

Investigating B2B Innovation Platforms from a Complexity Perspective: A Simulation-based Approach

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Marius Schmid

from
Germany

Approved on the application of

Prof. Dr. Robert Winter

and

Prof. Dr. Kazem Haki

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List of Abbreviations

ABM	Agent-based Modeling
B2B	Business-to-Business
B2C	Business-to-Consumer
BTP	Business Technology Platform
CAS	Complex Adaptive System
DSR	Design Science Research
ECIS	European Conference on Information Systems
e.g.	exempli gratia, for example
ERP	Enterprise Resource Planning
et al.	et alii, and others
i.e.	id est, in other words
ICIS	International Conference on Information Systems
IP	Intellectual Property
IS	Information Systems
ISV	Independent Software Developer
MISQ	MIS Quarterly
MPI	Multi-partner Innovation
RQ	Research Question

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Abstract

B2B innovation platforms serve as increasingly popular venues for value creation of firms. Such innovation platforms facilitate the generation of innovation between multiple partners in the form of multi-partner innovation (MPI). MPI is generally a complex process that poses several challenges. Through their offered leverages, B2B innovation platforms are assumed to tame these complexity challenges and foster MPI outcomes. Thus, B2B innovation platforms create a novel and promising organizing logic in the context of MPI. The circumstances under which B2B platform leverages tame complexity challenges posed by MPI processes in business ecosystems have not been investigated, however. Thus, this dissertation aims to examine the roles of B2B platform leverages in taming complexity challenges and to specify whether and how platforms truly are a promising organizing logic.

To this end, complexity science is applied as a theoretical foundation to understand how complexity emerges and why it causes challenges in business ecosystems. Subsequently, agent-based modeling is employed as a research method to account for the interrelations of the central constructs, model the resulting complexity, and conduct simulation experiments to derive new theoretical insights. The developed simulation model and the interpretation of its results is iteratively refined over the dissertation's constituent papers.

The resulting contributions constitute an extendible agent-based model of a B2B innovation platform within a complex business ecosystem as well as several theoretical insights. For research, the derived findings indicate that the ecosystem-level complexity of a business ecosystem represents a major contingency for B2B platform leverages' ability to tame complexity challenges. MPI complexity triggers distinct regions of complexity in the business ecosystem, and B2B platform leverages are found to only tame complexity challenges in the region of emergent complexity. For practitioners, the results imply that B2B innovation platforms are not uniformly disruptive to all industry contexts. The ecosystem-level complexity in a given business ecosystem should be accounted for, as it may determine when investing into a B2B innovation platform and adopting a platform organizing logic is particularly promising.

Keywords: B2B innovation platform, Complexity, Agent-based modeling, Simulation, Multi-partner innovation (MPI), Business ecosystem, Platform leverages

Kurzfassung

B2B-Innovationsplattformen erfreuen sich zunehmender Beliebtheit in der Wertschöpfung von Unternehmen. Solche Innovationsplattformen erleichtern das Innovieren zwischen mehreren Partnern, die sogenannte Multipartner-Innovation (MPI). MPI ist ein komplexer Prozess mit verschiedenen Herausforderungen. B2B-Innovationsplattformen versprechen diese komplexitätsbedingten Herausforderungen durch ihre Hebelwirkungen zu adressieren und MPI-Ergebnisse zu fördern. Daher gelten B2B-Innovationsplattformen als vielversprechende Organisationslogik im MPI-Kontext. Die genaueren Umstände, unter denen B2B-Plattformhebel die Komplexitätsherausforderungen von MPI-Prozessen in Business-Ökosystemen bewältigen, sind jedoch noch nicht definiert. Ziel dieser Dissertation ist es daher, die Rolle von B2B-Plattformhebeln bei der Bewältigung von Komplexitätsherausforderungen zu untersuchen und zu erklären, ob und wie Plattformen tatsächlich eine vielversprechende Organisationslogik darstellen.

Die Komplexitätswissenschaft dient dabei als theoretische Grundlage um aufzuzeigen, wie Komplexität entsteht und zu Herausforderungen in Business-Ökosystemen führt. Anschließend wird die agentenbasierte Modellierung als Forschungsmethode eingesetzt, um die zentralen Wechselbeziehungen und die resultierende Komplexität zu modellieren, Simulationsexperimente durchzuführen, und neue theoretische Erkenntnisse zu gewinnen. Das entwickelte Simulationsmodell und die abgeleiteten Erkenntnisse werden in den einzelnen Beiträgen der Dissertation iterativ verfeinert.

Das Ergebnis ist ein erweiterbares agentenbasiertes Modell einer B2B-Innovationsplattform in einem komplexen Business-Ökosystem sowie eine Reihe theoretischer Erkenntnisse. Aus Forschungssicht wird gezeigt, dass die Komplexität eines Business-Ökosystems die Fähigkeit von B2B-Plattformhebeln, Komplexitätsherausforderungen zu bewältigen, massgeblich beeinflusst. MPI-Komplexität erzeugt verschiedene Komplexitätsregionen im Business-Ökosystem. B2B-Plattformhebel können die Komplexitätsprobleme nur in der Region der emergenten Komplexität bewältigen. Für Praktiker impliziert dies, dass B2B-Innovationsplattformen nicht in allen Branchen gleichermaßen disruptiv sind. Die Komplexität auf Ökosystemebene sollte demnach bei der Frage berücksichtigt werden, ob eine Plattformorganisationslogik tatsächlich sinnvoll ist.

Stichworte: B2B-Innovationsplattform, Komplexität, Agentenbasierte Modellierung, Simulation, Multipartner-Innovation (MPI), Business-Ökosystem, Plattformhebelwirkungen

Part A – Synopsis

1 Introduction

Firms may opt to create value in different ways, be it within the boundaries of an individual firm or supply chain, or within a larger business ecosystem of upstream and downstream firms, for example (Baldwin, 2008; Ganco et al., 2020). In recent times, *digital platform ecosystems* have become an increasingly popular and successful venue to create value, giving rise to terms like *platform economy* or *platform revolution* (Kenney & Zysman, 2016; Parker et al., 2016). Platform ecosystems are considered as hybrid structures, characterized by a large collection of relationships that lie in between organizations and markets (Kretschmer et al., 2022). Thus, they combine elements and advantages of a centralized orchestration, as well as the generative capacity of the surrounding ecosystem (Tilson et al., 2010; Wareham et al., 2014).

Due to the eminent success of platform ecosystems, traditional firms increasingly face the decision of whether or not to adopt this organizing logic and convert their existing businesses to platform ecosystems (Constantinides et al., 2018; Hein et al., 2020; Sandberg et al., 2020; Sebastian et al., 2017). A prominent example of this is SAP, which has been operating a platform ecosystem since the launch of its cloud platform project in 2012 (Ceccagnoli et al., 2012; Schrieck et al., 2021). As a platform owner, SAP orchestrates a network of complementary partners that integrate resources and functionalities on its platform to co-create value in the form of innovation (Ceccagnoli et al., 2012; Schrieck et al., 2021; Wareham et al., 2014).

Interestingly, extant research on digital platforms and platform ecosystems has largely focused on consumer-oriented (i.e., B2C) and platform-native cases (Rietveld & Schilling, 2021). Examples like SAP, where a platform is established to enable innovation in the B2B context, are comparably less prominent in platform literature (Rietveld & Schilling, 2021). Such *innovation platforms* create value by facilitating the generation of innovation between multiple partners (Cusumano et al., 2019; Gawer, 2020), i.e., multi-partner innovation (MPI) (Davis, 2016; Furr et al., 2016). Thus, we refer to them as *B2B innovation platforms*.

Due to underlying transaction-related and production-related challenges, the process of MPI is inherently complex (Jarvenpaa & Majchrzak, 2016; Krishnan et al., 2006; Madhok & Tallman, 1998; Wolter & Veloso, 2008). B2B innovation platforms are

assumed to be an attractive organizing logic for value creation with multiple partners (Kretschmer et al., 2022; Wareham et al., 2014), as they promise to address the complexity challenges of MPI through their offered platform leverages (Thomas et al., 2014). Thus far, however, it has not been theorized *whether* and *how* they are successful in doing so. Delineating the circumstances under which B2B innovation platforms successfully account for the inherent complexity of MPI and tame the related challenges may help to explain when adopting a platform organizing logic through a B2B innovation platform is particularly promising. This would aid practitioners on the one hand, but also address the explicit need for theory on the potentially disruptive nature of digital platforms (de Reuver et al., 2018), particularly in the B2B context (Shree et al., 2021).

To summarize, there are several reasons, within the broader context of digital platforms and platform ecosystems, why B2B innovation platforms are an interesting phenomenon for research: For one, they are becoming increasingly relevant, as a growing number of incumbents are confronted with the consideration of adopting a platform logic. For another, the majority of existing platform literature and empirical research has focused on different cases, i.e., consumer-oriented platforms. Lastly, B2B innovation platforms generally form a promising organizing logic to address the complexity challenges of MPI in the B2B context, but a more nuanced understanding is required.

In response, this dissertation aims to establish under which circumstances B2B innovation platforms are able to successfully tame the complexity challenges of MPI. To this end, complexity science (e.g., Anderson, 1999; Cilliers, 1998; Holland, 1995; Tanriverdi & Du, 2020) is employed as a theoretical foundation to explain how and why complexity challenges emerge in such settings. Subsequently, the constituent research papers leverage simulation and agent-based modeling (ABM) as a research method to model, how complexity challenges emerge and unfold, and flexibly experiment with B2B innovation platforms' ability to tame these complexity challenges. The derived theoretical insights from simulation experiments also yield implications for practitioners who consider adopting a platform organizing logic by establishing a B2B innovation platform. In the following, the problem statement as well as the resulting research objective and research approach are explained in more detail.

