Essays on Platform Sponsor Scope: Implications for Ecosystem Emergence and Growth

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ABSTRACT

Platform sponsors and complementors co-create value in platform ecosystems. This dissertation sheds light on a critical aspect – *platform sponsor scope* – of such value co-creation. *Platform sponsor scope* constitutes the sponsor's choice of activities to perform internally, their decision rights on the complements, and their orchestration in the ecosystem. Platform sponsor scope signals value co-creation opportunities to complementors and shapes the latitude of the platform sponsor in governing the ecosystem. The dissertation comprises of three essays (chapters 2, 3, and 4) that together demonstrate (i) the platform sponsor's agency in choosing their scope vis-à-vis complementors, (ii) the interplay of platform sponsor scope with elements of problem, platform ecosystem design, and dynamics, and (iii) the implications of scope choices on ecosystem emergence and growth at different stages of the lifecycle. The first essay (chapter 2) demonstrates that the platform sponsor can facilitate ecosystem emergence by aligning their scope choice with the problem they are seeking to solve. Using a dataset of crowdfunding campaigns and fuzzy-set qualitative comparative analysis (fsQCA), I find distinct configurations of problem and scope for different types of ecosystems. The second essay (chapter 3) examines the interplay between the ecosystem structure and governance as exemplified in the platform sponsor scope choices. The study uses a configurational approach and inductively identifies configurations of scope and ecosystem structure across different ecosystems and at the incipient and mature stages of the lifecycle. The third essay (chapter 4) examines the role of platform sponsor scope in ecosystem dynamics of indirect network effects and ecosystem growth. Using a formal model, I find that the ecosystem growth trajectory differs based on the symmetricity of indirect network effects. However, the growth can be augmented by aligning the scope choice with the type of benefits the actors accrue within the ecosystem. I examine the micro-level dynamics using Wikipedia editing activity data and find that scope changes influence complementors' participation decisions. Collectively, these essays contribute to the literature on platform ecosystems and firm scope, bringing fresh insights into how platform sponsor scope choices shape value co-creation in platform ecosystems.

To my family,

whose countless sacrifices

gave me the courage

and instilled the confidence

to take the path less traversed.

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CHAPTER 1

INTRODUCTION

Over the last few years, platform ecosystems such as Google, Amazon, and Facebook have emerged across multiple industries and grown at a remarkable rate. Platform ecosystems represent a group of interacting firms or actors who are organized around a central platform infrastructure (Adner & Kapoor, 2010; Kretschmer et al., 2020; McIntyre & Srinivasan, 2017) and depend on each other for the co-creation of value. Platform ecosystems differ from traditional firms as they leverage an ecosystem of autonomous actors to co-create value without direct hierarchical control (Jacobides et al., 2018).

Value co-creation occurs in different ways in the platform ecosystem. Platform sponsors facilitate innovations, transactions, or both among the interacting actors within the ecosystem (Cusumano et al., 2019). Platform sponsors facilitate innovation when the complementors leverage the platform to innovate and produce products termed complements that enhance the value of the platform to consumers. Open-source software ecosystems like Mozilla Firefox and Linux are examples of such ecosystems. In contrast, platform sponsors may facilitate transactions between the complementors and consumers within the ecosystem. eBay marketplace is an example of such an ecosystem. Platform ecosystems like Google's Android and Apple iOS smartphone ecosystem foster innovation from app developers and enable transactions of app purchases between these developers and consumers.

Platform ecosystems have emerged as a new organizational form where the locus of value creation has shifted from the inner core of the focal firm to co-creation with external autonomous complementors with no legal linkages to the focal firm (Gawer, 2014; Jacobides et al., 2018). The success of an ecosystem is attributed to the potential of the platform sponsors and complementors to co-create value (Kapoor, 2018) with each actor performing different parts of the value co-creation process. Accordingly, the actor that performs a focal process retains control over the corresponding part of value creation. Such an arrangement begins with the platform sponsor, as the initiator of the ecosystem, choosing to perform parts of the value creation process while opening the rest to the complementors. So, the sponsors choose their scope in the value creation process vis-à-vis the complementors. I refer to such a choice as the *platform sponsor scope*.

I define *platform sponsor scope* as constituting of three distinct elements: (i) the activities that the sponsor chooses to perform internally while opening the others to complementors, (ii) the sponsor's decision rights over complements, and (iii) the sponsor's degree of orchestration within the ecosystem. Researchers have termed the platform sponsor scope as one of the key choices made at the outset as well as continually (Gawer, 2011; Gawer & Cusumano, 2008; Kapoor & Lee, 2013). This is because the scope choice signals the value creation opportunities available to potential complementors and consumers and consequently shapes their participation decisions.

The scope of the firm and its impact on firm performance has long been considered a key issue in strategic management research (Ahuja & Novelli, 2017; Conner, 1991; Rumelt et al., 1991). In the case of collaborative organizational forms like alliances and joint ventures, the literature suggests that focal firms consider the complementarities between internal and partner resources and capabilities to define their scope in the collaboration (Parmigiani & Rivera-Santos, 2011; Wang & Zajac, 2007). However, such strategies are not fully applicable in the case of platform ecosystems, where the architecture of the platform ecosystem is comprised of a stable core in the form of the platform and variable peripheral components that manifest as complements (Gawer, 2011, 2014). Such an architecture allows simultaneous development of multiple complements with no impact upon each other or the core and also requires minimal coordination among the complementors (Baldwin & Clark, 2000; Cennamo & Santaló, 2019).

Value co-creation in platform ecosystems is unique in at least two ways. First, the platform sponsors (owners and providers of the platform infrastructure) do not select the complementors but rather attract them to participate and produce complements for the platform. Consequently, the complementors are ex-ante unknown to the platform sponsors. Second, the expected outcome of value co-creation efforts is also ex-ante unknown as multiple value propositions are possible (Dattée et al., 2018) when the consumer selects from competing complements and combines them with the platform offerings. Thus, the platform sponsors face a challenge of "unknown unknowns" (Tajedin et al., 2019), where both the complementors and their final products are ex-ante unknown.

The scope of the platform sponsor is a key tool to manage the situation of unknown unknowns as not only does it signal value co-creation opportunities and attract participation but also shapes the latitude of the platform sponsor in governing the ecosystem. The platform literature has documented two distinct conceptualizations about the scope of the platform: platform technology boundaries and platform sponsor boundaries (Boudreau, 2017; McIntyre et al., 2020). The platform technology boundaries define the platform technology components available to complementors. The degree of modularity in the platform architecture and the extent to which the platform sponsor opens the interfaces to the platform modules determine the platform technology boundaries (Baldwin & Clark, 2000; Boudreau, 2010; Tiwana et al., 2010). The technology boundaries limit the complementors' innovation but provide the platform sponsor opportunities to capture value. Thus, technology boundaries are argued to shape the complementors' participation decisions (Boudreau, 2012; Boudreau & Jeppesen, 2015; Boudreau & Lakhani, 2015). However, as McIntyre et al. (2020) rightly point out, "while technology choices on platform design and interfaces have an influence on complementors' incentives to innovate, and can affect to some extent complementors' capability, they constitute only one of the levers of action that platform owners can manipulate. The scope of the platform [sponsor] is another lever of action" (McIntyre et al., 2020, p. 19).

Early studies considered platform sponsor scope as the choice of complements to make internally as opposed to those left to complementors (Gawer, 2011; Gawer & Cusumano, 2008). Researchers have demonstrated that platform sponsors made in-house complements to get the ball rolling and fill the gaps that are not addressed by third-party complementors (Cennamo, 2018; Hagiu & Spulber, 2013). The conceptualization of platform sponsor scope as the choice of in-house complements vis-à-vis third-party complements is close to the make vs. ally argument that has underpinned much of the scope of the firm literature in traditional firms (Parmigiani & Mitchell, 2009; Parmigiani & Rivera-Santos, 2011; Shi et al., 2012). Yet, this treatment of platform scope does not adequately focus on how scope choices shape participation decisions of autonomous complementors and therefore value co-creation. A parallel conceptualization of platform scope expansion relates to competitive interactions where the focal platform sponsor bundles or ties together offerings of a rival platform with their own (Eisenmann et al., 2011). Whereas the treatment of platform sponsor scope as the choice of complements is too restrictive in a situation of unknown unknowns as compared to the traditional notion of firm scope, the treatment of scope expansion through bundling does not consider the sponsor's investment and ownership of critical assets for value creation (McIntyre et al., 2020).

1.1 Relevant Literature

Platform literature has three distinct streams of research that leverage the technology management, economics, and strategic management perspectives (McIntyre & Srinivasan, 2017). As detailed below, platform sponsor scope is important to each of the streams (see Table 1.1 for a summary).

Table 1. 1: Platform Sponsor Scope in Platform Literature

	Technology Management literature	Economics literature	Strategic Management literature
Dominant orientation of the stream	Modular platform architecture and interface openness affect complementors' ability to innovate.	Network effects dynamics, pricing, and competition.	Strategies of pricing, quality, variety, timing to leverage network effects and build competitive advantage.
Focus on 'platform sponsor scope'	Opening technology interfaces foster complementary innovation. Optimal interface design choices.	Platform sponsors' scope expansion as bundling features or entering adjacent markets to gain market power.	Scope expansion through in-house complements. Scope shapes platform-enabled markets.
Implications of platform scope choice	Shapes complementors' behavior and innovation within the ecosystem	Market power, entry barriers and profitability	Platform growth, ecosystem value, and value capture
Limitations	Focus on technology boundaries does not address platform sponsor boundaries.	Focus on scope expansion in relation to competitive dynamics but not governance implications.	Scope as a 'given'. Alternative scope choices and their implications not addressed.
Research gap identified	Combined optimal technology and platform boundary choices (Essay 2).	Implications of scope choice on ecosystem dynamics (Essay 3) and popularity (Essay 1).	Alternative scope choices and factors shaping them (Essay 1, 2, and 3).

The technology stream has focused on the technological and architectural aspects of the platform. Researchers have studied the platform scope issue through their focus on the technology boundaries of the platform and its importance for platform governance as well as in fostering complementors' participation within the ecosystem (Gawer, 2014; Tiwana, 2008; Tiwana et al., 2010). The opening up of the interfaces of the platform to complementors is shown to improve innovation (Boudreau, 2010, 2017). In contrast, the closing of interfaces have been shown to not just impact complementor innovation but also to thwart competitive rivalry, such as in the example of Twitter closing its API to cease adding value to LinkedIn, a rival platform (McIntyre et al., 2020). However, this stream of literature with its focus on technology boundaries does not examine the platform sponsor's boundaries vis-à-vis the complementors.

The economics stream has predominantly focused on the platform dynamics and network effects[1] that fuel ecosystem growth. In this stream, researchers have demonstrated that pricing and non-pricing strategies can help foster direct and indirect network effects and, consequently, platform ecosystem growth (Armstrong, 2006; Hagiu & Wright, 2015b; Rochet & Tirole, 2006). Here, the issue of platform scope has been studied in relation to platform competition (McIntyre et al., 2020). Platform sponsors undertake scope expansion to overcome entry barriers emerging from a rival's network effects. This strategy, termed platform envelopment, is accomplished by bundling the features of the rival platform into the focal platform's offerings and targeting the overlapping user base (Eisenmann et al., 2011). Yet another way of scope expansion relates to preserving market power by tying two or more products together and selling them only as a bundle (Carlton et al., 2010; McIntyre et al., 2020). In addition to studying the implications of platform sponsor scope in the context of competition, research has considered consumer utility and pricing strategies as a result of the extent of benefits that the consumers accrue from platform offerings and transactions (Jullien & Pavan, 2018; Weyl, 2010). However, this stream of literature has not considered the governance implications of the platform sponsor scope within the ecosystem.

The strategy stream builds upon both the network effects and technology architecture arguments and focuses on firm dynamics to understand the growth strategies of the different actors

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[1] Network effects is a condition where the value an actor derives from participating in a platform increases when a greater number of actors participate on the same side (termed direct network effects) or on other sides (termed indirect network effects) of the platform (Katz and Shapiro 1994; Rochet and Tirole 2003). Consequently, a large number of actors on one side can attract more actors to participate on the same or other sides of the platform. This dynamic results in a positive loopback such that more participation attracts even more actors.

(Gawer 2014; McIntyre and Srinivasan 2017; Thomas, Autio, and Gann 2014). At a general level, the platform scope is viewed more broadly as the role played by the platform in the digital markets they enable (Cennamo, 2019) and the "vision that defines the ecosystem value proposition" (Dattée et al., 2018, p. 467). At a more specific level, the platform scope decision is viewed as a choice of complements that the platform sponsor chooses to make in-house versus that opened to complementors (Gawer & Cusumano, 2008). The platform sponsors produce in-house complements whilst supporting third-party complements because such a strategy can help kickstart the feedback loop of network effects (Cennamo, 2018; Hagiu & Spulber, 2013). Despite the focus on platform sponsor strategies to drive ecosystem performance, this stream considers platform scope choice as "given" (Boudreau, 2017) and thereby does not examine the implications of alternative scope choices.

In line with their respective interests, the three streams of platform literature have respectively examined issues related to platform sponsor scope in a limited manner. In accordance with its origins, the focus of the technology stream of research has largely remained on issues related to the platform technology boundaries rather than platform sponsor scope. As Boudreau (2017) highlights, the technology boundaries and platform sponsor's boundaries vary distinctly and interact with each other to influence organizational and governance issues. The economics stream of research on platform scope has focused on scope expansion and its implications on competitive interaction. This stream has also demonstrated the implications of differences in consumer utility accrued from platform and complementors' offerings. However, the influence of such differences on organizational and governance issues has received less attention. Finally, the strategy stream of research has demonstrated the implications of platform sponsors making complements internally. However, even though this stream of research has begun to more directly examine the issue of platform sponsor scope, it acknowledges that platform scope as an issue that "drives the investment incentives and control of critical assets across the ecosystem" has not received enough attention (McIntyre et al., 2020, p. 19).

The choice of scope has key implications for each of the streams. For instance, a choice of the platform sponsor to retain a broad scope would mean that the technological interfaces can remain more closed, thereby allowing better control (for example, a broad scope Apple ecosystem as compared to a narrow scope Android ecosystem of smartphones). In turn, such a choice of broad scope would mean fewer types of complementors. Moreover, consumer utility would depend more on benefits accrued from the platform sponsor offerings. Additionally, broad scope would mean that the platform sponsor has more control over critical assets and, therefore, more levers for platform governance. From the above, it is clear that platform sponsor scope choices have implications for all three streams of research. To emphasize the essential point, as with much of the platform literature (Gawer, 2014; McIntyre & Srinivasan, 2017), an integrated understanding of the implications of scope choices across technology, dynamics, and strategy is necessary to better understand the phenomena.

1.2 Overview of the Dissertation

In my dissertation, I shed light on the important topic of platform scope by studying the implications of the platform sponsor's scope choices on ecosystem emergence and growth (Figure 1.1 summarizes the focus of the dissertation). I focus on a platform sponsor's agency in defining its scope vis-à-vis the complementors to co-create value.

To fully understand the role of platform sponsor scope, I identify the implications of alternative scope decisions on ecosystem performance as relevant at different stages of the ecosystem lifecycle. Specifically, I study how a platform sponsor chooses a scope that facilitates the emergence of an ecosystem at the incipient stage (essay 1). Then, I focus on how a platform sponsor can choose its scope and configure the platform ecosystem structure accordingly at the incipient and mature stages of the ecosystem lifecycle (essay 2).

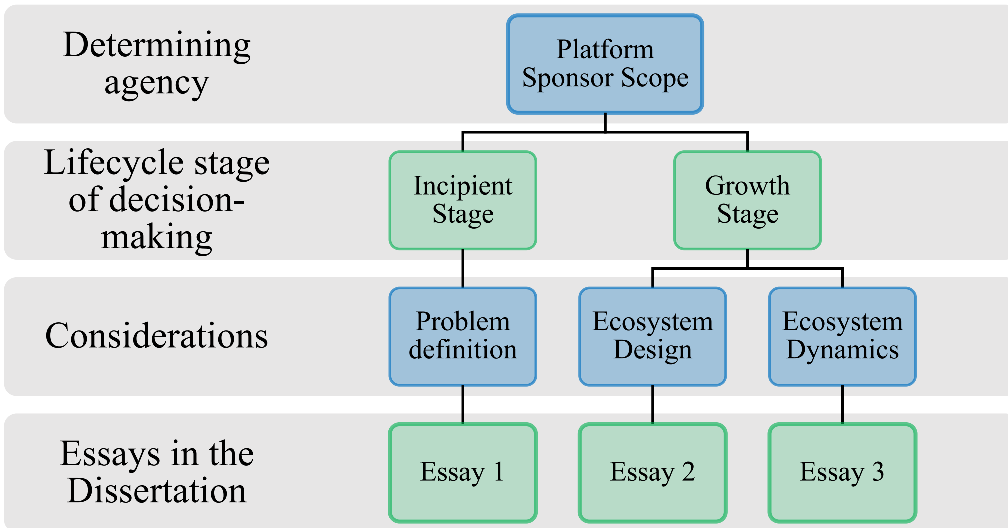

Figure 1. 1: Focus of the Dissertation

With an aim to better understand the underlying dynamics of the ecosystem model, I then examine how a platform sponsor's scope choices can influence the indirect network effects that drive the growth engine of the ecosystem (essay 3). I draw upon all the three streams of platform literature and analyze the above issues from the perspective of the platform sponsor. The essays leverage various archival data sources and are motivated by the insights from interviews with executives of platform sponsoring firms. Table 1.2 provides a summary of the essays.

1.2.1 Essay 1[2]

In the first essay, I focus on the incipient stage of the ecosystem and the agency of a platform sponsor in choosing its scope in conjunction with the problem they are seeking to solve. I ask the following research question: *How does the platform sponsor's choice of scope facilitate the*

[2] Essay 1 is forthcoming at the *Journal of Management Studies.*

emergence of a platform ecosystem? I answer the above question by building on knowledge-based theories, specifically the problem-solving perspective (Macher, 2006; Nickerson et al., 2007; Nickerson & Zenger, 2004). I develop a problem-solving perspective of platform ecosystems to suggest that the platform sponsor as the focal economic actor seeks to efficiently solve a problem whose solution, in the form of complements, creates value.

Table 1. 2: Summary of the Essays in the Dissertation

	Technology Management literature	Economics literature	Strategic Management literature
Essay 1 Focus: Platform ecosystem emergence Key argument: A platform ecosystem emerges when there is an alignment between the problem dimensions and the platform sponsor's scope.		Theory: Hayek's (1945) distributed assets argument to show the similarity between platform and knowledge contexts	Theory: Problem-solving perspective DV: Platform ecosystem emergence IV: Problem structure, problem context, problem complexity, property rights, platform sponsor scope Method: fsQCA
Essay 2 Focus: Configurational approach and typology of platform ecosystems Key argument: A fit between the platform sponsor's scope and platform governance characteristics enables the growth of the ecosystem.	Theory: Platform architecture-governance fit argument IV: Platform interface openness, access control		Theory: Configurational approach, set theory-based typology DV: Platform growth IV: Complementarity, complement variety Method: fsQCA
Essay 3 Focus: Indirect network effects and growth Key argument: The ecosystem growth trajectory differs based on the symmetricity of indirect network effects and platform sponsor's scope choices.		Theory: Network externalities theory, asymmetric indirect network effects Method: Formal model drawing on Rysman (2004) for a Cobb-Douglas form for indirect network effects	Theory: Platform sponsor's scope DV: Rate of growth of the platform ecosystem IV: Indirect network effects (function of membership and usage benefits), platform sponsor scope

I contend that platform ecosystems emerge successfully when the platform sponsor, through its choice of scope, stimulates an efficient search process for the problem they seek to solve. On the one hand, problem dimensions such as problem structure, complexity, and context shape the type of search process required to find solutions. On the other hand, the platform sponsor's latitude to govern the search process is shaped by their scope choices. Since orchestration within the ecosystem is not relevant at the incipient stages, I define platform sponsor scope as constituting the choice of activities to perform internally and decision rights over complements in this essay. I contend that for an efficient solution search and thereby ecosystem emergence, an alignment between the problem dimensions and platform sponsor scope is required. I use an abductive reasoning approach (Mantere & Ketokivi, 2013) and fuzzy-set qualitative comparative analysis (fsQCA) on a dataset of campaigns posted on Kickstarter, a crowdfunding website, to raise funds to launch digital platforms. I find distinct configurations of problem dimensions and platform sponsor scope for open-source ecosystems, complementary innovation ecosystems, and information ecosystems.

1.2.2 Essay 2[3]

In the second essay, I examine the interplay between elements of platform ecosystem structure and governance in the incipient and mature stages across different types of ecosystems.

As a first step, I develop a typology of platform ecosystems and examine how the ecosystem structure and governance differ across the different types of ecosystems and over time. I ask the following questions: *How can a platform sponsor configure the ecosystem structure and governance for superior performance across different types of ecosystems? And how does the configuration vary between the incipient and mature stages of the ecosystem lifecycle?* I contend that a platform sponsor's latitude in the governance of platform ecosystems is shaped by its choice of scope vis-à-vis the complementors. The platform sponsor's choice of scope comprises of the activities to perform internally, extent of decision rights over complements, and degree of

[3] Essay 2 was a finalist for the Corporate Strategy Interest Group Best Paper Award at the *Strategic Management Society Conference 2020*.

orchestration within the ecosystem. Using a configurational approach (Fiss, 2007; Miller, 1986), I explore the interplay between the elements of platform sponsor scope and ecosystem structure associated with the ecosystem's superior performance. I use fuzzy-set qualitative comparative analysis (fsQCA) and data from 40 platform ecosystems at both the incipient and mature stages to inductively identify configurations of ecosystem structure and governance. I find empirical support for the typology in the form of distinct configurations of ecosystem structure and platform sponsor scope. Further, I show that ecosystems exhibit superior performance when there is an alignment between the elements of governance and structure. Finally, I shed light on the temporal aspects of ecosystems by demonstrating that the configurations of ecosystem structure and scope differ from the incipient to mature stages.

1.2.3 Essay 3[4]

In the third essay, I examine the implications of the platform sponsor's scope decisions on the underlying dynamics of the ecosystem and ask the question: *How does the platform sponsor scope decision influence the platform ecosystem growth dynamics?* Fundamental to the functioning and growth of the ecosystem is the dynamics of network effects, particularly the cross-side or indirect network effects (Rochet & Tirole, 2003, 2006; Rysman, 2004). Since platform scope decisions signal the value co-creation opportunities to attract actors to the platform, it is important to understand how the scope decisions might influence the network effects that are a result of the participation decisions of these actors in the first place. With a focus on ecosystem growth dynamics in this essay, I use a higher-level abstraction in the treatment of platform sponsor scope and define it as the choice of value creation processes to be performed by the platform sponsor vis-à-vis the complementors. Using a formal model of platform growth, I find that the platform

[4] Essay 3 was a finalist for both the Corporate Strategy Interest Group Best Paper Award as well as Best Ph.D. Conference Paper Award at the *Strategic Management Society Conference 2020*.

growth trajectory differs based on the symmetricity of indirect network effects. However, the platform sponsor can augment the ecosystem growth by aligning their scope with the type of benefits the actors accrue within the ecosystem. The model helps identify conditions under which the platform sponsors can augment the ecosystem growth. Specifically, the platform sponsors can augment the growth rate of the platform ecosystem by increasing the platform sponsor's scope when the consumer accrues more membership benefits than usage benefits.

I delve deeper into the micro-level dynamics to examine how the platform sponsor scope choices influence complementors' participation decisions and thereby ecosystem growth. Platform sponsor scope changes redefine the value co-creation and capture opportunities available to the ecosystem actors. In examining the micro-level dynamics, I contend that when such scope changes are inconsistent with the composition of membership and usage benefits, the actors' participation decisions may change as co-creation opportunities may no longer seem attractive. I find support for the above argument using editing activity data from Wikipedia. This study highlights that not all platforms grow at an increasing rate and, importantly, the platform sponsor scope can influence ecosystem dynamics and thereby shift the growth trajectory.

1.2.4 Alignment of Platform Ecosystem Considerations

The three essays in the dissertation contend that an alignment between the platform sponsor's scope choice and problem at hand (Essay 1), platform ecosystem structure (Essay 2), and composition of benefits (Essay 3) can lead to superior performance outcomes. Prior studies have considered alignment as a structural aspect where actors' construal of the positions and activities of other actors is key for the success of an ecosystem (Adner, 2017) as it shapes the relationships and complementarities among ecosystem participants (Jacobides et al., 2018). The argument advanced in the dissertation involving both macro and micro-level alignment bring more depth to the existing notion of alignment in the platform literature. Specifically, the macro-level alignment involving strategic actions of matching incentives with objectives can be implemented through micro-level alignment in configurations of distinct yet interrelated elements. The micro-level configurational alignment involves the codetermination of configurations comprising of distinct elements coming together to produce an outcome.

The essays 1 and 2 in the dissertation demonstrate the macro-level matching alignment as well as the micro-level configurational alignment. In essay 1, I argue that the platform sponsor scope choice should be aligned with the problem, depicting a macro-level matching argument. However, by considering various elements of problem and scope, I show that alignment at a micro-level should be achieved through a configuration of these interrelated elements. In essay 2, I find that platform ecosystem structure should match the governance choice of platform sponsor scope. However, at a micro-level I find that a configurational alignment of different structure and scope elements is vital. With a focus on ecosystem dynamics in essay 3, I argue that platform sponsor scope should match the composition of benefits. In examining micro-level dynamics, I find the implications of a mismatch on complementors' participation. Taken together, the findings highlight the importance of studying alignment with a more nuanced approach in the platform ecosystem context as there exist multiple levels of actors, strategies, and implications.

Overall, this dissertation develops the idea of platform sponsor scope choice as a strategic decision that, in combination with platform ecosystem design elements, shapes value co-creation. The dissertation comprises three essays that have a common theme of platform sponsor scope and examine various aspects of platform ecosystem design at different stages of ecosystem lifecycle. The dissertation contributes to the platform literature by establishing the platform sponsor's agency in defining its scope, and along with problem dimensions, ecosystem structure, and dynamics, examines the implications of such choices. In doing so, the dissertation integrates the different streams of platform literature and contributes to theories about value creation under uncertainty. Finally, the dissertation contributes to the firm scope literature by establishing the distinction of platform sponsor scope vis-à-vis existing conceptualizations of firm scope.

CHAPTER 2

OVERCOMING THE EARLY-STAGE CONUNDRUM OF DIGITAL PLATFORM ECOSYSTEM EMERGENCE: A PROBLEM-SOLVING PERSPECTIVE

2.1 Introduction

"Technology takes a back seat in the early days. Time is of essence then. So, focus is to get scale before we can look at unit economics and technology."

- Senior executive of a ridesharing platform

Digital platform-based ecosystems (hereafter referred to as platform ecosystems) have proliferated across several industries and geographies. As an organizational form, they have shifted the locus of value creation from the inner core of the focal firm to co-creation with external autonomous actors called complementors (Adner & Kapoor, 2010; Kapoor, 2018). Much of the research on platform ecosystems has shown keen interest in larger and well-established platforms like Apple and Amazon, with scholars seeking to understand the sources of their value creation and growth (McIntyre et al., 2020). In contrast, the long tail of platforms that struggle in the incipient stage remains largely ignored (Dattée et al., 2018). Moreover, although a shared understanding and agreement of the scope of activities of the respective actors — in this case platform sponsors and complementors — is fundamental to co-creation of value (Gulati et al., 2012), yet there has been a limited understanding about the choice of the scope of the platform sponsor vis-à-vis complementors (McIntyre et al., 2020). Our paper focuses on the long tail of platforms in the incipient stage, with a specific focus on the role of the platform sponsor's scope on platform ecosystem emergence.

The successful emergence of a platform ecosystem implies that the platform survived the incipient stage by attracting voluntary participation of complementors and consumers (Ceccagnoli et al., 2012; McIntyre & Srinivasan, 2017). Yet firms in the incipient stage are faced with a major conundrum. In the case of more established ecosystems, factors such as superior technology infrastructure (Constantinides et al., 2018; Tiwana, 2013), first mover advantage (Gawer & Cusumano, 2014), incentives and subsidies (Caillaud & Jullien, 2003; McIntyre & Subramaniam, 2009) and creation of social forums (Fang et al., 2020), among others, have been shown to attract the contributions of potential participants to their ecosystems. However, incipient platform firms typically do not have recourse to these avenues, nor do they possess the resources to create them in order to make the platform attractive to potential participants.

We propose that a platform sponsor's scope choices offer a way out of this dilemma. Platform sponsors have to make key decisions about their scope, at the outset as well as continually, in order to signal to autonomous complementors potential opportunities for value creation and capture (Cusumano & Gawer, 2002; Kapoor & Lee, 2013). The platform sponsor's choice of scope is particularly critical at the initial stage to attract participation and ensure commitment from the autonomous actors to the "*de novo* ecosystem" (Autio & Thomas, 2020; Dattée et al., 2018, p. 467; Hannah & Eisenhardt, 2018). Prior research has suggested that platform sponsors should choose their scope considering factors such as their dependence on complementors (Cusumano & Gawer, 2002), modular design attributes (Tiwana et al., 2010) and the value proposition of the ecosystem (Adner, 2017). Although a useful guideline, these studies do not sufficiently emphasize that complementors are unknown ex-ante (Gawer, 2011), a scenario particularly relevant for digital platforms. It is thus not clear how platform sponsors can define their scope at the initial stage to attract potential participants.

In this paper we ask: *How does a digital platform sponsor's choice of scope facilitate the emergence of a platform ecosystem?* To answer this research question, we base our arguments on one strain of the knowledge-based theory of the firm, namely the problem-solving perspective

(PSP), which argues that "problem-solving effectiveness is key to superior organizational performance" (Jeppesen & Lakhani, 2010, p. 1016; Nickerson & Zenger, 2004). The PSP posits that the efficiency of the solution search, at its core, is dependent on the alignment between the problem dimensions and the governance mode of the search process (Macher, 2006; Nickerson et al., 2012; Nickerson & Zenger, 2004). From this line of argument, the platform sponsor as the focal economic actor seeks to efficiently solve a problem whose solution, in the form of complements, creates value for the consumers and is a manifestation of the commitment of complementors to the ecosystem. Our major premise is that a digital platform ecosystem emerges when the platform sponsor stimulates an efficient search process through a choice of scope that accords with the problem they seek to solve. We theorize that, on one hand, problem dimensions shape the type of search process required to find solutions and, on the other hand, the platform sponsor scope shapes the extent to which the sponsor can govern the search process. Platform sponsor scope comprises of (a) the set of activities that the sponsor chooses to perform internally and (b) the extent to which the sponsor holds decision rights over the complementors' solutions. As the search process moves from being semi-directed by the sponsor to being undirected, a corresponding reduction in the platform sponsor scope is required for the search to be efficient and lead to the emergence of an ecosystem.

Our investigation identifies distinct pathways to survive the incipient stage and enable ecosystem emergence. We adopt abductive reasoning (Mantere & Ketokivi, 2013) and fuzzy set qualitative comparative analysis (fsQCA) to arrive at various configurations of problem dimensions and platform sponsor scope that lead to ecosystem emergence. Our analysis utilizes a dataset of campaigns posted on a crowdfunding website to raise funds to launch digital platforms. Using the fsQCA results and case knowledge, we identify configurations of problem dimensions and platform sponsor scope for complementary innovation ecosystems, open-source ecosystems, and information ecosystems. Complementary innovation ecosystems align a semi-directed search process with a broad sponsor scope. Open-source ecosystems employ a new type of search that we term as community-directed search with a moderate sponsor scope. Finally, information ecosystems utilize an orchestrated-undirected search with a narrow sponsor scope.

Our paper makes a number of contributions: First, we shed light on the much-neglected incipient stage and demonstrate both theoretically and empirically how platform sponsors can facilitate the emergence of digital platform ecosystems. The framework we provide helps visualize and better understand the alignment between the problem and scope, a novel set of considerations to tackle the early-stage challenge of attracting participation to an unknown platform. Second, in extending the problem-solving perspective to the platform literature and accordingly shifting the analytical lens from the actors to the problem, we overcome the difficulty in examining emergence of ex-ante unknown complementors in the ecosystem (Gawer & Cusumano, 2014). In doing so, we also demonstrate how micro-level aspects such as problem and scope have broader ecosystem-level implications, a finding that can be beneficial to study broader digital strategy issues. Finally, we bring a configurational approach with abductive reasoning to the study of digital platforms. The configuration of problem dimensions and platform sponsor scope highlights equifinality in reaching the outcome and identifies multiple pathways for successful ecosystem emergence. Here, we empirically identify a distinct solution search process, i.e., community-directed search, that complements the search processes highlighted in the PSP literature.

2.2 Emergence of Digital Platform Ecosystems

The fundamental tenet of value creation in platform ecosystems is the platform sponsor co-creating value with autonomous complementors (Ceccagnoli et al., 2012; Kapoor, 2018). With the participation of complementors and availability of valuable complements thereof, consumers are attracted to consume the ecosystem offerings. Such a positive loop of attraction of actors across the different sides of the platform drives overall participation and leads to the emergence of an ecosystem of complementors and consumers around the platform (Gawer, 2014; McIntyre & Srinivasan, 2017). In the broader ecosystems literature, it has been argued that platform sponsors can attract participation by identifying a compelling blueprint (Iansiti & Levien, 2004) or value proposition (Adner, 2017), balancing cooperation and competition tensions (Hannah & Eisenhardt, 2018) and producing a few complements in-house (Schilling, 2002). However, these strategies may be insufficient when the platforms are built on digital technologies that can support a variety of visions and complements (Dattée et al., 2018).

With digital technologies typically characterized by a modular platform architecture, which allows a diverse set of actors to develop their own products over the platform with little or no coordination (Zittrain 2005; Cennamo and Santaló 2019; Baldwin and Clark 2006; Tiwana, 2013), digital platforms can be best characterized as a context of *distributed assets*. The modular nature of such technologies makes it impossible for a single firm to conceptualize, modify or extend the technologies in-house to produce all variants of value-enhancing complements. Importantly, in this context, not only are complementors unknown ex ante but also their complements are unknown ex ante to the platform sponsor, a condition of unknown unknowns (Tajedin et al., 2019). The digital context has close similarities to that characterizing the knowledge setting where "knowledge of the circumstances of which we must make use never exists in concentrated or integrated form, but solely as the dispersed bits of incomplete and frequently contradictory knowledge which all the separate individuals possess" (Hayek, 1945, p. 519). Whereas the economic problem in the knowledge context is to find the best way to utilize knowledge "not given to anyone in its totality" (Hayek, 1945, p. 520), that in digital platforms is to find the best way to utilize assets not owned by any single firm in totality, but rather affiliated with a platform (Hagiu & Wright, 2015a). Thus, digital platform ecosystems readily lend themselves to the lens of knowledge-based theories to analyze value creation.

One recent and increasingly prominent strain of the knowledge-based theory of the firm argues that a focal firm's effectiveness in problem-solving is vital for superior organizational performance (Jeppesen & Lakhani, 2010; Nickerson et al., 2007; Nickerson & Zenger, 2004). The central theme of the problem-solving perspective (PSP) is that the focal economic actor seeks to solve a problem but is unable to do so efficiently by itself due to limitations of resources, time, and cognition. Consequently, the actor engages in solution search in close proximity or at a distance, the choice of which is based on the problem and solution landscape (Afuah & Tucci, 2012; Macher, 2006; Nickerson & Zenger, 2004). Since the search for solutions can be afflicted by hazards, such as actors misguiding the search for their own benefit or misappropriating the value created through solutions, the focal actor chooses a governance mode that mitigates hazards to facilitate efficient search and value creation.

In the digital context, the problem to be solved constitutes finding valuable complements that enhance the overall value of the ecosystem. By analyzing the problem as the unit of analysis from the point of view of a focal actor, the PSP can help overcome a major hindrance in studying emergence of ecosystems – the difficulty in assessing and following ex-ante unknown complementors and users who are vital for ecosystem emergence (Gawer & Cusumano, 2014).

