamics in response to increased platform competition in contexts that differ in terms of users' preferences? Can a platform provider leverage this pricing strategy to select out consumers who prefer size, attract those who prefer innovativeness, and successfully compete against larger rival platforms based on ecosystem innovativeness? Anecdotal evidence from the mobile app context, in which the small but more innovative and lucrative Apple iOS ecosystem competes with its dominant but less lucrative Android counterpart, seems to support this possibility. Furthermore, there is some empirical evidence suggesting a possible market segmentation between the two platforms over the type of users in this context (e.g., Bresnahan et al., 2015) and possibly also for media and entertainment content and services (e.g., Cennamo & Santaló, 2013; Seamans & Zhu, 2014). The extent to which this could be the result of platform providers' deliberate strategies to shape the nature and strength of network effects is an interesting open question for future research.

Following our analysis, we would expect that, under weakening network effects and users' relative preferences for innovativeness, the smaller platform ecosystem may prove more innovative and attractive for users and more lucrative for complementors, inducing value migration across ecosystems following complementors' migration. In contrast, from a platform provider's point of view, the larger ecosystem is more lucrative. This leads to a straightforward empirical implication that could be tested by studying profitability levels among ecosystem participants within and across ecosystems that differ in terms of size and level of innovativeness. The challenge that we anticipate here would be to isolate the effect from other confounding factors, such as the counter-moves of the larger platform providers to prevent value migration to smaller platforms. In fact, some of the recent debate (see, e.g., the Stigler Committee on Digital Platforms, 2019) on the social impact of tech platform giants, and the need to break them up into smaller firms, speaks very eloquently to the trade-offs between ecosystem size and ecosystem innovativeness that we have identified here, with the accusation that these large platforms are leveraging their power to nip potential competitors. Thus, the analysis of how the strength of network effects plays out on the strategic and competitive dynamics within and across ecosystems can also have relevant policy implications.

We believe that our analysis represents a first step toward the theoretical foundation for future work. However, as in any formal model, we bring a few important aspects into the picture while leaving many more outside it. In line with the extensive literature, we have focused here on pricing strategies on the two sides, but platform providers can also use other strategies to induce innovative efforts on the part of complementors—for instance, through design choices regarding a platform's technological architecture (e.g., Cennamo et al., 2018) or through development kits that reduce development costs (the parameter c in our model) and facilitate the production of higher-quality and novel complements (see Anderson et al., 2014). Alternatively, the platform provider itself could invest to improve the technological functionalities of the core technology (e.g., Schilling, 2003) and reduce the marginal cost of production (the parameters T and C in our model), or marketing for selected complementors (Rietveld et al., 2019), or enhance the level of ecosystem innovativeness by producing the high-quality complements required in-house (e.g., Cennamo, 2018; Hagiu & Spulber, 2013), as demonstrated in reality by many platforms (e.g., Apple or Google in mobile operating systems, or Microsoft or Nintendo in video game console systems). Exploring the different sources of innovativeness and revenue would enrich our knowledge of platform value-creation dynamics and extend our knowledge of platform strategies. In principle, these extensions could be introduced in a modified version of our model and provide a fascinating research agenda for future studies.

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