1.1 Problem statement

Within business ecosystems, firms typically create value in the form of innovation to meet customers' demands (Ahuja et al., 2008; Ganco et al., 2020). While firms may

innovate within their own boundaries, meeting the demands of customers may also require engaging with other firms and integrating each other's resources to generate the respective innovation (Baldwin, 2008; Ganco et al., 2020; Ozcan & Eisenhardt, 2009; Uzzi, 1997). When multiple firms collaborate and jointly innovate, they engage in the process of MPI (Davis, 2016; Furr et al., 2016). Expanding beyond the boundaries of the firm and engaging in MPI brings additional complexity, and with it, several associated challenges.

Partnering firms must establish trust in each other, decide how much of their intellectual property (IP) to reveal and share, and potentially resolve disputes or conflicts that may arise as part of the collaboration, for example (Jarvenpaa & Majchrzak, 2016; Krishnan et al., 2006; Madhok & Tallman, 1998). Similarly, partnering firms must be able to integrate each other's resources in the process of developing innovations, which presupposes a compatibility and interoperability of the respective resources (Wolter & Veloso, 2008). Thus, the process of MPI inevitably creates numerous transaction-related and production-related challenges for the respective partners.

Complexity dynamics in the surrounding business ecosystem are also triggered when an increasing number of partners collaborate to generate innovation. More linkages, or interconnections, amongst partners yield more mutual dependencies, creating a system that is more complex as a whole (Benbya et al., 2020; Nan & Tanriverdi, 2017). The increased business ecosystem-level complexity makes it difficult to predict the outcomes of MPI (Anderson, 1999; Cilliers, 1998; Holland, 1995; Tanriverdi & Du, 2020), and raises associated costs (Wolter & Veloso, 2008). In summary, from a complexity perspective, the MPI process posits various challenges for the innovating partners.

B2B innovation platforms like SAP's cloud platform promise to address these challenges and facilitate the generation of innovation by multiple collaborating firms (Ceccagnoli et al., 2012; Schrieck et al., 2021). They offer specific mechanisms in this regard. Examples discussed in platform literature include recommender systems, review systems, and certification programs to facilitate search matching and establish trust amongst partners, and between partners and customers (e.g., Huang et al., 2018; Malgonde et al., 2020; Rietveld et al., 2019). These kinds of mechanisms address transaction-related challenges of MPI. Other platform mechanisms include the standardization of a platform's core and interfaces, or the provision of modularized resources to foster the development of innovations by collaborating partners (Ceccagnoli et al., 2012; Tiwana, 2015b). These kinds of mechanisms, in turn, address the production-related challenges of MPI. Strategy literature synthesizes these fragmented mechanisms into the

transaction leverage and production leverage that a platform organizing logic offers (Thomas et al., 2014).

Ultimately, for the B2B innovation platform to function properly, the offered platform leverages must attract a critical mass of complementary partners to innovate and transact on the given platform (e.g., Gawer & Cusumano, 2008; Rochet & Tirole, 2003). In turn, the aim of these potential platform partners is value creation to meet their customers' requirements, and value appropriation to gain profit from their developed innovation (Ahuja et al., 2008; Jacobides et al., 2006). Thus, B2B platform leverages must aid partners in taming the complexity challenges of MPI, by enabling them to generate innovations that meet customers' needs profitably (Ceccagnoli et al., 2012; Schrieck et al., 2021).

From an academic view, however, current research has not theorized under which circumstances B2B platform leverages are successful in doing so. From a practitioner view, it is similarly unclear when to opt for a platform organizing logic and establish a B2B innovation platform (de Reuver et al., 2018; Hein et al., 2020; Kretschmer et al., 2022). Considering the surrounding business ecosystem within which B2B innovation platforms are situated, and adopting a complexity perspective to understand whether and how B2B platform leverages are able to tame the complexity challenges of MPI, may help to address the academic research gap as well as provide practical implications.

1.2 Research objective

Based on the presented problem statement, the aim of this dissertation is to contribute to a better understanding of B2B platform leverages' ability to tame the complexity challenges of MPI.

To achieve this overarching objective, it must first be understood how the complexity of MPI unfolds in business ecosystems, within which B2B innovation platforms are situated. Recent literature on digital platforms explicitly calls for conducting computational modeling of platforms and their surrounding ecosystems to explore rules and outcomes of the ecosystem (de Reuver et al., 2018). Thus, the following research question is raised:

RQ1: *How can the complexity of multi-partner innovation (MPI) and B2B platform leverages be modeled for business ecosystems?*

Addressing RQ1 requires deriving a conceptual model of the constituent components and their interrelations, before translating it into a computational environment that enables simulation (Davis et al., 2007). Once the complexity of MPI and B2B platform leverages is modeled, the behavior and outcomes of the system can be investigated in more detail. Fundamentally, the described challenges associated with MPI (production-related and transaction-related challenges) may differ for any given MPI. In other words, some MPI processes may be more complex than others. In turn, B2B platform leverages' ability to tame complexity challenges of MPI may depend on the level of complexity of the given MPI. Therefore, in light of the overall research objective, the following research question is raised:

RQ2: *Under which circumstances do B2B platform leverages help to tame the complexity challenges of multi-partner innovation (MPI)?*

To answer RQ2, the developed computational model is adapted over time and leveraged for investigation. In effect, RQ1 thereby provides the basis for answering RQ2.

In summary, the aim of this dissertation is to make contributions to theory on B2B innovation platforms in subsequent steps. First, the complexity of MPI that posits challenges that B2B platform leverages promise to address is modeled in a simulation environment. This provides a basis for flexibly investigating in how far the B2B organizing logic may account for the complexity of MPI, and how B2B platform leverages may tame challenges of MPI under different circumstances. This research process will manifest, in differing outcomes, which show the performance of the B2B platform organizing logic given the B2B platform leverages at different levels of complexity. Together, this shall lead to a more nuanced understanding of B2B platform leverages' general ability to tame the complexity challenges of MPI. Ultimately, the derived theoretical insights should also yield implications for practitioners, by providing a more precise understanding of the contexts in which investing into a B2B innovation platform is particularly promising.

1.3 Research approach

The first step in achieving the objective of this dissertation is to model the complexity of MPI and B2B platform leverages. Complexity science informs on *how* complexity emerges in a given system, and why it poses challenges (e.g., Anderson, 1999; Benbya et al., 2020; Cilliers, 1998; Holland, 1995; Tanriverdi & Du, 2020). Thus, it is leveraged

as a theoretical foundation to provide the basis for addressing RQ1. Fundamentally, complexity science argues that local-level interactions amongst the constituent components of a system yield ecosystem-level complexity that posits different challenges (e.g., Anderson, 1999; Benbya et al., 2020; Cilliers, 1998; Tanriverdi & Du, 2020) (see Section 2.1 for a more detailed account). Therefore, a method is required that can capture how local-level behavior impacts system-level outcomes and produces ecosystem-level complexity.

Simulation in general, and ABM in particular, is a suitable approach to model local behavior and observe system-level outcomes of complex phenomena (Beese et al., 2019; Haki et al., 2020; Nan & Tanriverdi, 2017). More specifically, ABM models how individual actors (i.e., agents) interact amongst each other and with their surrounding environment, depending on defined behavioral rules. Thereby, ABM enables capturing the system-level structures that emerge from local interactions (Amaral & Uzzi, 2007; Nan, 2011). This facilitates predictive “what-if” analyses regarding system-level outcomes to derive implications for theoretical propositions that may be infeasible to obtain with empirical or literature-based approaches (Haki et al., 2020; Nan & Tanriverdi, 2017). ABM thus enables a flexible investigation of system behavior and outcomes under different conditions.

Following common approaches to ABM development (Haki et al., 2020; Nan, 2011), the operational modeling step requires capturing agents, interactions among agents, and the surrounding environment in which interactions occur. Thus, to model the complexity of MPI and B2B platform leverages in business ecosystems, the integral agents have to be defined as well as their interactions and the surrounding environment. Across the constituent papers of this dissertation, the modeling of these three aspects evolved iteratively. This process builds on the theoretical insights on B2B platform leverages and MPI complexity, and was guided by existing ABM studies in the context of platforms (e.g., Brunswicker et al., 2019; Malgonde et al., 2020) and beyond (e.g., Haki et al., 2020; Nan & Tanriverdi, 2017).

The developed ABM, in turn, provides the basis for flexibly experimenting with different circumstances and conditions to derive new theoretical insights on the performance of B2B innovation platforms, the role of B2B platform leverages within this organizing logic and their ability to tame MPI complexity challenges. Thus, the dissertation is structured into two modules, as depicted in Figure 1. A more detailed account of how the

dissertation's constituent components complement and build on each other is provided in Section 4.