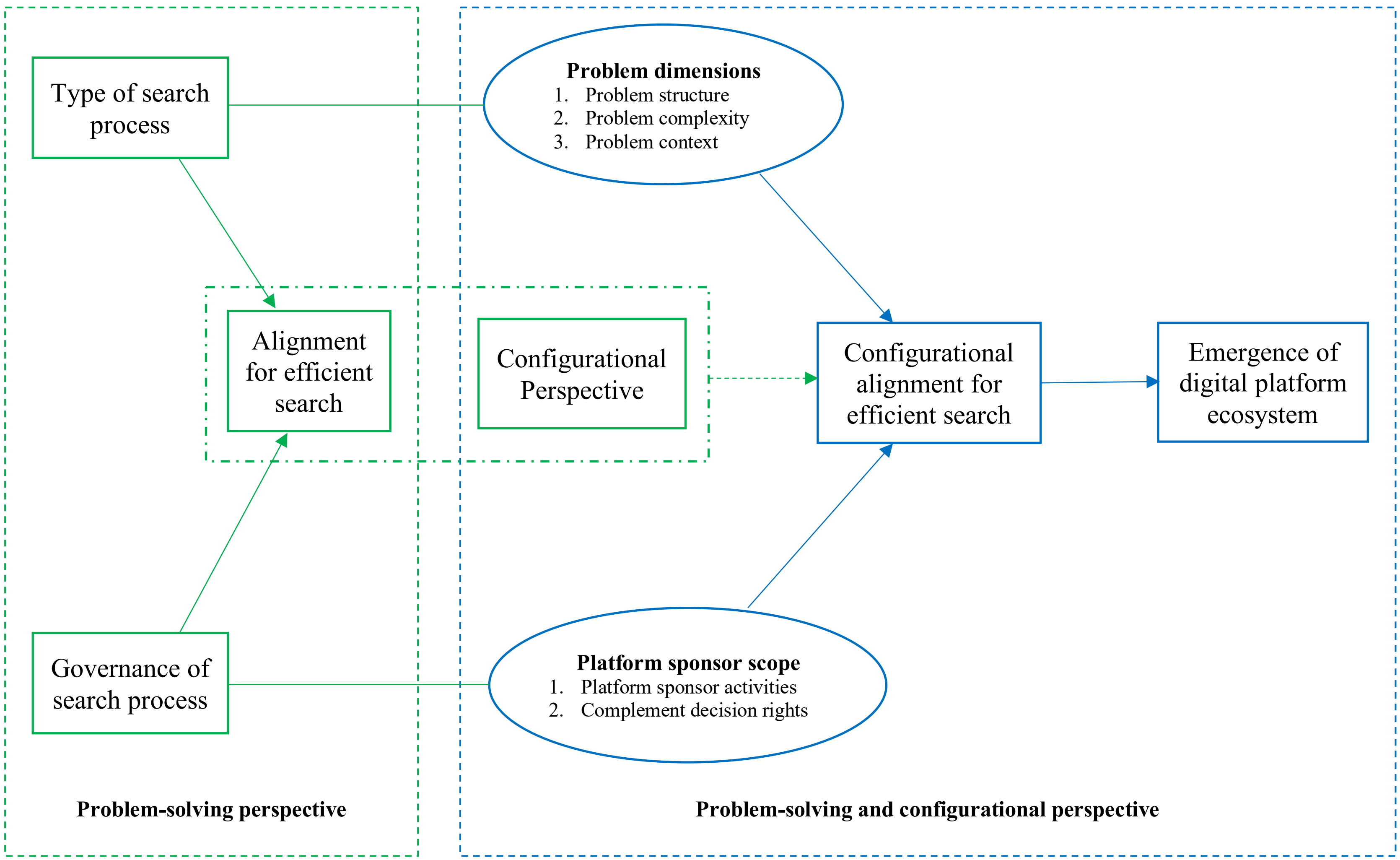

Figure 2. 1: Emergence of Digital Platform Ecosystems

We can assess ecosystem emergence from the platform sponsors' perspective by studying the efficacy of problem-solving, which occurs through the contributions of complementors and thereby participation of consumers. Thus, analyzing how valuable solutions to a problem, in the form of complements, may be found leads to assessing the emergence of the ecosystem.

Figure 2.1 summarizes our theoretical framework. We develop our arguments to explain the emergence of digital platform ecosystems based on the problem-solving perspective. As we detail in the following sections, the platform sponsor choice of scope should be aligned with the problem for an efficient search for valuable complements. We identify configurational alignments among the different dimensions of problem and scope that manifest as pathways to successful ecosystem emergence.

2.2.1 Problem Solving in Digital Platform Ecosystems

The problem dimensions shape the type of search process required to find solutions (Macher, 2006). The problem-solving perspective matches search process with governance forms that support efficient solution search (see Figure 2.2). When the problem can be solved independently by diverse actors without direction from the focal actor, it is more efficient to use an undirected search for a greater reach (Nickerson & Zenger, 2004). Undirected search is a process where independent actors "sequentially alter one solution design choice at a time, observe whether the solution value improves or declines in response and then update accordingly" (Felin & Zenger, 2014, p. 916). Such a trial-and-error-driven undirected search that is decentralized is best supported using a market form of governance (Nickerson & Zenger, 2004). Markets use a discovery process to access multiple agents and mobilize their dispersed knowledge (Hayek, 1945) and are best suited to discover problem-solution pairs (von Hippel & von Krogh, 2015) or solve uncertainty problems where the focal actor does not know what to look for beforehand.

In contrast, when the problem is complex and solution design choices have interdependencies that are poorly understood, direct feedback from independent trial and error is less useful. Such a problem requires a central actor or group of actors to take a more holistic approach to "assemble relevant knowledge, then recombine it, and then compose a theory" that can drive the search (Felin & Zenger, 2014, p. 917). Here, the solution may need to be found in proximity to the cognitive landscape of the focal actor to allow the use of their heuristics or theories (Nickerson & Zenger, 2004). A hierarchical governance form can best support such a centrally directed search process. Such a search is suitable to solve uncertainty problems that have a known starting point in the form of theories, consensus, or heuristics.

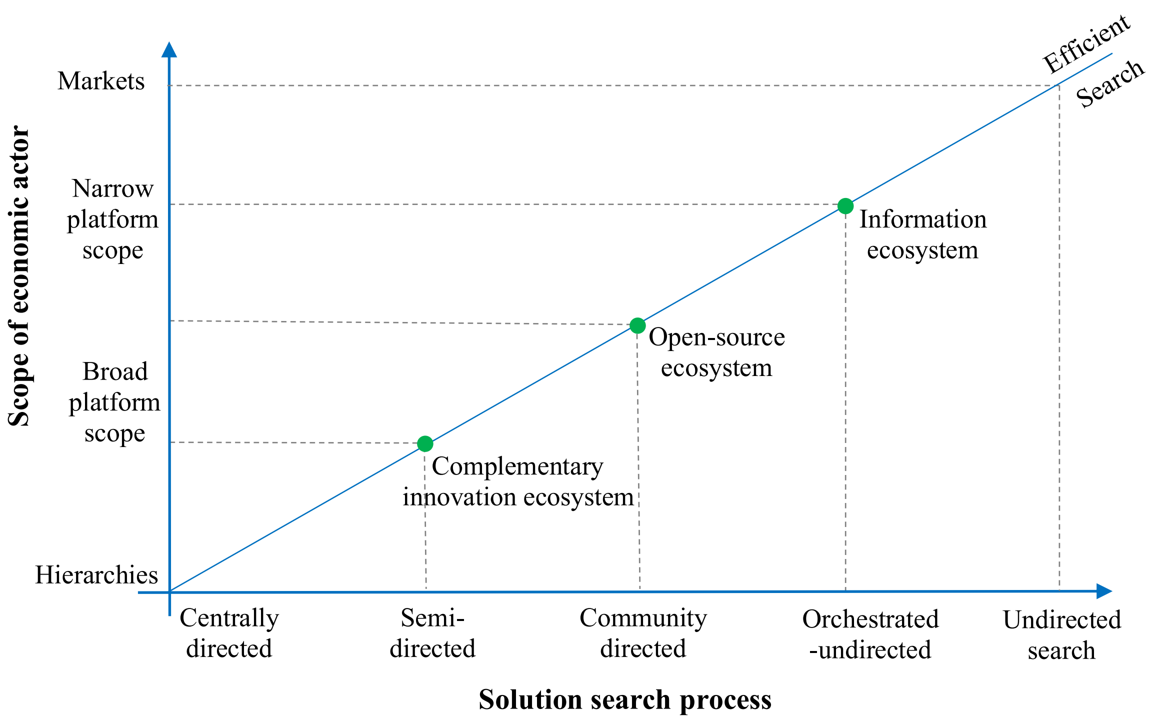

Figure 2. 2: Search Process and Scope alignment

In sum, the extreme positions of a centrally directed search and an undirected search are governed efficiently using the hierarchy and market forms of governance respectively. Next, we theorize about the search processes between the two extremes, building on problem-solving in platform ecosystems.

Digital platform ecosystems are argued to offer organizational efficiency relative to other forms with their ability to solve uncertainty problems while using a discovery procedure that is orchestrated for the benefit of the focal firm. Here, the "distributed knowledge of a mass of outside participants is leveraged" and augmented with the firm's knowledge (Tajedin et al., 2019, p. 339). When the focal actor knows the problem, the ecosystem facilitates finding a solution by broadcasting the problem to a diverse set of actors and enabling efficient access to cognitively distant knowledge sets (Afuah & Tucci, 2012; Jeppesen & Lakhani, 2010). Since the starting point of "what to look for" is known, the search process is termed to be *semi-directed* (Figure 2.2), with the market elements employed only on the demand side of economic value creation. Unlike the centrally directed search process where the relevant knowledge is assembled by the focal actor, the semi-directed search process involves "broadcasting the problem in hopes that those with valuable information or valuable solutions will reveal themselves" (Felin & Zenger, 2014, p. 917; Jeppesen & Lakhani, 2010). The semi-directed search also differs from the undirected search as the discovery procedure is constrained by the known problem definition.

In contrast, when the focal actor does not know the problem to be solved, then market elements are employed on both the supply and demand sides of economic value creation. We term such a search process as *orchestrated yet undirected* (hereafter referred to as *orchestrated-undirected*) search (Figure 2.2). The search process no longer relies on the focal firm's knowledge to define the problem or assemble relevant knowledge. Consequently, the search process is undirected where the "supply side crowd focuses on a variety of problems specified by the demand side crowd" (Tajedin et al., 2019, p. 330). In this scenario, the platform sponsor's role is to facilitate the market matching mechanisms through the platform while orchestrating the search indirectly for their own benefit.

2.2.2 Problem and Scope Alignment

We argued above that digital platform ecosystems employ semi-directed and orchestrated-undirected search processes to find valuable solutions (Tajedin et al., 2019). The problem-solving perspective suggests that the search process to solve a problem is efficient when it is governed by the right governance mode (Nickerson & Zenger, 2004). In digital platform ecosystems, for an efficient search the platform sponsor as the focal actor should have the required latitude in the governance of the search process. As we detail below, the platform sponsor scope choices shape the extent to which the sponsor has latitude to govern the search process within ecosystems. The semi-directed and orchestrated-undirected search processes of the ecosystem are efficiently governed when the platform sponsor has a broad and narrow scope respectively (Figure 2.2). Specifically, we contend that, when the problem requires the platform sponsor to direct the search, their scope should be broad enough to have latitude over a greater range of activities and assets. The semi-directed search process requires that the platform sponsor retain latitude in governance to define the problem, broadcast the problem for a solution search and select the suitable solution. Thus, the platform sponsor should retain a broad scope to define the problem as well as absorb the solution complements into existing offerings.

In contrast, when the search process tends to require less direction from the platform sponsor due to the nature of the problem, their scope should be correspondingly narrower for the search to be efficient. The limited role of the platform sponsor in facilitating the market matching mechanisms in an undirected search implies that they choose to retain a narrow scope of value creation activities and limited latitude in governing the search process. This arrangement of limited governance may be more conducive to serendipitous discovery of problem-solution pairs (von Hippel & von Krogh, 2015). However, the platform sponsor as the designer of the market has the ability to orchestrate (Boudreau & Hagiu, 2009; Choudary et al., 2016) the search process indirectly for their own benefit (Helfat & Raubitschek, 2018).

In sum, platform ecosystems offer a middle ground — i.e., between undirected and centrally directed — in efficient search processes, such that a known problem can be solved using semi-directed search whereas an unknown problem may be solved using an undirected but orchestrated search process. The search is efficient when the problem aligns with the platform sponsor scope, such an alignment depicting attractive opportunities for value creation and capture to the potential complementors and consumers. An efficient search would find valuable solutions in the form of complements, which is a manifestation of the attraction as well as commitment of complementors and consumers to the ecosystem. Thus, our major premise is that *a digital platform ecosystem emerges when there is an alignment between the problem and platform sponsor scope*.

In the following sections we explicate the elements constituting the problem and platform sponsor scope. Then, using abductive reasoning we identify practically relevant configurations of these elements associated with successful ecosystem emergence. We then specify our minor premises that bring more granularity to our argument of alignment between problem and scope.

2.3 Digital Platform Sponsor Scope

The scope of the firm is a major strategic decision for firms and its impact on firm performance has long been considered a critical issue in strategic management research, with much scholarship having been dedicated to identify factors that the focal firm has to consider in making this key decision (Ahuja & Novelli, 2017). The choice of firm scope shapes firms' strategies, likelihood of survival, performance outcomes and its competitive environment (Zenger et al., 2011).

Broadly speaking, there are two aspects defining firm scope: external scope, which refers to the choice of products and markets in which the firm chooses to compete, and internal scope, which refers more specifically to which value creation activities the firm chooses to retain within its boundaries. For our purposes we are more concerned with internal scope. Retaining activities within their boundaries facilitates firms to maintain control over decision-making regarding those criteria that, in the ecosystem context, enables them to facilitate coordination with other actors (Boudreau, 2010; Tiwana, 2013; Tiwana et al., 2010). However, such hierarchical control is not the only avenue available to firms. An alternate avenue for control over decision-making is through contracts with complementors, which assigns them decision rights over select aspects of complements and complementors' actions, such as timing of release and integration of the complement with other offerings on the focal platform. Our treatment of the term scope incorporates both aspects of broader control and more selective decision-rights.

Early work referred to platform scope as the platform sponsor's choice of which complements to make internally and which to leave to autonomous complementors (Cusumano & Gawer, 2002). More recent studies have adopted broader definitions of platform scope as the role played by the platform in the digital markets they enable (Cennamo, 2019) and the "vision that defines the ecosystem value proposition" (Dattée et al., 2018, p. 467). We refer to *platform sponsor scope* as constituting the activities that the sponsor chooses to perform internally and the extent of decision rights over complements. Our conceptualization of platform sponsor scope as the activities a firm chooses to engage in encompasses prior definitions because at a more granular level activities are what ultimately underpin the delivery of the value proposition. At the same time, by considering decision rights of complements we address the firm scope issue from the perspective of control (Boudreau, 2010; Gawer, 2014; Gawer & Henderson, 2007), which is vital for a collaborative arrangement.

2.3.1 Platform Sponsor Activities

Consumers derive value from both platform offerings as well as complements. Consequently, value creation activities are performed by both the platform sponsor and the complementors (Adner & Kapoor, 2010). The distribution of value creation activities between the platform sponsor and complementors manifests in the ecosystem design (Adner, 2017), wherein actors undertake activities to materialize the value proposition by assuming distinct positions within the ecosystem. Since value propositions often not fully known ex ante (Dattée et al., 2018), platform sponsors choose at the outset which activities to perform internally depending on their resource configurations. Such a choice of activities to perform internally is in effect the choice of the platform sponsor scope. As Adner (2017) rightly highlights, the scope decision puts forth a "vision of structure and roles [to which] others defer" (p. 48). Thus, the platform sponsor's agency in choosing its scope to materialize the value proposition or solve the focal problem is a first step for the rest of the ecosystem design to emerge.

The platform sponsor's choice of activities to perform internally is fundamental at the initial stage in order to attract complementors and consumers and ensure their commitment to the *de novo* ecosystem (Dattée et al., 2018; Hannah & Eisenhardt, 2018). The platform sponsor's activities signal its vision for the future ecosystem and the digital market in terms of how value may be created and the kind of complementors that can participate on the platform. When complementors and consumers perceive these signals as beneficial, they choose to participate on the platform that then ultimately leads to the emergence of an ecosystem. Furthermore, the platform sponsors' activity choices define the kind of interactions that are available to prospective complementors on the platform and thereby shapes the type of market the platform enables (Cennamo, 2019; Hagiu & Wright, 2019; Jerath & Zhang, 2010).

2.3.2 Complement Decision Rights

In addition to defining their scope in terms of value creation activities, platform sponsors can expand their scope through assuming decision rights over the complements. When they have decision rights over the complements, the platform sponsors can better control the quality, variety, and timing of release of the complements and thereby improve their competitive position (Cennamo & Santalo, 2013; Wareham et al., 2014). We contend that the platform sponsors make a strategic decision about the complement decision rights similar to the choice of value creation activities to perform internally. The platform sponsors' authority over the complement decision rights signals the extent of control complementors would have on their contributions to the ecosystem and the opportunities for value capture. The potential for value capture is particularly important in the initial stages to attract participation of complementors.

Platform sponsor scope expansion through complement decision rights may occur through arrangements such as quality control and review procedures (Wareham et al., 2014) as well as when the complementors cede complete control of the complements after producing them, such as in crowdsourcing and innovation contests (Felin & Zenger, 2014). In ecosystems aimed at producing open source hardware and software, the decision rights of the platform offerings and the complements resides within the community of ecosystem participants (Jeppesen & Frederiksen, 2006). In ecosystems where the sponsor is more like a market intermediary, the decision rights of the complements remains with the complementors (Hagiu & Yoffie, 2009; Thomas et al., 2014). In sum, there exists heterogeneity in who holds the complement decision rights within the ecosystem, which contributes to alternative platform sponsor scope choices.

Overall, the platform sponsor scope choice shapes the sponsor's latitude to govern the search process and, more broadly, the ecosystem. Ecosystems are governed to foster complementary innovation but "appropriately bound [the] participant behavior" to result in coherent value propositions (Wareham et al., 2014, p. 1195). Platform sponsors govern the ecosystem using strategies such as controlling the core platform modules opened to complementors (Boudreau, 2010; Parker & Van Alstyne, 2017), restricting the variety of complements (Wareham et al., 2014) and selectively incentivizing specific behavior and products over others (Rietveld et al., 2019). Such strategies can be implemented when the platform sponsors have access and control over the corresponding parts of the value creation process. However, the platform sponsor's scope limits their access and control, and therefore their latitude to govern, to the value creation activities they choose to perform internally or to the complements they control.

2.4 Problem Dimensions

So far, we have argued that efficient search processes in ecosystems are those where the scope of the platform sponsor is in accordance with the search process. Facilitating an efficient search process is particularly important in the early stages of the ecosystem as the platform sponsor as the entrepreneur tries to discover valuable entrepreneurial opportunities in problem-solution pairs or at least increase the likelihood of discovering such opportunities (Hsieh et al., 2007). In this regard, prior research has established that search processes are shaped by problem dimensions such as structure, context, and complexity (Felin & Zenger, 2014; Macher, 2006; Nickerson & Zenger, 2004). Thus, we now turn to examine how the different problem dimensions shape search processes (summarized in Figure 2.3) in platform ecosystems.

2.4.1 Problem Structure

The PSP posits that the solution to a problem is a process of searching for relevant knowledge sets within a solution landscape (Jonassen, 2004; Macher & Boerner, 2012). Problem structure refers to the level of understanding of the interdependencies among knowledge sets and the availability of formalized processes to reach the solution (Macher, 2006).

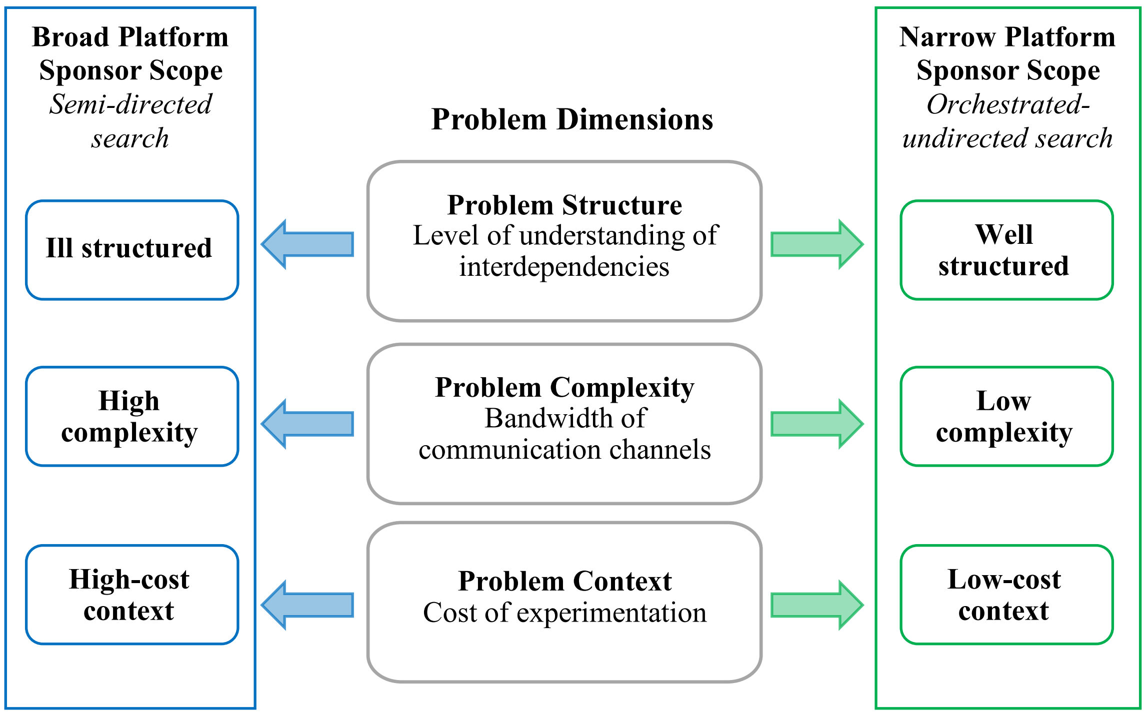

Figure 2. 3: Problem dimensions, Search Processes, and Platform Sponsor Scope Alignment

Problems can vary along a continuum from ill-structured to well-structured, well-structured problems being "those with well-defined initial states and known elements, explicit approaches for solving, and accepted end states [whereas] ill-structured problems have poorly defined initial states and indefinite problem-solving approaches" (Macher, 2006, p. 828). The underlying principle here is that, when knowledge set interdependencies are well understood, then formalized problem-solving processes exist that allows the search process to proceed undirected using independent trial and error-driven feedback mechanisms. In contrast, when the knowledge set interdependencies are not fully understood, a centrally directed search process driven by the central actor's heuristics and theories to fulfill the lack of formalized problem-solving processes.

Extending the above logic to digital platform ecosystems it follows that the problem is well-structured when formalized problem-solving processes exist within the ecosystem and the complementors and sponsor recognize initial and accepted end states. Here, the actors operate independently within the formal processes, a setup that is conducive for an undirected search involving second-order uncertainty since "all relevant knowledge sets are included and the path to high value solutions is clear" (Macher, 2006, p. 829). The platform ecosystem as a firm-designed market (Tajedin et al., 2019) then enables matching and finding problem-solution pairs among the available knowledge sets. Marketplaces such as eBay are examples of such ecosystems where the platform matches buyers and sellers of pre-defined products and uses formalized processes to complete the transactions. Additionally, the platform sponsor orchestrates the market to ensure enough participation on all sides as well as efficient and reliable transactions among the participants. Thus, well-structured problems are efficiently solved using an orchestrated-undirected search where the platform sponsor retains a narrow scope (Figure 2.3) to facilitate interaction between the supply and demand sides of the platform.

In contrast, when problems are ill-structured in platform ecosystems, actors may have poorly defined initial states and indefinite problem-solving processes. The platform sponsor as the central actor is required to guide the solution search by providing heuristics about the "probable consequences of search decisions" (Macher, 2006, p. 829). The search guidance may involve the platform sponsor selecting or specifying the problems that are likely to be more valuable. The platform sponsor may also need to provide guidance on the accepted end state of the solution by defining conditions of valuable solutions and their absorption into the ecosystem (Tajedin et al., 2019). In sum, the platform sponsor plays a larger role of identifying the problem as well as absorbing the solution. Hence, ill-structured problems can be solved efficiently using a semi-directed search process where the platform sponsor retains a broader scope (Figure 2.3). Innovation platforms of video games are examples of such ecosystems where the console manufacturers control and orchestrate the game developers using technological bounds and procedural constraints (Cennamo, 2018; Ozalp & Kretschmer, 2019).

2.4.2 Problem Complexity

Solving a complex problem involves "highly interdependent elements, choices, and knowledge sets that must be creatively recombined to compose valuable solutions" (Felin & Zenger, 2014, p. 916). Problem complexity is related to problem structure yet distinct from it. Whereas problem structure relates to the level of understanding of the interdependencies among knowledge sets, problem complexity relates to the magnitude of interdependencies between knowledge sets (Macher, 2006; Macher & Boerner, 2012). Consequently, as complexity increases, knowledge transfer and interaction between the actors holding dispersed knowledge sets becomes more costly. However, it is possible to economize on knowledge transfer costs by choosing an appropriate communication channel. Communication channel bandwidth refers to the "degree of intensity of communication among individuals" and can vary between a more intense high bandwidth channel and less intense low bandwidth channel (Heiman & Nickerson, 2004, p. 404; Hsieh et al., 2007). Since a complex problem involves higher interdependencies, the central actor's "cognitive evaluations of the probable consequences of particular [search] decisions" are required, which is enabled by greater communication bandwidth (Macher, 2006, p. 830). In contrast, a simple problem with limited interdependencies can rely on low bandwidth trial-and-error feedback to guide solution search, thereby making an undirected search more efficient.

Extending the above argument to the case of digital platform ecosystems, it follows that when the problem is complex there would be high levels of interdependencies between the platform and the complements as well as among complements. Thus, for a coherent solution to take shape, the interdependencies should be resolved through extensive knowledge sharing and communication. The platform sponsor is required to facilitate such knowledge sharing and high bandwidth communication channels in addition to cognitive evaluations of potential solutions. However, in an ecosystem the emphasis is to reach beyond local knowledge sets to diverse complementors. Hence, a semi-directed search where the platform sponsor balances the need to direct the search whilst using market mechanisms to alleviate knowledge constraints is most efficient to find valuable solutions. The need for cognitive inputs from the platform sponsor during the search process implies that the sponsor should retain a broad scope (Figure 2.3). For example, platform sponsors like Apple enable solving complex problems through the development of apps by providing guidance on their platform, evaluating apps for performance, and enabling wider reach to diverse developers through easy-to-use software development kits.

In contrast, simple problems entail a lower magnitude of interdependencies between the platform and complements as well as among complements. The actors within the ecosystem may not need extensive knowledge sharing in developing their offerings and thus require only low bandwidth communication channels. Consequently, the complements are often not only highly fungible within the ecosystem but also can be made available on competing platforms, a scenario termed multi-homing (Cennamo et al., 2018). In terms of problem-solving, the solution search in such a scenario needs little guidance from a central actor and can thus proceed undirected but orchestrated to achieve solutions that benefit the sponsor and ecosystem at large. The limited role of the platform sponsor allows them to retain a narrow scope (Figure 2.3). Marketplaces like eBay are examples of ecosystems where sellers seek to sell largely standardized products and often sell same products on multiple marketplaces simultaneously.

2.4.3 Problem Context

Recent work in the PSP literature has argued that the problem context shapes the cost of experimenting to find valuable solutions and has implications for the search process (Furr et al., 2016; Nickerson et al., 2007). A high cost to experiment implies that the search for solutions requires costly resources or longer periods of time, resulting in a more constrained problem-solving process. Whereas cost of experimentation is vital, especially in the early stages, problem context can also include other factors that constrain problem-solving, such as the regulatory environment, that in effect increases the costs. The focal firm's choice of the problem implicitly includes the context since that often cannot be changed. Thus, similar to the other problem dimensions discussed above, the context should be considered in choosing the governance form for efficient solution search.

A high-cost problem context involves costly experimentation to find valuable solutions. In such a context, the actors would plausibly prefer to invest their resources judiciously in design choices that could yield potentially valuable solutions. When the problem context is resource intensive or more constraining, and thus costly, then outcomes of experimental search are viewed through a risk averse lens (Furr et al., 2016). However, identifying what constitutes a valuable solution requires knowledge from prior trials and a broader vision of competing solutions, or simply put heuristics and theories. In digital platform ecosystems, solving a problem in a high-cost context would deter complementors from investing in developing complements around the *de novo* platform. The platform sponsor's guidance on the design choices for potentially valuable complements are key to overcome such deterrence in experimentation. Thus, the platform sponsor would require a broad scope to provide such guidance to aid the search (Figure 2.3). At the same time, the platform sponsor should allow room for innovation from diverse actors. The balance between guiding the search and fostering innovation (Boudreau, 2010, 2012) is attained using a semi-directed search process in platform ecosystems (Tajedin et al., 2019).

In contrast, a low-cost problem context is less expensive to experiment and find valuable solutions. Here, the problem solvers can perform independent trial-and-error based search and rely on feedback from their own trials to proceed with the search process, a scenario of orchestrated-undirected search. In digital platform ecosystems, a low-cost problem context could attract diverse set of complementors to experiment since the downsides are not significant. Moreover, problems with second-order uncertainty may be more conducive for such a search since platform sponsors' guidance is not required to identify valuable problem-solution pairs. Hence, the platform sponsor may choose to retain a narrow scope (Figure 2.3).

In sum, each of the problem dimensions shapes the extent to which the search for solutions requires guidance and direction of the platform sponsor and consequently the choice of the search process. However, the problem dimensions and the corresponding search process are rarely dichotomous and, as depicted in Figure 2.2, we expect that the search process varies over a continuum with centrally directed and undirected as the two ends.

2.5 Analytical Approach

To reiterate, each of the problem dimensions impacts some aspect of the solution search process. However, and importantly, the efficiency of the solution search depends not just on the focal problem dimension but also on the other dimensions that co-occur. Even though a problem has various distinct dimensions, such as structure, complexity, and context, these are interconnected and occur together as they describe different facets of the problem. Whereas each problem dimension may require a particular type of search process to find valuable solutions efficiently, it is plausible that the problem dimensions may require conflicting search processes. For example, consider a problem with high complexity in a low-cost context. Whereas high complexity would suggest a semi-directed search to be efficient, a low-cost context allows for independent experimentation and therefore an undirected search. In such scenarios, it is not entirely clear which dimensions become important in determining the search process. Moreover, it is futile to determine the relative importance of problem dimensions since they co-occur and may not be effectively altered. Hence, it is necessary to consider the problem dimensions holistically in determining the efficient search process for the problem.

Furthermore, it is essential to consider both the elements of platform sponsor scope – platform sponsor activities and complement decision rights – in determining the most suitable governance form for an efficient search. The two elements co-occur in the context of platform ecosystems yet are distinct and shape the governance of the search process in different ways. The platform sponsor's choice of activities shapes the extent to which the sponsor can choose and define the problem, facilitate knowledge sharing and communication, as well as select and absorb solutions. The decision rights on complements defines who determines the value of solutions and how those solutions would be absorbed into the value propositions.

As we detail in the following sections, to address the above issues we employ a configurational perspective that relies on abductive reasoning as the mode of inquiry. The configurational perspective enables us to analyze the problem dimensions and platform sponsor scope elements more holistically, the alignment between the two for successful ecosystem emergence being our major premise. The abductive reasoning mode helps identify minor premises encompassing practically relevant configurations of the different elements of problem and scope, a vital step to bring more granularity to our major premise.

2.5.1 Configurational Perspective

The configurational approach constitutes a holistic mode of inquiry examining "multidimensional constellations of conceptually distinct characteristics that commonly occur together" (Meyer et al., 1993, p. 1175). Fundamental to the configurational approach is the focus on identifying complex causal relationships, in the form of patterns or profiles of conditions related to an outcome of interest, rather than individual variables to identify the combined effects of causal conditions (Furnari et al., 2020; Meyer et al., 1993; Ragin, 2009). In our context, using a configurational approach helps identify patterns of problem dimensions and platform sponsor scope associated with successful emergence of ecosystems.

The configurational approach facilitates examining conjunctural causation of the various causal conditions, equifinality in outcomes, and asymmetry in causal relationships. Conjunctural causation is helpful to examine causal complexity where the outcomes "result from the interdependence of multiple conditions" (Misangyi et al., 2017, p. 256) and thus the effect of a condition may vary based on the other co-occurring conditions, such as our scenario of co-occurring problem dimensions. Equifinality allows for the possibility that there can be "more than one pathway to a given outcome" (Misangyi et al., 2017, p. 256), which is consistent with our context where ecosystems emerge in many formats. Finally, asymmetry of causal relationships allows the possibility that the values of a particular problem dimension in one configuration may be unrelated in another configuration or may have very different values.

2.5.2 Abductive Reasoning

While a configurational approach "facilitates the exploration of complex models, however, complex configurational models are difficult to specify a priori" (Park & Mithas, 2020; White et al., 2020, p. 6). Besides, as with most social phenomena, not all configurations are practically possible and relevant, a scenario referred to as limited diversity (Ragin, 2009). We use abductive reasoning to elaborate the theory we have described so far by identifying data-driven practically relevant patterns or configurations of the different problem dimensions and platform sponsor scope that enable successful ecosystem emergence. Such an approach to theory building is argued to be a "practical compromise of induction and deduction [that] more realistically captures the authentic process by which theorizing occurs" (Shepherd & Suddaby, 2017, p. 79).

Abductive reasoning involves forming a conclusion from known information or "inference to the best explanation" (Kathuria et al., 2020, p. 418) when the "major premise is evident but the minor premise and therefore the conclusion are only probable" (Merriam-Webster Dictionary, 2020). Abductive reasoning can transparently select the configurations of interest from alternatives (Mantere & Ketokivi, 2013; Van Maanen et al., 2007). We employ abductive reasoning at two stages – first, we employ fuzzy-set qualitative comparative analysis (fsQCA) as the empirical basis (Douglas et al., 2020; Ragin, 2009) to reveal configurations of problem and scope elements. Second, we abduct away (Kathuria et al., 2020) from the fsQCA results and abstract to generate propositions encompassing configurations of problem and scope elements associated with successful ecosystem emergence. Such a two-staged process enables iterating between theory and empirical evidence and progressively develop theory through abductive discovery.

2.6 Methods

2.6.1 fsQCA technique

In brief, fuzzy-set qualitative comparative analysis (fsQCA) seeks to identify configurations of causal conditions that are related with the outcome of interest based on subset relations between the two across multiple cases (Fiss 2011; Greckhamer et al. 2008; Ragin 2009; see Greckhamer et al. (2008) for an in-depth explanation of fsQCA). Using set theory and Boolean minimization, fsQCA can identify the combination of theoretically relevant attributes or causal conditions for the occurrence or non-occurrence of the outcome of interest (Greckhamer et al., 2018). In our context, the procedure helps identify the combination of different problem and platform sponsor scope dimensions for the occurrence or non-occurrence of successful ecosystem emergence. As we explain in the subsequent sections, the initial steps in the procedure involve selection of theoretically relevant cases as samples and the calibration of their degree of membership in the sets of the causal conditions and the outcome.

2.6.2 Research Setting

Our dataset comprises of crowdfunding campaigns to launch digital platforms posted on Kickstarter, the largest crowdfunding site. This dataset is well-suited to answer our research question for a number of reasons. As a repository of both successful and unsuccessful campaigns, Kickstarter serves as an excellent source of counterfactuals, which is typically difficult to find in the early stages of firms (Mollick, 2014). The detailed campaign information provides insight into how aspiring platform sponsors frame their perspective of the problem to be solved and their choice of platform scope. Furthermore, it has been established that fundraising campaigns on crowdfunding websites like Kickstarter also serve to validate the feasibility of the idea and understand market potential (Elia et al., 2020; Short et al., 2017). In our context, such validation signals the perception of potential complementors and consumers, who as backers indicate their preferences through their funding pledges to the campaigns that propose to launch the platform.

We selected our cases using the following criteria: First, we chose campaigns under the category of 'Technology' and sub-categories of Apps, Web, Hardware and Software that were active during 2016-17. The campaigns listed under the technology category are argued to have a significant technological and scientific component and higher funding goals, both of which make them attractive to professional investors (Roma et al., 2017). Furthermore, we selected only those campaigns that proposed to use digital technologies. Whereas the apps and web categories clearly leverage the technologies of established digital platforms (internet, Apple iOS, Android), the software and hardware categories were manually verified to encompass generativity in their proposed technologies i.e., if they were modular and extendable without affecting the core modules. Second, we selected campaigns that self-described as a platform and met the accepted academic definition of a platform as enabling direct interactions between two or more distinct sides and where each side is affiliated with the platform (Hagiu & Wright, 2015a). Third, we selected campaigns that had at least ten backers. Whereas successful campaigns under the Technology category are known to have an average number of backers higher than this threshold (Mollick, 2014), we chose the above threshold as it allows us to capture both successful and unsuccessful campaigns yet include only those that are substantial enough to gather the interest of at least ten distinct backers. We arrived at a dataset of 52 cases or campaigns based on the above criteria.

2.6.3 Measures

The standard fsQCA procedure involves transforming conventional measures (dependent and independent variables) into fuzzy set membership scores by calibrating them against three qualitative thresholds: full membership, the crossover point, and full non-membership. We set thresholds for each measure, based on extant theory and substantial knowledge of the context. Following Ragin (2009), we used the direct method of calibration available in the fsQCA software. Table 2.1 summarizes the measures, the fuzzy sets, and their calibration thresholds.

Table 2. 1: Set Calibrations and Descriptive Statistics

	Fuzzy Set Calibrations			***Measure Descriptives***			
Measure / Fuzzy Set	***Fully In***	***Crossover***	***Fully Out***	***Mean***	***SD***	***Max***	***Min***
Well-structured problem	0.8	0.6	0.4	0.72	0.19	1	0.25
High bandwidth channel	1	0.66/0.33	0	0.30	0.38	1	0
High-cost context	80	50	20	70.6	117.9	500	0
Complement decision rights	1	0.66/0.33	0	0.26	0.34	1	0
Narrow scope of sponsor activities	0.6	0.4	0.2	0.48	0.18	1	0.25

2.6.4 Outcomes

2.6.4.1 Campaign Funding Success

We measure campaign success as the ratio of funds raised to the funding goal of the campaign. The primary objective of starting campaigns on Kickstarter is to raise funds in the form of pledges from backers who are then rewarded for their contribution through early access to the platform, products, or other such perks. However, the growing literature on crowdfunding has established that in addition to raising funds, crowdfunding campaigns such as those on Kickstarter enable entrepreneurs to conduct an open search for ideas (Stanko & Henard, 2017), engage backers in innovation and product development (Eiteneyer et al., 2019), and collect information on the potential interest of consumers on the product (Viotto da Cruz, 2018). A recent study has thus argued that crowdfunding campaigns help in the "transition from an abstract idea to a concrete social entity" (Clough et al., 2019, p. 241; Soublière & Gehman, 2020). Hence, with campaign funding success as an outcome variable, we are measuring not just the entrepreneur's success in raising funds but also the interest of potential consumers and complementors, their willingness to suggest ideas and eventually the creation of a social entity in the form of an ecosystem.