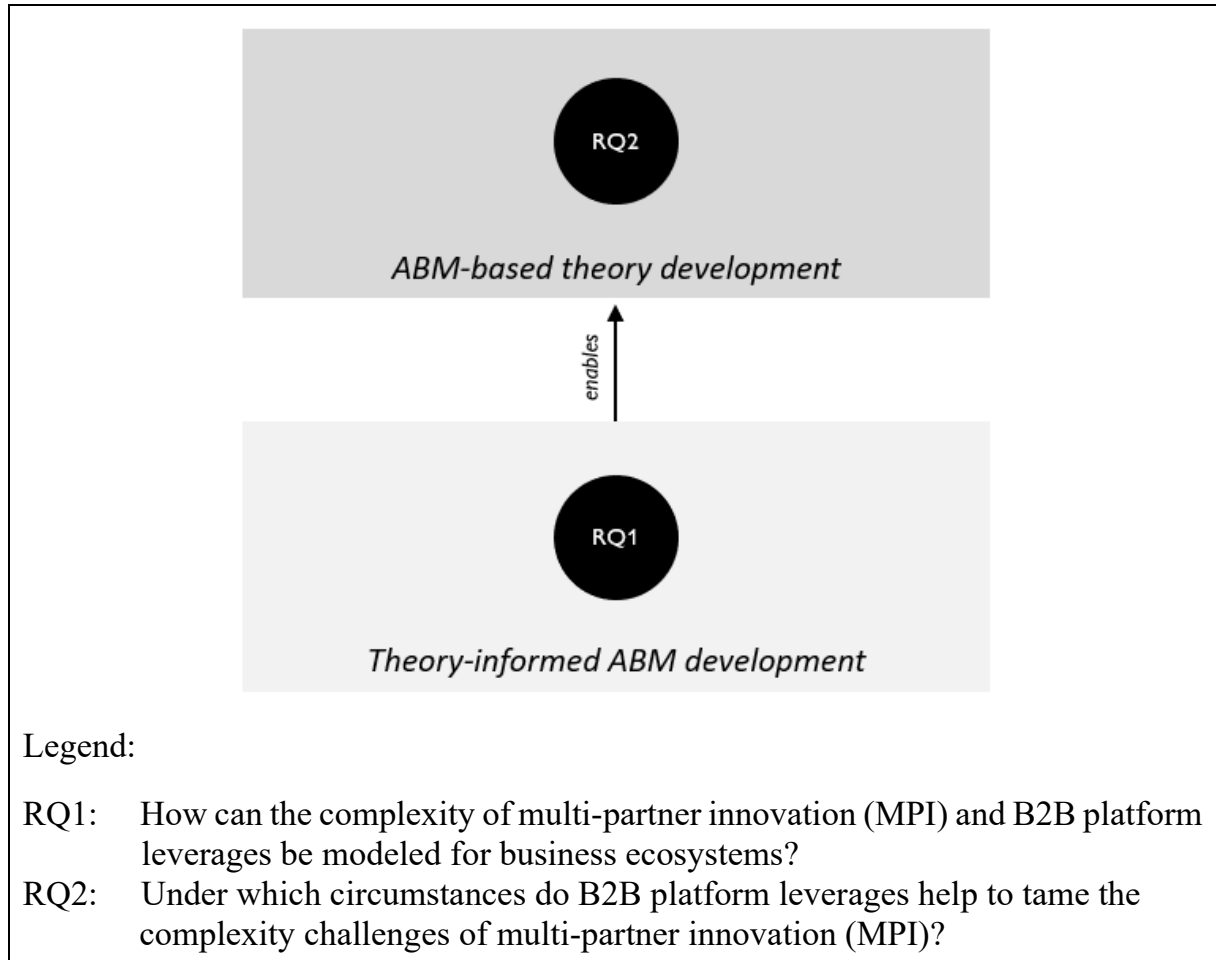


Figure 1. Applied research approach

In short, the complexity perspective is applied onto MPI and B2B innovation platforms in the context of a business ecosystem to develop the ABM. In turn, the simulation environment enables flexible experimentation to derive new theoretical insights on the performance of B2B innovation platforms within their surrounding business ecosystems. Overall, this approach accounts for the recommendation to consider the surrounding ecosystem in theorization, as well as the recommended use of computational methods to examine digital platforms (de Reuver et al., 2018), particularly in the B2B context (Shree et al., 2021). Additionally, it contributes to the need for theorization on the disruptive nature of digital platforms in general (de Reuver et al., 2018). Ultimately, the theoretical insights derived from this investigation shall also inform practitioners in the decision of adopting a B2B innovation platform.

2 Conceptual foundation

The following section explains the main concepts of this dissertation, including complexity science and MPI complexity on the one hand, and B2B innovation platforms and the associated B2B platform leverages on the other hand.

2.1 Complexity science

Complexity can generally be understood as an attribute of systems that constitute a large numbers of diverse and interdependent agents that influence each other in nonlinear ways and are constantly adapting to internal or external tensions (Benbya et al., 2020; Holland, 1995). Complexity science posits that if a system has many nodes, interconnections, or linkages, amongst those nodes, and mutual dependencies, it becomes more complex (Benbya et al., 2020). At the system-level, complexity generates properties, such as non-decomposability, nonlinearity, emergence, and non-predictability (Anderson, 1999; Cilliers, 1998; Tanriverdi & Du, 2020). These properties can present significant challenges.

The non-decomposability property states that system-level outcomes cannot be understood by decomposing the system's constituent components and studying these components in isolation. System-level outcomes are not the sum of local-level outcomes (Cilliers, 1998; Tanriverdi & Du, 2020). The nonlinearity property means that the magnitude of inputs in a system is not proportional to the magnitude of the resulting outcome (Cilliers, 1998). That is, small changes to the system may have disproportionately large effects, whilst large changes may have negligible effects (Tanriverdi & Du, 2020).

The emergence property means that bottom-up interactions among components of a complex system can generate serendipitous, unforeseen outcomes without the intervention and guidance of a central planner (Anderson, 1999; Cilliers, 1998; Dooley, 1997; Holland, 1995). Finally, the non-predictability property states that the non-decomposability, nonlinearity, and emergence properties make the outcomes of complex systems non-predictable (Tanriverdi & Du, 2020). Complexity science thus explains *why* complexity, and particularly its ecosystem-level properties, posit challenges in a given system, but not how to tame these challenges.

2.2 Multi-partner innovation (MPI) complexity

Adopting a complexity perspective thus provides a basis to understand why the process of collaboration amongst several partners to generate innovation in a business ecosystem, i.e., MPI (Davis, 2016; Furr et al., 2016), may be complex, and why this posits challenges.

In broader terms, innovation in a business ecosystem may be considered as a process of search for novel combinations of resources (Ganco et al., 2020; Levinthal, 1997) to ultimately serve customer requirements (Ahuja et al., 2008). When customer requirements are relatively simple, a collaboration amongst multiple partners may not be needed, as the individual partners can rely on their internal resource combinations to generate the respective innovations. As customer requirements become more complex, the internal resource combinations may not suffice to generate the needed innovations, however. Thus, partners engage in a process of search for complementary resources to combine and generate innovations (Ganco et al., 2020; Levinthal, 1997; Nan & Tanriverdi, 2017). In other words, more complex customer requirements may necessitate the MPI process.

When partners engage in the MPI process and collaborate, more linkages amongst partners in the business ecosystem are formed. Similarly, if customers have more complex requirements, they may also need to engage in more exhaustive search efforts (Levinthal, 1997) to find and connect with new partners who can meet their requirements. From a system-level complexity perspective (Benbya et al., 2020), as a result of MPI, partners and customers in the business ecosystem are more interconnected and mutually dependent through the resources that are shared in multi-partner collaborations. The business ecosystem thus becomes more complex as a whole, generating the four mentioned system-level properties of complexity (Anderson, 1999; Cilliers, 1998; Holland, 1995; Tanriverdi & Du, 2020).

In the context of MPI, the non-decomposability property signifies that a given customer's requirement for innovation may not be easily decomposed into its constituent resources (Cilliers, 1998). As such, partners may not preemptively know which resources are needed to generate a required innovation, or who may possess them. According to the nonlinearity property, the relationships amongst partners and between customers and partners are nonlinear, and the size of resources brought in by collaborators may not be proportional to their impact on MPI outcomes (Cilliers, 1998). In turn, the emergence property implies an element of chance in the MPI process. Partners may need to engage in several resource integration and configuration processes that may, in

turn, generate unexpected and surprising outcomes (Anderson, 1999; Cilliers, 1998; Holland, 1995). Similarly, according to the non-predictability property, partners cannot predict whether a given MPI process results in an innovation and whether it will yield profitability (Anderson, 1999; Cilliers, 1998; Holland, 1995).

The ecosystem-level properties of complexity can also increase the costs associated with MPI. Partners' *transaction costs*, for example incurred in searching for and finding partners to collaborate with, establishing trust amongst each other, or addressing IP and revenue sharing issues, may increase (Jarvenpaa & Majchrzak, 2016; Krishnan et al., 2006; Madhok & Tallman, 1998). Similarly, partners' *production costs*, for example incurred in acquiring other partners' resources or ensuring their compatibility and interoperability to jointly innovate, may increase (Wolter & Veloso, 2008). Due to the ecosystem-level complexity, it is thus unclear whether a given MPI would meet a customer requirement, and if so, whether a transaction would be profitable (Anderson, 1999; Cilliers, 1998; Holland, 1995; Tanriverdi & Du, 2020).

2.3 B2B innovation platforms

Confronted with this uncertainty and the complexity challenges of MPI, it can be observed that incumbent firms increasingly turn to innovation platforms (Stonig et al., 2022) to orchestrate MPI in their respective business ecosystem. Before examining how such B2B innovation platforms may tame the challenges of MPI complexity, they are conceptually defined and delineated as a subtype of *digital platforms*.

Adopting the sociotechnical perspective of IS (information systems) research, digital platforms comprise both technical and organizational elements (de Reuver et al., 2018; Ghazawneh & Henfridsson, 2015). Platform research generally distinguishes between two types of digital platforms: *transaction platforms* and *innovation platforms* (Cusumano et al., 2019; Gawer, 2020). Whereas transaction platforms create value by facilitating exchange or transaction of existing goods or services, innovation platforms create value by facilitating innovation (Cusumano et al., 2019; Gawer, 2020). Thus, innovation platforms build the technological core, typically provided by the platform owner, that can be extended by autonomous and self-organized third parties (platform partners) to jointly create value for customers (Ceccagnoli et al., 2012; Eaton, Elaluf-Calderwood, Sørensen, et al., 2015; Wareham et al., 2014; Yoo et al., 2010). Together, platform owner, partners, and customers form a *platform ecosystem* (Ceccagnoli et al., 2012; Jacobides et al., 2018; Parker et al., 2017).

In the case of a B2B innovation platform, aside from platform owner and partners, customers are also firms, as opposed to individual consumers. For example, SAP provides its core ERP system on a B2B innovation platform, granting open access to partners (e.g., SAP application developers, SAP consultants) to leverage the technological core and generate innovations for customers (e.g., Nestlé) in a modular way (Benlian et al., 2018; Ceccagnoli et al., 2012). Ultimately, SAP intends to design the platform such that partners' developed innovations meet customers' need profitably (Ceccagnoli et al., 2012; Schrieck et al., 2021).

B2B innovation platforms themselves are inherently complex systems (Hein et al., 2019; Shree et al., 2021). The central value propositions of such platforms are typically complex solutions in response to customers' complex problems that require an effective and innovative integration of resources of several platform partners (Sarker et al., 2012; Wareham et al., 2014). In other words, customer requirements, developed offerings, and integration tasks are typically complex. Hence, B2B innovation platforms, specifically, and MPI, in general, share some of the same properties of complexity. Though perhaps counterintuitive at first, following complexity science (Merali, 2006), it may be precisely required to have a complex system like a B2B innovation platform to account for the complexity of MPI. The ways in which B2B innovation platforms account for and tame MPI complexity, however, may vary depending on the level of complexity and the interplay of platform leverages for a given platform.

2.4 B2B platform leverages

Platform owners may generally resort to a variety of different mechanisms to address the production-related and transaction-related challenges of MPI, as extensively discussed in the related IS literature (e.g., Ceccagnoli et al., 2012; Malgonde et al., 2020; Tiwana, 2015b). These mechanisms can be conceptually organized around three kinds of leverage: production, transaction, and innovation leverage (Thomas et al., 2014). Production leverage refers to sharing and reusing assets to enable economies of scale and scope (Thomas et al., 2014), thus decreasing the *production costs* of innovating on the platform. Production leverage is materialized through investments by the platform owner into direct subsidies for partner firms' access to the platform (Gawer & Henderson, 2007; Lan et al., 2019), standardization of platforms' core and interfaces, or investments into the modularity and interoperability of platforms to facilitate the sharing and integration of resources, for example (Boudreau, 2017; Brunswicker et al., 2019; Ceccagnoli et al., 2012; Cennamo et al., 2018; Tiwana, 2015a).

Transaction leverage refers to manipulating the market access and market pricing mechanism to drive economies of transaction and search (Thomas et al., 2014), and reduce the *transaction costs* of innovating on the platform. Transaction leverage is materialized through investments into two-sided recommender systems (Malgonde et al., 2020), customer reviews systems (Tae et al., 2020), or certification programs for partners and offerings, for example (Rietveld & Eggers, 2018; Rietveld et al., 2019).

Lastly, innovation leverage is also based on the sharing and reuse of resources, however, with the goal of fostering economies of innovation and complementarity (Thomas et al., 2014). Attracting a plethora of heterogeneous partners with complementary resources enables network effects and positive spillover effects to unfold for partners innovating on the platform (Foerderer et al., 2018; Li & Agarwal, 2017). Innovation leverage therefore manifests itself in the concept of *generativity*, i.e., platforms' capacity to foster complementary innovation by integrating resources of autonomous and heterogeneous partners (Cennamo & Santaló, 2019; Wareham et al., 2014).

Next to generativity in the form of innovation leverage, the platform owner also strives for *profitability* of innovation, to gain profit from the created value (Ahuja et al., 2008; Jacobides et al., 2006). Effectively, the platform owner invests in transaction and production leverage to facilitate the search for and integration of resources on the platform, respectively, to ultimately foster generativity and gain profitability from the generated innovations in the process of MPI.

3 Related work

As established earlier, successfully adopting a platform logic generally requires attracting a critical mass of partners that contribute their diverse resources to the platform and conduct their economic transactions there (e.g., Gawer & Cusumano, 2008; Rochet & Tirole, 2003). In adopting a platform logic for complex MPI, the role of partners and the relationship between platform owners and partners on the platform becomes crucial. This resembles a widely researched stream in platform literature (Rietveld & Schilling, 2021) that can be accounted to the topic of platform governance (Zhang et al., 2022). Platform governance generally deals with the variety of different mechanisms available to platform owners to influence and encourage consistent behavior on the platform (Staub, 2021; Tiwana et al., 2010). This section provides an overview of related work in the targeted literature stream and on the core concepts of the dissertation to outline the addressed research gaps.

3.1 Relationship between platform owner and platform partners

Research on the relationship between platform owner and platform partners comprises several aspects. It addresses how platform owners can incentivize partners to join their platform (e.g., Boudreau, 2017; Gawer & Henderson, 2007), why partners could benefit from joining a platform in the first place (e.g., Ceccagnoli et al., 2012; Wareham et al., 2014), and how these benefits from the platform can be optimized (e.g., Brunswicker et al., 2019; Malgonde et al., 2020). It also addresses how platform owners may align partners' resource contributions on their platform (e.g., Huang et al., 2018; Tae et al., 2020), and the broader collaboration and competition dynamics between platform partners (e.g., Boudreau, 2012; Rietveld et al., 2019). Based on the results of one of this dissertation's constituent papers (Paper E), Table 1 provides an overview of the literature on the role of partners and the relationship between platform owners and partners.

In summary, despite the breadth of research on this topic, existing studies have not theorized on the roles of platform leverages in the context of complex MPI. Thus, broader platform literature is considered for its findings on platform leverages and complexity.

Research sub-streams	Major research topics	Fundamental insights	Literature
Partners in-interest to join	Benefit of joining a platform ecosystem for partners	- Access to resources as a basis for creating and appropriating value - Lowered costs associated with search for and development of resources - Access to installed base of customers, i.e., indirect network effects - Individual partner's benefit may vary (e.g., due to presence of IP rights or competitive aspirations)	(Casadesus-Masanell & Halaburda, 2014; Ceccagnoli et al., 2012; Gawer & Cusumano, 2008; Gawer & Henderson, 2007; Karhu et al., 2018; Rietveld et al., 2019; Wareham et al., 2014)
	Performance of partners on a platform ecosystem	- Shaped by platform's architectural design (e.g., degree of constraints or presence of recommender systems) - Delineated by competition on-platform, i.e., market thickness (positive direct network effects and negative competitive crowding effects)	(Boudreau, 2012; Brunswicker et al., 2019; Cennamo et al., 2018; Dinerstein et al., 2018; Foerderer et al., 2018; Geva et al., 2019; Li & Agarwal, 2017; Malgonde et al., 2020; Rietveld et al., 2018; Tae et al., 2020; Tiwana, 2015b)
	Multihoming of partners on several platforms	- Depends on platforms' technological complexity and technical adaptation costs - Indicative of partners' potential to adapt to changes in the competitive environment more easily - Having partners who multihome may be detrimental to an individual platform	(Boudreau, 2012; Cennamo et al., 2018; Cennamo & Santaló, 2019; Ghazawneh & Henfridsson, 2013; Rietveld et al., 2019; Tae et al., 2020; Tiwana, 2015b)
Owner-partner relations	Owner's means to incentivize partners to join a platform ecosystem	- Lowered barriers to entry through subsidies (e.g., by sharing IP or providing core technological infrastructure) - Establishing trust in the platform (e.g., by ensuring quality through certification of partners and offerings) - Active selection of partners	(Boudreau, 2017; Casadesus-Masanell & Halaburda, 2014; Ceccagnoli et al., 2012; Gawer & Cusumano, 2008; Gawer & Henderson, 2007; Geva et al., 2019; Ghazawneh & Henfridsson, 2013)
	Owner's means to stimulate partners' innovation and to align partners' portfolio of complements on a platform ecosystem	- Definition of participation requirements (e.g., requesting fees or transparency on sensitive information) - Definition of architectural design (e.g., decoupling platform components or altering partners' design decision rights) - Definition of incentivization logic (e.g., emphasizing customer feedback or promoting certain kinds of offerings) - Entry in platform market (may lead to attention spillover effects or crowd out innovation) or explicitly refraining from entry	(Boudreau, 2017; Brunswicker et al., 2019; Dinerstein et al., 2018; Foerderer et al., 2018; Gawer & Henderson, 2007; Ghazawneh & Henfridsson, 2013; Huang et al., 2018; Li & Agarwal, 2017; Malgonde et al., 2020; Rietveld et al., 2019; Rietveld et al., 2018; Tae et al., 2020; Tiwana, 2015b)
Partner-partner relations	Collaboration among partners	- Enables unintended outcomes, i.e., generativity - Can be directly impacted by platform owner (e.g., by developing own offerings or installing dedicated partner-finding capabilities) - May be inhibited by competitive crowding	(Ceccagnoli et al., 2012; Cennamo & Santaló, 2019; Huang et al., 2018; Wareham et al., 2014; Zhang et al., 2022)
	Competition among partners	- Delineated by individual partners' competitive aspirations and general market thickness - Can be directly impacted by platform owner (e.g., by altering customers' search metrics or through selective promotion)	(Boudreau, 2012; Brunswicker et al., 2019; Dinerstein et al., 2018; Geva et al., 2019; Rietveld et al., 2019; Rietveld et al., 2018; Tae et al., 2020; Zhang et al., 2022)

Table 1. Current research on relationship between platform owner and partners (result of Paper E)

3.2 Platform leverages and complexity in platform research

Current research acknowledges that specific instantiations of platform leverages may increase partners' profitability (e.g., Tae et al., 2020), and that joining a platform ecosystem may overall lead to increases in profitability for partners (e.g., Ceccagnoli et al., 2012). However, a systematic understanding of how production leverage and transaction leverage affect profitability and generativity outcomes, both independently and jointly, is currently lacking.