Kickstarter considers a campaign successful when it raises funds equal to or higher than its goal. We calibrated membership in the set of *successful campaigns* using the following thresholds: campaigns that raised funds equal to or higher than their set funding goal were coded as "fully in" the set of successful campaigns; campaigns that did not raise any funds (i.e., 0% of the set funding goal) were coded as "fully out" of the set of successful campaigns; and the halfway mark was used as crossover point (i.e., campaigns that raised 50% of the set goal).

2.6.4.2 Ecosystem Emergence

Although Kickstarter campaigns are argued to serve the purposes of early validation, idea generation, and creation of a social entity in addition to raising funds, we supplement our analysis of campaign success with a different outcome variable that explicitly captures ecosystem emergence. *Ecosystem emergence* is the outcome variable that captures if the ecosystem came into being after and as a result of the Kickstarter campaign. We collected data from announcements on Kickstarter and social media pages of the respective campaigns. The ecosystem existence variable is coded 1 if the platform was launched and gained traction through participation of complementors and consumers within one year of the campaign and coded 0 otherwise. We calibrated the set of *ecosystem emergence* using the following typical thresholds of crisp sets: the campaign was coded as "fully in" when the score was at 1, "fully out" at 0, and crossover point at 0.5 where the membership was neither fully in nor fully out.

2.6.5 Causal Conditions

<u>Problem Structure</u>: The understanding of interdependencies between components of the platform and the complements manifests through the sponsors' identification of initial states, problem-solving approaches and end states that collectively contribute to the dimension of problem structure. Since Kickstarter allows the campaigns to have free text describing their projects, we

captured the presence or absence of the above three elements — initial states, problem-solving approaches, and end states — in the campaigns by posing questions that had binary responses (Yes/No), as summarized in Table 2.2.

Table 2. 2: Coding scheme for Problem Structure

Problem structure elements	***Questions (Yes/No)***
Initial state	Is a gap/need identified?
	Have all the sides of the platform been identified?
Problem-solving approaches	Are the activities to be performed by each of the sides identified?
	Does the campaign refer to existing/established platforms or business models?
End state	Is a working solution or prototype provided?

We calculated the problem structure for each campaign as the ratio of the sum of scores of the above questions to the maximum possible total score, i.e., all questions receive 'Yes' response). We then calibrated the set of *well-structured problem* using the following thresholds: the campaign was coded as "fully in" when the score was at or above 0.8, "fully out" at 0.4, and crossover point at 0.6 where the membership was neither fully in nor fully out. We chose these thresholds because a score of 0.8 (4 of the 5 questions received 'Yes') indicates that all three elements have been addressed as at least one question in each element has received a 'Yes' response and a score of 0.4 (2 of the 5 questions received 'Yes') indicates at least one element has not been addressed.

Problem Complexity: The magnitude of interdependencies between the platform components and the complements drives the nature of communication between actors and thus the corresponding communication channel bandwidth. Following recommendation from Hsieh et al. (2007), we operationalize problem complexity as the magnitude of bandwidth of the communication channel proposed in the Kickstarter campaign to enable interaction among the platform sponsor and complementors. We coded the campaigns using a four-value fuzzy set of *high bandwidth channel* as follows: campaigns that sought to use in-person or face-to-face or phone calls were coded as fully in this set (= 1); campaigns that were based on open-source licensing and proposed to follow open-source community practices were coded as more in than out in the set (0.66); campaigns that proposed offering application programming interfaces (APIs) and design manuals to complementors were coded more out than in the set (0.33); and campaigns that only offered online transactions were coded as fully out of the set of high bandwidth channels (0).

<u>Problem Context</u>: The complementors engage in experimentation to find valuable complements and thus encounter costs of experimentation that are shaped by the problem context. We measured problem context as the least cost incurred by the complementors to access all available features of the platform to experiment and produce complements. We calibrated membership in the set of *high-cost context* using the following thresholds: Since according to Kickstarter the average pledge amount across all categories is about \$80 (Kickstarter, 2019), we coded campaigns that proposed to charge the complementors equal to or more than \$80 as fully in the set; campaigns that proposed to charge the complementors less than \$20 as fully out of the set; and campaigns that proposed to charge the complementors \$50 as the crossover point.

<u>Platform Sponsor Activities</u>: One of the elements of platform sponsor scope relates to the activities that the sponsor chooses to perform internally. The extent to which these activities are organized within the firm reflects in the different types of markets that these platforms seek to enable, namely information markets, multisided transaction markets and complementary innovation markets (Cennamo, 2019). Although digital platforms can encompass a combination of these markets, the distinct types can help identify the distinct activities of the platform. In enabling information markets, the platform serves as an "information channeling infrastructure that enables the categorization and search of relevant information, and facilitates users' exchange of information and matching" (Cennamo, 2019, p. 8). We identified that the activities underpinning information

markets are information exchange and matching or categorization of information. In multisided transaction markets, the platform provides the "infrastructure to connect providers of goods and services with final customers, and facilitate value-exchange transactions among them" (Cennamo 2019, 6). Thus, the activities underpinning multisided transaction markets are trading, matching demand and supply, and enabling competition. In complementary innovation markets, the platform provides a "common assets' infrastructure for innovation, making sure that complementarity and product system integration are achieved *ex ante*" to enable the complementors to extend the platform functionality (Cennamo 2019, 7). Consequently, the primary activities underpinning complementary innovation markets are group-level coordination of complementors to generate and commercialize innovation.

Overall, we identified the key activities underpinning each of the above three markets as – information exchange, matching, trading, competition, and group-level coordination. When most of these above-mentioned activities are encompassed within the platform rather than being internal to the sponsor firm, then it follows that the platform sponsor has retained few activities to be performed internally (Hagiu & Wright, 2015a) and therefore has a narrow scope. We coded each campaign for the activities they propose to perform from the above list. The presence of an activity was coded as 1 or 0 otherwise. We then calculated the platform sponsor scope as the ratio of the sum of the activities performed by the platform to the maximum score of 5 when all activities are proposed. Next, we calibrated the set of *narrow scope of activities* using the following thresholds: the campaign was coded as "fully in" when the score was at or above 0.6, "fully out" at 0.2, and crossover point at 0.4 where the membership was neither fully in nor fully out. We chose the above conservative threshold for full membership in the set of *narrow scope of activities* as the combination of any three activities requires the platform to forego control over key parts of the value creation process.

<u>Complement Decision Rights:</u> The decision rights of the complements can remain with the complementors, within a subgroup or community, or with the platform sponsors. The campaigns on Kickstarter provide this information as it indicates the possible ways backers can capture value in addition to the rewards laid out as part of the campaign. We coded the campaigns using a four-value fuzzy set of *platform sponsors' decision rights on complements* as follows: campaigns that proposed to centrally hold decision rights over complements were coded as fully in this set (1); campaigns where the decision rights of the complements resided within platform sponsor-identified clusters or sub-groups were coded as more in than out in the set (0.66); campaigns that proposed distributing the decision rights within the community were coded more out than in the set (0.33); and campaigns that allowed complementors to retain decision rights were coded as fully out of the set of platform sponsors' decision rights on complements (0).

2.6.6 Data Analysis

We used the standard fsQCA software 3.0 to perform our analyses. As a first step we sought to identify any necessary conditions, which are the causal conditions that must be present for an outcome to occur. We conducted necessity analyses of all conditions and their negation using the recommended benchmark of 0.9 for consistency scores (Greckhamer et al., 2018; Ragin, 2009). We did not find any necessary conditions from our dataset. Next, we conducted sufficiency analyses using the Quine–McCluskey algorithm to logically minimize from all possible combinations. The results of the sufficiency analyses identified configurations of conditions consistently linked to an outcome. Following recommended guidelines for an intermediate-N dataset like ours, we chose a minimum frequency threshold for a configuration's inclusion in causal analyses as 1, which included 80% of our cases (Greckhamer et al., 2013). We applied a consistency threshold of ≥ 0.8 and a PRI (proportional reduction in inconsistency) of ≥ 0.7, as recommended for analyses involving fuzzy sets. We performed the sufficiency analyses for both the outcome and non-outcome using the same thresholds and cut-offs.

2.7 Results

Table 2.3, 2.4, and 2.5 summarize the results of the fsQCA analyses using the standard notation (Ragin, 2009) for the occurrence and non-occurrence of the outcomes. In each configuration, the full circles indicate the presence of a condition, and the crossed-out circles indicate the absence of a condition. Further, the larger circles indicate core conditions that occur in both the parsimonious and intermediate solutions and thus indicate strong causal relationship. The smaller circles indicate peripheral conditions that occur only in intermediate solutions and thus indicate weak causal relationships (Fiss, 2011).

We report in Table 2.3, 2.4, and 2.5 standard measures of consistency, raw coverage, and unique coverage for each of the configurations as well as overall consistency and coverage for the solution formula. The consistency score is a measure of the number of cases consistent with the outcome and is calculated as the ratio of number of cases that exhibit the configuration of causal conditions and the outcome to the number of cases that exhibit the configuration of causal conditions but not the outcome (Ragin, 2009). The coverage score is a measure of the empirical importance of a configuration and is calculated as the percentage of cases that follow a given pathway to the outcome (Fiss, 2011). Our results show that the overall solution consistency is 0.86 (coverage of 0.48) for the outcome of successfully funded campaigns and 0.78 (coverage of 0.36) for ecosystem existence, both exceeding recommended threshold for consistency scores. We first present the various results, following which we derive select insights and abduct away (Kathuria et al., 2020) to offer propositions.

Table 2. 3: Configurations of Successfully Funded Campaigns

Taxonomy of Digital Platform Ecosystems	**Complementary Innovation Ecosystems**		**Open Source Ecosystems**		**Information ecosystems**
Search process and platform sponsor scope alignment	*(Semi-directed search and broad scope)*		*(Community-directed search and less broad scope)*		*(Orchestrated-undirected search and narrow scope)*
Solution	**1a**	**1b**	**2**	**3**	**4**
Problem dimensions					
Well-structured problem	⨂	⨂		⊗	•
High complexity		•	●	•	⊗
High cost context	●	●	⨂		•
Platform sponsor scope					
Complement decision rights	•		⨂	⊗	
Narrow scope of activities	⊗	⊗	⨂	⊗	•
Consistency	0.87	0.87	0.92	0.90	0.82
Raw Coverage	0.14	0.15	0.22	0.23	0.14
Unique Coverage	0.02	0.01	0.04	0.01	0.21
Overall Solution Consistency		**0.86**			
Overall Solution Coverage		**0.48**			

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition. Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

2.7.1 Configurations of Successfully Funded Campaigns

Solutions represented in the columns of Table 2.3 represent the configurations related to the outcome of successful campaigns. Solution 1a (consistency score of 0.87 and raw coverage of 0.14) shows that campaigns were successfully funded when they proposed to solve problems that were not well-structured in a high-cost context as long as they also proposed to retain both a high platform sponsor scope and decision rights over complements. Solution 1b (consistency score of 0.87 and raw coverage of 0.15) shows that campaigns were successfully funded when they proposed to solve problems that were not well-structured and highly complex in a high-cost context as long as the platform sponsor retained a broad scope of activities. In both solution 1a and 1b the conditions of not well-structured problems and high-cost context are core conditions.

Solution 2 (consistency score of 0.92 and raw coverage of 0.22) shows that campaigns were successfully funded when they proposed to solve problems that were highly complex in a low-cost context when the platform sponsor scope of activities was broad, but the sponsor did not exert decision rights over the complements. All the conditions appeared as core conditions. Solution 3 (consistency score of 0.9 and raw coverage of 0.23) shows that campaigns were successfully funded when they proposed to solve high complexity problems that are not well-structured and combined them with distributed decision rights while retaining a high share of activities. Finally, solution 4 (consistency score of 0.82 and raw coverage of 0.14) shows that campaigns were funded when they proposed to solve well-structured and simple problems but in a high-cost context as long as the platform sponsor retained a narrow set of activities.

2.7.2 Configurations for Successful Ecosystem Emergence

Solutions 5 to 7 in Table 2.4 depict the outcome of successful ecosystem emergence, as distinct from successful funding. Solution 5 (consistency score of 0.78 and raw coverage of 0.235) represents a configuration that is identical to solution 2 in Table 2.3, where the outcome was successful funding of the campaign. Solution 6 (consistency score of 0.77 and raw coverage of 0.25) is similar to solution 3 in Table 2.3, the one difference being that the former depicts all conditions as core conditions whereas the latter had all peripheral conditions. Finally, solution 7 is similar to solution 4 with an additional condition of the platform sponsor exerting decision rights of complements as a core condition of the causal recipe. Such tight overlap of the solutions across the two outcomes validates the argument that a successful funding may also indicate progress in the emergence of the ecosystem.

Table 2. 4: Configurations for Ecosystem Emergence

Taxonomy of Digital Platform Ecosystems	**Open Source Ecosystems**		**Information ecosystems**
Search process and platform sponsor scope alignment	*(Community-directed search and less broad scope)*		*(Orchestrated-undirected search and narrow scope)*
Solution	**5**	**6**	**7**
Problem dimensions			
Well-structured problem		⊗	●
High complexity	●	●	⊗
High-cost context	⊗		●
Platform sponsor scope			
Complement decision rights	⊗	⊗	●
Narrow scope of activities	⊗	⊗	●
Consistency	0.78	0.77	0.91
Raw Coverage	0.23	0.25	0.13
Unique Coverage	0.05	0.06	0.05
Overall Solution Consistency		**0.78**	
Overall Solution Coverage		**0.36**	

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition. Large circles indicate core conditions and small circles indicate peripheral conditions.

2.7.3 Not successful campaigns

Table 2.5 summarizes the configurations related to the non-occurrence of the outcomes of successful funding of campaigns and ecosystem emergence. Solution 8 (consistency score of 0.83 and raw coverage of 0.22) shows that campaigns were not successfully funded when they proposed to solve problems that were well-structured and highly complex in a high-cost context and the platform sponsor proposed to not exert decision rights over the complements. Solution 9-13 (consistency score of 0.88 and raw coverage of 0.48) shows the configurations where the campaigns failed to launch platforms and facilitate ecosystem emergence. These configurations do not have any overlap with the configurations for successful funding and ecosystem emergence depicted in Table 2.3 and 2.4. Furthermore, as we argued in our theory, the configurations in solutions 9-13 of Table 2.5 depict a mismatch between the problem dimensions and platform sponsor scope. Whereas solutions 11, 12, and 13 show recipes of the platform sponsor retaining a narrow scope and exerting decision rights over complements, the problem dimensions move the search towards a more semi-directed process, thereby creating a misalignment. Solution 10 also suffers from a misalignment between a broad scope with complement decision rights and problem dimensions requiring an undirected search process. In contrast, solution 9 suffers from a misalignment between a narrow scope and problem requiring cognitive guidance of the sponsor.

Table 2. 5: Configurations for Negation of Outcomes

Outcome	**Not funded**	**No Ecosystem existence**				
Solution	**8**	**9**	**10**	**11**	**12**	**13**
Problem dimensions						
Well-structured problem	●	⨂	●		•	●
High complexity	●	⊗		●	•	●
High cost context	●	⊗	●	⨂	⊗	•
Platform sponsor scope						
Complement decision rights	⨂		⊗	●	•	●
Narrow scope of activities		•	⨂	●	•	●
Consistency	0.83	0.84	0.83	0.90	0.87	0.88
Raw Coverage	0.22	0.17	0.15	0.22	0.14	0.11
Unique Coverage	0.22	0.07	0.06	0.10	0.06	0.04
Overall Solution Consistency				0.88		
Overall Solution Coverage				0.48		

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition.
Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

Finally, we conducted a number of sensitivity analyses to examine the robustness of our findings (see Appendix A). We considered alternative crossover points by varying the crossover points for all measures by +/- 25 percent. Although minor changes appear in the solution in the form of the number of solutions and sub-solutions, the interpretation of the results remain unchanged indicating the robustness of the findings.

2.8 Pathways to Ecosystem Emergence

We expected an alignment between the problem dimensions and platform sponsor scope to enable ecosystem emergence but relied on abductive reasoning to identify the exact configurations of problem dimensions and scope. So far, we discussed such configurations where the campaign was successfully funded and led to ecosystem emergence as well as those that did not receive sufficient funding and did not emerge as an ecosystem. Following prior studies (Kathuria et al., 2020), we now abduct away from the configurations to offer generic propositions encompassing pathways to ecosystem emergence. We employ a taxonomy of ecosystems as our baseline for interpreting the empirical results and draw on substantial and case knowledge (Ragin, 2009) to abstract from the configurations and highlight alignment between platform sponsor scope and search process.

2.8.1 Complementary innovation ecosystems

Platform ecosystems have been exhaustively studied as innovation engines "providing the core technological architecture other firms build upon to create new products that extend the core functionality and reach of the platform to final users" (Cennamo 2019, 7; Gawer 2014). Examples of such ecosystems include the Apple iOS ecosystem and SAP NetWeaver computing ecosystem. The primary source of value in such platforms comes from the platform offerings that are then enhanced by complementing products (McIntyre & Srinivasan, 2017). As a result, the platform sponsors play a wider role in the value creation process and exert considerable influence on the solutions to the problems. Such broad scope of activities allows the platform sponsors to better understand the interdependencies among the different modules and thereby become better equipped to solve ill-structured problems. The interdependencies sometimes requires that the sponsor retain decision rights over the complements for better absorption into the value propositions. The search process in solving such problems would tend to be a more semi-directed one that is aligned with a broad platform sponsor scope, as depicted in Figure 2.2. Also, the platform sponsors can charge the complementors a higher price for allowing access to the core infrastructure and reach to final users, which is often valuable to the complementors, and thereby make the problem context more constrained for experimentation (Weyl, 2010). These observations are found in the configurations of solution 1a and 1b (Table 2.3) in our results and can be summarized as in the proposition below:

> *Proposition 1: The emergence of complementary innovation ecosystems is associated with solving ill-structured, complex problems in a high-cost context where the platform sponsor retains a broad set of activities to perform internally and holds decision rights over the complements.*

2.8.2 Open-source platform ecosystems

Comparing the configurations of solution 2 and 3 (Table 2.3) as well as solution 5 and 6 (Table 2.4) with the cases representing these configurations, we found that both these configurations correspond to campaigns aimed at building open-source platforms. Digital technologies have enabled the rise of open-source hardware and software platforms that foster open innovation, which is a "distributed innovation process based on purposively managed knowledge flows across organizational boundaries" (Chesbrough & Bogers, 2014, p. 17). Examples of such ecosystems include Mozilla and Linux open-source software ecosystems. Value creation in the ecosystems around such platforms is dependent on the contribution of participating complementors as well as on the management of these contributions to form a coherent and valuable solution to the problem. Hence, a less-constrained problem context is fundamental to such ecosystems so that complementors can experiment easily and contribute to the solution.

The platform sponsors retain a broad scope of activities to enable the creation of coherent solutions from the contributions of complementors. Notably, the underlying premise of these ecosystems is that the decision rights to the solutions rest within the community of contributors and the solutions are often free for everyone to use (Bogers et al., 2017). Thus, the platform sponsor scope is less broad than that in the complementary innovation ecosystem discussed above. With such a scope choice, the platform sponsors open the core infrastructure and seek solutions to complex ill-structured problems. We refer to the search process for solving such problems as a community-directed search (Figure 2.2) that is less dependent on the sponsor yet not undirected. Thus, as shown in the configurations of solution 2 and 3, open-source ecosystems depict the problem and scope configurations as summarized in the following proposition:

Proposition 2: The emergence of open-source ecosystems is associated with solving highly complex and ill-structured problems in a low-cost context where the platform sponsor retains a broad set of activities to perform internally but does not exert decision rights over complements.

2.8.3 Information ecosystems

The configurations of solution 4 (Table 2.3) and solution 7 (Table 2.4) in the results represent cases that can be described as information ecosystems, where the platform primarily serves as an "information channeling infrastructure that enables the categorization and search of relevant information, and facilitates users' exchange of information and matching" (Cennamo, 2019, p. 8). Examples of such ecosystems include Google's search engine, LinkedIn, and Slack messaging platforms. The primary sources of value in these ecosystems are: one, the platform infrastructure that allows for a reliable and accurate matching of relevant information; and two, the information that is often generated by the complementors of the platform. The complementors of information ecosystems include, on one hand, advertisers and content creators who rely on the platform infrastructure to match with the right target users and, on the other hand, the users who generate information for other users on the platform. Since the complementors are engaged in solving the problem of targeting the right users with right information and the platform sponsors provide the tools to filter and match relevant information, the problem being solved is a well-structured one with known initial and end states and formalized problem-solving procedures. Thus, the search process may be undirected yet orchestrated by the platform sponsor (Figure 2.2).

At the same time, the sponsor retains control over the information generated to enhance its matching tools and provide better targets to the complementors. In our terminology, this shows that the platform sponsors exert decision rights over the complements. Though the platform sponsors provide the core infrastructure for matching, they do not engage in activities of creating the information or in disseminating them. Hence, the platform sponsors can retain a narrow scope of activities and facilitate the complementors to perform other activities for value creation (Figure 2.2). However, despite their narrow scope the platform sponsors can charge a high price and constrain access to the platform, the information, and the users as they exert decision rights on the overall solution. The above findings may be summarized in the following proposition:

Proposition 3: The emergence of information ecosystems is associated with solving well-structured and simple problems in a high-cost context where the platform sponsor retains a narrow set of activities to perform internally and holds decision rights over complements.

2.9 Discussion

In this paper we demonstrated how a digital platform sponsor's choice of scope vis-à-vis complementors can facilitate the emergence of an ecosystem around its platform. The context of digital platforms being similar to that of knowledge, we extended the problem-solving perspective to explain how two distinct decisions – problem to be solved and platform sponsor scope – have implications for the successful emergence of an ecosystem of complementors and consumers. Since the configuration of problem dimensions influence aspects of the search process, as the PSP suggests, governing such a search process suitably to overcome hazards of value creation is essential to identify valuable solutions efficiently. However, the governance of the search is constrained by the scope of the platform sponsor. Hence, we considered both problem dimensions and platform sponsor scope in our analysis of ecosystem emergence. Using a configurational perspective, we showed that an alignment between the problem dimensions and the platform sponsor's scope would facilitate an efficient search and thereby attract autonomous complementors and consumers, leading to the emergence of an ecosystem.

Our paper makes a number of theoretical and empirical contributions to both the platform and the problem-solving perspective literatures. First, it sheds light on the underexplored topic of how platform sponsors can facilitate the emergence of digital platform ecosystems in the incipient stages. Through its distinct focus and logic, the paper complements the stream of studies arguing that managers aspiring to build ecosystems must consider the benefits for ecosystem users as a way of attracting them to participate (Gawer, 2011; Thomas et al., 2014). Our findings highlight a novel set of considerations — problem dimensions and platform sponsor's scope choices — to tackle the early-stage challenge of attracting autonomous actors to participate and contribute to an incipient less-known platform ecosystem. Our theoretical framework of alignment between problem and scope for efficient search, supported by empirical evidence encompassing distinct configurations of these two dimensions, demonstrates how platform sponsors can attract participation and thus enable ecosystem emergence. We also contribute to the firm scope literature by demonstrating that, in the context of digital platform ecosystems, selective decision rights over complements are a facet of scope choice in addition to ownership.

Second, by establishing that the context of digital platforms is similar to that of knowledge, we extend the problem-solving perspective to platform ecosystems. As we have demonstrated in this paper, the problem-solving perspective is useful to examine how the micro-level aspects of problem and sponsor scope link with broader ecosystem-level considerations (Felin & Zenger, 2014). The problem-solving perspective and problem as the unit of analysis is helpful to address innate challenges in studying digital platform ecosystems and more broadly digital strategy. For example, the difficulty in tracking ex-ante unknown complementors (Gawer & Cusumano, 2014) is a major reason why research on ecosystem emergence has remained scant (Dattée et al., 2018). The focus on the value proposition (Adner, 2017) also suffers from a similar drawback as it assumes that the value proposition is known ex-ante whereas in most cases the value proposition evolves as more complements are offered to consumers. We demonstrate that applying 'problem' as a unit of analysis in ecosystems helps overcome the challenges in explaining emergence of ex-ante unknown actors in the ecosystem as it is not required to know '*who'* solves the problem, rather it is sufficient to know '*what'* problem is being solved. Our approach shows how we can study issues pertinent to digital strategy without knowing or tracking these multiple actors.

Third, our study is among the few to employ abductive reasoning for theory development (for a detailed discussion see Kathuria et al. 2020 and Shepherd and Subbady 2017) in combination with a configurational approach (Misangyi et al., 2017). In empirically identifying a new search process – community-driven search – we demonstrate the benefits of such an analytical approach where abductive logic can refine and bring granularity to theory using empirical evidence. By using a configurational approach to understand the implications of the problem dimensions and platform sponsor scope choice, we established that there are multiple pathways to successful emergence so long as there is an alignment between the problem and scope. The result of equifinality in outcomes underscores that digital platform ecosystems can emerge in multiple forms and types. Fundamental to our configurational alignment argument is the inherent trade-offs that managers face at the outset in choosing their scope in accordance with the problem dimensions. In identifying the configurations of the three distinct ecosystem types, our study provides exemplars of such trade-offs and thereby the pathways to ecosystem emergence. Furthermore, by employing an analytical strategy combining a configurational approach alongside problem-solving perspective, we have demonstrated the importance of studying different problem dimensions holistically as they shape the search process together, a finding that has implications for the problem-solving perspective.

Our study is not without limitations. Firstly, we coded our measures based on the free-form text of the campaigns. Although care has been exercised to use objective criteria for coding the conditions, there is scope to use a dataset that provides more objective measures for problem structure and platform sponsor scope to further test our arguments. Whereas the QCA technique allowed us to handle the subjectivity involved in these measures, future studies may benefit by considering the implications of subjective measures if a large sample is involved. Relatedly, although we have employed a crisp set of successful ecosystem emergence outcome in addition to the fuzzy set of campaign funding success, the outcomes may not fully capture the potential complementors' interest in the platform ecosystem as they are closely aligned to success in raising funds through crowdfunding. Future studies can address this limitation by employing objective measures of ecosystem emergence such as number of participants on each side of the platform or number of complements. However, such attempts should employ measures that are comparable across the different types of platform ecosystems under study. Furthermore, we restricted our analysis of ecosystem emergence to one year after the end of the Kickstarter campaign in order to capture the impact of problem dimensions and scope alignment proposed in the campaign. Future work may examine these relationships over a longer period of time and in particular examine the evolution of these configurations.

Secondly, although we expected an alignment between problem dimensions and platform sponsor scope, we relied on fsQCA analyses to identify the ideal configurations. Consequently, we did not find consistent configurations for multi-sided transaction platforms from our dataset. A closer examination of the dataset revealed that the inconsistencies emerged from the apps and web categories that had a very low-cost context. Future studies can explore the reasons for varied problem configurations for multi-sided transaction platforms and the underlying reasons for the inconsistencies in low-cost contexts. Thirdly, the scope of this study was limited to explaining the scope decisions of platform sponsors of ecosystems that emerge as a deliberate action. Future work can contrast such ecosystems with ones that emerge in a non-deliberate manner or as communities. Furthermore, our study focused only on governance of search processes and thus restricted itself to scope in terms of activities and decision rights. There is also room to consider other governance aspects such as monetization methods, incentives, and subsidies. Finally, our study focused on the early stage of ecosystem emergence. Future work can identify how these ecosystems survive and grow over a period of time and how problem configurations and scope choices change with time.

In conclusion, with the proliferation of platform ecosystems, there is a need for more research that focuses on the incipient stage to better understand how platform sponsors can enable the emergence of platform ecosystems. As we demonstrated, the problem-solving perspective has immense potential to deepen insight into the strategic choices available to lesser known platform sponsors and their implications. We see much promise in this stream of research to advance theory at the intersection of platform ecosystems and entrepreneurship, as well as provide practically relevant knowledge.

CHAPTER 3

PLATFORM SPONSOR SCOPE AND ECOSYSTEM STRUCTURE: A CONFIGURATIONAL APPROACH TO ECOSYSTEM HETEROGENEITY

3.1 Introduction

"As we scale, technology architecture and APIs are built to support the throughput of transactions. We need a governance model that understands what technology can offer."

- Executive of a pharmacy platform

The rapid proliferation and growth of platform-based firms and the ecosystems accompanying them have drawn the interest of both practitioners and researchers. A platform-based ecosystem (hereafter referred to as platform ecosystems or ecosystems) refers to a set of symbiotic actors who depend on each other to create value over a central infrastructure called the platform (Adner & Kapoor, 2010; McIntyre & Srinivasan, 2017; Shipilov & Gawer, 2020). A prominent issue that the burgeoning literature on this topic has sought to understand is how the platform ecosystem structure and governance strategies influence the growth of the ecosystem (McIntyre et al., 2020; McIntyre & Srinivasan, 2017). Broadly, the ecosystem structure includes elements such as access control points, interface openness, complementarity, and complement category (Shipilov & Gawer, 2020; Thomas et al., 2014). The governance choices include aspects such as the ecosystem participants' activities, decision rights, and platform sponsor's orchestration within the ecosystem (Jacobides et al., 2018; Kretschmer et al., 2020).

Although scholars have extensively studied the role of ecosystem structure and governance separately, it is not clear how the "overall mixes of [these] strategic choices that platform [sponsors] undertake" shape ecosystem performance (Dushnitsky et al., 2020, p. 3). This is particularly important because the platform sponsors simultaneously choose the ecosystem structure and governance elements. Moreover, it is unclear how the strategic choices of structure and governance span out across different types of ecosystems. Scholars have argued that "multidimensional constellations of conceptually distinct characteristics that commonly occur together" are best studied using configurational theories (Meyer et al., 1993, p. 1175). A configurational approach emphasizes causal complexity where one factor's implication on the outcome depends on the other factors that co-occur (Miller, 1986; Misangyi et al., 2017). Such an approach examines the phenomenon holistically and brings clarity through boundary conditions and typologies in the form of discrete configurations of explanatory factors (Greckhamer et al., 2018). Despite the merits of a configurational approach, the platform literature has so far not fully documented how ecosystem structure and governance elements combine holistically to shape performance (for an exception, see Dushnitsky et al. (2020)).

Furthermore, we do not fully understand how the mix of these strategic choices varies temporally over different ecosystem lifecycle stages (Gawer, 2020). It is particularly important to understand how the strategic choices may change before and after the market tips, i.e., at the incipient and mature stages. Whereas the platform sponsors are keen to rapidly grow their ecosystems in the initial stages to enjoy the benefits of winner-take-all dynamics (Arthur, 1989; Katz & Shapiro, 1994), their goal at the mature stages shifts towards value capture (Gawer, 2020). We do not fully understand how the shift in platform sponsor's priorities affects the ecosystem structure and governance across different types of ecosystems.

In this paper, we fill the above gaps in the literature by asking the following questions: *How can a platform sponsor configure the ecosystem structure and governance for superior performance across different types of ecosystems? And how does the configuration vary between the incipient and mature stages of the ecosystem lifecycle?* As a first step, we build on prior research that studied the differences in platform-enabled markets (Cennamo, 2019; Cusumano et al., 2019) to identify four types of platform ecosystems – complementary innovation, open-source, information exchange, and marketplace ecosystems. This typology is consistent with the prior classification of ecosystems as enabling transactions, innovation, or both (Cusumano et al., 2019; Gawer, 2020) but brings more granularity to the differences in their value proposition.

In platform ecosystems, both the platform sponsors and autonomous complementors co-create value (Adner & Kapoor, 2010; Kapoor, 2018) by performing different parts of the value creation process. Consequently, the actor who performs a focal process has control over the corresponding part of value creation. Thus, we contend that a platform sponsor's latitude in the governance of platform ecosystems is shaped by its choice of scope vis-à-vis the complementors. We conceptualize *platform sponsor scope* as constituting of the following elements of governance: (i) the platform sponsor's choice of activities to perform internally, (ii) the degree to which the platform sponsor exerts decision rights over the complements, and (iii) the extent to which the platform sponsor orchestrates value creation in the ecosystem.

Using a configurational approach (Fiss, 2007; Miller, 1986), we explore the interplay between the elements of platform sponsor scope and ecosystem structure associated with the ecosystem's superior performance. Specifically, we examine how the platform sponsor's extent of control, degree of interface openness, type of complementarity, and complement categories vary alongside the elements of platform sponsor scope across different types of ecosystems in the incipient and mature stages. We use fuzzy-set qualitative comparative analysis (fsQCA) and data from 40 platform ecosystems at both the incipient and mature stages to inductively identify configurations of ecosystem structure and governance.

The principal insights from our analysis are threefold. First, we find empirical support for our typology as distinct configurations of ecosystem structure and governance emerge, and those configurations map to the four different types of ecosystems. We propose that the typology of ecosystems represent points on a broader *ecosystem continuum*, an organizing framework based on platform sponsor scope that helps visualize ecosystem heterogeneity. Second, we find that ecosystems exhibit superior performance when there is an alignment between the elements of governance and ecosystem structure. Specifically, we find that a broad platform sponsor scope aligns with a more restricted ecosystem structure, whereas a narrow platform sponsor scope aligns with a less restricted ecosystem structure. Third, we find that the configurations of ecosystem structure and governance change from the incipient stage to the mature stage for each of the ecosystem types. However, we find that despite the change in configurations, the alignment between the ecosystem structure and governance is preserved.

This paper makes several contributions. First, we provide an empirically validated typology of ecosystems and provide a framework to organize ecosystem heterogeneity in the form of an ecosystem continuum. We demonstrate that the elements of ecosystem structure and governance vary across the different types of ecosystems. Second, using the configurational approach, we show that an alignment among the elements of ecosystem structure and governance is associated with superior ecosystem performance. The configurations show that there exist tradeoffs among the different elements. For instance, a wide variety in complement categories is found in ecosystems with open interfaces and low variety in those with more closed interfaces. Finally, we shed light on the temporal aspects of ecosystems by demonstrating that the configurations of ecosystem structure and platform sponsor scope differ from the incipient to mature stages. This finding demonstrates that not only are structure and scope static decisions made at the outset but also are choices made in consideration of the market tipping point.

3.2 Typology of Platform Ecosystems

Some of the early studies differentiated among two-sided markets and multi-sided markets (Evans, 2003; Rochet & Tirole, 2006). Later studies have juxtaposed the market dynamics within ecosystems with architectural differences to arrive at meta-logics. One such typology differentiates platform ecosystems based on how the ecosystems reuse assets, interfaces, and standards in production, innovation, or transactions to drive economies and efficiencies in operating the platform (Thomas et al., 2014). Another typology based on organizational settings and form classifies platforms as internal platform, supply-chain platform, and industry platform (Gawer, 2014). The typologies aimed at integrating research streams to arrive at meta-logics have not focused on the differences in the value propositions of the platform ecosystems.

A few recent studies have addressed the above gap by focusing on the "role played by the platform" to "reveal differences in the way they operate" (Cennamo, 2019, p. 6). Platform ecosystems are classified as innovation or transaction platform ecosystems depending on whether the platform facilitates innovation or transaction (Cusumano et al., 2019). Another study focuses on the differences in the markets that emerge around platforms and classifies ecosystems as complementary innovation, marketplace, or information ecosystems (Cennamo, 2019). This classification captures the underlying differences in value proposition but does not consider another important type of ecosystem – open-source ecosystems – which are similar to complementary innovation ecosystems in terms of the activities and actors' positions (Adner, 2017) but are distinct in the overall value proposition.

We identify four types of platform ecosystems based on the differences in their value propositions as *complementary innovation, open-source, marketplace, and information ecosystems.* This typology is in accordance with the earlier classifications based on value propositions but is broadened to include open-source ecosystems. Further, the typology brings more granularity to the classification of ecosystems as innovation or transaction ecosystems (Cusumano et al., 2019). As we detail in the following sections, the typology recognizes the differences between complementary innovation and open-source ecosystems although the platform facilitates innovation in both types. Similarly, information and marketplace ecosystems are different although the platform facilitates transactions in both types.

3.2.1 Complementary Innovation Ecosystems

In these ecosystems, the value proposition is to make available optional complementary products that enhance the value of a core product (McIntyre & Srinivasan, 2017). The platform is the innovation engine and serves as the core infrastructure over which complementors produce their products (Gawer, 2014). However, its value is further enhanced when the users choose to use complementary products. The Apple app store and video game consoles and their corresponding game stores are examples of this type of ecosystem.

3.2.2 Open-Source Ecosystems

Open-source ecosystems are similar to complementary innovation ecosystems as the value proposition includes making available optional complementary products. However, these ecosystems differ from the complementary innovation ecosystems as the platform sponsor opens the complete platform infrastructure to third-party complementors to contribute to the platform as well as to produce complements over the platform (Jacobides et al., 2018). Furthermore, the platform sponsor often plays a minimal role or may be replaced by a core community of users. Mozilla Firefox, Linux, and LibreOffice are examples of this type of ecosystem.

3.2.3 Marketplace Ecosystems

The platform sponsor of this ecosystem provides an infrastructure to match actors on two sides of the platform and facilitate transactions among them. Amazon, eBay, Amazon MTurk, and Kickstarter ecosystems are examples of this type of ecosystem. Such ecosystems have been referred to as two-sided markets (Rochet & Tirole, 2003). The sellers list their products on the platform for buyers to view. In some cases, such as Kijiji or Craigslist, buyers list their needs on the platform, which is then catered to by the sellers. However, unlike an ideal market, the platform sponsor seeks to benefit from facilitating the transactions between the two sides.

3.2.4 Information Ecosystems

In these ecosystems, the primary role of the platform is to serve as an information exchange channel, categorize information, and enable the search of the relevant information (Cennamo, 2019). These ecosystems match the users with the information they require and thus differ slightly from marketplace ecosystems that match the goods and services of sellers with buyers. Similar to the marketplace ecosystems, the platform sponsors seek to benefit from matching and information exchange over the platform. Examples of this type of ecosystem include Google's search engine, Facebook, and dating service platforms.

Overall, the above typology depicts the differences in the value proposition of the platform ecosystems. With these differences as the starting point, in the following section, we explore how the ecosystem structure and governance may vary across the different types of ecosystems. We also examine how the ecosystem structure and governance for each type of ecosystem varies between the incipient and mature stages of the ecosystem lifecycle.

3.3 Configurational Approach to Platform Ecosystems

Scholars have examined several aspects of platform ecosystems including platform technology, ecosystem design, pricing, governance, and dynamics that influence performance of the platform sponsor and complementors (Kretschmer et al., 2020; McIntyre & Srinivasan, 2017; Shipilov & Gawer, 2020). However, there exists a lacuna in our understanding of how the factors combine and interact to shape performance outcomes. This gap is attributed to the distinct origins of the platform literature in technology management, economics, and strategy streams. Consequently, there have been calls to integrate the findings from the different streams to build a comprehensive understanding of platform ecosystems (McIntyre & Srinivasan, 2017).

The few studies that have integrated the different streams or the underlying explanatory factors have provided greater clarity of the phenomenon. In studying the influence of platform interface openness on innovation outcomes, Boudreau (2010) demonstrates that opening platform interfaces promotes innovation. However, the magnitude of such innovation reduces when the platform sponsor completely devolves control as such a strategy shifts the bottleneck from the sponsor to the complementors. This study demonstrates that platform sponsors should balance the design choice of openness with their governance choice of control.

In a recent study of transaction platform ecosystems, Dushnitsky et. al. (2020) show that platform sponsors' strategic choices of pricing and governance factors cluster around three strategy mixes. This study makes an important contribution by highlighting the prevalent mix of strategic choices in transaction ecosystems as well as equifinality in ecosystem performance. However, the study does not consider different types of ecosystems and the underlying configuration of factors. This limitation may be overcome using a configurational approach based on set-theory as it is particularly well-suited to examine typological differences (Fiss, 2011; Furnari et al., 2020).

A configurational approach constitutes a holistic mode of inquiry that examines "multidimensional constellations of conceptually distinct characteristics that commonly occur together" (Meyer et al., 1993, p. 1175). Management scholars using different theoretical lenses have argued that "organizational outcomes tend to depend on the alignment or conflict among interdependent [factors]" (Fiss, 2007; Miller, 1986; Misangyi et al., 2017, p. 256; Siggelkow, 2002). The focus of the configurational approach is to identify complex causal relationships, in the form of patterns of factors related to an outcome of interest, rather than individual variables to identify the net effects of causal conditions (Meyer et al., 1993; Ragin, 2009).

Three features of a configurational approach make it particularly suitable to study complex organizational phenomenon such as platform ecosystems – causal complexity, equifinality, and asymmetry (Fiss, 2007; Furnari et al., 2020; Misangyi et al., 2017). *Causal complexity* is found when outcomes "result from the interdependence of multiple conditions" (Misangyi et al., 2017, p. 256) and thus the effect of a condition may vary based on the other co-occurring conditions. *Equifinality* in outcomes demonstrates that the desired outcome may be reached from different initial conditions and paths. *Asymmetry* implies that factors related in one configuration may be unrelated or inversely related to the outcome in another configuration.

In this paper, we develop a configurational model (Figure 3.1) of platform ecosystems considering various elements of ecosystem structure and governance. The model explores how the elements of structure and governance are configured in high-performing ecosystems across the different types. In the following sections we elaborate on the different elements of governance (as shaped by the platform sponsor scope) and ecosystem structure.

3.3.1 Platform Sponsor Scope

The success of a platform ecosystem is attributed to the potential of the platform sponsors and complementors to co-create value (Kapoor, 2018). Such a value co-creation process entails the platform sponsor and the complementors performing different parts of the process. Consequently, the actor that performs a focal process retains control over the corresponding part of value creation.

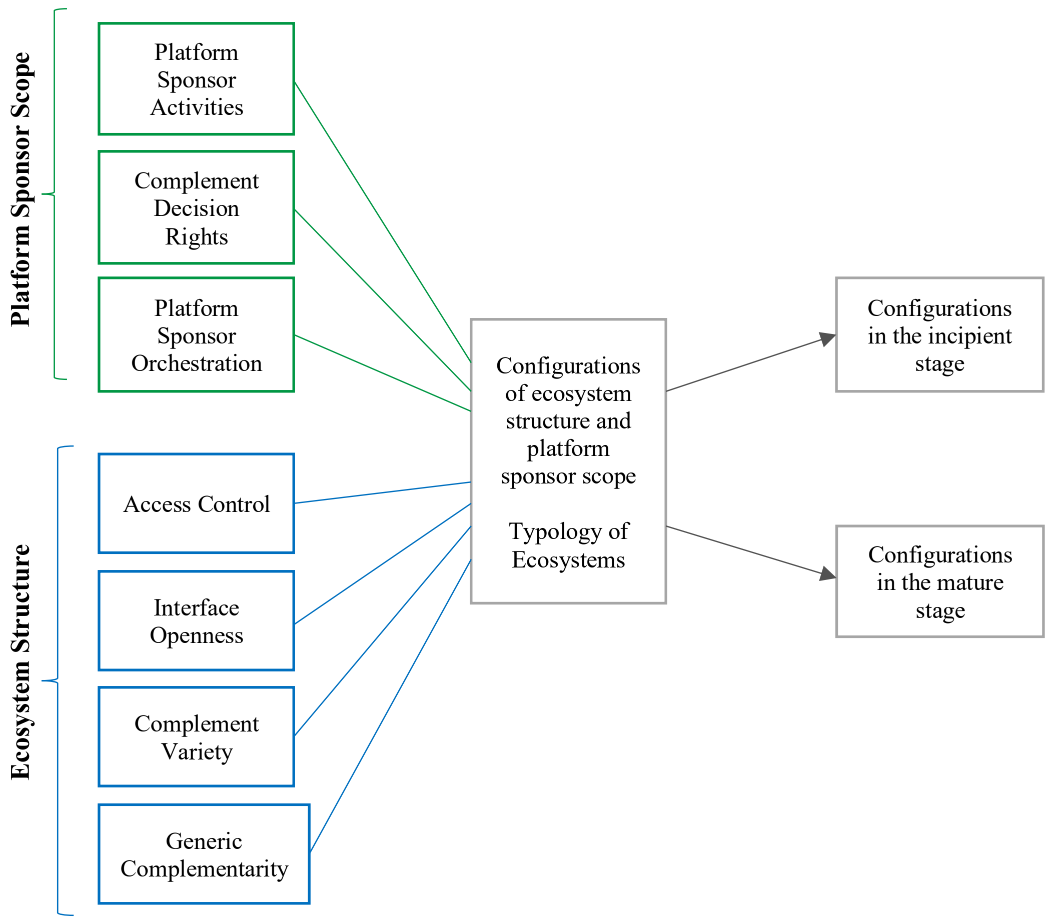

Figure 3. 1: Configurational Model of Platform Ecosystem Structure and Sponsor Scope

Such an arrangement begins with the platform sponsor, as the initiator of the ecosystem, choosing to perform parts of the value creation process while opening the rest to the complementors. In essence, the platform sponsor chooses their scope in the value creation process vis-à-vis the complementors. We refer to such a choice as the *platform sponsor scope*.

Early work referred to platform scope as the platform sponsors' choice of which complements to make internally and which to leave to autonomous complementors (Cusumano & Gawer, 2002). More recent studies have adopted broader definitions of platform scope as the role played by the platform in the digital markets they enable (Cennamo, 2019) and the "vision that defines the ecosystem value proposition" (Dattée et al., 2018). Gawer (2020) refers to platform scope as comprising of the assets owned, labor employed, and activities performed by the platform sponsor. Building on these, we refer to *platform sponsor scope* as constituting of three distinct elements: (i) the activities that the sponsor chooses to perform internally while opening the others to complementors, (ii) the sponsor's decision rights over complements, and (iii) the sponsor's degree of orchestration within the ecosystem. Our definition of platform sponsor scope encompasses prior conceptualizations as activities underpin the delivery of the value proposition and the nature of the market around the platform. It also includes a focus on orchestration which is not only key to the emergence of a coherent value proposition of the ecosystem (Adner, 2017) but also vital to maintain the quality of the ecosystem (Tiwana, 2013).

Platform sponsor scope shapes the latitude that the sponsor has to govern the ecosystem. Three elements of platform sponsor scope contribute to the sponsor's latitude in ecosystem governance. First, the platform sponsor has complete control on the activities it performs internally. When complementors depend on the sponsor's activities, the platform sponsor has greater flexibility to frame rules and procedures involving such dependencies. Second, the platform sponsor can define governance rules for complementors and the broader ecosystem by defining who exerts decision rights over the complements. Finally, the platform sponsor as the orchestrator of the ecosystem can govern through indirect mechanisms such as incentives, subsidies and coordination between the different ecosystem actors. Thus, we contend that examining the three elements of platform sponsor scope can shed light on how the platform sponsor governs the ecosystem.

3.3.1.1 Platform Sponsor Activities

Since the platform sponsor and the complementors together co-create value in ecosystems, the value creation activities are performed by both the actors. At the outset, the platform sponsor as the "hub" (Jacobides et al., 2018) and initiator of the ecosystem chooses the activities to perform internally. Such a choice implicitly signals to the complementors the other activities available to be performed. The platform sponsor has complete control on the activities it performs internally. The complementors are often dependent on the platform sponsor's activities. Such dependence provide latitude to the platform sponsor to frame rules for complementors' activities beyond its boundaries. Such latitude of the platform sponsor to frame rules and govern the ecosystem increases as complementors' dependence on platform activities increases. Thus, the choice of activities to perform internally constitutes a key element of platform sponsor scope definition. Although the choice of activities to perform internally is made at the outset, platform sponsors continually (Cusumano & Gawer, 2002) make these choices to facilitate value co-creation.

Furthermore, the platform sponsors' activity choices define the kind of interactions that are available to prospective complementors on the platform. The nature of interactions restricts not only the type of complementors and users who would participate on the platform but also the type of market the platform enables (Cennamo, 2019). Thus, the platform sponsor's choice of activities to perform internally while opening the other activities to complementors shapes the value proposition and the alignment structure necessary to materialize it (Adner, 2017).

3.3.1.2 Complement Decision Rights

Complementors leverage the platform infrastructure to produce their products or complements (Thomas et al., 2014). Such dependence on the platform infrastructure allows the sponsors to exert decision rights over the complements to a varying degree. With decision rights over the complements, the platform sponsors can better control the quality, variety, and timing of the release of the complements and thereby improve their own competitive position (Cennamo & Santalo, 2013; Wareham et al., 2014).

We contend that platform sponsors make a strategic decision about the complement decision rights similar to the choice of value creation activities to perform internally. The platform sponsors' choice of decision rights over complements signals the extent of control complementors would have on their contributions to the ecosystem and the opportunities for value capture. Such signaling about value capture also shapes the participation decisions of the complementors.

Platform sponsors exert decision rights over the complements through various types of arrangements such as exclusivity agreements, where the complement is available solely to the users of the focal platform ecosystem (Cennamo & Santalo, 2013) as well as when the complementors cede complete control of the complements after producing them, such as in crowdsourcing and innovation contests (Felin & Zenger, 2014). In ecosystems aimed at producing open-source hardware and software, the decision rights of the platform offerings and the complements reside within the community of ecosystem participants (Jeppesen & Frederiksen, 2006). On the other hand, in ecosystems where the sponsor is more like a market intermediary, the decision rights of the complements remain with the autonomous complementors (Hagiu & Yoffie, 2009; Thomas et al., 2014).

3.3.1.3 Platform Sponsor Orchestration

Extant research has increasingly acknowledged the orchestrating role of platform sponsors in platform ecosystems (Tajedin et al., 2019; Tee & Gawer, 2009; Tiwana, 2013). Platform sponsors' ability to orchestrate is aimed at facilitating innovation (Tee & Gawer, 2009) as well as matching demand and supply whilst benefiting from it (Tajedin et al., 2019). Since the platform sponsor does not have direct control over the actors within the ecosystem, tacit and indirect mechanisms like coordination of complementors, incentives, and selective promotion of complements are used to maneuver value creation, encourage loyalty, and capture value from the ecosystem (Jacobides et al., 2018; Kretschmer et al., 2020; Rietveld et al., 2019).

Broadly speaking, orchestration mechanisms may be implemented either before the complements are made or after the complements are hosted within the ecosystem. This distinction of the type of orchestration mechanism employed, i.e., ex ante or ex post, is key to understand the extent to which the platform sponsor intervenes, albeit indirectly, in value creation and capture in the ecosystem. This is because the platform sponsor's ex-ante orchestration is a more focused involvement to maneuver value creation in a particular direction whereas an ex-post orchestration is a more tacit involvement to induce market forces into action in a way that benefits itself. Specifically, ex-ante orchestration involves mechanisms such as coordination of complementors, explicit identification of potential complements or areas for contributions from complementors. In contrast, ex-post orchestration involves mechanisms such as selective promotion of complements and targeted discounts on platform fees.

We posit that the platform sponsor's choice of orchestration is another way of defining their scope vis-à-vis the complementors in the ecosystem. This is because each orchestration type enables the sponsor to intervene to varying degrees and forms in the value creation process. The platform sponsor scope broadens when the sponsor chooses to employ orchestration mechanisms both before and after the complements are hosted in the ecosystem. With this approach, the platform sponsor not only orchestrates how value is created ex-ante but also is able to affect competition among complementors ex-post. In contrast, the platform sponsor scope is narrower when the orchestration mechanisms are restricted to one of the two orchestration types – ex-ante or ex-post mechanisms.

3.3.2 Platform Ecosystem Structure

The term 'platform ecosystem structure' has received a variety of treatment in the platform literature. Ecosystem structure is used to depict the technological and modular architectures (Baldwin & Clark, 2000; Tiwana, 2013) as well as the arrangement of different actors and their activities (Adner, 2017). In this paper, we consider the following four elements of platform ecosystem structure – access control, interface openness, complement categories, and type of complementarity. As we detail next, the above four elements encompass the key dimensions of ecosystem structure considered in the literature.

3.3.2.1 Access control

The literature on collaboration among firms has established that, after partner selection, the focal firm can retain a certain level of control over the outcome of collaboration through structural arrangements such as contracts (Dyer, 1997; Gulati & Singh, 1998). In the case of ecosystems, similar structural arrangements are not so suitable as the participants are not selected by the firm. However, architectural and processual constraints over access to the platform can enforce some levels of control on the output and behavior of complementors (Boudreau, 2010; Tiwana, 2015).

The platform sponsor may exercise such control in multiple ways. First, *ex-ante control* where the platform sponsor approves complementors' participation and their complements before hosting them within the ecosystem. This form of proactive control is an intervention by design where complementors are free to participate once approved. Second, *ex-post control* where the platform sponsor intervenes as a corrective measure to maintain the ecosystem integrity. Third, the most restrictive control is where the platform sponsor employs a combination of both ex-ante and ex-post methods of control.

3.3.2.2 Interface openness

Interface openness refers to the extent to which the platform provider grants access to core modules of the platform to outside complementors. Whereas some studies have considered openness as an inherent part of platform architecture (Baldwin & Clark, 2006; Boudreau, 2010), others have shown that a flexible platform architecture can lend itself to changes in the extent of openness (Tiwana et al., 2010). Furthermore, as the platform interface becomes more open, it is expected that more complementors would co-create in the ecosystem (Gawer, 2014). Interface openness plays a key role in attracting complementors and facilitating innovation through their contributions to the ecosystem (Boudreau, 2010; Parker & Van Alstyne, 2017).

3.3.2.3 Complement Category

The platform sponsor plays a key role in grouping the complements into pre-defined categories. The complement categories define the breadth and depth of the ecosystem that in turn shape the adoption decisions of users (Rietveld et al., 2019). Further, complement categories can negatively influence complementors' performance when competitive crowding within the same category (Rietveld et al., 2020) outweighs user preferences (Zhu & Iansiti, 2012). Platform sponsors leverage the complement categories to selectively promote complements or their categories (Rietveld et al., 2019). Moreover, the users of different types of platforms place a different value on the variety of complements, which in turn influences the strength of network effects in the ecosystem (Zhu & Iansiti, 2012). Users across different ecosystems may value the complements differently because the platform's intrinsic value, in addition to the complements, determines the users' overall utility (Parker & Van Alstyne, 2017). If the platform's intrinsic value increases, then the complements may be less important to users.

3.3.2.4 Complementarity

Modularity in the architecture of platforms allows building value-enhancing complements. However, these complements may either be standardized and not need specific coordination to create value or be specific to a structure or architecture provided by the platform (Jacobides et al., 2018). The former is referred to as generic complementarities and the latter as non-generic complementarities. Jacobides et al. (2018) argue that ecosystems are those that have non-generic complementarities on both the production and consumption sides. This means that two-sided markets that do not need "nonfungible relational investment" (p. 2266) are not ecosystems. Thus, we can expect the type of complementarity to differ across the different types of ecosystems.

In summary, the configurational model (Figure 3.1) explores the interplay between the elements of ecosystem structure and governance. We argued that the platform sponsor's latitude in governance of ecosystems is shaped by the platform sponsor scope. Hence, in the configurational model, we considered three elements of platform sponsor scope – platform sponsor activities, complement decision rights, and platform orchestration – and four elements of ecosystem structure – access control, interface openness, complement category, and complementarity – to find configurations in high-performing platform ecosystems. Next, we develop the rationale to explore the configurations of ecosystem structure and platform sponsor scope in the incipient and mature stages of the ecosystem lifecycle.

3.3.3 Platform Ecosystem Life Cycle Stages

Research about the lifecycle stages of the platform ecosystem and its implications for the platform sponsor's and complementors' strategies has been scant, with the exception of a few recent studies. Dattèe et al. (2018) demonstrate that in the incipient stages, when uncertainty is high, value creation is a "collective discovery" (p.467) process performed by both the platform sponsor and complementors. They argue that the platform sponsor should exercise dynamic control over the creation process in this stage. Thus, in the incipient stage, the ecosystem structure and scope choices should be flexible to accommodate the emerging value propositions.

Furthermore, the platform sponsor's priorities at the incipient stage (i.e., before the market tipping point) are different from those at the mature stage (i.e., after the market tipping point) (Gawer, 2020). During the incipient stage, the platform sponsor is focused on growing the ecosystem to reach a critical mass of users (Schilling, 2002; Schmalensee, 2010) as this is key to initiate network effects and enjoy winner-take-all dynamics (Arthur, 1989; Katz & Shapiro, 1994). Thus, it is plausible that the ecosystem structure and scope choices are geared towards attracting complementors' participation. In contrast, during the mature stages, the platform sponsor seeks to capture value from the ecosystem by prioritizing profits "while building and maintaining barriers to entry against rivals or newcomers" (Gawer, 2020, p. 8). Thus, it is likely that the ecosystem structure and platform sponsor scope are configured to facilitate value capture.

Overall, the nascent literature around ecosystem lifecycle stages suggests that ecosystem structure and governance elements may differ between the incipient and mature stages. In considering the ecosystem lifecycle stage, we can examine how the various elements combine in the two stages across the different ecosystem types. In other words, we can compare the configurations of the elements of platform sponsor scope and ecosystem structure in both stages for each type of ecosystem. Next, we elaborate our analytical approach to inductively identify configurations of ecosystem structure and scope across the different types of ecosystems and in the incipient and mature stages.

3.4 Method

We use the fuzzy-set qualitative comparative analysis (fsQCA) method to empirically validate our typology and inductively identify configurations of the ecosystem structure and platform sponsor scope. The fsQCA method adopts a configurational approach and relies on "logical minimization to identify necessary and sufficient conditions that predict the occurrence and non-occurrence of an outcome" (Vergne & Depeyre, 2016, p. 1657). fsQCA is suitable for testing typologies because it "conceptualizes cases as combinations of attributes and emphasizes that it is these very combinations that give cases their uniqueness" (Fiss, 2011, p. 401). Further, the method is helpful to examine a core-periphery model of typologies to identify causally relevant characteristics. In this model, a core characteristic encompasses the conditions under which the causal relationship with the outcome is strong, and peripheral characteristics are those conditions where the causal relationship is weaker (Fiss, 2011).

3.4.1 Data

Our dataset comprised of 40 platform ecosystems such that each type of ecosystem had ten platforms across two categories. Table 3.1 depicts the chosen categories and the corresponding platform ecosystems. We chose this dataset for a number of reasons. First, fsQCA does not rely on probabilistic statistical inference and hence does not generalize the findings beyond the sample (Misangyi & Acharya, 2014; Ragin, 2009). So, we chose ecosystems covering all the types but under two separate categories. This approach to case selection ensures a broad coverage of ecosystems within each type. Second, the outcome-based sample selection is not a problem in fsQCA as it employs calibrated sets for all constructs. Such "calibration reduces sample dependence, as set membership is defined relative to substantial knowledge rather than the sample mean, thus further reducing the importance of sample representativeness" (Fiss, 2011, p. 402). Finally, the number of cases chosen in our dataset meets the recommendations corresponding to the number of attributes considered (Greckhamer et al., 2018; Marx, 2010).

Table 3. 1: Dataset Construction - Categories and Timelines

Ecosystem Type	Category	Year of 25th percentile Popularity	Year of Peak Popularity
Complementary innovation ecosystems	Smartphone OS	2009	2013
	Customer data management platforms	2011	2019
Open-source ecosystems	Image editing	2004	2012
	Password manager	2006	2019
Information exchange ecosystems	Social networking platforms	2008	2012
	Dating service platforms	2014	2019
Marketplace ecosystems	Crowdfunding	2012	2015
	MOOC	2012	2017

We identified the popularity of each category using search data from Google Trends. We considered the time frame of 2004 to 2019 to exclude any influence of the pandemic on search popularity scores. Next, we identified the year the category hit the 25th percentile in popularity for the first time. This year was designated as the incipient stage. Similarly, the year at which the category peaked in popularity was identified as the mature stage. Table 3.1 depicts the incipient and mature stages for each category. For each platform, we collected data on outcomes and explanatory factors during both stages. The outcome is lagged by one year, and data for incipient and mature stages correspond to the year of 25th percentile and 100th percentile category popularity, respectively. Our data sources comprised of Google Trends, archived platform webpages from

Wayback Machine, ProgrammableAPI (a global repository of APIs and SDKs), and company reports and news releases. We calibrated our measures using the direct calibration method as detailed next and summarized in Table 3.2 (Greckhamer et al., 2018; Ragin, 2009).

3.4.2 Outcome

We measure the outcome of platform ecosystem performance in terms of the relative *popularity* of the focal ecosystem at the incipient and mature stages of the category. Following prior research (Ren et al., 2019), we measure relative popularity as the relative frequency of search for the platform ecosystem using Google's search engine. As Ren et al. (2019) highlight, Google Trends data "provides volume indexes for queries consumers have entered into the Google search engine" (p.264). Google Trends data provides the search frequency information by comparing up to five search terms (in our case, five platform ecosystems) for years dating as far back as 2004.

Table 3. 2: Set Calibrations and Descriptive Statistics

	Fuzzy Set Calibrations			***Measure Descriptives***			
Measure / Fuzzy Set	***Fully In***	***Crossover***	***Fully Out***	***Mean***	***SD***	***Max***	***Min***
Access control	1	0.67/0.33	0	0.54	0.35	1	0
Interface openness	1	0.5	0	0.31	0.46	1	0
Generic complementarity	1	0.5	0	0.51	0.49	1	0
Complement variety	15	10	5	10.4	8.4	33	0
Complement decision rights	1	0.66/0.33	0	0.41	0.46	1	0
Narrow scope of sponsor activities	1	0.5	0	0.63	0.32	1	0
Platform sponsor orchestration	1	0.5	0	0.53	0.34	1	0

The Google Trends popularity data is particularly well suited for our purpose for a number of reasons: First, the popularity scores are ranked based on comparison across the five platforms within a category. Second, the popularity scores serve as a proxy for the interest of complementors and consumers in the focal ecosystem. Third, as an indexed measure the popularity scores help us to compare the outcomes across different ecosystems and types. We coded the platform ecosystems using a four-value fuzzy set of *high popularity* as follows (Table 3.2): ecosystems that had the highest search frequency within the category were coded as fully in this set (=1); the next highest search frequency ecosystems were coded as more in than out in the set (=0.67); the third-highest search frequency was coded more out than in the set (=0.33), and the least two search frequencies were coded as fully out of the set of high popularity (=0).

3.4.3 Explanatory Factors

3.4.3.1 Access Control

The platform sponsor may exercise ex-ante control, ex-post control, or a combination of both. The combination of ex-ante and ex-post control is the most restrictive, whereas ex-post control is the least restrictive as the control measures are reactive in nature. In the ex-post scenario, the complementors have had a chance to participate in the ecosystem, albeit restricted later on. In contrast, the ex-ante control is more restrictive than the ex-post but less restrictive than the combination because once the complementors are approved, the platform sponsor does not intervene in their participation. Using this data, we calibrated a four-value fuzzy set of *high access control* (Table 3.2) such that the platform ecosystems with the combination of control were coded as fully in the set (=1.0), the ecosystems with ex-ante control were coded as more in than out (=0.67), the ecosystems with ex-post control were coded as more out than in the set (=0.33), and the ecosystems with no control were coded as fully out (=0).

3.4.3.2 Interface Openness

Though interface openness has received much attention in the platform literature, its operationalization has been mostly categorical or often specific to a single platform. Since we were interested in comparing the level of openness across different platforms, we needed an operationalization that was consistent across the different platform architectures. As Gawer (2014) argues, application programming interfaces (APIs) are “a key resource for the digital platforms' ecosystem developers, allowing them to access the platform user data and build applications” (p. 1246). Thus, from the API documentation data, we measured interface openness as the number of APIs comprising of distinct methods or unique functionality (ex. APIs that yield a search result or user ratings against a product). The distinct API methods indicate the different platform functionality accessible to complementors. We calibrated the set of *high interface openness* (Table 3.2) as: full membership when the platform provided at least 100 distinct API methods, non-membership when the platform provided fewer than 30 API methods, and crossover point of neither in nor out when the platform provided 60 API methods. We arrived at these thresholds by examining the API data from ProgrammableWeb. We found that the above thresholds are consistent with ProgrammableWeb’s report of the API listings against each provider (Santos, 2018). Further, the open-source ecosystems were coded as fully in the set of high interface openness (=1.0) as the complete platform infrastructure is opened to complementors.

3.4.3.3 Complement category

As discussed earlier, the platform ecosystems match demand with supply, buyers with sellers, and problems with solutions. In order for this matching to be efficient, platforms tag the complements into related categories. The process of tagging involves attributing labels that are searchable as keywords as well as serve as a classification mechanism for the complements listed on the website. For example, on the Kickstarter website, a project may be tagged as 'Arts' or as 'Film' depending on the relevance. We used this property of platforms to measure complement category as the number of distinct categories of complements available on the platform. Though a complement may often be tagged under multiple categories to enable efficient matching, it does not conflate our measure as we are only concerned with the number of distinct categories. We calibrated (Table 3.2) the set of *high complement category* as: full membership when the platform has at least 15 categories, non-membership when the platform has fewer than 5 categories, and crossover point of maximum ambiguity when the platform has 10 categories. We relied on average number of categories in the ecosystems in our dataset to arrive at these thresholds as no estimates of complement category were found in the literature.

3.4.3.4 Complementarity

We are interested to understand whether the configuration of ecosystems varies between generic and non-generic complementarity. The non-generic complementarities require the "creation of a specific structure of relationships and alignment to create value" (Jacobides et al., 2018, p. 2263). This can be equated to the platform's mandate to complementors to use a specific software development kit (SDK) or a particular core module for creating complements. Thus, we coded the ecosystems as comprising of non-generic complementarities when such a mandate existed and otherwise as comprising of generic complementarities. We calibrated a crisp set of *non-generic complementarity* (Table 3.2) as: full membership score of 1 when the platform mandated use of at least one platform-provided SDK, non-membership score of 0 when complements could be produced on any infrastructure, and crossover point of 0.5, that is neither in nor out when the platform provided SDKs but did not mandate its use.

3.4.3.5 Platform Sponsor Activities

The platform sponsor performs the activities that are not performed by the market around the platform. The platform sponsor may be argued to have a broad scope of activities when the market performs few activities whereas the sponsor has a narrow scope of activities when the market performs most of the activities for value creation. We identified the key activities underpinning the markets (Cennamo, 2019) in each type of ecosystem. The markets in the complementary innovation and open-source ecosystems primarily performed matching and information exchange activities to enable complementors to seek platform resources and reach consumers. Some complementary innovation ecosystems additionally enabled trading of complements and competition between complementors in the markets around their platforms. The information ecosystems primarily performed matching and information exchange activities. The marketplace ecosystems performed matching and information exchange activities as well as enabled trading of complements and competition between complementors. Overall, the markets around platforms perform one or more of the following activities – information exchange, matching, trading, and competition. When the market around the platform encompasses most of these activities, then it follows that the platform sponsor has retained few activities to be performed internally and therefore has a narrow scope.

We coded each campaign for the activities encompassed within the markets around the platform. The presence of activity was coded as 1 or 0 otherwise. We then calculated the platform sponsor scope as the ratio of the sum of the activities performed by the platform to the maximum score of 4. Next, we calibrated the set of *narrow scope of activities* using the following thresholds: the campaign was coded as "fully in" when the score was 1.0, "fully out" at 0, and crossover point at 0.5 where the membership was neither fully in nor fully out.

3.4.3.6 Complement Decision Rights

The decision rights of the complements can remain with the complementors, within a subgroup or community, or with the platform sponsors. We coded the ecosystems using a four-value fuzzy set of *platform sponsors' decision rights on complements* as follows: ecosystems where decision rights over complements were centrally held by the platform sponsor were coded as fully in this set (=1); ecosystems where the decision rights of the complements resided within platform sponsor-identified clusters or sub-groups were coded as more in than out in the set (=0.66); ecosystems that distributed the decision rights within the community were coded more out than in the set (=0.33); and ecosystems that allowed the complementors to retain decision rights were coded as fully out of the set of platform sponsors' decision rights on complements (=0).

3.4.3.7 Platform Sponsor Orchestration

We coded campaigns for the type of orchestration depending on whether the mechanisms were implemented before the complements are made or after the complements are hosted within the ecosystem. The orchestration mechanisms used before the complements are produced include the complement approval process, listing areas requiring complementors' contributions, and release of SDKs for targeted complement areas. In contrast, orchestration mechanisms used after the complements are hosted in the ecosystem include the selective promotion of complements and targeted incentives to complementors (Kretschmer et al., 2020; Rietveld et al., 2019). We coded the presence of each type of orchestration mechanism as 1 and absence as 0. We then computed the average orchestration scores across both types. We calibrated the fuzzy set of *high platform orchestration* as follows: the ecosystem was coded as "fully in" when the score was 1, "fully out" at 0, and crossover point at 0.5 where the membership was neither fully in nor fully out.

3.4.4 Analytical procedure

We used the standard fsQCA software 3.0 to perform our analyses. The analysis was performed on the sample of platform ecosystems at the incipient stage (N=40), and then repeated for the same platform ecosystems at the mature stage (N=40). The following procedure and thresholds were used in both analyses. As a first step, we sought to identify any necessary conditions, which are the causal conditions that must be present for an outcome to occur. We conducted a necessity analyses of all conditions and their negation using the recommended benchmark of 0.9 for consistency scores (Greckhamer et al., 2018; Ragin, 2009). We did not find any necessary conditions from our dataset.

Next, we conducted sufficiency analyses using the truth table algorithm, which lists all logically possible combinations of causal conditions and outcomes. The results of the sufficiency analyses identified configurations of conditions consistently linked to an outcome. Following recommended guidelines for an intermediate-N dataset like ours, we chose a minimum frequency threshold for a configuration's inclusion in causal analyses as 1, which included 80% of our cases (Greckhamer et al., 2013). Finally, we applied a consistency threshold of ≥ 0.75 and a PRI (proportional reduction in inconsistency) of ≥ 0.7, as recommended for analyses involving fuzzy sets. We performed the sufficiency analyses for both the outcome and non-outcome using the same thresholds and cut-offs.

3.5 Results

Tables 3.3 and 3.4 depict the fsQCA results for the occurrence of high popularity during incipient and mature stages, respectively. Table 3.5 and 3.6 depict the results for the non-occurrence of the outcome during incipient and mature stages, respectively. In each configuration, the full circles indicate the presence of a factor or condition, and the crossed-out circles indicate the absence of the factor. Further, the larger circles indicate core conditions that occur in both the parsimonious and intermediate solutions and thus indicate a strong causal relationship. The smaller circles indicate peripheral conditions that occur only in intermediate solutions and thus indicate weak causal relationships (Fiss, 2011). We also report the standard measures of consistency, raw coverage, and unique coverage for each of the configurations, as well as overall consistency and coverage for the solution formula. The consistency score is a measure of the number of cases consistent with the outcome and is calculated as the ratio of the number of cases that exhibit the configuration of causal conditions and the outcome to the number of cases that exhibit the configuration of causal conditions but not the outcome (Ragin, 2009). The coverage score is a measure of the empirical importance of a configuration and is calculated as the percentage of cases that follow a given pathway to the outcome (Fiss, 2011). Our results show that the overall solution consistency is 0.75 (coverage of 0.58) for the high popularity configurations in the incipient stage and 0.75 (coverage of 0.46) for high popularity configurations in the mature stage, both exceeding the recommended threshold.

Table 3. 3: Configurations of Ecosystems with High Popularity - Incipient Stage

	Solution					
	Complementary Innovation Ecosystems		Open Source Ecosystems	Marketplace ecosystems		Information ecosystems
	1a	1b	2	3a	3b	4
Platform Structure						
High access control	•	⊗	•	●	●	⨂
High interface openness	⨂	●	●	●		⊗
Generic complementarity	⊗	⊗	⊗	●	●	•
High complement variety	⨂	●	●		●	⨂
Platform sponsor scope						
Narrow scope of activities	⨂	•	•	•	•	•
Complement decision rights	•	⊗	•	⨂	⨂	⊗
Broad scope of orchestration		•	•	•	•	●
Consistency	0.75	0.92	0.80	1.00	0.83	0.75
Raw Coverage	0.23	0.17	0.14	0.22	0.26	0.15
Unique Coverage	0.13	0.06	0.03	0.02	0.10	0.04
Overall Solution Consistency		**0.75**				
Overall Solution Coverage		**0.58**				

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition. Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

The fsQCA results indicate distinct configurations (solutions 1a through 4b and solutions 5a through 8b) of the different elements of platform sponsor scope and ecosystem structure (Table 3.3 and 3.4). Using the underlying case data for each of the configurations, we find that the cases map onto the different ecosystem types. Thus, we have labeled the configurations corresponding to the respective ecosystem types. Below we elaborate the configurations for each type of ecosystem in the incipient and mature stages.

Table 3. 4: Configurations of Ecosystems with High Popularity - Mature Stage

	Solution					
	Complementary Innovation Ecosystems		Open Source Ecosystems	Marketplace ecosystems		Information ecosystems
	5a	**5b**	**6**	**7a**	**7b**	**8**
Platform Structure						
High access control	●	⊗	⨂	●	⬤	⊗
High interface openness	⊗	⊗	⬤	⬤	⊗	⊗
Generic complementarity	⊗	⊗	⨂	⬤	⬤	●
High complement variety		⊗	●	●	⨂	⊗
Platform sponsor scope						
Narrow scope of activities	⨂		●	●	●	●
Complement decision rights	●	●	⊗	⊗	⊗	⊗
Broad scope of orchestration	●	●	●	●	●	⨂
Consistency	0.92	0.83	0.86	1.00	0.79	0.76
Raw Coverage	0.2	0.18	0.15	0.16	0.16	0.18
Unique Coverage	0.01	0.03	0.05	0.06	0.01	0.03
Overall Solution Consistency		**0.75**				
Overall Solution Coverage		**0.46**				

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition. Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

3.5.1 Configurations in the Incipient Stage

Solutions 1a through 5 (Table 3.3) depict the configurations for high popularity in the incipient stage. We found two configurations (solution 1a and 1b) for complementary innovation ecosystems. From solution 1a (Table 3.3), we find that platform sponsors exerted decision rights over the complements, retained a broad scope of activities to perform internally and exercised high access control. The platform interfaces were more closed, the ecosystem imposed non-generic complementarity requirements from the complementors and had fewer categories of complements. Overall, the configuration in solution 1a depicts a broad scope of the platform sponsor and a restricted ecosystem structure with controlled access, interfaces, and few categories. The complementary innovation ecosystems with this configuration (e.g., Apple iOS and Emarsys data management ecosystems) were successful in the incipient stage with a restricted approach to scope and ecosystem structure as the platform sponsors created most of the value and the complementors were heavily dependent on the platform infrastructure.