In addition, existing research finds opposing generativity and profitability outcomes of platforms. Positive generativity effects are found, e.g., in the form of spillover and network effects (Boudreau, 2017; Cennamo & Santaló, 2019), whilst simultaneously negative generativity effects are found, e.g., in the form of freeriding and competitive crowding (Boudreau, 2017; Casadesus-Masanell & Hałaburda, 2014; Cennamo & Santaló, 2019). Similarly, existing research highlights positive profitability effects of platforms, particularly when partners have greater IP rights or when the creation of innovations requires unique bundling (Ceccagnoli et al., 2012; Kapoor & Agarwal, 2017). Contrarily, research also finds negative profitability effects, e.g., when the ecosystem is saturated with innovation, and partners find themselves trapped in a prisoner's dilemma (Mantovani & Ruiz-Aliseda, 2016). To this date, however, the role of complexity and platform leverages in these contrary findings have not been examined. Thus, the circumstances under which B2B platform leverages affect generativity and profitability outcomes of partners in complex MPI are yet to be defined.

Lastly, regarding the key construct of complexity, existing platform research has simply focused on innovation complexity as an outcome based on the number of interdependent and unique components of the developed innovations (Cennamo et al., 2018; Kapoor & Agarwal, 2017). Though it has generally recognized complexity as a source of competitive advantage (Kapoor & Agarwal, 2017), the bottom-up emergence of ecosystem-level complexity resulting from partners engaging in MPI, as well as the resulting challenges that platforms may address, have thus far not been investigated.

In summary, although they are established constructs in platform literature, the effects and interrelations of platform leverages and complexity have not been addressed. Thus, this dissertation aims to contribute to the discussion on the role of platform leverages and MPI complexity in platform research. Moreover, it aims to contribute to the literature on the relationship between platform owner and platform partners, as part of the broader topic of platform governance (Zhang et al., 2022).

4 Results

The following section presents the results of the dissertation. More specifically, Section 4.1 presents an overview of the papers and their main contributions. Subsequently, Section 4.2 contains a summary of each individual research paper and its respective results.

4.1 Overview

The overarching research questions are answered across five research papers. Table 2 depicts an overview of how the individual papers contribute to addressing the two research questions.

Paper	Title	RQ1	RQ2
A	Developing Design Principles for Digital Platforms: An Agent-based Modeling Approach	●	◐
B	Towards an Understanding of the Platform Phenomenon: An Agent-based Simulation Approach	●	◐
C	Platform Over Market: When is Joining a Platform Beneficial?	◐	●
D	Taming Complexity in Business Ecosystems: Investigating the Role of Platforms	◐	●
E	Taming Complexity of Multi-Partner Innovation: The Roles of B2B Platform Leverages	◐	●
Legend: ◐ ● Partial answer to RQ Main contribution to RQ RQ1: How can the complexity of multi-partner innovation (MPI) and B2B platform leverages be modeled for business ecosystems? RQ2: Under which circumstances do B2B platform leverages help to tame the complexity challenges of multi-partner innovation (MPI)?			

Table 2. Overview of research papers' contributions to research questions

Following the iterative nature of the theory-informed ABM development throughout the dissertation, Paper B provides the main answer to **RQ1**. It shows that ABM can be employed to model the complexity of MPI and B2B platform leverages in a business ecosystem. Paper A models a digital platform in the B2B context from a complexity perspective, whose system-level properties are shaped by the bottom-level interactions of its constituent actors. The ABM in Paper B extends on this by explicitly accounting for

the surrounding business ecosystem and the complexity challenges that are induced by customer requirements, as well as a first instance of B2B platform leverages to tame these complexity challenges.

Similar to the iterative approach to address RQ1, the ABM-based theory development to answer **RQ2** evolved over the constituent research papers. Accordingly, Paper E provides the main answer by showing that B2B platform leverages are only able to tame the complexity challenges of MPI when the business ecosystem operates in the region of emergent complexity. Paper C makes a first contribution by comparing the performance of partners on the platform with those in the surrounding market, or business ecosystem. Paper D builds on the insight that complexity in the competitive environment is an important contingency for the performance of partners on B2B innovation platforms and investigates this aspect in more depth. The individual and interaction effects of complexity, production leverage, and transaction leverage on partners' innovation performance are investigated and quantified. Lastly, Paper E extends on these findings by investigating if, when, and how B2B platform leverages tame the complexity challenges of MPI. Thus, it addresses how MPI complexity emerges in business ecosystems, how it causes ecosystem-level complexity and associated challenges, as well as whether and how B2B platform leverages are able to tame these complexity challenges.

To summarize, Figure 2 illustrates the interrelations between the individual papers.

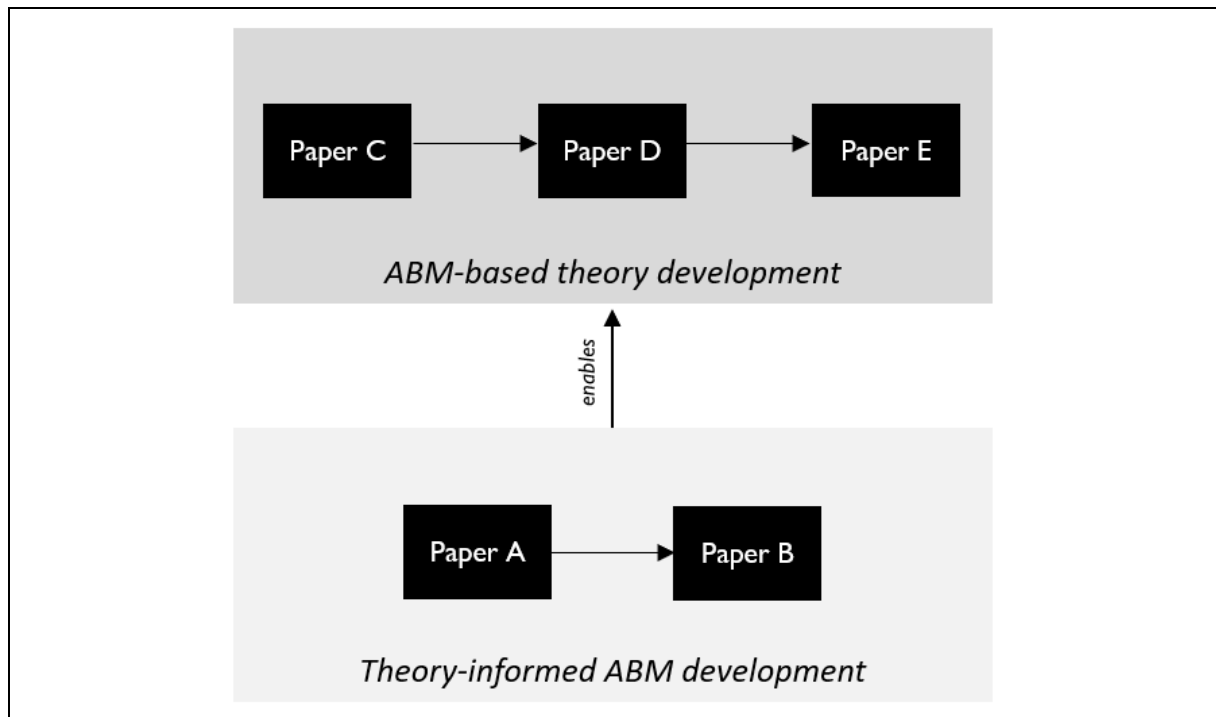


Figure 2. Interrelation of research papers

4.2 Papers of the dissertation

The subsequent section provides a short summary of each research paper of the dissertation, including bibliographical information, synopsis and main results.

4.2.1 Paper A

Citation

Schmid, M., Haki, K., Aier, S., and Winter, R. 2020. “Developing Design Principles for Digital Platforms: An Agent-based Modeling Approach,” in *Proceedings of the 15th International Conference on Design Science Research in Information Systems and Technology (DESRIST 2020)*, Kristiansand, Norway.