From solution 1b (Table 3.3), we found that the platform sponsors retained a broad scope of activities to perform internally and also had a broad scope of orchestration but did not exert decision rights over the complements. The platform sponsors imposed non-generic complementary requirements but did not exercise high control. They also opened the interfaces to the platform that fostered more categories of complements. Thus, the configuration in solution 1b depicts a narrower scope of the platform sponsor compared to the one in solution 1a and a less restrictive ecosystem structure with no access control and open interfaces that result in more complement categories. The complementary innovation ecosystems with this configuration (e.g., Google Android) were successful by leveraging complementors' contributions in a less restrictive ecosystem structure.

Solution 2 depicts configurations for open-source ecosystems where we found that the platform sponsors retained a narrow scope of activities to perform internally but exerted decision rights over complements and retained a broad scope of orchestration. The platform sponsors also exercised high control within the ecosystem and imposed non-generic complementarity requirements. However, the interfaces were kept open, and the ecosystem exhibited more complement categories. The configuration in solution 2 depicts a narrower scope of the platform sponsor and a less restricted ecosystem structure compared to those in solution 1a discussed above. Similar to the ecosystems in solution 1b, the open-source ecosystems (e.g., image editing software platforms like GIMP and password managers like Bitwarden) leveraged complementors' contribution through less restrictive ecosystem structure. However, the higher levels of access control in these types of ecosystems ensured that the contributions of complementors lead to the development of a coherent product as well as helped maintain the integrity of the ecosystem.

Solutions 3a and 3b (Table 3.3) depict the configurations for high popularity in marketplace ecosystems. Across both the configurations, the elements of scope exhibit the same configuration. The platform sponsors retain a narrow scope of activities to perform internally and exert no decision rights on the complements but retain a broad scope of orchestration. This choice of scope elements may be attributed to the fact that the platform sponsors play a minimal role in enabling matching, interactions, and transactions over the platform. However, the platform sponsor retains a broad scope of orchestration which implies that they choose to not only orchestrate how value is created before the complements are hosted in the ecosystem but also to affect competition among complementors. Such a scope choice allows the platform sponsor to match actors on the platform in a way that benefits itself.

From solution 3a (Table 3.3), we find that platform sponsors exercise a high level of access control but foster open interfaces and generic complementarity. The high level of access control helps the platform sponsor maintain the quality and integrity of the platform, especially in the context of a narrow scope of activities. However, the complement category was not of significance in this configuration. The marketplace ecosystems with this configuration (e.g., Coursera and edX) were popular with a moderately restrictive ecosystem structure and a narrower scope as they focused on maintaining the quality of the ecosystem.

From solution 3b (Table 3.3), we find that the platform sponsors exercise a high level of access control and ecosystems exhibit generic complementarity and more complement categories. However, interface openness is not of significance in this configuration. The marketplace ecosystems with this configuration (e.g., Kickstarter and Ulule) were popular with a moderately restrictive ecosystem structure as they leveraged more complement categories to overcome the downsides of enhanced access control and not having open interfaces. This counterintuitive configuration in solution 3b may be explained by the presence of generic complementarity as a core condition which implies that the complementors make only fungible investments in these ecosystems. Such an investment fosters multihoming on different ecosystems (Cennamo et al., 2018) and attracts more participation from complementors.

From solution 4, we find that in the information ecosystems with high popularity, the platform sponsor retains a narrow scope of activities to perform internally, does not exert decision rights over the complements and retains a broad scope of orchestration. The broad scope of orchestration helps the platform sponsor enable matching in a way that benefits itself. The platform sponsor does not exercise a lot of control within the ecosystem but maintains closed interfaces and thereby fewer complement categories. The ecosystem also requires generic complementarity. In a nutshell, the configuration in solution 4 depicts a narrow platform sponsor scope and a least restrictive ecosystem structure. The information ecosystems with this configuration (e.g., Facebook and Tumblr) were successful as they leveraged the complementors' contributions that were facilitated by a less restrictive ecosystem structure and also attracted more complementors with their generic complementarity requirements.

3.5.2 Configurations in the Mature Stage

Solutions 5a through 8 (Table 3.4) depict the configurations for high popularity in the mature stage. Solutions 5a and 5b (Table 3.4) depict the configurations for complementary innovation ecosystems. From solution 5a (Table 3.4), we find that the platform sponsor exerted decision rights over the complements, held a broad scope of activities to perform internally as well as a broad scope of orchestration. In the mature stages, the ecosystem has attained a significant size and hosts several complementors. The element of broad scope of orchestration is important to ensure value creation is coherent and benefits the platform sponsor. The platform sponsors exercise high control, keep the interfaces more closed, and impose non-generic complementarity requirements. However, the restriction of complement category is not of concern here. The configuration in solution 5a depicts complementary innovation ecosystems (e.g., Apple iOS) with a broad platform sponsor scope and a restricted ecosystem structure.

From solution 5b (Table 3.4), we find that the platform sponsors exerted decision rights over the complements as well as retained a broad scope of orchestration regardless of the scope of activities to perform internally. In the mature stage, such a scope choice helps maintain the quality of the ecosystem and coherence in value co-creation. The platform sponsors imposed non-generic complementary requirements and did not exercise high control. However, ecosystems exhibited closed interfaces and few complement categories. Overall, the configuration in solution 5b depicts, on one hand, a narrower platform sponsor scope (compared to the one in solution 5a) as the scope of activities are not of significance and, on the other hand, a less restricted ecosystem structure. The complementary innovation ecosystems with this configuration (e.g., Google Android) succeeded by not only leveraging the ecosystem growth from the incipient stage but also maintaining ecosystem quality through restrictive ecosystem structure and broad platform sponsor scope in the mature stage.

From solution 6 (Table 3.4), we find that the platform sponsors in open-source ecosystems retain a narrow scope of activities to perform internally, a broad scope of orchestration but do not exert decision rights on the complements. The platform sponsor does not exercise high levels of control in the ecosystem. The ecosystem exhibits open interfaces, non-generic complementarity requirements, and more complement categories. The configuration in solution 6 depicts a narrower platform sponsor scope and a less restricted ecosystem structure than the one in solution 5b discussed above. The open-source ecosystems with this configuration (e.g., image editing software GIMP) leveraged complementors' contribution through a less restrictive ecosystem structure whilst orchestrating value creation for their own benefit.

Table 3. 5: Configurations of Unpopular Ecosystems - Incipient Stage

	Solution					
	9	**10**	**11**	**12**	**13**	**14**
Platform Structure						
High access control	⨂	•		•		•
High interface openness	⨂	⨂	●	●	⨂	
Generic complementarity	●	⨂	⊗		●	•
High complement variety			⊗	⨂	⨂	⨂
Platform sponsor scope						
Narrow scope of activities	•		⨂	•	•	•
Complement decision rights	⊗	●	•	⨂	⨂	⨂
Broad scope of orchestration		●	⊗	•	●	•
Consistency	0.82	0.88	0.89	0.90	0.84	0.82
Raw Coverage	0.37	0.25	0.18	0.11	0.13	0.11
Unique Coverage	0.26	0.17	0.09	0.01	0.01	0.01
Overall Solution Consistency				0.82		
Overall Solution Coverage				0.72		

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition. Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

Solutions 7a and 7b (Table 3.4) correspond to the marketplace ecosystem in mature stages. From solution 7a (Table 3.4), we find that the ecosystem structure remains the same as in the incipient stage (solution 3a in Table 3.3) with the exception that complement category now becomes significant. This may be attributed to the presence of generic complementarity and open interfaces that attract more participation of complementors. The marketplace ecosystems with this configuration (e.g., Coursera and edX) leveraged complementors' contributions extensively through less restrictive ecosystem structure but orchestrated the value co-creation efforts for coherence in value proposition and their own benefit.

From solution 7b (Table 3.4), we find that the configuration of platform sponsor scope is similar to the one in the incipient stage (solution 3b in Table 3.3). The ecosystem structure depicts high levels of access control and generic complementarity as core conditions. The platform interfaces are more closed, and consequently, the ecosystem exhibits few complement categories. In the mature stages, such a choice of a restrictive ecosystem structure may be explained by the platform sponsor's goal to maintain the quality of the ecosystem through access control and closed interfaces. Moreover, the platform sponsors seek to leverage the growth from the incipient stage when the ecosystem structure was less restrictive. The marketplace ecosystems with this configuration (e.g., Facebook and Tumblr) have leveraged the ecosystem growth from the earlier stages and focused on quality of the ecosystem in the mature stage.

Table 3. 6: Configurations of Unpopular Ecosystems - Mature Stage

	Solution				
	15	**16**	**17**	**18**	**19**
Platform Structure					
High access control	●	⬤	⬤	⊗	●
High interface openness	●	⨂		⊗	⊗
Generic complementarity	⨂	⬤	⨂	●	⊗
High complement variety	⨂		⨂	⊗	⬤
Platform sponsor scope					
Narrow scope of activities	⬤	●	⬤	●	⨂
Complement decision rights		⨂	●	⊗	●
Broad scope of orchestration	●	●	●	⨂	●
Consistency	0.84	0.86	0.82	0.80	0.95
Raw Coverage	0.19	0.29	0.22	0.15	0.11
Unique Coverage	0.03	0.15	0.05	0.05	0.02
Overall Solution Consistency				0.80	
Overall Solution Coverage				0.54	

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition. Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

Solution 8 (Table 3.4) depict the configurations for information ecosystems. We find that the configuration of platform sponsor scope and ecosystem structure remains the same as in incipient stage (solution 4 in Table 3.4) except for the choice of a narrow scope of orchestration.

In the mature stage, as the platform grows, the sponsor is required to assume a more neutral role in order to signal fairness in matching and transactions. In other words, the ecosystem tends closer to an ideal market, diminishing the centrality of the platform sponsor. However, this is not to imply that the platform sponsor ceases to capture the value and rather the use of market forces to accomplish the same goals.

Finally, we conducted the negation of outcome analyses (Table 3.5 and 3.6) and a number of sensitivity analyses to examine the robustness of our findings, the results of which are provided in Appendix B. The negation analysis examines the configurations for non-occurrence of the outcome to rule out any overlap with the configurations for occurrence of the outcome. We considered alternative crossover points by varying the crossover points for all measures by +/- 25 percent. As we detail in the Appendix B, although minor changes appear in the solution in the form of the number of solutions and sub-solutions, the interpretation of the results remains unchanged, indicating the robustness of the findings.

3.6 Interpretation of Results

The fsQCA results described above across the incipient and mature stages highlight three broad insights that capture the importance of (i) ecosystem heterogeneity, (ii) alignment between scope and ecosystem structure, and (iii) ecosystem lifecycle stages. We interpret the fsQCA results in the following sections.

3.6.1 Ecosystem Continuum: An Organizing Framework for Ecosystem Heterogeneity

The fsQCA results depict distinct configurations of platform sponsor scope and ecosystem structure that map onto the different types of ecosystems. This finding supports our fundamental argument that ecosystems are heterogeneous in terms of their platform sponsor scope and ecosystem structure. Such heterogeneity is seen in both the incipient and mature stages, indicating that the differences endure the lifecycle stages.

In comparing the configurations across the different ecosystem types (solutions 1a through 4 for incipient stage and solutions 5a through 8 for mature stage), we find that there exists a pattern in the configuration of platform sponsor scope elements. The complementary innovation ecosystems (solution 1a, 1b, 5a and 5b) depict a broad platform sponsor scope owing to choices such as a broad scope of activities to perform internally, hold complement decision rights, and a broad scope of orchestration within the ecosystem. In contrast, the information ecosystems (solution 4 and 8) depict a narrow platform sponsor scope due to choices such as a narrow scope of activities to perform internally, no decision rights over the complements and minimal orchestration within the ecosystem. Furthermore, the configurations of the open-source ecosystems depict a narrower platform sponsor scope compared to complementary innovation ecosystems. The configurations of the marketplace ecosystems depict a broader platform sponsor scope compared to the information ecosystem.

We build on the above findings and extant literature to propose an organizing framework in the form of an *ecosystem continuum* to understand ecosystem heterogeneity. Ecosystems are argued to be distinct from hierarchies and markets because of the presence of modularity that allows distinct structural configuration as well as coordination mechanisms (Jacobides et al., 2018). On the one hand, modularity allows the platform provider to set overarching architectural parameters and forego some degree of coordination among value cocreators; on the other hand, it leads to the emergence of markets (Baldwin & Clark, 2006). Thus, the value creation systems comprise elements of both hierarchies and markets yet remain distinct from both. Jacobides et al. (2018) place ecosystems in between the hierarchy-based and market-based value systems.

We propose that the differences among ecosystems can be explained by the degree of market attributes employed in an ecosystem, which itself is a result of the choice of platform sponsor scope. The differences in platform sponsor scope manifest as different types of ecosystems that can be placed on a continuum between *firm*s on one end and *the market* on the other end (Figure 3.2). The position of an ecosystem on the continuum is defined by the platform sponsor scope such that a broad platform sponsor scope places the ecosystem closer to the firm end and a narrow scope moves it closer to the market end.

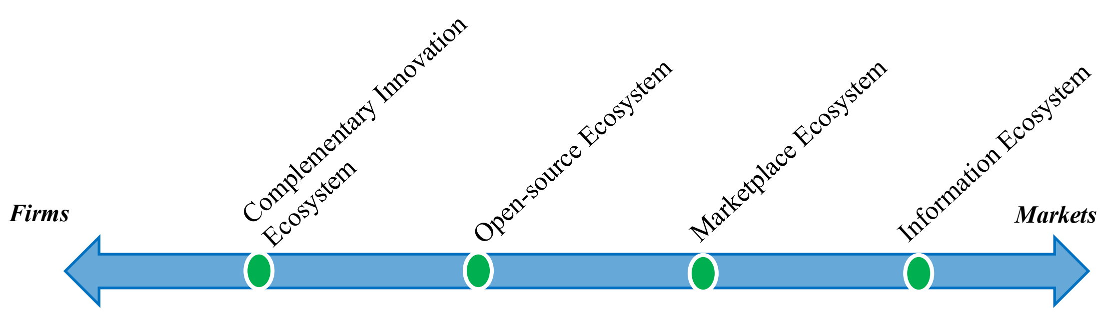

Figure 3. 2: Ecosystem Continuum - Platform Sponsor Scope-based Organizing Framework

In figure 3.2, we have placed the complementary innovation ecosystem closer to the firm end as the configurations depict a broad scope of the sponsor. In contrast, we have placed the information ecosystem with a narrow sponsor scope closer to the market end of the continuum. This argument is consistent with the placement of ecosystems in between hierarchical and market-based value systems but brings more granularity by differentiating the different ecosystems based on platform sponsor scope.

3.6.2 Platform Sponsor Scope and Ecosystem Structure Alignment

As stated earlier, one of the key advantages of a configurational approach is its ability to conduct a holistic and systemic analysis (Meyer et al., 1993). As a consequence of using such an approach, we find that there exist multiple pathways for ecosystems to attain high popularity in the form of distinct configurations of platform sponsor scope and ecosystem structure. The results depict a configurational alignment between scope and ecosystem structure. As the platform sponsor scope narrows, corresponding changes are found in the ecosystem structure to balance the change in value co-creation processes such that the ecosystem structure supports the complementors to create most of the value. In contrast, when the platform sponsor scope is broad, the ecosystem structure supports the sponsor to create most of the value even as it attracts complementors.

The first set of configurations for the complementary innovation ecosystems (solution 1a and 5a) show that a broad platform sponsor scope is aligned with a restricted ecosystem structure. However, in the second set of configurations for these ecosystems (solution1b and 5b), we find that a less restrictive ecosystem structure is aligned with a narrower platform sponsor scope. The configurations for open-source ecosystems (solution 2 and 6) show that whereas a broader scope is aligned with a more restrictive ecosystem structure in the incipient stage, a narrower scope is aligned with a less restrictive ecosystem structure in the mature stage. In the marketplace and information ecosystems, a narrow scope is aligned with a moderate to less restrictive ecosystem structure. These findings show that high popularity ecosystems preserve the alignment between scope and ecosystem structure across the incipient and mature stages.

The alignment between the platform sponsor scope and ecosystem structure attracts participation on all sides of the platform as it helps the complementing actors and users perceive fair and beneficial outcomes from participation. More broadly, our basic thesis is that there is no one dominant path for superior performance but rather the alignment between the type of ecosystem and configurational characteristics in terms of scope and ecosystem structure as defined by the platform sponsors. The configurational alignment manifests as tradeoffs between the different elements of scope and ecosystem structure as discussed in the results section.

3.6.3 Ecosystem Lifecycle Stages

The network effects dynamics fuel the growth of platform ecosystems (Katz & Shapiro, 1994; Rochet & Tirole, 2006) and are argued to result in winner-take-all dynamics (Arthur, 1989) once the market tips in favor of the ecosystem with the strongest network effects (Gawer, 2020; McIntyre & Srinivasan, 2017). In the incipient stage, i.e., before the market tips, the platform sponsor is focused on attracting participation and thereby leveraging network effects. In the mature stages, i.e., after the market tips, the platform sponsor is focused on capturing the value created. Our results show how the ecosystem structure and platform sponsor scope span out in response to the above goals of the platform sponsor. For each type of ecosystem, the configurations depict a change in one or more elements of platform sponsor scope and ecosystem structure across the incipient and mature stages. This finding demonstrates that the lifecycle stage is a key factor to be considered in studying ecosystems. We now delve deeper into the change in configurations across the incipient and mature stages for each type of ecosystem (summarized in Figure 3.3).

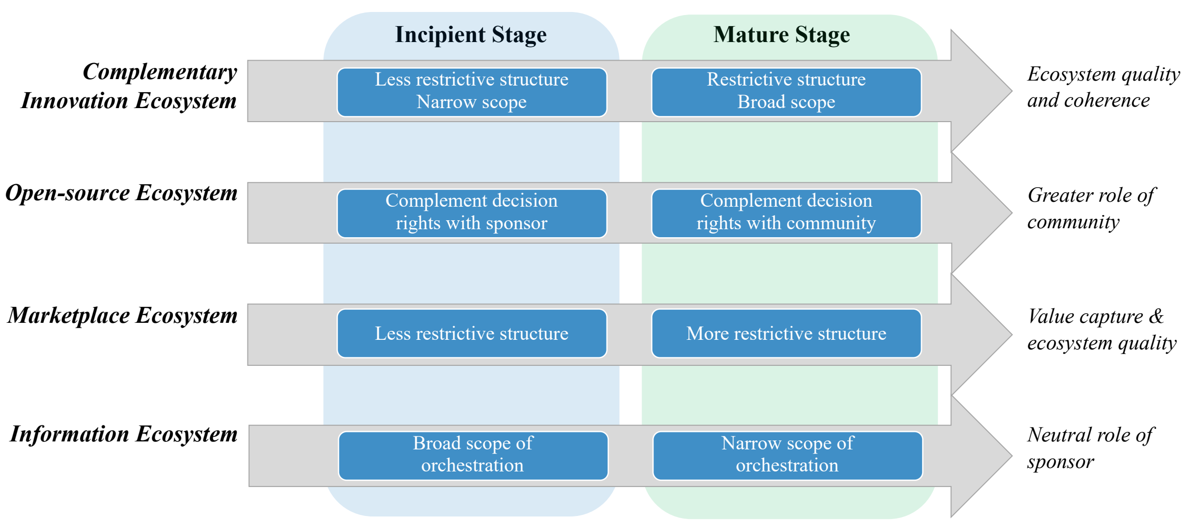

Figure 3. 3: Ecosystem Lifecycle Stages

From the configurations for complementary innovation ecosystems (solution 1b and 5b in the incipient and mature stages respectively), we find that the elements of both ecosystem structure and platform sponsor scope change from the incipient to mature stages (see Figure 3.3). Whereas the ecosystem structure changes from being less restrictive in the incipient stage to more restrictive in the mature stage, the platform sponsor scope changes from a narrower scope in the incipient stage to a broader scope in the mature stage. The less restrictive ecosystem structure coupled with a narrower scope attracts complementors with attractive opportunities to create and capture value in the incipient stages. The shift in the mature stage may be attributed to the need to manage the ecosystem quality, enable coherence in value co-creation in the mature stage and counter the effects of open interfaces and complement variety in the initial stages. Such an approach was seen in Google's Android ecosystem, where Google increasingly made its app review procedures more stringent in an effort to maintain the quality and integrity of the ecosystem during the mature stage. In terms of ecosystem structure, we find that the platform sponsors continued to impose non-generic complementary requirements and not exercise high control. However, they pivoted to a more closed interface and restricted variety configuration in the mature stage.

In the open-source ecosystems, the platform sponsor's hold decision rights over complements in the incipient stage but no longer exert such decision rights in the mature stages. This shift may be explained by the emergence of a strong community that substitutes for the platform sponsor in maintaining the quality and integrity of the ecosystem. For the same reason, the platform sponsor no longer exercises high levels of control in the ecosystem. This change in configuration from the incipient stage to the mature stage depicts the important role the community plays in facilitating value co-creation in open-source ecosystems.

From the configurations for marketplace ecosystems (solution 3b and 7b in the incipient and mature stages respectively), we find that whereas the platform sponsor scope remains similar across the lifecycle stages, the ecosystem structure changes from being less restrictive in the incipient stage to being more restrictive in the mature stage. Specifically, in the mature stage the interface becomes more closed, and the complement categories reduce compared to the incipient stage. The less restrictive ecosystem structure in the incipient stage attracts complementors' participation. With a high popularity in the mature stage, the platform sponsor may adopt the above changes to capture value as well as maintain ecosystem quality.

Finally, in the information ecosystems (solution 4 and 8 in the incipient and mature stages respectively), we find that although the ecosystem structure remains similar across the stages, the platform sponsor moves from having a broad scope of orchestration to a narrow scope of orchestration. There are two plausible explanations to this change. First, the shift to a narrow scope of orchestration in the mature stage may be attributed to the need for the platform sponsor to assume a neutral role of market facilitator. Second, it is plausible that in the incipient stages, the platform sponsor faced with uncertainty had to maneuver value creation in response to evolving value propositions (Dattée et al., 2018) but in the mature stages with reduced uncertainty such orchestration was unnecessary.

Overall, the above configurations depict that for each type of ecosystem, the configuration of ecosystem structure and platform sponsor scope changes from the incipient stage to mature stages in response to both the platform sponsor's goals before and after market tipping point as well as the emerging dynamics and value propositions of the ecosystem.

3.7 Concluding Remarks

To recapitulate, in this paper, we developed a typology of platform ecosystems and a configurational model of ecosystem structure and platform sponsor scope. We inductively identified configurations of ecosystem structure and scope across four different types of ecosystems and found that an alignment between ecosystem structure and scope exist in high-performing ecosystems. We explicated how the configurations change temporally between the incipient and mature stages. We also developed an organizing framework in the form of ecosystem continuum with traditional firms and markets as its endpoints. This framework serves to better understand ecosystem heterogeneity.

Our paper makes several related contributions to the literature. First, we provide an empirically validated typology and bring more granularity to the distinction between innovation and transaction ecosystem and identify four types of ecosystems. In doing so, we demonstrate that ecosystems may differ despite having similar functionality (innovation or transaction), and thus an organizing framework in the form of an ecosystem continuum based on platform sponsor scope provides a better way to consider ecosystem heterogeneity. The platform sponsor scope-based organizing framework that we provide enables us to understand in a fresh and novel manner the differences across distinct ecosystems in the co-creation of value by the participants. By focusing on ecosystem heterogeneity, our study responds to calls to diversify the empirical context of platform research (McIntyre et al., 2020).

Second, using a configurational approach, we show the importance of alignment between the platform sponsor scope and ecosystem structure for superior performance. In doing so, we respond to calls to consider a comprehensive approach to studying platform ecosystems (McIntyre & Srinivasan, 2017). We demonstrate that high popularity ecosystems depict an alignment of narrow scope with less restrictive ecosystem structure and broad scope with more restrictive ecosystem structure regardless of the presence or absence of individual attributes in a configuration. These findings underscore the importance and benefits of using a configurational approach that highlights the combined effect of the attributes. Furthermore, the configurations show that the alignment is achieved when tradeoffs between individual attributes are managed appropriately. For instance, ecosystems with more complement categories also exhibit open interfaces whereas those with few complement categories exhibit closed interfaces.

Finally, we explicate how the alignment and the configuration of the ecosystem structure and scope span out before and after the market tipping point. This study brings fresh insights into the temporal aspect of ecosystems by demonstrating that ecosystem structure and platform sponsor scope are not static decisions made at the outset rather are choices made in consideration of the market tipping point. Except for a few studies (Cennamo, 2018; Kretschmer & Claussen, 2016; Tiwana, 2015), the temporal aspect, especially in relation to ecosystem structure, has not received enough attention in the literature. Our study fills this gap in the literature. Furthermore, we highlight how the platform sponsor's goals before and after the market tips takes shape through the choices in scope and ecosystem structure.

Our study is not without limitations. First, since our focus was to capture ecosystem heterogeneity in a granular manner, the dataset we used in this paper was not a comprehensive and large-N sample. Some of our explanatory factors were coded as crisp sets and four-value fuzzy sets to enable meaningful comparison of factors across the different types of ecosystems. Future work can focus on identifying alternate measures provide more robust comparisons of elements of ecosystem structure and scope across ecosystems. Second, with a focus to compare snapshots of configurations of scope and ecosystem structure across different types of ecosystems and lifecycle stages, our analysis has not examined if the configurations resulted as a deliberate action of the platform sponsor or co-evolved in response to feedback from ecosystem participants. The interplay between platform sponsor's deliberate choices and co-evolution is a fruitful area of research for future studies. Thirdly, there is scope for future work to understand how heterogeneity within a type of platform ecosystem may be associated with performance outcomes. Finally, we have examined ecosystem structure at two stages of the lifecycle. Future work can examine how ecosystem structure changes dynamically and continuously over time.

In conclusion, with the proliferation of ecosystems it is important to explore different perspectives to enrich our understanding of the underlying mechanisms and their manifestations even as we understand the distinctiveness of these mechanisms. Notwithstanding the importance of architecture-based studies, new perspectives on ecosystems have raised new questions and provided opportunities to address ongoing debates not addressed by earlier work. This paper provides a further basis for such an effort by considering the role of platform sponsor scope in ecosystems. The framework we offer casts a novel lens to further enrich our understanding of ecosystems, and one with the potential to enhance empirical understanding of the phenomenon.

CHAPTER 4

PLATFORM ECOSYSTEM DYNAMICS AND GROWTH: ROLE OF PLATFORM SPONSOR SCOPE AND INDIRECT NETWORK EFFECTS

4.1 Introduction

Platform ecosystems are a rapidly proliferating organizational form which comprise of complementors and consumers who interact over a central platform infrastructure (Cennamo, 2019; Jacobides et al., 2018; McIntyre & Srinivasan, 2017). Such ecosystems represent an arrangement that has shifted the locus of value creation from the inner core of the focal firm to co-creation with external autonomous complementors. Fundamental to such value creation is a shared understanding and agreement of the scope of activities of the respective actors, in this case platform sponsors and the complementors. The scope of the platform sponsor vis-à-vis the complementors is a key decision that the platform sponsors have to make continually (Gawer, 2020; Kapoor & Lee, 2013) as it specifies the extent of value to be created by the platform sponsor and that "opened" to the autonomous complementors (Boudreau, 2017).

In this paper we ask: *How does the platform sponsor scope decision influence the platform ecosystem growth dynamics?* This decision is key to attract complementors because it signals the existence of opportunities for value co-creation and value capture around the platform (Gawer, 2014; Jacobides et al., 2018; Wu et al., 2014). The literature has acknowledged the importance of platform sponsor agency in defining the scope (Boudreau, 2017; Gawer, 2015), yet we do not fully understand the implications of the scope decision on the ecosystem (McIntyre et al., 2020). This is because most studies in the platform literature make "a simplifying assumption that platform boundaries are 'given'" (Boudreau 2017, 228) and thus have not examined the implications of alternative scope decisions, particularly on the ecosystem dynamics and growth.

To understand the influence of platform sponsor scope decisions on ecosystem growth, we unpack the "black-box" of indirect network effects (McIntyre & Srinivasan, 2017) and study the underlying dynamics. Indirect network effect dynamics that arise when the actors on one platform side benefit from the number of actors on the other platform sides is fundamental to the functioning and growth of the ecosystem (Panico & Cennamo, 2020; Rochet & Tirole, 2006). Specifically, we examine the sources and directional symmetricity of indirect network effects between any two sides of a platform. Indirect network effects arise from the membership and usage benefits that participating actors accrue in the ecosystem (Rochet & Tirole, 2006). Whereas membership benefits relate to direct utility from platform offerings, usage benefits arise from interacting with actors and products on the other platform sides (Jullien & Pavan, 2018; Weyl, 2010). We contend that platform sponsor scope choices mould the value co-creation and capture opportunities available to complementors by shaping the composition of membership and usage benefits within an ecosystem. The underlying argument enhances understanding of the relationship between these choices and platform ecosystem growth.

Furthermore, we show that platform ecosystems may not always encompass symmetric indirect network effects. With the exception of a few recent studies (e.g., Hagiu & Wright 2015), much of the literature has assumed that indirect network effects are directionally symmetric between the different sides of the platform (Weyl, 2010). Specifically, when the platform's complementors benefit from access to a large number of consumers, the consumers are assumed to also benefit from the availability of a large number of complementors and their products. Though such directional symmetry exists in platforms like smartphone app stores, video games and other technology platforms, this assumption does not hold in case of platforms like newspapers where readers may not like too many advertisements (Hagiu & Wright, 2015b).

We develop a formal model of platform ecosystem growth and consider alternative scope choices for three scenarios of directional symmetricity of indirect network effects: ecosystems with (i) symmetric, (ii) asymmetric, and (iii) no indirect network effects. The first scenario confirms the validity of our model by predicting an increasing growth rate for platform ecosystems' growth, a scenario that causes winner-take-all dynamics (Eisenmann et al., 2006). In the second scenario with asymmetric indirect network effects, we find that the ecosystem growth takes an S-shaped trajectory. Finally, the model for ecosystems with no indirect network effects predicts a concave trajectory with a diminishing growth rate akin to a traditional firm.

Importantly, contingent on the relative composition of membership and usage benefits, changes in platform sponsor scope can augment or diminish the platform ecosystem growth rate, resulting in a shift in growth trajectory. We find that a platform sponsor's scope expansion can result in an increase in the growth rate when the membership benefits exceed usage benefits. In contrast, a reduction in the platform sponsor scope can result in a higher growth rate when the usage benefits exceed membership benefits. However, augmenting the growth rate from such scope changes is not beneficial in ecosystems with asymmetric indirect network effects as the shift in trajectory brings an early plateauing of growth. Hence, we suggest that platform sponsors can beneficially alter growth trajectories by choosing their scope in accordance with the composition of benefits and the directional symmetricity of indirect network effects.

We build on the above insights from the model and delve deeper into the importance of aligning platform sponsor scope with membership and usage benefits. Platform sponsor scope changes redefine the value co-creation and capture opportunities available to the actors within the ecosystem. In examining the micro-level dynamics, we contend that when such scope changes are inconsistent with the composition of membership and usage benefits, the actors' participation decisions may change as co-creation opportunities may no longer seem fair and attractive. We use the context of Wikipedia, following prior research (Klapper & Reitzig, 2018), to illustrate how changes in platform sponsor scope can influence participation decisions of ecosystem actors, which in turn causes a shift in the ecosystem's growth trajectory.

Our paper contributes by linking the literatures on indirect network effects, platform sponsor scope and growth to build a dynamic model (Gawer, 2020) of platform ecosystems. We are thus able to leverage the established literature of indirect network effects dynamics to examine the influence of alternative scope choices on ecosystem growth. We also demonstrate the agency of the platform sponsors to vary the platform ecosystem growth rate through their scope choice. This has implications on how platform sponsors can build strategies to open or close parts of the value creation process in an effort to alter the platform ecosystem growth rate. Finally, we bring more nuanced insight to the argument that platforms should grow fast to attain dominance. We show that in cases of asymmetric indirect network effects, such an accelerated growth would mean hitting a plateau earlier.

4.2 Platform Sponsor Scope

Platform ecosystems enable value creation through the collaboration of different actors. As with any collaboration arrangement, fundamental to value co-creation is an understanding and agreement of the respective actors'—platform sponsors and complementors—scope of value creation activities. Platform sponsor scope in essence captures such an understanding of the value co-creation process. Although recent studies have adopted broader definitions of platform scope as the role played by the platform in the digital markets they enable (Cennamo, 2019) and the "vision that defines the ecosystem value proposition" (Dattée et al., 2018, p. 467), we align with earlier work (e.g., Cusumano & Gawer, 2002) and define platform sponsor scope as *the parts of* *value creation process that the platform sponsor chooses to perform internally whilst opening the other parts of the process to autonomous complementors*. This choice of the platform sponsor to perform parts of the value creation process encompasses aspects such as the choice of activities, the extent to which they exert decision rights on complements, and the degree to which they orchestrate value creation within the ecosystem. Thus, our definition encompasses the broader conceptualizations because, at a more granular level, activities, decision rights and orchestration are what ultimately underpin the delivery of the value proposition. Moreover, this definition clearly captures the platform sponsor agency in defining their scope vis-à-vis the complementors (Boudreau, 2017; Dushnitsky et al., 2020; Gawer, 2015). Importantly, our definition refers to the boundaries of the sponsor along a value chain of activities where value is co-created by autonomous *ex-ante* unknown actors, a distinct aspect of the ecosystem context (Dattée et al., 2018). This scope definition is distinct from the external firm scope that focuses on the choice of products and markets in which to compete.

The choice of platform sponsor scope is also critical for other ecosystem actors since it signals the sponsor's vision for the future ecosystem and the market in terms of how value may be created, the kind of complementors that can participate on the platform, and how all the actors can capture value. When complementors and consumers perceive these signals as attractive, they choose to participate. As more actors participate in this ecosystem, the actors on the same and opposite sides are attracted to participate as well, thereby triggering the positive loopback of network effects (Katz & Shapiro, 1985; McIntyre & Subramaniam, 2009). Thus, platform sponsor scope indirectly contributes to the network effect dynamics. Scholars have identified that platform sponsors, in defining their scope, should consider a number of factors such as the extent of dependency on complementors (Cusumano & Gawer, 2002), perceptions of rivalry among complementors and other ecosystems (Hannah & Eisenhardt, 2018), and the ecosystem's value proposition (Adner, 2017). However, the implications of alternative scope choices have not been the focus of these studies.

Most efforts to understand platform sponsor scope have been on the sponsor's boundary expansion strategies (McIntyre et al., 2020). Platform sponsors expand their scope and produce complements in-house to "get the ball rolling" with indirect network effects (Cennamo, 2018; Hagiu & Spulber, 2013; McIntyre et al., 2020, p. 15). Platform sponsors also expand their scope and bundle features of a rival platform ecosystem into their own to overcome the rival platform's network effects (Carlton et al., 2010; Eisenmann et al., 2011). Despite a focus on competitive interactions based on platform sponsor scope expansion, the literature considers the scope as a given (Boudreau, 2017) and thus does not explore the implications of alternative scope choices. Moreover, as McIntyre et al. (2020) rightly point out, "not all platforms follow an expansion trajectory" (p. 20). Understanding the implications of scope decisions, outside of competitive expansion strategies, on the ecosystem, its actors, and the underlying dynamics is thus warranted.

4.3 Indirect Network Effects

Fundamental to the functioning and growth of the ecosystem is the dynamics of network effects, particularly the cross-side or indirect network effects (Clements, 2004; Evans, 2003; Rochet & Tirole, 2006). Indirect network effects make platform ecosystems distinct in their operations because these effects are known to result in a positive loopback mechanism (Katz & Shapiro, 1985, 1994) that leads to an increased participation on each side of the platform. McIntyre and Srinivasan (2017) identify that indirect network effects have so far been treated as a "black-box" and, as a result, we do not fully understand the drivers and strategies of both the platform sponsor and complementors. We address this issue by examining the sources and directionality of indirect network effects.

4.3.1 Membership and Usage Benefits

The economics literature on indirect network effects usefully characterizes the sources of indirect network effects as the benefits that actors can accrue from their membership and usage of the platform, which together shapes their participation decisions (Armstrong, 2006; Rochet & Tirole, 2003, 2006). Membership benefits relate to the direct utility that actors derive from platform offerings if no actor participates on the other sides, whereas usage benefits arise from interacting with other actors and their products on the other sides (Jullien & Pavan, 2018; Weyl, 2010).

Platform scope choices signal the value co-creation and capture opportunities to attract actors to the platform. A broad platform sponsor scope implies that the sponsor chooses to perform many parts of the value creation process and, thus, consumers can derive most of the value from the platform offerings. A narrow platform sponsor scope implies that the sponsor performs fewer parts of the value creation process and opens the rest to complementors. Consumers then rely on complementors and their products to derive value from the ecosystem. Thus, platform sponsor scope shapes the composition of the membership and usage benefits that the actors accrue from participating in the ecosystem. A platform sponsor also makes its initial scope choice at the very outset, with the composition of membership and usage benefits taking shape accordingly as ecosystem actors respond to value co-creation opportunities. However, the scope choice is one that the sponsor makes not just at the outset but continually during the ecosystem lifecycle (Cusumano & Gawer, 2002). As Gawer (2020) highlights, a platform sponsor scope choice "will differ depending on their stage of evolution" (p. 9) as during the early stages the sponsors may prioritize ecosystem growth and therefore open large parts of the value creation process. As the ecosystem grows, sponsors may expand their scope for better control of the ecosystem and to capture a larger share of the value created (Wareham et al., 2014).

For example, Amazon launched its marketplace model in 1999 aimed at achieving scale and market dominance. The ecosystem witnessed tremendous growth, particularly with the introduction of unlimited free shipping for a fixed subscription fee on eligible products. Until this point, the usage benefits exceeded membership benefits, as may be expected in any e-commerce marketplace. However, membership benefits increased with the introduction of a subscription model through its Prime program. The consumers then shopped on Amazon to take advantage of the free shipping service rather than for product characteristics. Building on this dynamic, Amazon ventured into many of these product categories with its own products, often competing with complementors. This example shows how platform sponsors modify their scope and benefits composition at different points in the platform lifecycle to capture more value.

In sum, whereas ecosystem participants derive value from membership and usage benefits, changes to platform sponsor scope may alter the value co-creation and capture opportunities which may or may not be consistent with the composition of benefits. Thus, understanding how both scope decisions and composition of membership and usage benefits interact and influence the network effects' dynamics and, thus, the growth of the platform ecosystem is pertinent.

4.3.2 Directional Symmetricity of Indirect Network Effects

The indirect network effect literature of multi-sided platforms implicitly assumes that actors on each side of the platform benefit from an increased participation of actors on other sides (Weyl, 2010). However, this assumption fails in case of ecosystems where actors on one of the sides do not value the actors on the other side as much as the latter values the former. An example is the ecosystem of newspapers where advertisers benefit from a large reader base, but the readers may not derive much value from a large number of newspaper advertisements[5] (Hagiu & Wright, 2015b). Thus, a directional asymmetricity of indirect network effects exists that needs to be better understood in terms of its implications as the engine of platform ecosystem growth.

Recent studies have modeled the directional symmetricity of indirect network effects in determining pricing structures and governance mode (Hagiu & Wright, 2015b; Weyl, 2010). Weyl (2010) focuses on symmetricity as an allocation problem where the platform sponsor's choice of the desired participation rates in each side comprised of heterogenous sets of users, drives the pricing structure[6]. Since Weyl's (2010) article focuses on developing a general monopoly price theory of multi-sided platforms, the implications of unequal participation rates across the sides, albeit designed by the platform, on the growth trajectory is ignored. Hagiu and Wright (2015) have developed a model for the choice between platforms and vertical integration as the governance form. Their platform definition and the subsequent formal model allows for the possibility of asymmetric as well as complete absence of indirect network effects. However, given their focus on governance mode choices, implications on ecosystem growth are lacking.

Below, we examine three possibilities of directional symmetricity of indirect network effects: (i) symmetric indirect network effects across the sides of the platform; (ii) asymmetric indirect network effects between two or more sides such that these effects exist in one of the directions between any two sides and are absent in the reverse direction; and (iii) lack of indirect network effects across the sides of the platform. With these scenarios we are concerned with the directional symmetricity, but not the relative intensity of network effects across the sides

[5] We refer to newspapers whose main aim is to report news content. In the case of classifieds section (or newspapers comprised of classifieds), advertisements may be valuable to readers; we are not concerned with those examples.
[6] The term 'users' refers to actors on all sides of a platform and its usage is to be interpreted as a collective term to refer to both complementors and consumers.

(Chintakananda & McIntyre, 2014; McIntyre & Subramaniam, 2009). However, our model can be readily extended to examine the relative intensity within the aforementioned scenarios.

4.4 Platform Ecosystem Growth Model

We develop a formal mathematical model of platform ecosystem growth for different scenarios of directional symmetricity of indirect network effects and examine the influence of alternative platform scope decisions (logic summarized in Figure 4.1).

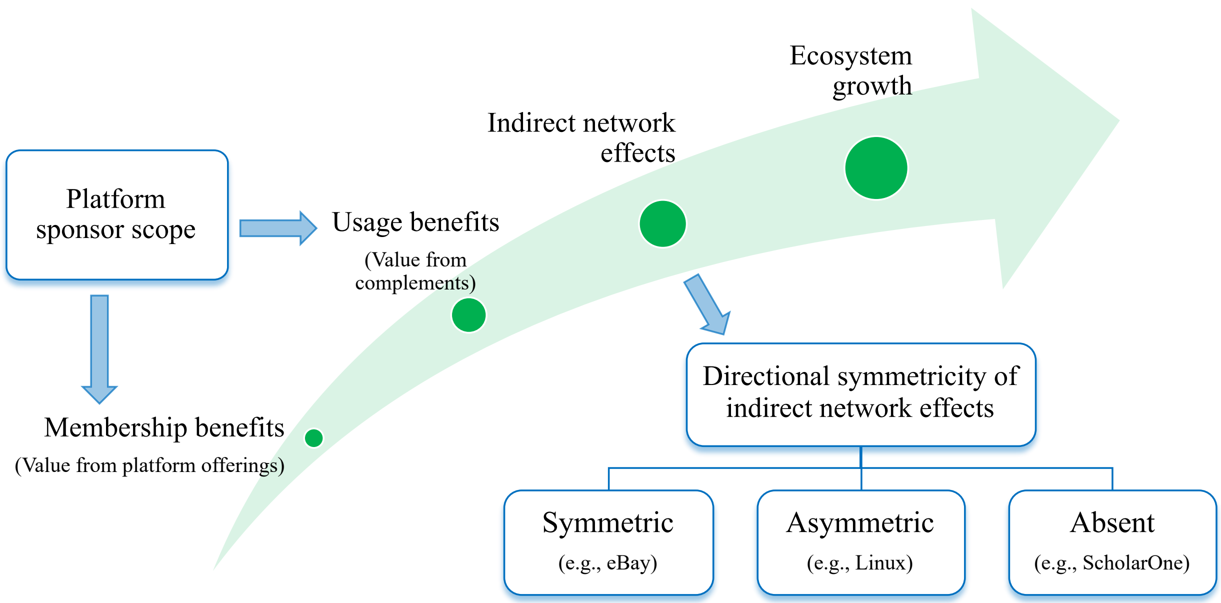

Figure 4. 1: Platform Ecosystem Growth Dynamics

The formal model approach helps explicate the nuances of indirect network effects' dynamics by overcoming limitations in accessing data for alternative scope choices and the difficulty in measuring indirect network effect strengths. However, we illustrate our arguments using the example of Wikipedia in the subsequent section. Whereas we use a higher abstraction level of ecosystem dynamics in the formal model to uncover indirect network effects (Hannah et al., 2020), the Wikipedia illustration delves deeper to understand the micro-level dynamics of scope changes influencing ecosystem actors' participation decisions.

For simplicity, our model focuses on two sides of a platform—consumers (c) and developers (d)—with the term 'developers' more broadly referring to the complementors. We let δ represent the platform sponsor scope. Following Rysman (2004), we use the Cobb-Douglas function with constant returns to scale to define the consumer-side indirect network effects as $\mu^c = \left\{\omega^c B^c \left[\frac{b^c}{B^c}\right]^\delta\right\}$, where B^c is the usage benefits accrued by the consumers, b^c is the membership benefits accrued by the consumers, and ω^c is a scaling parameter to transform the benefits into number of consumers. Similarly, the developer-side indirect network effects are $\mu^d = \left\{\omega^d B^d \left[\frac{b^d}{B^d}\right]^\delta\right\}$, where B^d is the usage benefits accrued by the developers, b^d is the membership benefits accrued by the developers, and ω^d is a scaling parameter to transform the benefits into number of platform developers. Table 4.1 summarizes our notation.

Table 4. 1: Variable Definitions

Variable	Description
μ^c	Indirect network effect on the consumer side
θ^c	Percentage of consumers leaving the platform ($\theta^c \leq 1$)
N^c	Number of consumers of the platform
μ^d	Indirect network effect on the developer side
θ^d	Percentage of developers leaving the platform ($\theta^d \leq 1$)
N^d	Number of developers of the platform
ω^c	Scaling parameter to transform benefits to number of consumers
B^c	Usage benefits for consumers
b^c	Membership benefits for consumers
ω^d	Scaling parameter to transform benefits to number of developers
B^d	Usage benefits for developers
b^d	Membership benefits for developers
δ	Platform sponsor scope ($0 \leq \delta \leq 1$)

This functional form of indirect network effects captures the overall value as comprised of membership and usage benefits. This form also depicts that (a) the platform sponsor scope drives the amount of value the respective actors can contribute to the overall value; and (b) the platform sponsor's value creation contributes to the membership benefits whereas users accrue usage benefits through interactions with the opposite side of the platform. Following the standard constant returns to scale logic, this tradeoff between the sources of indirect network effects implies that an x% increase in membership benefits and an x% increase in usage benefits can only result in an x% increase in indirect network effects.

Although we assume that both membership and usage benefits are necessary for the existence of indirect network effects, minimal usage benefits would render the platform more similar to a hierarchical firm and minimal membership benefits more similar to a market. The multiplicative functional form of the sources of indirect network effects does not contradict prior studies with additive functions for membership and usage benefits contributing to utility (Rochet & Tirole, 2003, 2006), since we are concerned with only the development of indirect network effects. Also, unlike studies of two-sided markets concerned with pure membership and usage models (Armstrong, 2006; Rochet & Tirole, 2006), we adopt the broader definition of platforms as central infrastructures that provide value to users through their own offerings and complements accrued as membership and usage benefits, as captured in our multiplicative functional form.

We borrow from the network externalities literature whereby an increase in the installed base size (or number of users on a platform side) over time is dependent on the number of users on the other sides (Katz & Shapiro, 1985, 1994; McIntyre & Subramaniam, 2009). This is because the consumers benefit from variety and competitive pricing when a large number of developers offer complements whereas the developers benefit from better reach and access with a large number of consumers (Cennamo, 2018; Panico & Cennamo, 2020; Rochet & Tirole, 2006; Zhu & Iansiti, 2012). Building on this evidence, we consider the platform's growth pattern to be influenced by the network effects, μ, and the size of the opposite side, N. In addition to these factors contributing to positive externalities, we consider the possibility that the focal side users may leave the platform. We thus include a deterioration rate, θ, expected to be lower than the indirect-network-effects-driven increases in the installed base size, and define the platform ecosystem growth function over time for the consumer and developer sides as, respectively, $\frac{dN^c}{dt} = \mu^c f(d) - \theta^c N^c$ and $\frac{dN^d}{dt} = \mu^d f(c) - \theta^d N^d$.

The functions $f(d)$ and $f(c)$ allow us to model the directional symmetricity such that when the indirect network effects do not exist in a particular direction between the two sides, these functions can be set to 1. When the indirect network effects exist in the focal direction, the functions are set equal to the size of the opposite side exerting network externalities; this is without loss of generality as the functional form for μ^c (resp. μ^d) contains a scaling parameter, ω^c (resp. ω^d). We thus examine four scenarios of directional symmetricity: (i) symmetric indirect network effects between consumers and developers such that $f(d) = N^d$ and $f(c) = N^c$; (ii) asymmetric indirect network effects where developers exert positive externalities on consumers, but consumers do not exert externalities on developers' participation decisions such that $f(d) = N^d$ and $f(c) = 1$; (iii) asymmetric indirect network effects where consumers exert positive externalities on developers, but developers do not exert externalities on consumers' participation decisions such that $f(d) = 1$ and $f(c) = N^c$; and (iv) absence of indirect network effects where neither side exerts externalities on the other side such that $f(d) = 1$ and $f(c) = 1$.

The platform ecosystem grows with increases in the consumer installed base size and developer participation (McIntyre & Srinivasan, 2017). Thus, a platform ecosystem size is the sum of the sizes of the different sides and the increases in this overall size can be referred to as the ecosystem growth. We setup the ecosystem growth trajectory by modelling the change of platform ecosystem size over time for the four aforementioned scenarios of directional symmetricity. Then we examine changes to the platform sponsor scope for each scenario to find the impact on the ecosystem growth trajectory over time.

4.5 Model Analysis

Scenario 1: Symmetric indirect network effects across both the consumers and developers

This first scenario has been extensively studied in prior literature—ecosystems with directionally symmetric indirect network effects. In such platform ecosystems, the developers' participation decisions are influenced by the number of consumers or simply put, the consumers exert a positive externality on the developers. Similarly, the developers exert a positive externality on the consumers. Examples include Amazon, Expedia, shopping malls, and credit cards. The network dynamics of the consumer and developer sides are, respectively, $\frac{dN^c}{dt} = \mu^c N^d - \theta^c N^c$ and $\frac{dN^d}{dt} = \mu^d N^c - \theta^d N^d$. We solve for N^c and N^d to arrive at the total network size, which enables us to portray the ecosystem growth trajectory of total ecosystem size over time. Figure 4.2's top-left quadrant depicts the growth trajectory; *all* formal developments are detailed in the Online Appendix. The ecosystem grows at an increasing rate over time t since both consumer and developer sides grow with a convex trajectory and thus at an increasing rate, as long as the ecosystem does not experience a deterioration rate greater than the incremental increase in size on both platform sides (i.e., $\mu^c \mu^d > \theta^c \theta^d$). This result is in line with the argument (Eisenmann et al., 2006; Katz & Shapiro, 1994) that ecosystems with symmetric indirect network effects exhibit positive loopbacks that result in dominant platform ecosystems and winner-take-all dynamics. Therefore, this first scenario serves to validate our model.

Next, we analyze the ecosystem growth implications of alternative platform sponsor scope choices and thereby the relative composition of value created by the platform sponsor and developers. We find that a platform ecosystem can grow faster over time contingent on the alignment between the relative composition of the membership and usage benefits and platform sponsor scope (Figure 4.3, top-left quadrant). In other words, the ecosystem can grow faster when one of the following two conditions are met: (i) increase in platform sponsor scope when both sides have users who accrue membership benefits greater than usage benefits such that $b^c > B^c$ and $b^d > B^d$; and (ii) decrease in platform sponsor scope when both sides have users who accrue usage benefits greater than membership benefits such that $B^c > b^c$ and $B^d > b^d$.

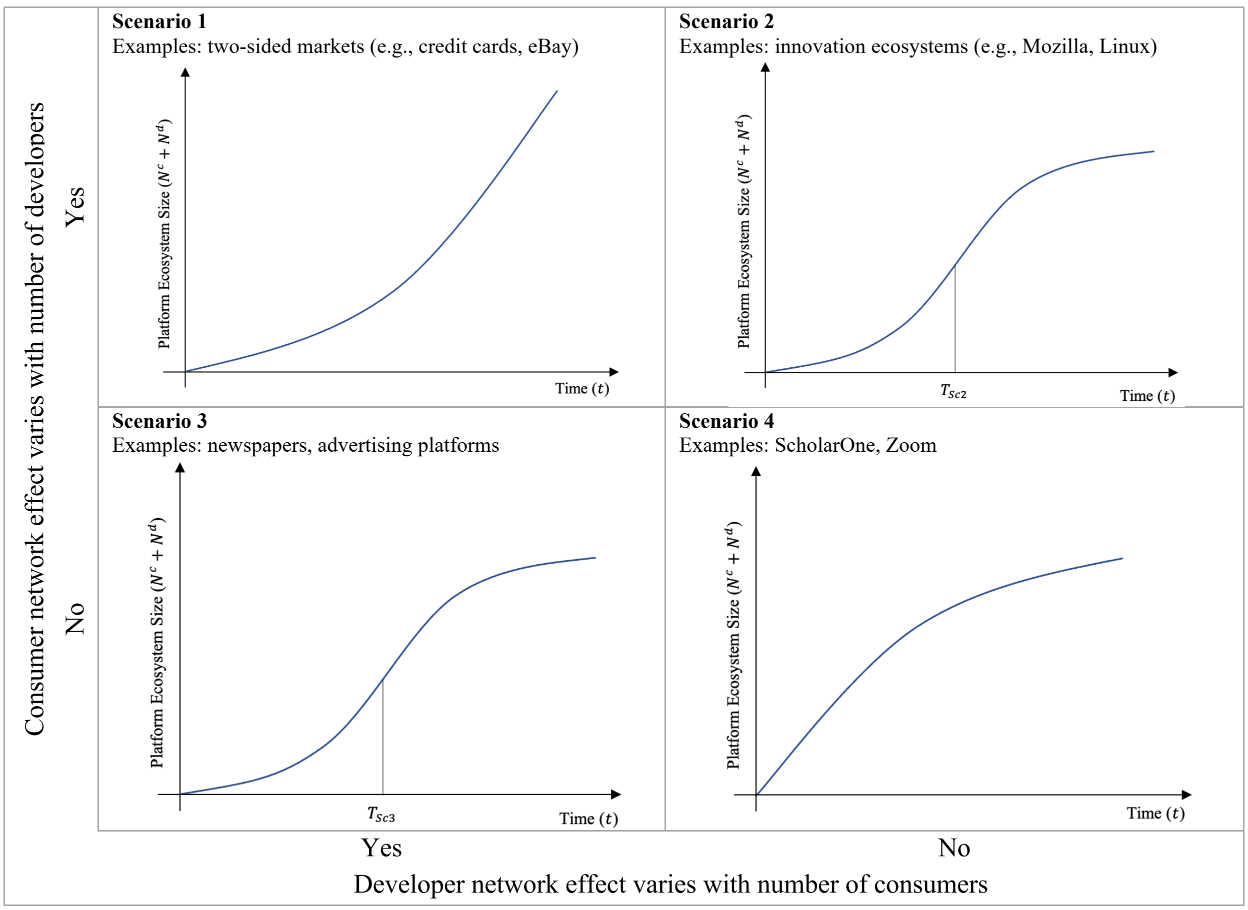

Figure 4. 2: Platform Ecosystem Growth Trajectories

In the first condition, we find that in ecosystems where the users derive most of the value from membership benefits or platform offerings, increasing the platform sponsor scope augments ecosystem growth. This means that the platform sponsor retains more parts of the value creation process and thereby contributes to a larger membership benefit. This change attracts consumers who value the platform offerings more than the interaction with the developers and thus fuel a faster growth. In contrast, in a platform ecosystem where the users derive more value from usage benefits, if the platform sponsor decreases its scope, then the consumers are now forced to interact with the developers to derive value. This can disincentivize the consumers who prefer platform offerings rather than complements and thus results in a decreasing growth (i.e., flatter slope) as depicted in Figure 4.3, top-left quadrant. The shift in growth trajectory due to increasing the platform sponsor scope, is guaranteed to be toward a faster growth only beyond a time threshold, T_{sc1}. This threshold can also be explained as the time taken to build a critical mass of platform users (Bonardi & Durand, 2003; Schmalensee, 2010).

In the second condition, we find that in a platform ecosystem where the users derive more value from interacting with users on the opposite side and thus derive a larger usage benefit, the ecosystem growth can be augmented by decreasing the platform sponsor scope and facilitating the accrual of even higher usage benefits through interaction with developers. In contrast, if a platform ecosystem with high usage benefits chooses to increase the platform sponsor scope, then it disincentivizes the developers in producing for the platform and results in a weak or no growth situation on that side. This may lead to an overall slower ecosystem growth over time as depicted in Figure 4.3. However, the trajectory shift towards a faster growth rate is seen only after a certain time threshold, T_{sc1}. This shift is not guaranteed to be positive before this threshold even though the composition of benefits aligns with the platform sponsor scope. Prior studies (Bonardi & Durand, 2003; Schmalensee, 2010) show that a critical mass of users is necessary to signal the platform growth potential and kickstart the indirect network effects, which can explain this result. The time threshold, T_{sc1}, can be viewed as the time taken to build a critical mass.

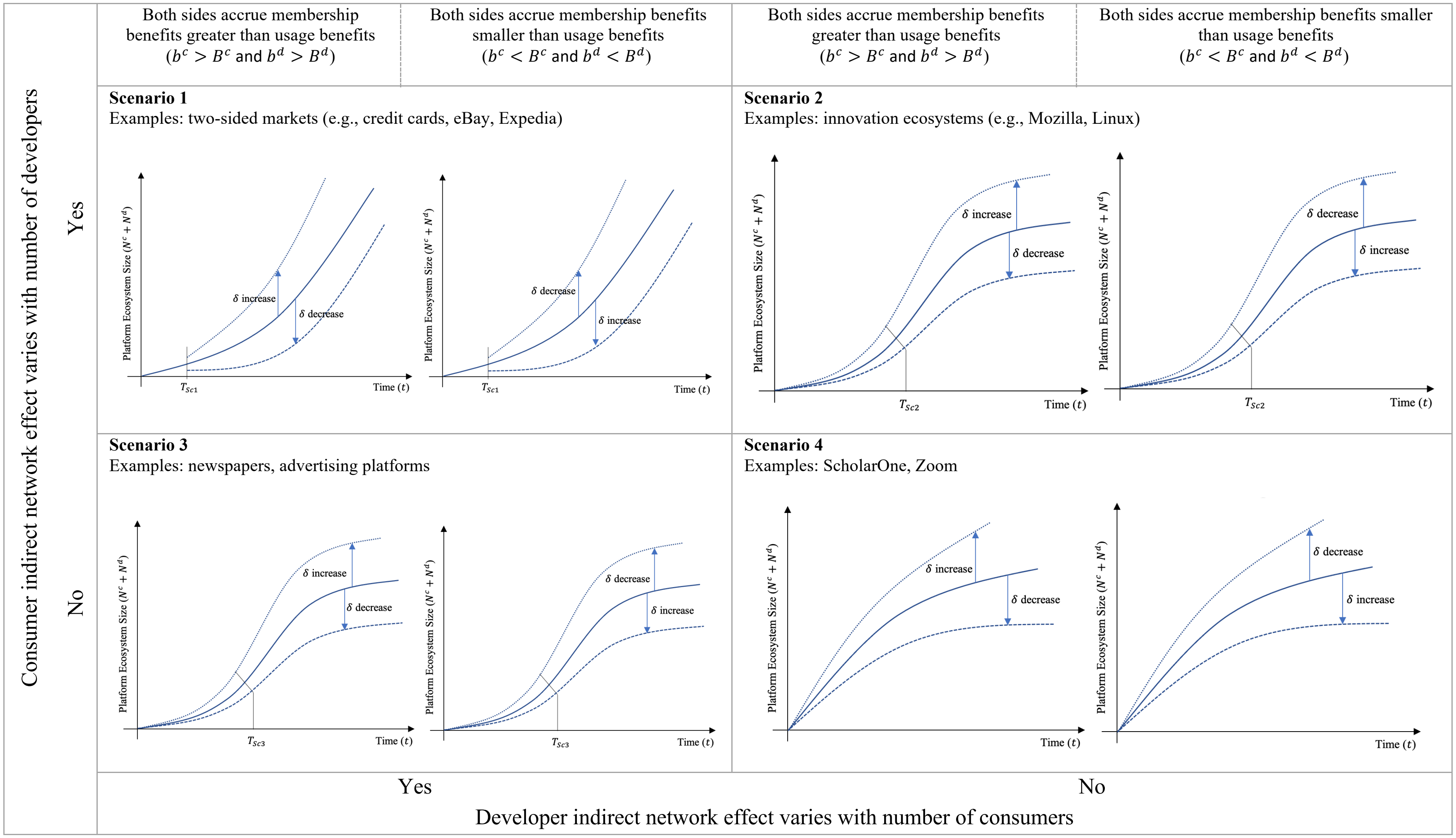

Figure 4. 3: Implications of Alternative Platform Sponsor Scope Choice on Ecosystem Growth

Overall, from the above analysis of symmetric indirect network effect ecosystems, we find that our model predicts an increasing growth rate over time. At any time t, this growth rate can be further augmented by changing the platform sponsor scope in accordance with the composition of benefits. However, the growth rate is guaranteed to be positive in response to such changes in platform sponsor scope only beyond a time threshold that depicts the time taken to build a critical mass of users. Overall, platform sponsor scope expansion consistent with the composition of membership and usage benefits is beneficial as it can accelerate the growth of the ecosystem to potentially result in dominance or winner-take-all dynamics (Eisenmann, 2006; Eisenmann et al., 2006). These results are consistent with prior platform literature and therefore serves to validate our model, which we next extend to the lesser studied scenarios of asymmetric and lack of indirect network effects on one or more sides of the platform. Thus, we propose that:

Proposition 1: A platform ecosystem with symmetric indirect network effects

a) *grows at an increasing rate over time* t *as long as the deterioration rates are less than the indirect network effects (i.e.,* $\mu^c\mu^d > \theta^c\theta^d$*);*
b) *can augment its growth rate by increasing (or decreasing) platform sponsor scope when* $b^c > B^c$ *and* $b^d > B^d$ *(or* $B^c > b^c$ *or* $B^d > b^d$*) and*
c) *the shift in growth trajectory due to changes in platform sponsor scope is guaranteed to be toward a faster growth beyond a certain time threshold* T_{sc1}.

Scenario 2: Asymmetric indirect network effects with consumer side externalities

We now examine the influence of asymmetric indirect network effects on ecosystem growth. Consider the case of ecosystems where developers exert positive externalities on consumers, but consumers do not exert externalities on the developers' participation decisions. In other words, consumers' participation decisions are influenced by the number of developers, but the developers' participation decisions are not influenced by the number of consumers. Examples include Mozilla Firefox, Linux and other open-source software platforms. The network dynamics from the consumer and developer sides are thus, respectively, $\frac{dN^c}{dt} = \mu^c N^d - \theta^c N^c$ and $\frac{dN^d}{dt} = \mu^d - \theta^d N^d$.

We again solve for N^c and N^d to arrive at the total network size and then derive the ecosystem growth trajectory as the total platform size over time, as depicted in Figure 4.2, top-right quadrant. The ecosystem grows at an increasing rate (a convex function of t) but only before an inflection point of time T_{Sc2}. Beyond this point, the ecosystem continues to grow but at a decreasing rate (a concave function of t). The growth trajectory thus takes a S-shaped form with an increasing rate in the initial time period followed by a decreasing rate of growth.

The above result depicts an important deviation from the notion that platform ecosystems grow at an increasing rate and is as such important for platform sponsors who aim to see increasing growth and avoid plateauing in the platform's later life stages. This result may be illustrated with open-source software platforms like Mozilla Firefox, where consumers are attracted to the availability of a stable product and a variety of extensions (or complements) and thus contribute to the initial trajectory of increased growth. But since the number of consumers does not motivate the developers who rather participate to build and use personal expertise or contribute to the platform's larger good, they plausibly participate more in the initial stages and as the platform stabilizes their contributions reduce resulting in a decreasing growth rate.

An analysis of the impact of alternative platform sponsor scope choices on ecosystem growth shows that, similar to the previous scenario, a platform ecosystem can grow faster over time contingent on the alignment between the relative composition of membership and usage benefits (Figure 4.3, top-right quadrant). Specifically, the ecosystem growth can be augmented through (i) increases in platform sponsor scope when both sides accrue membership benefits greater than usage benefits such that $b^d > B^d$ and $b^c > B^c$, and (ii) decreases in platform sponsor scope when both sides accrue usage benefits greater than membership benefits such that $B^d > b^d$

and $B^c > b^c$. However, the increased growth rate moves the inflection point T_{Sc2} to an earlier time such that the ecosystem growth rate begins to slow down much earlier, as depicted in Figure 4.3.

The first condition highlights that ecosystem with higher membership benefits than usage benefits can augment their growth rate by further increasing the platform sponsor scope. The users would be able to derive even more membership benefits from platform offerings with this move. This implies that any increases in platform sponsor scope can increase the growth rate only when the developers derive value from affiliating with the platform. In the example of open-source software platforms, this could mean that the developers would not mind the platform sponsor retaining more parts of the value creation process as long as their affiliation with the platform provides them access to valuable core modules of the platform.

In contrast, the second condition highlights that a reduction in the platform sponsor scope accelerates growth in ecosystems where the users derive more usage benefits than membership benefits. As we argued for Scenario 1, the users who derive more value from usage would benefit even more when more parts of the value creation process are opened to developers. However, in the current case of asymmetric indirect network effects where only the developers exert positive externalities on consumers' participation decisions, we find a condition where the usage benefits of developers should exceed their membership benefits. This implies that any decrease in platform sponsor scope will have the benefit of faster growth only when the developers derive value from using the platform. A possible explanation is that unless developers 'use' the platform, they are unlikely to produce complements, a scenario that is further exacerbated as more parts of the value creation process is opened up. For example, in an open-source software platform, when the platform sponsor scope is decreased, more platform modules are available to developers. Unless developers derive value from using these modules, they are not incentivized to produce complements as consumer base does not motivate their participation.

Although changes to platform sponsor scope in accordance with the composition of usage and membership benefits can hasten platform growth rate, it also accelerates the inflection point when the growth switches from an increasing to a decreasing rate. Thus, unlike the symmetric indirect network effect scenario, platform sponsor scope expansion to hasten growth rate is not beneficial in ecosystems with asymmetric indirect network effects even if the change is in accordance with the composition of benefits. This may be explained with the earlier example of open-source platforms. Since the developers are motivated in the initial period to participate and contribute to the platform’s larger good, a platform sponsor may increase its scope to facilitate, coordinate and integrate developer contributions more extensively and thereby achieve a stable configuration much earlier. The growth rate on the developer side thus increases with such a scope expansion. But as the platform stabilizes and matures, developers’ interest to participate weakens since fewer opportunities exist to build expertise through experimentation. This leads to a quicker withdrawal of developers and renders the growth rate hitting a plateau earlier.

Overall, our analysis predicts a S-shaped growth trajectory with an increasing growth rate that switches to a decreasing one at an inflection point. At any time t, the growth rate in this trajectory can be accelerated by changing the platform sponsor scope in accordance with the composition of membership and usage benefits as long as the conditions of the composition of benefits on both sides are met. However, a faster growth rate has downsides in that it leads to a faster switchover to decreasing growth rate and thus faster plateauing of growth. We propose that:

Proposition 2: A platform ecosystem with asymmetric indirect network effects where only the developers exert positive externalities on the consumers

a) *grows at an increasing rate over time* t *until an inflection point,* T_{Sc2}*, beyond which it grows at a decreasing rate as long as the deterioration rates are less than the indirect network effects on the developer side (i.e.,* $\theta^d < \theta^c < \mu^d$*);*
b) *can augment its growth rate by increasing (or decreasing) platform sponsor scope when* $b^c > B^c$ *and* $b^d > B^d$ *(or* $B^c > b^c$ *and* $B^d > b^d$*); and*
c) *the shift in growth trajectory toward a faster growth also accelerates the time when the inflection point* T_{sc2} *is reached.*

Scenario 3: Asymmetric indirect network effects with developer side externalities

We next examine the case of ecosystems with asymmetric indirect network effects such that the consumers exert positive externalities on the developers' participation decisions, but the developers do not exert similar externalities on the consumers' decisions. The developers thus derive an increased benefit with the participation of a greater number of consumers, but the consumers do not derive benefit from the participation of more developers. Examples include newspapers and magazines, where the advertisers benefit from more readership, but the readers may not like more advertisements. The network dynamics from the consumer and developer sides are, respectively, $\frac{dN^c}{dt} = \mu^c - \theta^c N^c$ and $\frac{dN^d}{dt} = \mu^d N^c - \theta^d N^d$. Again, as we solve for N^c and N^d and derive the platform growth trajectory, Figure 4.2's bottom-left quadrant depicts similar results to the previous scenario. That is, the platform ecosystem grows at an increasing rate but only before an inflection point of time T_{Sc3}. Beyond this inflection point, the platform continues to grow but at a decreasing rate. Therefore, the ecosystem growth trajectory takes a S-shaped form with increasing rate in the initial period followed by a decreasing rate of growth.

This result depicts the impact of asymmetric indirect network effects and how they do not result in positive loopbacks and an increasing growth rate. Let us consider the example of newspapers as a platform to better understand the result. In such ecosystems, the consumers exert positive externalities on advertisers but not *vice-versa*. The result shows that the ecosystem grows at an increasing rate in the initial period as advertisers are attracted to the readers on the platform.

However, with time the ecosystem size increases, and presumably more advertisers are participating on the platform. Since the readers do not derive value from the advertisements (rather, they experience negative externalities), they either leave the platform or fewer new readers join the platform. These decisions slow the growth rate on the reader side and subsequently influence the advertisers' participation decisions. Consequently, the platform experiences a decreasing growth rate that eventually hits a plateau.

We now analyze the implications of changes in platform sponsor scope on the platform growth, depicted in Figure 4.3, bottom-left quadrant. Similar to the previous scenario, the growth can be augmented through (i) increases in platform sponsor scope when users on both sides accrue membership benefits greater than usage benefits such that $b^c > B^c$ and $b^d > B^d$, and (ii) decreases in platform sponsor scope when users on both sides accrue usage benefits greater than membership benefits such that $B^c > b^c$ and $B^d > b^d$. However, the increased growth rate moves the inflection point T_{Sc3} to an earlier time such that the platform growth rate slows down much earlier. Thus, platform sponsor scope expansion to hasten the growth rate may not be beneficial even if the scope changes are in accordance with the composition of benefits.

The first abovementioned condition highlights that in ecosystems where the users derive more membership than usage benefits, the ecosystem growth can be accelerated by further increasing the platform sponsor scope. The developers of such platforms are able to derive even more membership benefits from platform offerings with this move. But we find that such a result is possible only when the membership benefits for consumers is more than their usage benefits. In the newspapers example, this condition implies that when readers derive more value from newspaper content rather than advertisements, and advertisers derive value from being affiliated with the newspaper, ecosystem growth rate can be increased by increasing the platform sponsor scope. As in Scenario 2, augmenting the growth rate by changing platform sponsor scope also accelerates the inflection point when the growth switches from an increasing to a decreasing rate.

The second condition above highlights that in ecosystems where consumers accrue higher usage than membership benefit, decreasing the platform sponsor scope augments the ecosystem growth rate. We again find that for such an increased growth rate, the usage benefits of consumers should exceed their corresponding membership benefits. This implies that any increase in the platform sponsor scope will have the desired benefit of faster growth only when the consumers derive value from using the platform. When consumers derive membership benefits, they are motivated to continue participating on the platform though they may not be influenced by the large number of developers. Their continued participation exerts positive externalities on the developers who are then motivated to participate in the ecosystem. For example, the readers of newspapers as consumers should maintain their readership and the value derived from using the platform in order to attract a greater number of advertisers.

Overall, our analysis predicts a S-shaped growth trajectory with increasing growth rate that switches to a decreasing growth rate at an inflection point. At any time t, the growth rate in this trajectory can be accelerated by changing the platform sponsor scope in accordance with the composition of membership and usage benefits as long as the conditions of the composition of benefits on both sides are met. A faster growth rate has downsides in that it leads to a faster switchover to decreasing growth rate and thus faster plateauing. We propose that:

Proposition 3: A platform ecosystem with asymmetric indirect network effects where only the consumers exert positive externalities on the developers

a) *grows at an increasing rate over time t until an inflection point, T_{Sc3}, beyond which it grows at a decreasing rate as long as the deterioration rates are less than the indirect network effects on the consumer side (i.e., $\theta^c < \theta^d < \mu^c$);*
b) *can augment its growth rate by increasing (or decreasing) platform sponsor scope when $b^c > B^c$ and $b^d > B^d$ (or $B^c > b^c$ and $B^d > b^d$); and*

c) *the shift in growth trajectory toward a faster growth also accelerates the time when the inflection point T_{sc3} is reached.*

Scenario 4: Absence of indirect network effects

Although much of the multi-sided market literature posits that the presence of indirect network effects is one of the defining dynamics of this organization form, recent work argues that platforms can exist in the absence of indirect network effects (Hagiu & Wright, 2015b). We examine this possibility where neither the consumers' participation decisions are influenced by the presence of more developers nor are the developers' participation influenced by the presence of more consumers. Hagiu and Wright (2015) suggest that in such platforms, like ScholarOne that facilitates interaction among editors, referees and authors in the academic publication process, one of the sides makes the decision to participate which automatically brings the other sides to the platform. Other examples include Qualtrics, Doodle and Skype. The network dynamics from the consumer and developer sides are thus, respectively, $\frac{dN^c}{dt} = \mu^c - \theta^c N^c$ and $\frac{dN^d}{dt} = \mu^d - \theta^d N^d$. As we solve for N^c and N^d and derive the ecosystem growth trajectory depicted in Figure 4.2's bottom-right quadrant, we obtain an ecosystem growth that follows a decreasing rate or concave trajectory. With the absence of indirect network effects to fuel positive loopbacks, this growth trajectory is similar to that of a hierarchical firm without the multi-sided nature of platforms.

We then examine the implications of alternative platform sponsor scope choices on ecosystem growth. Consistent with the earlier scenarios, we find that a platform ecosystem can grow faster over time contingent on the alignment between the relative benefits composition and platform sponsor scope (Figure 4.3, bottom-right quadrant). Specifically, the platform ecosystem growth can be augmented through (i) increases in platform sponsor scope when both consumers and developers accrue membership benefits greater than usage benefits such that $b^c > B^c$ and

$b^d > B^d$ and (ii) decreases in platform sponsor scope when both consumers and developers accrue usage benefits greater than membership benefits such that $B^c > b^c$ and $B^d > b^d$.

In the first condition, we find that in ecosystems where the users derive more membership than usage benefits, further increasing the platform sponsor scope accelerates the ecosystem growth. Since consumers derive value from the platform offerings and developers from their affiliation with the platform, an increase in the platform sponsor scope will mean that the platform sponsor retains more value creation and therefore become more valuable to both the consumers and developers. For example, in automobile manufacturing platforms, the consumers derive more value from the car manufacturer due to quality, reliability, and accountability. The component manufacturers derive value from their association with the car manufacturers as it provides them access to the manufacturing business of components for different car models. Hence, when the platform sponsor scope is broadened, the consumers benefit from better quality and the component manufacturers benefit from increased support, better designs and integration (provided their own component manufacturing is not absorbed internally by the manufacturer). Thus, increasing the platform sponsor scope can attract more participation from consumers and developers and result in an accelerated growth. An increased growth rate also means that the growth hits a plateau later. A shift in the growth trajectory (Figure 4.3) also leads to a shift in the plateau. Hence, unlike the case of asymmetric indirect network effects, platform sponsor scope expansion in accordance with the composition of benefits may be beneficial in ecosystems with no indirect network effects as it delays hitting the plateau.