Synopsis

Paper A, a research-in-progress paper, presents an ABM as a basis to derive design principles for digital platforms in the B2B context. It acknowledges that platform owners face several immanent tensions in balancing the interests of a plethora of third-party actors (Mini & Widjaja, 2019) in their attempt to ensure both generativity and stability as vital platform-wide objectives (Wareham et al., 2014). Adopting complex adaptive systems (CAS) theory as the theoretical lens, it recognizes digital platforms as CAS, shaped by the surrounding environment and the interactions amongst of actors at the local level that delineate the system-level properties and produce unpredictable outcomes (Merali, 2006; Nan & Tanriverdi, 2017). In response, a theoretically grounded simulation model of a digital platform in the B2B context is generated that accounts for these emergent properties and captures the impact of design decisions on the system-level outcomes of generativity and stability in different environments. The developed ABM is then leveraged to analyze the effects of an exemplary design decision regarding a tension (i.e., control vs. openness) on a platform’s generativity and stability.

Results

The experimentation results reveal clear effects of the degree of openness, i.e., different manners of handling the control vs. openness tension, and the surrounding environment on generativity and stability outcomes. Figure 3 depicts these results.

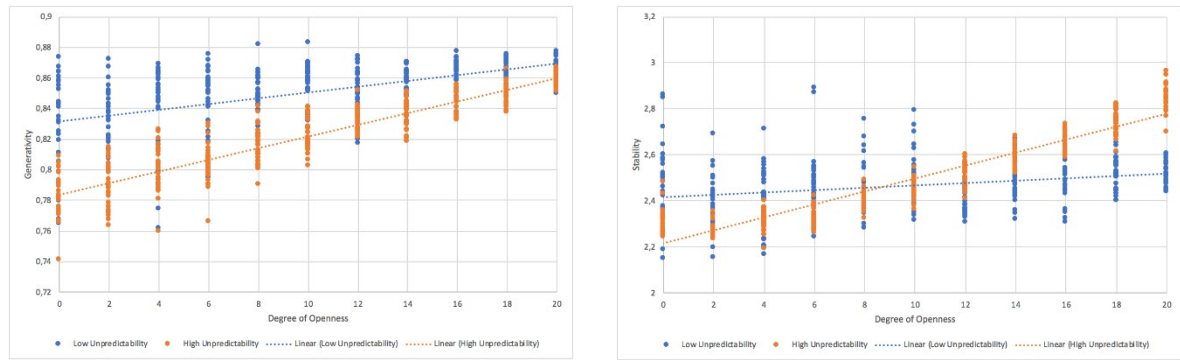


Figure 3. Effect of varying degrees of openness on generativity (left) and stability (right) in environments with low and high unpredictability (result of Paper A)

Aside from illustrating the impact of an exemplary design decision regarding a relevant tension faced by platform owners, Paper A thereby shows that ABM may be leveraged to model the complexity of B2B innovation platforms, and predict related outcomes. Its main overarching contribution is the presented ABM as an extendible tool to study B2B innovation platforms. On a broader scale, Paper A motivates the other papers in this dissertation to further leverage ABM and create more elaborate models with which to conduct additional (predictive) analyses on B2B innovation platforms.

4.2.2 Paper B

Citation

Schmid, M. 2021. “Towards an Understanding of the Platform Phenomenon: An Agent-based Simulation Approach,” in *Sustainable Digital Transformation – Paving the Way Towards Smart Organizations and Societies*, S. Za, R. Winter and A. Lazazzara (eds.). Cham: Springer Nature, pp. 219-235.

Synopsis

Paper B presents an ABM that captures a platform within its surrounding business ecosystem, as a basis for theory development. Importantly, the presented model accounts for platforms’ value proposition to lower search costs and resource costs associated with innovation (e.g., Malgonde et al., 2020; Yoo et al., 2010). It captures exemplary governance decisions faced by platform owners and conditions in the surrounding competitive environment, and tracks platform partners’ profitability and generativity outcomes. This enables a flexible investigation of different variants of platform governance decisions under varying competitive conditions. The resulting ABM is instantiated by experimenting with the levels of investment into search matching and modularity as well

as the platform owner's revenue share per transaction, in environments with low and high levels of complexity.

Results

The main contribution of Paper B is the developed ABM as an extendible tool to conduct predictive analyses. Underlying this computational model is a conceptual model that captures the constituent agents and the surrounding environment. Figure 4 depicts this abstract model design.

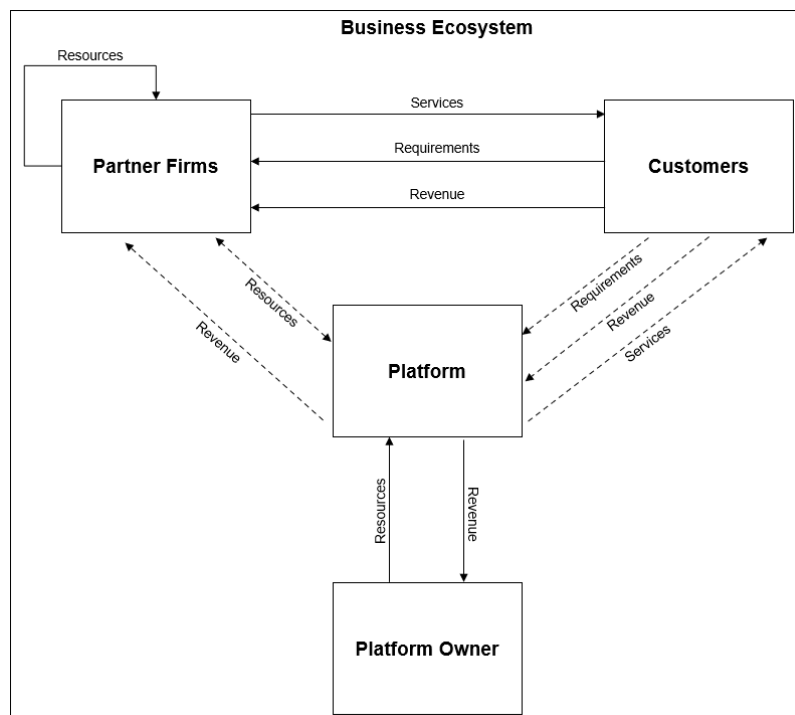


Figure 4. Abstract model design (result of Paper B)

Following the operationalization of the conceptual model, simulation experiments are conducted to track profitability and generativity levels in environments with low and high complexity for different levels of platform owner's revenue share. The results of simulation experiments suggest that the external environment plays a non-trivial role for profitability and generativity outcomes on platforms. More importantly, it highlights the potential of leveraging ABM to better understand the underlying mechanisms that drive platform-related outcomes.

Paper B thus extends on the developed ABM in Paper A in several ways. For one, beyond modeling a digital platform, the presented ABM in Paper B explicitly accounts for the possibility of customers and partners to conduct transactions off-platform (see Figure 4). The focus is expanded beyond the complexity of platforms (i.e., platforms as

CAS) to the complexity of their surrounding business ecosystem. This enables theorizing on the value of platforms in a broader context, and provides a different perspective on the role of complexity. In addition, the developed ABM tracks generativity and profitability as crucial outcomes related to innovation in business ecosystems (Garcia-Castro & Aguilera, 2015; Jacobides et al., 2018) and accounts for critical platform governance decisions like revenue sharing (Ghazawneh & Henfridsson, 2013; Karhu et al., 2018). Overall, Paper B presents an evolved ABM that accounts for the complexity of MPI and B2B innovation platforms in a broader business ecosystem.

4.2.3 Paper C

Citation

Schmid, M., Haki, K., Tanriverdi, H., Aier, S., and Winter, R. 2021. “Platform Over Market: When is Joining a Platform Beneficial?,” in *Proceedings of the 29th European Conference on Information Systems (ECIS 2021)*, A Virtual AIS Conference.

Synopsis

Paper C leverages ABM to investigate whether platforms improve innovation performance (i.e., generativity) and profitability of firms better than the market. It considers joining a platform as an alternative to employing the traditional market mechanism (Porter, 1985) for firms conducting innovative search in a business ecosystem. In turn, the developed ABM captures a market comprising various partner and customer firms that may engage in economic transactions via the market mechanism or via a digital platform (inspired by the empirical example of the B2B innovation platform of SAP). The ABM accounts for different levels of investments into search matching and modularity by the platform owner, as well as the complexity in the competitive environment, induced by the complexity of customer requirements. Throughout various rounds of experimentation, the individual and joint impact of these factors are investigated, which had been treated in isolation by previous research.

Results

The results of simulation experiments suggest a decisive role of complexity for firms' generativity and profitability levels on the platform compared to the market. Figure 5 depicts the profitability and generativity effects at different levels of complexity.

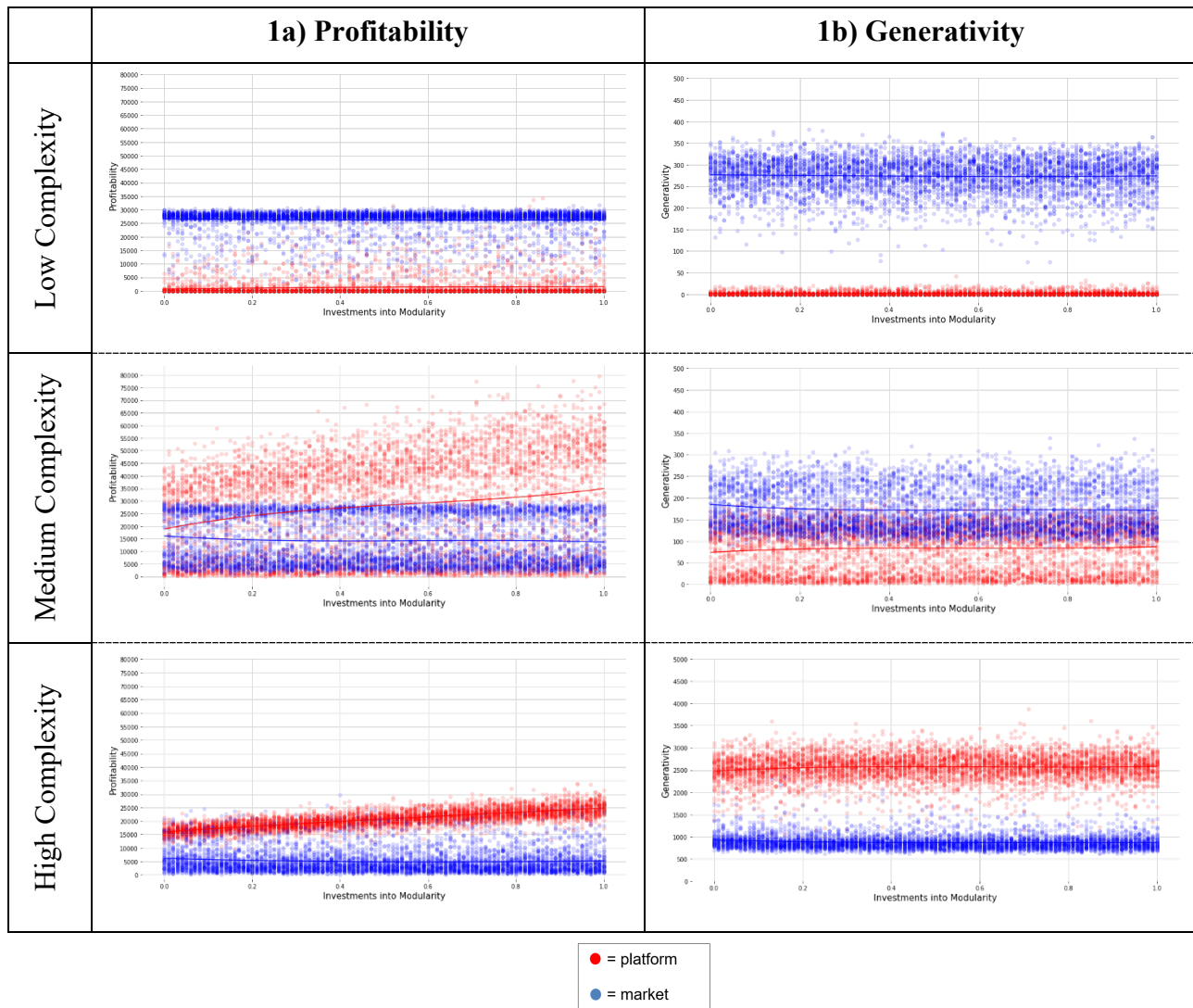


Figure 5. Profitability and generativity effects of platform vs. market (result of Paper C)

Evidently, firms are found to perform better in the market when environmental complexity is low. As environmental complexity increases to medium and high levels, firms begin to perform better on the platform, particularly when there are remarkable investments into search matching and modularity capabilities. Overall, complexity is carved out as an important contingency affecting the relationships amongst factors that have been previously studied in the platform context. The main contribution of Paper C is therefore the theoretical insight on the role of complexity for B2B innovation platforms, as well as showing that complexity, search matching, and modularity interact with each other to jointly affect generativity and profitability outcomes. For the dissertation, as a whole, the results imply that for different levels of MPI complexity, B2B innovation platforms' ability to tame the resulting challenges indeed varies.

4.2.4 Paper D

Citation

Schmid, M., Haki, K., Tanriverdi, H., and Aier, S. 2021. “Taming Complexity in Business Ecosystems: Investigating the Role of Platforms,” in *Proceedings of the 42nd International Conference on Information Systems (ICIS 2021)*, Austin, USA.

Synopsis

Paper D employs ABM to model a platform within its surrounding business ecosystem and analyze the effectiveness of platform capabilities under varying conditions. Fundamentally, it posits that innovation in business ecosystems is inherently complex due to the involvement of a multitude of heterogeneous firms that form mutual dependencies in their attempt to serve dynamically changing customer requirements (Anderson, 1999; Cilliers, 1998). It proposes that platforms are able to tame this complexity in business ecosystems, and foster generativity and profitability of the firms involved, due to the offered platform capabilities that revolve around three types of leverage (Thomas et al., 2014). To materialize these leverages, platform owners make dedicated production-related and transaction-related investments. In turn, it is hypothesized that the effectiveness of these investments to ultimately tame complexity challenges is delineated by the business ecosystem’s complexity in which innovation occurs. To test these hypotheses, the variables of interest are flexibly varied in several rounds of simulation experiments.

Results

As a main result of the conducted experimentation, the individual and joint effects of complexity, production-related investments and transaction-related investments is quantified in the form of regression analyses. In addition, three control variables (revenue share of the platform owner, inertia of partners, environmental stability) are considered. Table 3 displays the regression results.

	Dependent Variables	
	Generativity	Profitability
Intercept	481.6862***	17,730***
Complexity	646.1046***	6,143.2427***
Complexity ²	268.9339***	-6,023.7247***
Production-related investments	15.9382***	1,585.6485***
Production-related investments ²	-7.2020*	-85.4595*
Transaction-related investments	18.6645***	432.9804***
Transaction-related investments ²	-17.0378***	-315.0978***
Revenue share (owner)	-2.1725	-969.6209***
Revenue share ² (owner)	-1.3294	-158.1401***
Inertia (partners)	-7.8321**	-329.2217***
Inertia ² (partners)	-97.5681***	-535.2724***
Environmental stability	2.6465	-19.6811
Environmental stability ²	-54.7306***	-419.4151***
Complexity×Production-related investments	18.7937***	887.2634***
Complexity×Transaction-related investments	22.5060***	138.5117***
R ²	0.276	0.314
F-Statistic	5,037	6,056
AIC	3,142,000	4,025,000

Notes: *p < 0.05, **p < 0.01, ***p < 0.001; standardized coefficients in the cells.

Table 3. Regression analyses of on-platform results (result of Paper D)

Aside from quantifying the effects in terms of regression results, the interaction effects of complexity and both types of investments are visualized in 3D surface plots (see Figure 6).

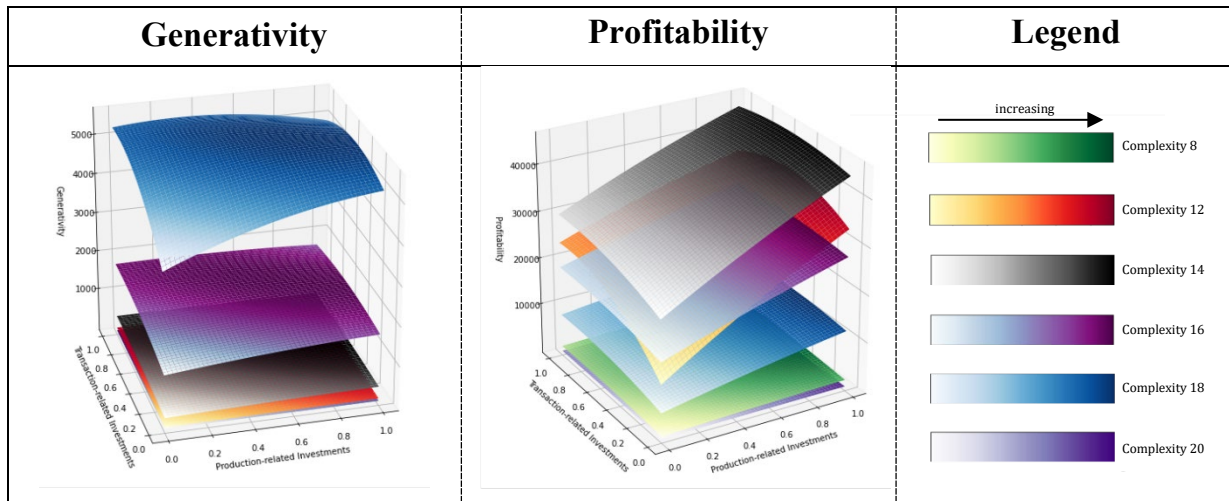


Figure 6. Interaction effects on generativity and profitability (result of Paper D)

These results imply that the generativity and profitability effects of platforms' production leverage and transaction leverage are indeed significantly moderated by complexity. The platform leverages only fulfill the promised generativity and profitability

benefits in medium to high levels of complexity. Additionally, the effects of platform leverages on generativity and profitability outcomes are found to be non-linear.

Paper D thereby extends on the insights on the critical role of complexity derived in Paper C. It quantifies the moderating effect of complexity in the form of regression results and provides a more nuanced explanation of complexity's decisive role in business ecosystems. Being built around the empirical example of SAP and the fundamental logic of innovation in B2B contexts, Paper D thus leverages ABM to derive new theoretical insights on B2B platform leverages and MPI complexity.

4.2.5 Paper E

Citation

Schmid, M., Haki, K., Tanriverdi, H., Aier, S., and Winter, R. "Taming Complexity of Multi-Partner Innovation: The Roles of Platform Leverages," in *MIS Quarterly* (under review in the second round).