In the second condition, we find that in ecosystems where both consumers and developers accrue higher usage than membership benefit, the ecosystem growth rate can be augmented by decreasing the platform sponsor scope. For example, in collaboration platforms like Zoom, the users draw more usage benefits than membership benefits. When the platform sponsor scope is decreased in such platforms, more parts of the value creation process are available to developers. As developers create different types of complements, more opportunities are now available for consumers to derive value from complements. This further enhances the usage benefits for the consumers and attracts more participation resulting in increased platform ecosystem growth rate.

Overall, our analysis predicts a decreasing growth rate trajectory for platforms with no indirect network effects. At any time t, the growth rate in this trajectory can be increased by aligning the platform sponsor scope in accordance with the composition of membership and usage benefits as long as the conditions of the composition of benefits on the consumer and developer sides are met. Thus, we propose that:

Proposition 4: A platform ecosystem with no indirect network effects

a) *grows at a decreasing rate over time* t *and*
b) *can augment its growth rate by increasing (or decreasing) platform sponsor scope when* $b^c > B^c$ *and* $b^d > B^d$ *(or* $B^c > b^c$ *and* $B^d > b^d$*).*

In summary, the formal model of platform ecosystem growth considering symmetricity of indirect network effects and alternative scope choices shows that whereas the ecosystem growth trajectory depends on the directional symmetricity of indirect network effects, the platform sponsor can alter the growth rate within the trajectory through changes to its scope decisions contingent on the composition of membership and usage benefits. However, such scope changes may result in a shift in the growth trajectory that may be beneficial only when the indirect network effects are symmetric or totally absent.

4.6 Micro Dynamics: Platform Sponsor Scope Change and Participation Behavior

We now explore the micro-level dynamics underlying the impact of platform sponsor scope changes on ecosystem growth trajectory, where the shift in this trajectory is fueled by a change in the number of new users joining or existing users leaving the platform ecosystem. A more micro-level examination allows us to delve deeper into how changes to the platform sponsor scope may impact the participation behaviors of users.

Platform sponsor scope signals value co-creation and capture opportunities to potential developers and consumers. Consequently, when sponsors choose to expand or reduce their scope, these opportunities get redefined. We can expect that new users join, and existing users continue to participate in the ecosystem, when they find that the redefined opportunities are fair and beneficial. However, these opportunities would be realized when the membership and usage benefits are also correspondingly reconfigured. For example, when the platform sponsor increases its scope in an ecosystem where usage benefits exceed membership benefits, efforts should be made to attract users to platform offerings and offset any decline in usage benefits due to attrition of users who perceive unfair value creation and capture opportunities. Similarly, when the platform sponsor reduces its scope in an ecosystem where membership benefits exceed usage benefits, the users may derive little value from participation if developers do not fulfill the void created by the sponsor's scope change. Thus, scope changes that are inconsistent with the composition of membership and usage benefits in the ecosystem may lead to a change in the users' participation decisions as value co-creation and capture opportunities may no longer seem fair and attractive. We next provide empirical evidence to the above argument that platform sponsor scope changes influence user participation decisions.

Our empirical context is English language Wikipedia, which was established in 2001 as an online platform of open-source encyclopedia and information repository (Wikipedia, 2020b). The Wikipedia platform serves as an infrastructure to harness contributions from its users and a repository and source for information to its consumers. Broadly speaking, Wikipedia comprises of two sides[7]—(a) *editors* who make edits to articles and thereby contribute to Wikipedia's information repository (akin to developers in our model), and (b) *readers* who are the consumers of the content. Editors accrue social benefits (Xu & Li, 2015) in the form of reputation and validation of their contributions and thus are likely to contribute more when there is a larger group of actively participating editors (Zhang & Zhu, 2011), which demonstrates the existence of same side or direct network effects. However, the editors do not have a view of the amount of readership of a focal article or their contributions, and thus, arguably, they do not accrue benefits from the readers' installed base size. In contrast, the readers benefit from the editors' installed base size because with a large number of editors, not only is there more content, but also frequent editing and reviewing that improve content quality. Thus, we can argue that Wikipedia is an example of an ecosystem with asymmetric indirect network effects (Scenario 2 discussed above) where usage benefits exceed membership benefits for the editors and readers.

Researchers have measured Wikipedia's growth in terms of number of editors (Aaltonen & Seiler, 2016), editing activity, and contributions (Gallus, 2017; Zhang & Zhu, 2011). Figure 4.4 depicts Wikipedia growth in terms of contributions (measured as cumulative editing activity across all articles) from the editor side[8]. Wikipedia's growth trajectory shows that the editor side grew at an increasing rate until 2006 and then experienced a decline. From this growth trajectory, the growth on the editor side switched from an increasing one to a decreasing one from 2007 onward. In response to a major vandalism attack of content, Wikipedia adopted several changes to its editing policy and guidelines from 2006 onward ("History of Wikipedia," 2020). Scholars argue

[7] Wikipedia has other sides to its platform such as administrators and bureaucrats who oversee the quality of contributions and content in general. In this scenario we restrict to editors and readers as the two sides as we are interested in the dynamics of indirect network effects between the developers and consumers.
[8] Wikipedia did not collect page views, website traffic or any other metrics for readership until 2007. It was deemed at the time that such data collection would put unnecessary load on the internal system (Wikipedia, 2020a). Hence, we restrict our focus to the growth on the editor side of the platform.

that these policy changes explain the editing activity's growth decline (Halfaker et al., 2013; Simonite, 2013) since they included software-based processes for identifying editors and protecting against vandalism and increased instances of edit reverts (Suh et al., 2009). We focus on edit reverts, which refers to the practice of reverting an edit made within an article to its previous state when the edit is deemed inappropriate (Halfaker et al., 2011). In principle, such a policy amounts to governing the editors' contributions to the ecosystem.

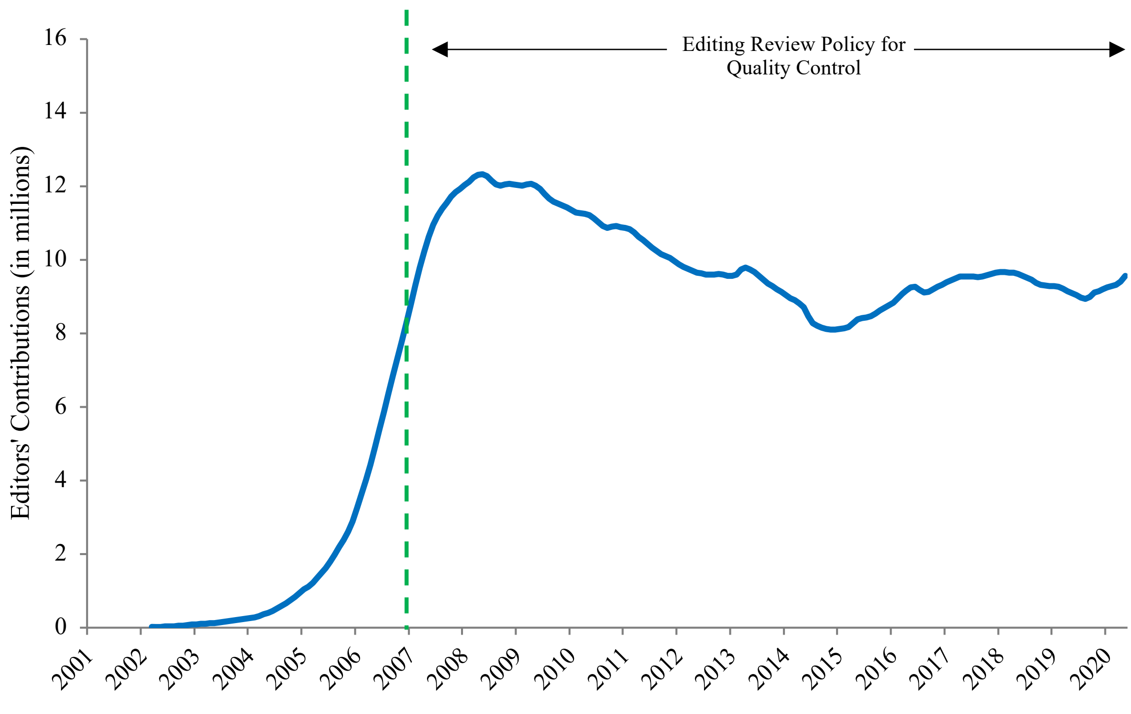

Figure 4. 4: Wikipedia Growth in Contributions

As an open community, the role of the platform sponsor is not distinct in Wikipedia. However, policy changes introduced in 2006 are implemented through a core community of administrators, custodians and veteran contributors, in addition to tacit directions from the founder, Jimmy Wales (Forte et al., 2009; Klapper & Reitzig, 2018). This entity of central actors is analogous to a platform sponsor who governs and orchestrates contributions within the ecosystem. Consequently, the editing policy changes to govern editors' contributions through edit reverts is an expansion of the platform sponsor scope. According to our theory, in an ecosystem such as

Wikipedia where usage benefits exceed membership benefits on both sides, an increase in platform sponsor scope will negatively impact users' participation decisions. Specifically, we test the following argument: *a scope expansion manifested through edit reverts during time* $t - 1$ *will negatively influence the editors' participation decisions in time* t.

4.6.1 Data and variables

We use publicly available data released by Wikimedia Foundation. The dataset comprises of a panel of monthly editing activity in English Wikipedia between 2004 and 2013. This focus allows us to track editors' participation before the editing policy changes in 2006 as well as the period after the change when the control of administrators (platform sponsors) progressively increased through deployment of software bots and cyborgs (Halfaker & Riedl, 2012). The full dataset is a panel of 6,920,398 editors making 15,507,658 edits across 120 months. The level of analysis is at the editor-month level.

Our main dependent variable is *contributions* that capture the editors' participation decisions. We use the number of monthly edits made by each individual editor at time t as a measure of their contributions to the platform. The main independent variable is *reverts* which is measured as the number of reverted edits among the contributions made by an editor in the preceding time period $t - 1$. We use a lagged measure to capture the impact of reverts on the motivation to contribute in the future. We consider a moderator variable, *editing policy*, to capture the scope differences before and after 2006. This variable is coded 0 for the months before 2006 to indicate the more democratic governance where the editors' community made collective decisions to maintain the quality of the content (Konieczny, 2009), and it is coded 1 for months after 2006 to indicate the implementation of editing policy changes and computational tools.

For control variables, we use *tenure*, which is the number of months elapsed at time t since the focal editor registered on Wikipedia as an editor. Since an editor gains experience with more time spent on the platform, we control for the effect of tenure on contributions. We also control for *historical contributions* that capture the editor's legacy of contributions to Wikipedia through a cumulative measure of all contributions until time $t-1$. Since editors gain social benefits by contributing to Wikipedia (Zhang & Zhu, 2011), the legacy of an editor's contributions likely motivates them to contribute even further. Finally, we capture the deletion history of the editors through a cumulative measure of all their edit reverts until time $t-1$ in the control variable *historical deletions*. Whereas social benefits from contributions may motivate editors to contribute more, these reverts may demotivate them from contributing to the platform.

4.6.2 Results

Table 4.2 reports the descriptive statistics for all variables. Table 4.3 summarizes the results of a panel OLS regression with fixed effects. Model 1 presents the results for the effect of key variables of interest. Model 2 reports the results with interaction effects. Across both models, *historical contributions* have a small but significant positive influence (Model 1: β = 0.0009, 95% CI [0.0008, 0.001]; Model 2: β = 0.001, 95% CI [0.0008, 0.0009]) whereas *historical deletions* have a negative and significant influence on contributions (Model 1: β = -0.024, 95% CI [-0.024, -0.023]; Model 2: β = -0.021, 95% CI [-0.022, -0.02]). *Tenure* has a negative effect on contributions (β = -0.451, 95% CI [-0.485, -0.417]), which may be attributed to the editors losing interest or hitting a plateau. Model 2 introduces the moderating effect of *editing policy* on the relationship between reverts and contributions. The interaction effect is a negative significant one (β = -0.286, 95% CI [-0.307, -0.265]). Thus, the policy changes introduced after 2006 and the reverts thereof had a negative impact on the editors' contribution efforts, which supports our argument that a scope expansion can have a negative influence on participation behavior.

Across both Models 1 and 2, *reverts* is positively related to contributions (Model 1: β = 0.0.491, 95% CI [0.0.487, 0.496]; Model 2: β = 0.766, 95% CI [0.745, 0.787]). Since we consider editors of all tenure in the sample underlying these models, we suspect that the result of a positive relationship of reverts to contributions is because of an acceptance of lateral authority (Klapper & Reitzig, 2018) through peer reviews from veteran editors. Halfaker et al. (2013) have demonstrated that deletion of edits impact newcomer editors' participation. With an aim to better understand the impact on newcomers vis-à-vis experienced editors, we split our sample into two, using the criteria of editors' joining date before or after 2006. Models 3-5 focus on repeating our analyses in the subsample of editors who joined after 2006 and those who joined before 2006.

Table 4. 2: Descriptive Statistics and Correlations

	Full sample (N = 15,507,658)	**Mean**	**S.D.**	**Min**	**Max**	**1**	**2**	**3**	**4**
1	Contributions	29.142	725.107	1	1712735	1			
2	Reverts	1.993	102.287	0	238871	0.19	1		
3	Editing Policy	0.865	0.342	0	1	-0.003	-0.006	1	
4	Tenure	15.149	22.404	-81	155	0.023	0.006	0.188	1
	Editors who joined after 2006 (N = 10,251,255)	**Mean**	**S.D.**	**Min**	**Max**	**1**	**2**	**3**	**4**
1	Contributions	20.658	790.695	1	1712735	1			
2	Reverts	1.694	74.028	0	136399	0.108	1		
3	Editing Policy	1	0.003	0	1	0.001	0.001	1	
4	Tenure	8.977	15.659	0	83	0.019	0.008	0.009	1
	Editors who joined before 2006 (N = 5,256,403)	**Mean**	**S.D.**	**Min**	**Max**	**1**	**2**	**3**	**4**
1	Contributions	45.688	575.738	1	498739	1			
2	Reverts	3.795	141.789	0	238871	0.361	1		
3	Editing Policy	0.602	0.489	0	1	0.016	0.001	1	
4	Tenure	27.189	27.988	0	155	0.022	-0.001	0.661	1

Model 3 reports results from panel OLS fixed effects regression on the subsample of editors who joined after 2006. Since this subsample constitutes only the editing activity after the policy changes, we do not consider the interaction effect of the *editing policy* dummy variable. The *reverts* have a negative significant impact on contributions, as we expected (β = -0.255, 95% CI [-0.266, -0.244]).

Table 4. 3: Panel OLS regression with editor fixed effects on contributions per month

	Full dataset of all editors				*Editors who joined after 2006*		*Editors who joined before 2006*			
	Model 1		**Model 2**		**Model 3**		**Model 4**		**Model 5**	
Reverts	0.4911	[0.000]	0.7664	[0.000]	**-0.2548**	**[0.000]**	0.8068	[0.000]	0.9010	[0.000]
	(0.0023)		(0.0107)		**(0.0055)**		(0.0016)		(0.0063)	
Editing Policy (dummy)	0.3041	[0.794]	1.7682	[0.129]					4.7643	[0.000]
	(1.1648)		(1.1661)						(0.7268)	
Tenure	-0.4512	[0.000]	-0.4527	[0.000]	-0.1548	[0.000]	-0.6191	[0.000]	-0.6634	[0.000]
	(0.0173)		(0.0173)		(0.0350)		(0.0103)		(0.0128)	
Historical Contributions	0.0009	[0.000]	0.0009	[0.000]	-0.0001	[0.279]	0.0030	[0.000]	0.0029	[0.000]
	(0.0000)		(0.0000)		(0.0001)		(0.0000)		(0.0000)	
Historical Deletions	-0.0237	[0.000]	-0.0212	[0.000]	-0.0792	[0.000]	-0.0226	[0.000]	-0.0214	[0.000]
	(0.0004)		(0.0004)		(0.0012)		(0.0003)		(0.0003)	
Reverts X Editing Policy			**-0.2858**	**[0.000]**					**-0.0992**	**[0.000]**
			(0.0109)						**(0.0064)**	
Constant	35.4385	[0.000]	33.9954	[0.000]	24.1642	[0.000]	57.5550	[0.000]	55.7199	[0.000]
	(0.9283)		(0.9298)		(0.4506)		(0.3465)		(0.4166)	
Number of editors	6,920,398		6,920,398		5,792,539		1,127,859		1,127,859	
R-squared	0.0059		0.0060		0.0019		0.0620		0.0621	
F	10202.8356		8618.0677		2131.3555		68220.4284		45529.4994	

Models 4 and 5 focus on the subsample of editors who joined before 2006. Since these editors have contributed before and after the policy change, we consider the two-way interaction effect of *editing policy* as a moderator. Model 4's subsample results are consistent with Model 1's full sample results. The *reverts* have a significant positive impact on contributions ($\beta = 0.807$, 95% CI [0.804, 0.81]). This may be attributed to the ability of long-time editors to absorb rejections of their edits.

In comparing Models 3 and 4, whereas newcomer editors react negatively to reverts, old-timers react more positively to them. Model 5 introduces the moderating effect of *editing policy* on the relationship between reverts and contributions. Similar to Model 2 on the full sample, the interaction effect is a negative significant one ($\beta = -0.099$, 95% CI [-0.111, -0.087]) indicating that policy changes introduced after 2006 and the reverts thereof had a negative impact on the editors' contributions effort, as we expected.

4.7 Discussion and Concluding Remarks

In this article, we examined how the platform sponsor scope choice influences platform ecosystem dynamics and growth. We explicated the effect of platform sponsor scope choices in ecosystems with different states of directional symmetricity of indirect network effects, the key underlying dynamic for ecosystem growth, and established that growth trajectories differ based on the symmetricity of underlying indirect network effects dynamics. The existing arguments in the literature around increasing growth rate and subsequent emergence of dominant platforms hold true when the indirect network effects are symmetric (Eisenmann, 2006; Nambisan, 2017; Nambisan et al., 2018). In contrast, asymmetric indirect network effects result in a S-shaped platform growth trajectory. An absence of indirect network effects between both sides results in a decreasing growth rate that reaches a plateau in the later stages. We found that across the different scenarios of indirect network effects, platform sponsors' scope choices can augment or diminish the ecosystem growth rate contingent on the alignment between the platform sponsor scope and the composition of membership and usage benefits. However, augmenting the growth trajectory was beneficial only for ecosystems with symmetric or no indirect network effects. In illustrating the underlying micro-level dynamics of how platform sponsor scope expansion impacts ecosystem growth, we provided empirical evidence to demonstrate that a misalignment between scope and composition of benefits clearly impacts users' participation decisions.

Our study responds to the call to open the "black-box" of indirect network effects (McIntyre & Srinivasan, 2017) and shows that indirect network effects—their sources, strength and their influence on ecosystem dynamics—must be examined more closely using dynamic models (Gawer, 2020). The literature on indirect network effects has mostly focused on explicating the dynamics to arrive at pricing strategies. Moreover, studies in this stream are more concerned with increasing returns (Arthur, 1989, 1994), but not as much with growth trajectory or platform sponsor scope. In contrast, the literature on platform scope has mostly focused on scope expansion and implications on competitive dynamics, but not as much on ecosystem growth. In linking these three disparate streams of literature—indirect network effects, platform ecosystem growth, and platform sponsor scope—we highlight key ecosystem dynamics and bring more nuance to our understanding of the governance implications of both the indirect network effects and platform sponsor scope.

At a more specific level, our research contributes in a number of ways to the platform literature. First, we demonstrate through a formal model that platform ecosystem growth trajectories differ for platforms with different types of indirect network effects; importantly, the asymmetric network effects do not support a trajectory of increasing growth rate. Although prior studies have modeled platforms, their focus has mostly been on optimizing pricing structures (Rochet & Tirole, 2003, 2006), entry decisions (Zhu & Iansiti, 2012), innovation outcomes (Parker & Van Alstyne, 2017), and organizational form (Parker & Van Alstyne, 2005). Moreover, the literature has either assumed symmetric network effects or not focused on platform ecosystem growth. We address both these literature gaps. We find that the nature of indirect network effects—symmetric or asymmetric—determines the platform ecosystem growth rate and trajectory over time. Therefore, not all platforms grow exponentially and attain winner-take-all dynamics, a scenario possible only when the platform ecosystem encompasses symmetric network effects.

Second, we demonstrate the agency of the platform sponsor in altering the ecosystem growth trajectory through its scope choices. We find that platform sponsor scope choices can increase the platform ecosystem growth rate, resulting in a shift in the growth trajectory when certain conditions of the composition of membership and usage benefits are met. This has practical implications on how platform sponsors can build strategies to open or close parts of the value creation process to alter platform ecosystem growth rates. Overall, our findings indicate that platform ecosystem growth rates depend on the symmetricity of indirect network effects *and* their sources in terms of composition of benefits. In examining the impact of platform sponsor scope changes on ecosystem users' participation behavior, we further show the importance of balancing value co-creation and capture opportunities among ecosystem users.

Finally, we identify conditions and the existence of time thresholds for platform ecosystem growth trajectory based on both the symmetricity of indirect network effects and the platform sponsor's scope decisions, which has direct implications for platform firms' strategies. On one hand, the time thresholds can help platform sponsors understand resource requirements before the platform ecosystem begins to grow, owing to indirect network effects. On the other hand, we show that increasing the growth rate can also result in the ecosystem reaching a plateau faster in platforms with asymmetric indirect network effects. Thus, platform sponsors could choose from either attaining a peak growth early on or delay reaching the peak and invest the resources elsewhere. This result also depicts that an accelerated growth may not be beneficial in all cases as plateauing may occur sooner in ecosystems with asymmetric indirect network effects.

Our research is not without limitations. First, we have assumed that both usage and membership benefits are necessary in the platform, although their relative composition may differ. This assumption is consistent with the definition of platforms that we have adopted from Hagiu and Wright (2015). However, if future work were to find the absence of either class of benefits or find newer avenues through which users accrue benefits, our model may be limited in predicting the growth trajectory. Second, as our focus was to examine indirect network effects, we have not included the influence of same-side network effects or platform competition explicitly in the model. Future work could extend our model to examine how the four scenarios would span out with the presence and absence of direct network effects or platform competition. Third, our illustration focuses on Wikipedia, which is a community-driven platform with virtually no rivals. Although recent work on ecosystems with commercial interests support the principal arguments we have advanced (Mahalingam, 2020), future work could explicitly test our propositions. Finally, growth trajectory findings assume that no explicit changes were brought midway through the platform sponsor's (or its competitors') strategies. Future work could accommodate such explicit changes and its impact on platform ecosystem growth trajectories.

CHAPTER 5
CONCLUSION

In this dissertation, I examine value co-creation in platform ecosystems by focusing on the role of the platform sponsor's scope choices. Specifically, I (a) focus on a platform sponsor's agency in defining its scope, (b) study the scope choices alongside the elements of ecosystem structure and dynamics, and (c) demonstrate the implications of such choices on ecosystem emergence and growth at different stages of the ecosystem lifecycle. In this final chapter, I summarize the findings of the three essays and discuss the implications for theory and practice.

The first essay examines how the platform sponsor's scope choice in conjunction with the problem they are seeking to solve can enable the emergence of an ecosystem around the platform. I develop a problem-solving perspective of platform ecosystems and provide a framework for alignment between the problem dimensions and platform sponsor scope that can aid in the efficient search for valuable complements and, thereby, the emergence of an ecosystem around the platform. Using a dataset of fundraising campaigns from Kickstarter, I abductively find configurations of problem and scope dimensions for complementary innovation ecosystems, open-source ecosystems, and information ecosystems.

The second essay examines the interplay between ecosystem structure and governance and the implications on ecosystem growth in the incipient and mature stages across different types of ecosystems. I provide an empirically validated typology of platform ecosystems and place them along an ecosystem continuum, applying a platform sponsor scope-based organizing framework that I develop. Using a configurational approach, I demonstrate that high-performing ecosystems exhibit an alignment between structure and platform sponsor scope elements. I also find that although the significance of individual elements differs, the alignment is preserved across different types of ecosystems as well as across the incipient and mature stages.

The third essay examines the platform ecosystem dynamics by focusing on the symmetricity of indirect network effects, the composition of benefits accrued by the actors, and the platform sponsor scope choices. Using a formal model, I find that the platform ecosystem growth trajectory differs based on the symmetricity of indirect network effects. However, the growth may be augmented when the changes in platform sponsor scope are aligned with the composition of membership and usage benefits. Additionally, using Wikipedia editing activity data, I demonstrate that the micro-level dynamics involving the participation decisions of the complementors are the reason for such changes in ecosystem growth. Specifically, when scope changes are inconsistent with the composition of benefits, I find a decline in the participation of complementors and, therefore, a decline in ecosystem growth.

5.1 Implications

In this section, I examine the implications of the findings of the three essays. The dissertation contributes to the platform literature as well as the firm scope literature.

5.1.1 Platform Ecosystem Design: Sponsor Agency and Temporal Dimension

The dissertation highlights two key insights – platform sponsor agency and the significance of the temporal dimension – that are important for platform ecosystem design. The essays examine alternative scope choices and the heterogeneity in such choices, thereby establishing the agency of the platform sponsor in defining its scope. The dissertation shows that platform sponsor scope is a valuable tool available to the platform sponsors to facilitate ecosystem emergence and growth. This finding contributes theoretically and empirically to the argument that ecosystems emerge and grow with not just direct but also indirect maneuvering by the platform sponsor and that the lack of such tacit intervention may lead to the failure of ecosystems (Dattée et al., 2018; Tiwana, 2013; Tiwana & Konsynski, 2010). The configurations of ecosystems (involving problem dimensions, ecosystem structure, and scope) identified in essays 1 and 2 depict some ways in which the platform sponsor can maneuver through platform design choices. Further, the configurations highlight tradeoffs between key elements of problem, structure, and platform sponsor scope, thereby providing insights into how the platform sponsor can balance the corresponding elements to sustain the superior performance of the ecosystem.

The dissertation also sheds light on a critical aspect that has received scant attention so far in the platform literature – implications of the temporal dimension for platform ecosystem design. Essay 1 focuses on the incipient stage when the ecosystem is still emerging, and the platform sponsor is focused on attracting participation rather than value capture. In the incipient stage, when the platform is relatively unknown and network effects are weak, this essay shows that signaling fair value creation opportunities can enable ecosystem emergence. Furthermore, essay 2 compares the configurations of ecosystem structure and scope between the incipient and mature stages. In doing so, the essay demonstrates how the platform sponsors redesign their ecosystems over time and do so in response to the market tipping point. Moreover, as essay 3 shows, the dynamics of indirect network effects results in distinct ecosystem growth trajectories over time depending on the symmetricity of these effects. I find time thresholds on the ecosystem growth trajectory, which highlights that platform sponsor and complementors' commitments should be made considering these thresholds. For instance, when the ecosystem has an S-shaped growth trajectory, making commitments to accelerate the growth would mean hitting the plateau faster. Overall, the three essays incorporate the temporal dimension in platform ecosystem design in different ways and thereby respond to calls for research (Kretschmer et al., 2020) considering the impact of time.

5.1.2 Value Creation under Uncertainty

The notion of platform sponsor scope developed in this dissertation contributes to theory on how platform sponsors manage the challenge of value creation under second-order uncertainty or unknown unknowns (Tajedin et al., 2019). Platform ecosystems face a unique value creation challenge where the platform sponsors co-create value with complementors but do not know ex-ante who are the complementors or what their products are, a situation of uncertainty described as unknown unknowns. Firm-designed markets such as platform ecosystems are argued to alleviate such uncertainty by leveraging the market process to harness distributed knowledge of external actors which is augmented with the sponsor's knowledge and capability to create value.

The essays in this dissertation respond to calls for a better understanding of heterogeneity in firm-designed markets (Tajedin et al., 2019) and their performance implications. Platform sponsor scope serves as a basis to further examine heterogeneity in firm-designed markets. As demonstrated in essays 1 and 2, different types of ecosystems emerge and grow due to heterogeneity in the choice of platform sponsor scope. In considering the heterogeneity in scope choices and corresponding problem and structure choices, these essays bring new insights into how the platform ecosystems overcome second-order knowledge constraints or unknown unknowns in different ways.

Furthermore, the platform sponsor scope captures how platform sponsors navigate the challenge of unknown unknowns to create value. The platform sponsor scope encompasses the platform sponsor's choice of value creation processes to perform internally while opening the other processes to complementors. Thus, the platform sponsor scope serves as a tool to attract the *right* set of complementors. The choice of scope signals to complementors the opportunities available for value creation and capture and thereby attracts them to participate in the ecosystem. In examining ecosystem emergence, essay 1 demonstrates these implications in the incipient stage. The alignment between platform sponsor scope and problem dimensions enables an efficient search for valuable complements. An efficient search involves finding the right complementors who can exploit the value creation and capture opportunities and thereby contribute to the ecosystem's emergence.

Furthermore, since the platform sponsor scope shapes the sponsor’s latitude to govern the ecosystem, it serves as a way to foster a more *predictable* set of complements. In examining the interplay between ecosystem structure and scope, essay 2 demonstrates that across both incipient and mature stages, the choice of structure and scope shapes the nature of complements, type of complementarity, and competition among complementors. Moreover, as essay 3 demonstrates, the nature of indirect network effects and the composition of benefits further shapes the kind of interactions between actors, thereby shaping the ecosystem constituents. In a nutshell, the platform sponsor can overcome the uncertainty of unknown unknowns through their choice of scope to foster the right complementors and a predictable set of complements.

5.1.3 Firm Scope and Platform Ecosystems

The scope of the firm has long been a central issue of strategic management. The choice of firm scope shapes firms’ strategies, likelihood of survival, performance outcomes, and competitive environment (Zenger et al., 2011). Two separate aspects shape firm scope: external scope, which refers to the choice of products and markets in which the firm chooses to compete, and internal scope, which refers more specifically to which activities the firm chooses to retain within its boundaries. The platform sponsor scope discussion in the three essays fits within the realm of internal scope. However, the conceptualization of platform sponsor scope differs from the firm scope literature involving hierarchical firms as well as hybrid arrangements like alliances.

Platform sponsor scope involves the choice of boundaries vis-à-vis the complementors who form an integral part of value co-creation in the ecosystem. Such a choice of boundary differs from those of a traditional firm where the relationship between the actors involved is often arm's length or transactional. In contrast, platform ecosystems encompass an arrangement of interdependence. Yet, the boundaries are distinct from those in hybrid organizational forms like alliances because the platform sponsor, as the focal economic actor, neither selects its partners nor establishes complex contracts involving firm scope. As conceptualized in this dissertation, platform sponsor scope is a tacit boundary choice that consequently shapes the ecosystem of actors around the platform. In a recent effort to capture the uniqueness of platform scope, Gawer (2020) refers to scope choice broadly as involving assets, activities, and resource ownership but does not capture the nuances involving boundaries with complementors and within the ecosystem. This dissertation sheds light on a new kind of firm scope that is important for platform ecosystems and thereby contributes to the firm scope literature.

5.1.4 Integrating Platform Literature Streams

The essays in this dissertation draw from and integrate the different streams of platform literature – technology management, economics, and strategy – to build a more integrated approach to understanding platform ecosystems. As McIntyre & Srinivasan (2017) highlight, such integration can help build a broader view of the phenomenon of platform ecosystems. In examining the interplay between ecosystem structure and platform sponsor scope, essay 2 integrates insights from the technology management and strategy literature streams to derive the different elements of ecosystem structure and platform sponsor scope, respectively. The findings contribute to both the streams by demonstrating the importance of aligning the two sets of elements.

Furthermore, essays 1 and 2 use a configurational approach to examine the platform sponsor scope's interplay with problem dimensions and ecosystem structure, respectively. In leveraging the management research insights of a configurational approach, the two essays demonstrate the importance of holistic analysis. These essays not only identify multiple paths to reach the outcome but also highlight tradeoffs between the underlying elements drawn from different literature streams.

Essays 1 and 3 bridge the economics and strategy literature in unique ways. In developing a problem-solving perspective of platform ecosystems in essay 1, I show that the platform ecosystem context is similar to the knowledge context in terms of distributed assets. I argue that whereas the economic problem in the knowledge context is to find the best way to utilize distributed knowledge (Hayek, 1945), that in digital platforms is to find the best way to utilize assets not owned by any single firm in totality, but rather affiliated with a platform (Hagiu & Wright, 2015b). Thus, the theories and arguments based on knowledge context become readily applicable to the platform context. In demonstrating the alignment between platform sponsor scope and problem dimensions, this essay depicts how governance choice plays a vital role in problem solving. In essay 3, I leverage the rich literature on indirect network effects to model ecosystem growth. I augment the model with strategy considerations that platform sponsor scope shapes the relative importance of the membership and usage benefits in the ecosystem. In bridging network effects with platform sponsor scope, I demonstrate the influence of governance choices on the network effects dynamics.

5.2 Limitations

The dissertation is not without limitations. First, the performance measures used in the three essays are best available proxies for emergence and growth in the respective research settings. Whereas an ideal measure of emergence and growth should involve the number of complementors, complements, and consumers, such data is rarely available in the public domain for platform ecosystems. Our choice of proxies of performance measures were driven by the consideration that comparing the number of complementors and consumers across different types of ecosystems may be misleading. For instance, comparing the absolute number of complementors in a transaction ecosystem like Amazon with that in an innovation ecosystem is meaningless as the complementors perform different parts of the value creation process. Second, with a focus on alignment of platform ecosystem considerations, the essays have uncovered multiple pathways to reach the outcome. In doing so, the datasets for fsQCA analysis represented the breadth of heterogeneity in terms of ecosystem types. Thus, the depth of ecosystem heterogeneity, i.e., variance within a given type of ecosystem, has not been the central focus of the analysis. Third, with an aim to study the influence of multiple explanatory factors on the outcome, the essays employed the fsQCA approach and analytical model of ecosystem dynamics. Although such an approach was suitable for the objective of the respective essays, the findings are limited to the sample and model assumptions.

5.3 Scope for Future Work

In this section, I identify avenues for future research in three distinct areas building on the construct of platform sponsor scope and the findings of the dissertation.

5.3.1 Platform Sponsor Scope and Ecosystem Strategy

Despite adopting the organizational logic of harnessing co-creation by autonomous complementors within their ecosystems, platform sponsors engage in alliances and joint ventures much like a traditional firm, and often simultaneously. Whereas the dissertation focused on platform sponsor scope as a choice made vis-à-vis the complementors, there exists the possibility of selectively modifying platform sponsor scope through inter-organizational arrangements.

Although platform sponsors leverage the complementors' intellectual property, resources and knowledge through their complements, several examples show that platform sponsors also depend on alliance partners. For example, GE, as the platform sponsor, announced partnerships with several firms and launched a four-tiered partnership program in its effort to encourage development of complementary products for its internet of things (IoT) platform, GE Predix, even as it offered open application programming interfaces (APIs) to its platform that the autonomous complementors can use to develop their products. Future studies can examine how the platform sponsor's corporate strategies interact with their scope choices and how these choices may shape complementors' strategies and overall ecosystem performance.

Furthermore, whereas this dissertation demonstrates that platform sponsor scope influences complementors' participation behavior, it is vital to understand how the complementors' strategies take shape in response to alternative scope choices and over time i.e., before and after the market tipping point. The dissertation's findings emphasize the importance of considering the temporal dimension in platform research. Future studies can build on the finding that platform sponsor scope plays a vital role in shaping the ecosystem dynamics. A promising line of research involves exploring complementors' strategies such as entry timing, pricing, and quality of complements under different ecosystem dynamics encompassing symmetric and asymmetric network effects.

5.3.2 Digital Strategy

Digital technologies can be modified, extended, and reused simultaneously by multiple actors with minimal coordination and with no impact to the core or other modules (Adner et al., 2019; Zittrain, 2005). Firms and products built on digital technologies, such as digital platforms, face a unique value creation challenge. The nature of digital technologies implies that no single firm can conceptualize and implement all possible extensions of the technology. Thus, as I argue in the dissertation, digital technologies have shifted the locus of value creation from the focal firm to co-creation with external autonomous actors. This condition leads to the challenge of "unknown unknown" at two levels – (i) the focal actor does not know ex-ante who the co-creators may be and what their products would be, and (ii) the focal actor may neither know the problem to be solved nor the solution to the problem that creates value.

The scope of the focal actor is a crucial tool to manage the challenge posed by the situation of unknown unknowns as such a scope choice signals value co-creation opportunities and attract participation. This dissertation has demonstrated that the platform sponsor scope is crucial to signal value creation opportunities in the context of platform ecosystems. The notion of platform sponsor scope has implications for understanding digital strategy in terms of how the focal actors can indirectly influence value co-creation with external actors. Future studies can examine how the scope choice interacts or influences broader digital strategies involving governance design choices in contexts other than digital platforms. This line of inquiry is also fruitful to examine how scope choices of a dominant player may shape entrepreneurial opportunities in the digital context. Another aspect of scope involves the broader boundary choice of the focal actor vis-à-vis other firms within the same market. Whereas much of the literature in this stream has focused on competitive positioning, there is scope to examine how this boundary choice interacts with the internal scope choice. Such an inquiry is particularly important for digital strategy because autonomous actors such as complementors often co-create with multiple firms simultaneously.

5.3.3 Empirical Opportunities

Future research can develop standard measures or indices to study the construct of platform sponsor scope. In focusing on platform sponsor scope, the dissertation demonstrated the importance of platform sponsor agency and identified performance implications of heterogeneous scope choices. However, the availability of standard indices can help operationalize platform sponsor scope more easily in large sample studies and thus further the research agenda. Further, whereas the essays considered a configurational approach involving specific elements of problem, structure, and scope, future research can leverage recent advances in qualitative comparative analysis (QCA) in the form of macro conditions to examine the interplay among all possible elements of governance, structure, and pricing. Such a study could use a large sample approach of QCA, given the possibility of a plethora of counterfactuals.

In conclusion, this dissertation studied value co-creation in platform ecosystems by focusing on the platform sponsor scope choices. In examining alternative scope choices and their implications, this research highlights the need for a more heterogeneous treatment of ecosystems in terms of their structure and dynamics. Although platform technologies offer the possibility of endless innovation, this dissertation shows that these occur in distinct patterns exemplified in configurations of scope, problem, structure, and dynamics of the ecosystem. As we build knowledge of the increasingly important phenomenon of platform ecosystems, I believe that different perspectives such as those advanced in this dissertation are fundamental to gaining a holistic yet granular understanding of the phenomenon.

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APPENDIX A

PLATFORM SPONSOR SCOPE AND ECOSYSTEM EMERGENCE: A PROBLEM-SOLVING PERSPECTIVE

Robustness checks

Following best practices and recent studies, we performed a number of robustness checks. Firstly, we varied the crossover point by +/- 25 percent of the original value for all causal conditions. The fsQCA configurations with the revised calibration scores are as shown in table A1, A2, A3 and A4. As expected in such analyses, changes to the crossover points have resulted in minor changes to the configurations but the interpretation of the results remains substantively unchanged. Secondly, we increased the frequency threshold for the number of cases to 2 and ran the same analyses. We found a subset of the original solutions reported under results. However, the interpretation of the results remained unchanged in this case too.

Robustness Test 2.1a
Crossover point + 25 percent – Successful campaign funding

Table A 1: Robustness test 2.1a

	Solution				
	Complementary Innovation Ecosystems		Open Source Ecosystems	Information ecosystems	
	1	2	3	4	5
Problem dimensions					
Well-structured problem	⨂	⨂	⨂	•	●
High complexity	⨂	●	●	⨂	⊗
High cost context	●	●	⨂	●	⊗
Platform sponsor scope					
Complement decision rights	●	●	⊗	⊗	●
Narrow scope of activities	⊗	●	⊗	●	⨂
Consistency	0.94	0.83	0.89	0.90	0.87
Raw Coverage	0.1	0.08	0.15	0.16	0.09
Unique Coverage	0.05	0.02	0.10	0.09	0.03
Overall Solution Consistency		**0.86**			
Overall Solution Coverage		**0.38**			

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition. Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

Robustness Test 2.1b
Crossover point + 25 percent – Successful ecosystem emergence

Table A 2: Robustness test 2.1b

	Open Source Ecosystems	Information ecosystems
	1	2
Problem dimensions		
Well-structured problem	⨂	●
High complexity	⬤	⨂
High cost context	⨂	⬤
Platform sponsor scope		
Complement decision rights	⊗	⊗
Narrow scope of activities	⊗	⬤
Consistency	0.77	0.83
Raw Coverage	0.16	0.19
Unique Coverage	0.13	0.15
Overall Solution Consistency	**0.79**	
Overall Solution Coverage	**0.31**	

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition. Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

Robustness Test 2.2a
Crossover point – 25 percent – Successful campaign funding

Table A 3: Robustness test 2.2a

	Complementary Innovation Ecosystems	Open Source Ecosystems	Information ecosystems
	1	2	3
Problem dimensions			
Well-structured problem	⨂	●	●
High complexity	●	●	⨂
High cost context	●	⨂	⬤
Platform sponsor scope			
Complement decision rights	⊗	⊗	⬤
Narrow scope of activities	⊗	⨂	●
Consistency	0.93	0.96	0.93
Raw Coverage	0.12	0.17	0.12
Unique Coverage	0.04	0.10	0.03
Overall Solution Consistency	**0.94**		
Overall Solution Coverage	**0.27**		

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition. Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

Robustness Test 2.2b
Crossover point – 25 percent – Successful ecosystem emergence

Table A 4: Robustness test 2.2b

	Solution		
	Complementary Innovation Ecosystems	Open Source Ecosystems	Information ecosystems
	1	2	3
Problem dimensions			
Well-structured problem	⨂	●	●
High complexity	●	●	⨂
High cost context	●	⨂	⬤
Platform sponsor scope			
Complement property rights	⊗	⊗	⬤
Narrow scope of activities	⊗	⨂	●
Consistency	0.88	0.83	0.84
Raw Coverage	0.15	0.19	0.13
Unique Coverage	0.04	0.10	0.04
Overall Solution Consistency		**0.82**	
Overall Solution Coverage		**0.29**	

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition. Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

APPENDIX B

PLATFORM SPONSOR SCOPE AND ECOSYSTEM STRUCTURE: A CONFIGURATIONAL APPROACH TO ECOSYSTEM HETEROGENEITY

Robustness checks

Following best practices and recent studies, we performed a number of robustness checks. Firstly, we varied the crossover point by +/- 25 percent of the original value for all causal conditions. The fsQCA configurations with the revised calibration scores are as shown in table B1, B2, B3 and B4. As expected in such analyses, changes to the crossover points have resulted in minor changes to the configurations but the interpretation of the results remains substantively unchanged. Secondly, we increased the frequency threshold for the number of cases to 2 and ran the same analyses. We found a subset of the original solutions reported under results. However, the interpretation of the results remained unchanged in this case too.

Robustness Test 3.1a
Crossover point + 25 percent – Popular Ecosystems (Incipient Stage)

Table B 1: Robustness test 3.1a

	Solution				
	Complementary Innovation Ecosystems	Open Source Ecosystems	Marketplace Ecosystems		
	1	2	3	4	5
Platform Structure					
High access control	⊗	●	⬤	⬤	●
High interface openness	⬤	⬤	⨂	⬤	⬤
Generic complementarity	⊗	⊗	⬤	⬤	●
High complement variety	●	●	⨂	⨂	●
Platform sponsor scope					
Narrow scope of activities	●	⊗	⬤	⊗	●
Complement decision rights	⊗	●	⨂	⊗	⊗
Broad scope of orchestration	⬤	⬤		⬤	⬤
Consistency	0.78	0.85	0.75	0.95	1.00
Raw Coverage	0.17	0.14	0.19	0.12	0.15
Unique Coverage	0.04	0.01	0.10	0.02	0.04
Overall Solution Consistency		**0.76**			
Overall Solution Coverage		**0.38**			

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition. Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

Robustness Test 3.1b
Crossover point + 25 percent – Popular Ecosystems (Mature Stage)

Table B 2: Robustness test 3.1b

	Solution	
	Complementary Innovation Ecosystems	Marketplace ecosystems
	1	2
Platform Structure		
High access control	●	●
High interface openness	⨂	●
Generic complementarity	⨂	●
High complement variety	⨂	
Platform sponsor scope		
Narrow scope of activities		●
Complement decision rights	●	⊗
Broad scope of orchestration	⨂	•
Consistency	0.83	0.80
Raw Coverage	0.15	0.14
Unique Coverage	0.09	0.08
Overall Solution Consistency	**0.83**	
Overall Solution Coverage	**0.23**	

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition. Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

Robustness Test 3.2a
Crossover point - 25 percent – Popular Ecosystems (Incipient Stage)

Table B 3: Robustness test 3.2a

	Solution			
	Complementary Innovation Ecosystems		Marketplace Ecosystems	
	1	2	3	4
Platform Structure				
High access control	•	⊗	●	●
High interface openness	⨂	●	⊗	
Generic complementarity	⊗	⊗	●	●
High complement variety	⨂	●		•
Platform sponsor scope				
Narrow scope of activities	⨂	•	•	•
Complement decision rights	•	⨂	⊗	⊗
Broad scope of orchestration		•	•	•
Consistency	0.98	0.94	0.89	0.92
Raw Coverage	0.18	0.10	0.25	0.23
Unique Coverage	0.12	0.05	0.05	0.06
Overall Solution Consistency	**0.92**			
Overall Solution Coverage	**0.48**			

Note: Full circles indicate the presence of a condition. Crossed-out circles indicate the absence of a condition. Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

Robustness Test 3.2b
Crossover point - 25 percent – Popular Ecosystems (Mature Stage)

Table B 4: Robustness test 3.2b

	Solution	
	Complementary Innovation Ecosystems	Marketplace ecosystems
	1	2
Platform Structure		
High access control	●	●
High interface openness	⊗	⬤
Generic complementarity	⊗	⬤
High complement variety	⨂	●
Platform sponsor scope		
Narrow scope of activities	⨂	●
Complement decision rights	●	⊗
Broad scope of orchestration	●	●
Consistency	0.87	0.85
Raw Coverage	0.14	0.15
Unique Coverage	0.09	0.10
Overall Solution Consistency		0.87
Overall Solution Coverage		0.24

Note: Full circles indicate the presence of a condition.
Crossed-out circles indicate the absence of a condition.
Large cirlces indicate core conditions and small cirlces indicate peripheral conditions.

APPENDIX C

PLATFORM ECOSYSTEM DYNAMICS AND GROWTH: ROLE OF PLATFORM SPONSOR SCOPE AND INDIRECT NETWORK EFFECTS

Table C 1: Models of Symmetric and Asymmetric Indirect Network Effects

Consumer network effect varies with number of developers	Developer network effect varies with number of consumers: Yes	Developer network effect varies with number of consumers: No
Yes	**Scenario 1** Examples: two-sided markets (e.g., credit cards, eBay, Expedia) Assumed network size dynamic: $\frac{dN^c}{dt} = \mu^c N^d - \theta^c N^c$ & $\frac{dN^d}{dt} = \mu^d N^c - \theta^d N^d$ Resulting network size: $N^c = e^{\frac{\Omega}{2}t}$ & $N^d = \frac{\left[\frac{\Omega}{2} + \theta^c\right]}{\alpha^c \mu^c} e^{\frac{\Omega}{2}t}$ with $\Omega \equiv \sqrt{[\theta^c - \theta^d]^2 + 4\mu^c\mu^d} - [\theta^c + \theta^d]$ Both N^c and N^d *increase at an increasing rate* (i.e., convex shape) over time t Required condition for a growing network size: and $\mu^c\mu^d > \theta^c\theta^d$	**Scenario 2†** Examples: innovation ecosystems (e.g., Mozilla, Linux) Assumed network size dynamic: $\frac{dN^c}{dt} = \mu^c N^d - \theta^c N^c$ & $\frac{dN^d}{dt} = \mu^d - \theta^d N^d$ Resulting network size: $N^c = \frac{\mu^c\mu^d}{\theta^c\theta^d[\theta^c - \theta^d]}\left\{\theta^c\left[1 - e^{-\theta^d t}\right] - \theta^d\left[1 - e^{-\theta^c t}\right]\right\}$ & $N^d = \frac{\mu^d}{\theta^d}\left[1 - e^{-\theta^d t}\right]$ N^c *is S-shaped increasing* (i.e., convex up to an inflexion point and then concave) over time t N^d *increases at a decreasing rate* (i.e., concave shape) over time t Required condition for an S-shaped network size: $\theta^d < \min\{\theta^c, \mu^c\}$ or $\theta^c < \theta^d < \mu^c$
No	**Scenario 3†** Examples: newspapers, advertising platforms Assumed network size dynamic: $\frac{dN^c}{dt} = \mu^c - \theta^c N^c$ & $\frac{dN^d}{dt} = \mu^d N^c - \theta^d N^d$ Resulting network size: $N^c = \frac{\mu^c}{\theta^c}\left[1 - e^{-\theta^c t}\right]$ & $N^d = \frac{\mu^c\mu^d}{\theta^c\theta^d[\theta^d - \theta^c]}\left\{\theta^d\left[1 - e^{-\theta^c t}\right] - \theta^c\left[1 - e^{-\theta^d t}\right]\right\}$ N^c *increases at a decreasing rate* (i.e., concave shape) over time t N^d *is S-shaped* increasing (i.e., convex up to an inflexion point and then concave) over time t Required condition for an S-shape network size: $\theta^c < \min\{\theta^d, \mu^d\}$ or $\theta^d < \theta^c < \mu^d$	**Scenario 4** Examples: ScholarOne, Zoom Assumed network size dynamic: $\frac{dN^c}{dt} = \mu^c - \theta^c N^c$ & $\frac{dN^d}{dt} = \mu^d - \theta^d N^d$ Resulting network size: $N^c = \frac{\mu^c}{\theta^c}\left[1 - e^{-\theta^c t}\right]$ & $N^d = \frac{\mu^d}{\theta^d}\left[1 - e^{-\theta^d t}\right]$ Both N^c and N^d *increase at a decreasing rate* (i.e., concave shape) over time t Required condition: none

† In Scenario 2, it is straightforward to verify that $\frac{dN^c}{dt} = \frac{\mu^c\mu^d}{[\theta^c - \theta^d]}\left[e^{-\theta^d t} - e^{-\theta^c t}\right]$ is positive regardless of whether $\theta^c > \theta^d$ or $\theta^c < \theta^d$ ($\frac{dN^c}{dt} = 0$ when $\theta^c = \theta^d$). Also, $\frac{d^2N^c}{dt^2} = \frac{\mu^c\mu^d}{[\theta^c - \theta^d]}\left[\theta^c e^{-\theta^c t} - \theta^d e^{-\theta^d t}\right]$ is positive if $t < \frac{\ln\theta^c - \ln\theta^d}{\theta^c - \theta^d}$ but negative if $t < \frac{\ln\theta^c - \ln\theta^d}{\theta^c - \theta^d}$ (again, regardless of whether $\theta^c > \theta^d$ or $\theta^c < \theta^d$). The shapes of the curves in Scenario 3 follow by symmetry.

Formal developments

Scenario 1: Symmetric indirect network effects

In this first scenario, the developer-side indirect network effects vary with the number of consumers, and the consumer-side indirect network effects varies with the number of developers. The network dynamics of the consumer side and the developer side are thus, respectively,

$$\frac{dN^c}{dt} = \mu^c N^d - \theta^c N^c \tag{A1}$$

$$\text{and } \frac{dN^d}{dt} = \mu^d N^c - \theta^d N^d. \tag{A2}$$

Eq. (A1) implies that

$$N^d = \frac{1}{\mu^c}\frac{dN^c}{dt} + \frac{\theta^c}{\mu^c}N^c. \tag{A3}$$

Also, if we differentiate Eq. (A1) we obtain

$$\frac{d^2N^c}{dt^2} = \mu^c \frac{dN^d}{dt} - \theta^c \frac{dN^c}{dt}. \tag{A4}$$

Now we use Eq. (A2) to replace $\frac{dN^d}{dt}$ in Eq. (A4) to obtain

$$\frac{d^2N^c}{dt^2} = \mu^c[\mu^d N^c - \theta^d N^d] - \theta^c \frac{dN^c}{dt} \tag{A5}$$

and use Eq. (A2) to replace N^d in Eq. (A5) to obtain

$$\frac{d^2N^c}{dt^2} + [\theta^c + \theta^d]\frac{dN^c}{dt} - [\mu^c\mu^d - \theta^c\theta^d]N^c = 0. \tag{A6}$$

Eq. (A6) is a homogeneous second-order linear differential equation with constant coefficients and its solutions are (see, e.g., Kreyszig 1983: 60-61) $N^c = e^{\lambda_1 t}$ and $N^c = e^{\lambda_2 t}$,

where $\lambda_1 = \frac{-[\theta^c+\theta^d]+\sqrt{[\theta^c-\theta^d]^2+4\mu^c\mu^d}}{2}$ and $\lambda_2 = \frac{-[\theta^c+\theta^d]-\sqrt{[\theta^c-\theta^d]^2+4\mu^c\mu^d}}{2}$.

Since λ_2 is negative, but we expect N^c to grow, we must focus on λ_1 and thus $N^c(t) = e^{\frac{\Omega}{2}t}$, where $\Omega \equiv \sqrt{[\theta^c - \theta^d]^2 + 4\mu^c\mu^d} - [\theta^c + \theta^d]$. However, Ω must be positive for N^c to grow with t, and thus we require $\mu^c\mu^d > \theta^c\theta^d$, which condition holds when focusing on growing platforms where network effects (i.e., μ^c and μ^d) exceed deterioration rates (i.e., θ^c and θ^d). We also note that N^c is increasing at an increasing rate (i.e., N^c is convex in t).

With $N^c = e^{\frac{\Omega}{2}t}$ and $\frac{dN^c}{dt} = \frac{\Omega}{2}e^{\frac{\Omega}{2}t}$, Eq. (A6) yields $N^d = \frac{\Omega}{2\mu^c}e^{\frac{\Omega}{2}t} + \frac{\theta^c}{\mu^c}e^{\frac{\Omega}{2}t}$ or, equivalently, $N^d = \frac{\left[\frac{\Omega}{2}+\theta^c\right]}{\mu^c}e^{\frac{\Omega}{2}t}$; note that N^d is also increasing at an increasing rate (i.e., N^d is also convex in t). To ensure that we have properly solved the system of two differential equations defined by Eq. (A4) and Eq. (A5), and avoid setting a constant that would violate satisfying these equations, we substitute $N^c = e^{\frac{\Omega}{2}t}$ in Eq.

(A5) to obtain $\frac{dN^d}{dt} + \theta^d N^d = \mu^d e^{\frac{\Omega}{2}t}$ and thus $N^d = \frac{\mu^d}{\left[\frac{\Omega}{2}+\theta^d\right]} e^{\frac{\Omega}{2}t} + Ke^{-\theta^d t}$. This suggests that K must be 0 and thus $N^d = \frac{\mu^d}{\left[\frac{\Omega}{2}+\theta^d\right]} e^{\frac{\Omega}{2}t}$.

From substituting $\Omega \equiv \sqrt{[\theta^c - \theta^d]^2 + 4\mu^c\mu^d} - [\theta^c + \theta^d]$ it is straightforward to verify that $\frac{\left[\frac{\Omega}{2}+\theta^c\right]}{\mu^c} = \frac{\mu^d}{\left[\frac{\Omega}{2}+\theta^d\right]}$ and thus indeed $N^d = \frac{\left[\frac{\Omega}{2}+\theta^c\right]}{\mu^c} e^{\frac{\Omega}{2}t} = \frac{\left[\sqrt{[\theta^c-\theta^d]^2+4\mu^c\mu^d}+[\theta^c-\theta^d]\right]}{2\mu^c} e^{\frac{t}{2}\left[\sqrt{[\theta^c-\theta^d]^2+4\mu^c\mu^d}-[\theta^c+\theta^d]\right]}$.

Thus, the total network size is

$$N^c + N^d = \left\{1 + \frac{\left[\sqrt{[\theta^c-\theta^d]^2+4\mu^c\mu^d}+[\theta^c-\theta^d]\right]}{2\mu^c}\right\} e^{\frac{t}{2}\left[\sqrt{[\theta^c-\theta^d]^2+4\mu^c\mu^d}-[\theta^c+\theta^d]\right]}, \tag{A7}$$

which increases at an increasing rate over time t, since the sum of two convex functions is also convex.[9]

Impact of platform sponsor scope on platform growth trajectory. To derive the sign of $\frac{d^2[N^c+N^d]}{d\delta dt}$, we first observe that with $\frac{dN^c}{dt} = \frac{\Omega}{2} e^{\frac{\Omega}{2}t}$ and

$$\frac{d\Omega}{d\delta} = \frac{d\Omega}{d\mu^c}\frac{d\mu^c}{d\delta} + \frac{d\Omega}{d\mu^d}\frac{d\mu^d}{d\delta} = \frac{2\mu^c\mu^d}{\sqrt{[\theta^c-\theta^d]^2+4\mu^c\mu^d}} \ln\frac{b^c b^d}{B^c B^d}, \tag{A8}$$

we obtain $\frac{d^2N^c}{d\delta dt} = \frac{e^{\frac{\Omega}{2}t}}{2}\left[1 + \frac{\Omega^2}{2}\right]\left\{\frac{2\mu^c\mu^c}{\sqrt{[\theta^c-\theta^d]^2+4\mu^c\mu^d}} \ln\frac{b^c b^d}{B^c B^d}\right\}$. Hence, $\frac{d^2N^c}{d\delta dt} > 0$ if and only if $\frac{d\Omega}{d\delta} > 0$ or, from Eq. (A8), $b^c b^d > B^c B^d$.

Similarly, since $\frac{dN^d}{dt} = \frac{\Omega[\Omega+2\theta^c]}{4\mu^c} e^{\frac{\Omega}{2}t}$, we derive that $\frac{d^2N^d}{d\delta dt} = \frac{e^{\frac{\Omega}{2}t}}{4}\left\{\frac{2[\Omega+\theta^c]}{\mu^c}\frac{d\Omega}{d\delta} + \frac{\Omega[\Omega+2\theta^c]}{\mu^c}\left[\frac{t}{2}\frac{d\Omega}{d\delta} - \frac{1}{\mu^c}\frac{d\mu^c}{d\delta}\right]\right\}$ and note that $\frac{t}{2}\frac{d\Omega}{d\delta} - \frac{1}{\mu^c}\frac{d\mu^c}{d\delta} > 0$ if and only if $\left\{\frac{\mu^c\mu^d}{\sqrt{[\theta^c-\theta^d]^2+4\mu^c\mu^d}} \ln\frac{b^c b^d}{B^c B^d}\right\} t > \ln\frac{b^c}{B^c}$.

Consequently, if $b^c b^d > B^c B^d$ (and thus $\ln\frac{b^c b^d}{B^c B^d} > 0$), which also leads to $\frac{d\Omega}{d\delta} > 0$, then we require that $t > T_{sc1} \equiv \left[\frac{\sqrt{[\theta^c-\theta^d]^2+4\mu^c\mu^d}}{\mu^c\mu^c}\right]\frac{\ln\frac{b^c}{B^c}}{\ln\frac{b^c b^d}{B^c B^d}}$ to obtain $\frac{t}{2}\frac{d\Omega}{d\delta} - \frac{1}{\mu^c}\frac{d\mu^c}{d\delta} > 0$. It follows that a sufficient condition for $\frac{d^2N^d}{d\delta dt} > 0$ is $b^c b^d > B^c B^d$ and $t > T_{sc1}$. We note that if $b^c < B^c$, then $\frac{d\mu^c}{d\delta} < 0$ and $T_{sc1} < 0$ and thus

[9] Although in this scenario the total network size at $t = 0$ is not zero, it is without loss of generality because we can rescale the corresponding curves so as to make both $N^c(0) = 0$ and $N^d(0) = 0$.

$\frac{d^2N^d}{d\delta dt} > 0$ for all $t \geq 0$ when $b^c < B^c$ and $b^c b^d > B^c B^d$. However, if $b^c b^d < B^c B^d$ (and thus $\ln \frac{b^c b^d}{B^c B^d} < 0$), which also leads to $\frac{d\Omega}{d\delta} < 0$, then we require that $t > T_{sc1} \equiv \left[\frac{\sqrt{\left[\theta^c - \theta^d\right]^2 + 4\mu^c\mu^d}}{\mu^c\mu^c}\right] \frac{\ln\frac{b^c}{B^c}}{\left[-\ln\frac{B^c B^d}{b^c b^d}\right]}$ to obtain $\frac{t}{2}\frac{d\Omega}{d\delta} - \frac{1}{\mu^c}\frac{d\mu^c}{d\delta} < 0$. It follows that a sufficient condition for $\frac{d^2N^d}{d\delta dt} < 0$ is $b^c b^d < B^c B^d$ and $t > T_{sc1}$. We note that if $b^c > B^c$, then $\frac{d\mu^c}{d\delta} > 0$ and $T_{sc1} < 0$ and thus $\frac{d^2N^d}{d\delta dt} < 0$ for all $t \geq 0$ when $b^c > B^c$ and $b^c b^d < B^c B^d$.

In other words, $\frac{d^2[N^c+N^d]}{d\delta dt} > 0$ for all $t \geq 0$ when $b^c < B^c$ and $b^c b^d > B^c B^d$, but there exists a threshold T_{sc1} after which $\frac{d^2[N^c+N^d]}{d\delta dt}$ is guaranteed to be positive when $b^c > B^c$ and $b^c b^d > B^c B^d$; these are sufficient conditions, but not necessary conditions, for both $\frac{d^2N^d}{d\delta dt} > 0$ and $\frac{d^2[N^c+N^d]}{d\delta dt} > 0$. A stricter condition is that there exists a threshold T_{sc1} after which $\frac{d^2[N^c+N^d]}{d\delta dt}$ is guaranteed to be positive when $b^c > B^c$ and $b^d > B^d$. Moreover, $\frac{d^2[N^c+N^d]}{d\delta dt} < 0$ for all $t \geq 0$ when $b^c > B^c$ and $b^c b^d < B^c B^d$, but there exists a threshold T_{sc1} after which $\frac{d^2[N^c+N^d]}{d\delta dt}$ is guaranteed to be negative when $b^c < B^c$ and $b^c b^d < B^c B^d$; these again are sufficient conditions, but not necessary conditions, for both $\frac{d^2N^d}{d\delta dt} < 0$ and $\frac{d^2[N^c+N^d]}{d\delta dt} < 0$. A stricter condition here too is that $\frac{d^2[N^c+N^d]}{d\delta dt}$ is guaranteed to be negative beyond T_{sc1} when $b^c < B^c$ and $b^d < B^d$.

By symmetry, the above formal development for Scenario 1 also yields another solution to the system of two differential equations represented by Eq. (A1) and Eq. (A2): $N^c = \frac{\left[\frac{\Omega}{2} + \theta^d\right]}{\alpha^d \mu^d} e^{\frac{\Omega}{2}t}$ and $N^d = e^{\frac{\Omega}{2}t}$. The only change to the above conditions is to replace comparing b^c to B^c by comparing b^d to B^d. In other words, we can also conclude that $\frac{d^2[N^c+N^d]}{d\delta dt} > 0$ for all $t \geq 0$ when $b^d < B^d$ and $b^c b^d > B^c B^d$, but there exists a threshold T'_{Sc1} after which $\frac{d^2[N^c+N^d]}{d\delta dt}$ is guaranteed to be positive when $b^d > B^d$ and $b^c b^d > B^c B^d$. A stricter condition is that there exists a threshold T'_{Sc1} after which $\frac{d^2[N^c+N^d]}{d\delta dt}$ is guaranteed to be positive when $b^d > B^d$ and $b^c > B^c$. And, $\frac{d^2[N^c+N^d]}{d\delta dt} < 0$ for all $t \geq 0$ when $b^d > B^d$ and $b^c b^d < B^c B^d$, but there exists a threshold T'_{Sc1} after which $\frac{d^2[N^c+N^d]}{d\delta dt}$ is guaranteed to be negative when $b^d < B^d$

and $b^c b^d < B^c B^d$. A stricter condition here too is that $\frac{d^2[N^c+N^d]}{d\delta dt}$ is guaranteed to be negative beyond T'_{Sc1} when $b^d < B^d$ and $b^c < B^c$.

Scenario 2: Asymmetric indirect network effects with consumer side externalities

We now assume that the consumer-side indirect network effects vary with the number of developers, but the developer-side indirect network effects remain unaffected by the number of consumers. The network dynamics from the consumer side and the developer side are thus, respectively, $\frac{dN^c}{dt} = \mu^c N^d - \theta^c N^c$ and $\frac{dN^d}{dt} = \mu^d - \theta^d N^d$. This is a first-order linear differential equation that can be readily solved (see, e.g., Spiegel, 1974).[10] Since at $t = 0$ the consumer side has not yet built up, we expect $N^d(0) = 0$, and we again obtain $N^d = \frac{\mu^d}{\theta^d}\left[1 - e^{-\theta^d t}\right]$. Substituting for N^d, the network dynamic from the consumer side becomes $\frac{dN^c}{dt} + \theta^c N^c = \frac{\mu^c \mu^d}{\theta^d}\left[1 - e^{-\theta^d t}\right]$. Solving this first-order linear differential equation yields $N^c = \frac{\mu^c \mu^d}{\theta^d}\left[\frac{1}{\theta^c} - \frac{e^{-\theta^d t}}{[\theta^c - \theta^d]}\right] + Ke^{-\theta^c t}$. With $N^c(0) = 0$, $K = \frac{\mu^c \mu^d}{\theta^c[\theta^c - \theta^d]}$ and thus $N^c = \frac{\mu^c \mu^d}{\theta^d \theta^c [\theta^c - \theta^d]}\left\{\theta^c\left[1 - e^{-\theta^d t}\right] - \theta^d\left[1 - e^{-\theta^c t}\right]\right\}$. Consequently, the total network size is

$$N^c + N^d = \frac{\mu^c \mu^d}{\theta^d \theta^c [\theta^c - \theta^d]}\left\{\theta^c\left[1 - e^{-\theta^d t}\right] - \theta^d\left[1 - e^{-\theta^c t}\right]\right\} + \frac{\mu^d}{\theta^d}\left[1 - e^{-\theta^d t}\right]. \quad \text{(A9)}$$

Since $\frac{d[N^c+N^d]}{dt} = \mu^d\left\{\frac{\mu^c}{[\theta^c - \theta^d]}\left[e^{-\theta^d t} - e^{-\theta^c t}\right] + e^{-\theta^d t}\right\}$, it therefore follows that $\frac{d^2[N^c+N^d]}{dt^2} = \mu^d\left\{\frac{\mu^c}{[\theta^c - \theta^d]}\left[\theta^c e^{-\theta^c t} - \theta^d e^{-\theta^d t}\right] - \theta^d e^{-\theta^d t}\right\}$. We observe that regardless of whether $\theta^c > \theta^d$ or $\theta^c < \theta^d$, $\frac{d^2[N^c+N^d]}{dt^2} < 0$ if $t > T_{Sc2} \equiv \frac{1}{[\theta^c - \theta^d]}\ln\left[\frac{\mu^c \theta^c}{\theta^d[\mu^c + \theta^c - \theta^d]}\right]$ and $\frac{d^2[N^c+N^d]}{dt^2} > 0$ if $t < T_{Sc2}$. In other words, $N^c + N^d$ increases at an increasing rate over time but only before a certain time threshold T_{Sc2} (i.e., $N^c + N^d$ is a convex function of t for $t < T_{Sc2}$). After that threshold, $N^c + N^d$ increases at a decreasing rate (i.e., $N^c + N^d$ is a concave function of t for $t > T_{Sc2}$). We also note that T_{Sc2} is nonnegative as long as $\theta^d < \min\{\theta^c, \mu^c\}$ or $\theta^c < \theta^d < \mu^c$.

Impact of platform sponsor scope on platform growth trajectory. We observe that $\frac{d^2[N^c+N^d]}{d\delta dt} = \frac{\mu^c \mu^d\left[e^{-\theta^d t} - e^{-\theta^c t}\right]}{[\theta^c - \theta^d]}\ln\left(\frac{b^c b^d}{B^c B^d}\right) + \mu^d e^{-\theta^d t}\ln\left(\frac{b^d}{B^d}\right)$, which is positive when $b^d > B^d$ and $b^c b^d > B^c B^d$, but negative when $b^d < B^d$ and $b^c b^d < B^c B^d$. As in Scenario 1, we adopt a stricter version of

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[10] We use the mathematical fact that $\frac{dy}{dx} + P(x)y = Q(x)$ has the solution $y = \frac{1}{e^{\int P(x)dx}}\left\{\int Q(x)e^{\int P(x)dx}dx + K\right\}$. We also note that $\int xe^{ax}dx = \frac{e^{ax}}{a^2}[ax - 1]$.

these conditions such that $\frac{d^2[N^c+N^d]}{d\delta dt} > 0$ when $b^d > B^d$ and $b^c > B^c$, but $\frac{d^2[N^c+N^d]}{d\delta dt} < 0$ when $b^d < B^d$ and $b^c < B^c$.

Scenario 3: Asymmetric indirect network effects with developer side externalities

As opposed to Scenario 2, we now assume that the developer-side indirect network effects vary with the number of consumers, but the consumer-side indirect network effects are unaffected by the number of developers. The network dynamics from the consumer side and the developer side are thus, respectively, $\frac{dN^c}{dt} = \mu^c - \theta^c N^c$ and $\frac{dN^d}{dt} = \mu^d N^c - \theta^d N^d$. We proceed exactly as we did for Scenario 2 to derive the total network size, which is (by symmetry)

$$N^c + N^d = \frac{\mu^c}{\theta^c}\left[1 - e^{-\theta^c t}\right] + \frac{\mu^c \mu^d}{\theta^d \theta^c [\theta^d - \theta^c]}\left\{\theta^d\left[1 - e^{-\theta^c t}\right] - \theta^c\left[1 - e^{-\theta^d t}\right]\right\}. \quad \text{(A10)}$$

Since $\frac{d[N^c+N^d]}{dt} = \mu^c\left\{\frac{\mu^d}{[\theta^d-\theta^c]}\left[e^{-\theta^c t} - e^{-\theta^d t}\right] + e^{-\theta^c t}\right\}$, it therefore follows that $\frac{d^2[N^c+N^d]}{dt^2} = \mu^c\left\{\frac{\mu^d}{[\theta^d-\theta^c]}\left[\theta^d e^{-\theta^d t} - \theta^c e^{-\theta^c t}\right] - \theta^c e^{-\theta^c t}\right\}$. We observe again that regardless of whether $\theta^c > \theta^d$ or $\theta^c < \theta^d$, $\frac{d^2[N^c+N^d]}{dt^2} < 0$ if $t > T_{Sc3} \equiv \frac{1}{[\theta^d-\theta^c]}\ln\left[\frac{\mu^d\theta^d}{\theta^c[\mu^d+\theta^d-\theta^c]}\right]$ and $\frac{d^2[N^c+N^d]}{dt^2} > 0$ if $t < T_{Sc3}$. In this scenario, T_{Sc3} is nonnegative as long as $\theta^c < \min\{\theta^d, \mu^d\}$ or $\theta^d < \theta^c < \mu^d$.

Impact of platform sponsor scope on platform growth trajectory. We observe that $\frac{d^2[N^c+N^d]}{d\delta dt} = \frac{\mu^c\mu^d\left[e^{-\theta^c t} - e^{-\theta^d t}\right]}{[\theta^d-\theta^c]}\ln\left(\frac{b^c b^d}{B^c B^d}\right) + \mu^c e^{-\theta^c t}\ln\left(\frac{b^c}{B^c}\right)$, which is positive when $b^c > B^c$ and $b^c b^d > B^c B^d$, but negative when $b^c < B^c$ and $b^c b^d < B^c B^d$. Similar to Scenario 2, we adopt a stricter version of these conditions such that $\frac{d^2[N^c+N^d]}{d\delta dt} > 0$ when $b^c > B^c$ and $b^d > B^d$, but $\frac{d^2[N^c+N^d]}{d\delta dt} < 0$ when $b^c < B^c$ and $b^d < B^d$.

Scenario 4: Absence of indirect network effects

Since we assume that the consumer network effect is unaffected by the number of developers, the network dynamics from the consumer side is $\frac{dN^c}{dt} = \mu^c - \theta^c N^c$. This is a first-order linear differential equation that can be readily solved to yield $N^c = \frac{\mu^c}{\theta^c} + Ke^{-\theta^c t}$ (see, e.g., Spiegel, 1974).[11] Since at $t = 0$ the consumer side has not yet built up, we expect $N^c(0) = 0$.

[11] We again use the mathematical fact that $\frac{dy}{dx} + P(x)y = Q(x)$ has the solution $y = \frac{1}{e^{\int P(x)dx}}\left\{\int Q(x)e^{\int P(x)dx}dx + K\right\}$, and note that $\int xe^{ax}dx = \frac{e^{ax}}{a^2}[ax - 1]$.

It therefore follows that $K = \frac{-\mu^c}{\theta^c}$ and $N^c = \frac{\mu^c}{\theta^c}\left[1 - e^{-\theta^c t}\right]$. Similarly, since in this scenario the developer network effect is unaffected by the number of consumers, the network dynamics from the developer side is $\frac{dN^d}{dt} = \mu^d - \theta^d N^d$. Considering that at $t = 0$ the developer side has not yet built up and thus $N^d(0) = 0$, by symmetry we obtain $N^d = \frac{\mu^d}{\theta^d}\left[1 - e^{-\theta^d t}\right]$. Consequently, the total network size (as a function of time t) is

$$N^c + N^d = \frac{\mu^c}{\theta^c}\left[1 - e^{-\theta^c t}\right] + \frac{\mu^d}{\theta^d}\left[1 - e^{-\theta^d t}\right]. \tag{A11}$$

With $\frac{d[N^c+N^d]}{dt} = \mu^c e^{-\theta^c t} + \mu^d e^{-\theta^d t}$, which is positive, and $\frac{d^2[N^c+N^d]}{dt^2} = -\mu^c\theta^c e^{-\theta^c t} - \mu^d\theta^d e^{-\theta^d t}$, which is negative, it follows that $N^c + N^d$ increases at a decreasing rate over time (i.e., a concave function of t).

Impact of platform sponsor scope on platform growth trajectory. If we recall that $\mu^c = \left\{\omega^c B^c \left[\frac{b^c}{B^c}\right]^\delta\right\}$ and $\mu^d = \left\{\omega^d B^d \left[\frac{b^d}{B^d}\right]^\delta\right\}$, we observe that $\frac{d^2[N^c+N^d]}{d\delta dt} = e^{-\theta^c t}\left\{\omega^c B^c \left[\frac{b^c}{B^c}\right]^\delta \ln\left[\frac{b^c}{B^c}\right]\right\} + e^{-\theta^d t}\left\{\omega^d B^d \left[\frac{b^d}{B^d}\right]^\delta \ln\left[\frac{b^d}{B^d}\right]\right\}$, which is positive when $b^c > B^c$ and $b^d > B^d$, but negative when $b^c < B^c$ and $b^d < B^d$.