Synopsis

Paper E develops new theory that explains if, when, and how a B2B innovation platform tames challenges of complexity in MPI, i.e., when two or more firms develop an innovation (Davis, 2016; Furr et al., 2016). It thereby addresses three theoretical gaps in the IS platform literature: how, in the context of MPI, platforms' transaction and production leverages affect partners' generativity and profitability outcomes; how the two platform leverages affect partners' generativity and profitability outcomes under different levels of MPI complexity; whether and how, in the context of MPI, platforms' transaction and production leverages interact with each other. To this end, it builds on the foundations of complexity science as a theory development approach (Benbya et al., 2020) and leverages ABM and simulation as a method. Specifically, MPI complexity is experimentally manipulated to trigger ecosystem-level complexity dynamics, whilst simultaneously varying the platform owner's investments into transaction and production leverages of the platform to observe if, when, and how the B2B platform leverages tame MPI's complexity challenges both independently and jointly. The main insights from simulation experiments are framed as a set of testable propositions to guide future empirical research.

Results

One contribution of Paper E is the refined conceptual model that creates the basis for the developed ABM. Figure 7 depicts how the business ecosystem and its constituent

actors (customers and partners), as well as the B2B innovation platform within this ecosystem is modeled. In addition, it depicts the interrelation of the main variables of interest, namely customer requirements complexity, or MPI complexity, as the independent variable, investments into transaction leverage and production leverage as moderating variables, and generativity and profitability of partners as dependent variables. Thus, evolving from Paper D, Paper E proposes and investigates a moderating effect of platform leverages on the main relationship between (MPI) complexity and generativity and profitability of partners, respectively.

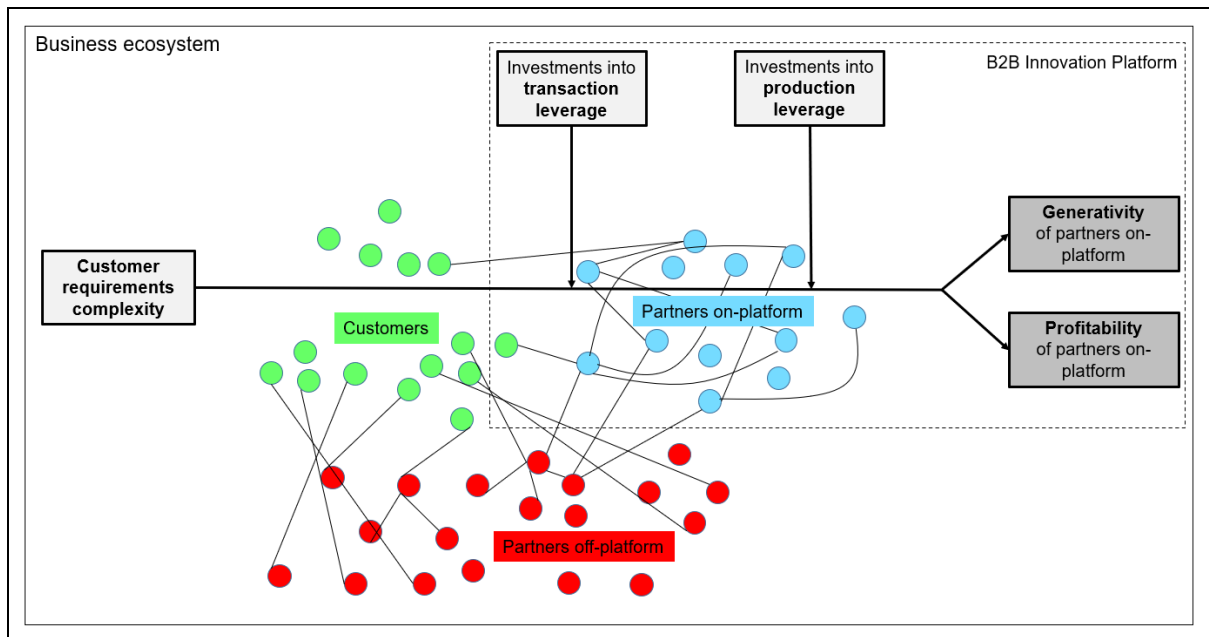


Figure 7. Simulation's conceptual model (result of Paper E)

On the basis of operationalizing this conceptual model, the paper presents how complexity dynamics unfold in the business ecosystem at different levels of MPI. Specifically, three regions of complexity, or regions of operation, are identified that delineate the boundary conditions of the derived theory: the region of order, the region of emergent complexity, and the edge of chaos.

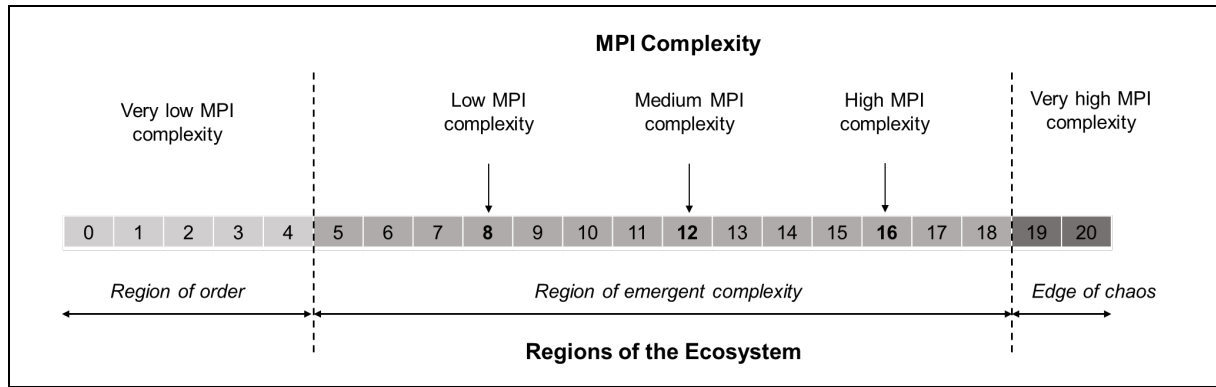
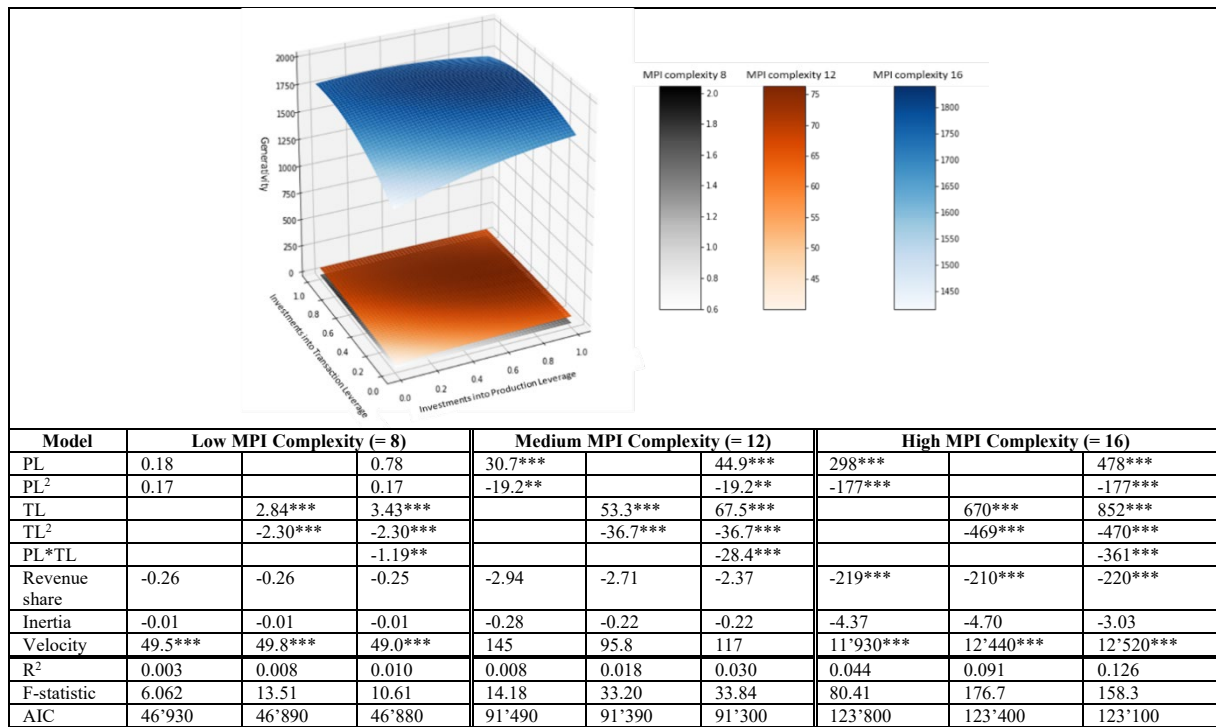


Figure 8. Regions of complexity in the business ecosystem (result of Paper E)

The leverages of B2B innovation platforms are found to only be effective in taming complexity challenges in the region of emergent complexity. The interaction effects of MPI complexity, production leverage and transaction leverage are subsequently further tested for the region of emergent complexity. The results reveal that both production leverage and transaction leverage moderate the link between MPI complexity and generativity (see Table 4) and profitability (see Table 5).



***p<0.001, **p<0.01, *p<0.05; PL = Investments into Production Leverage; TL = Investments into Transaction Leverage

Table 4. Interaction effects of MPI complexity, production leverage, and transaction leverage on generativity (result of Paper E)

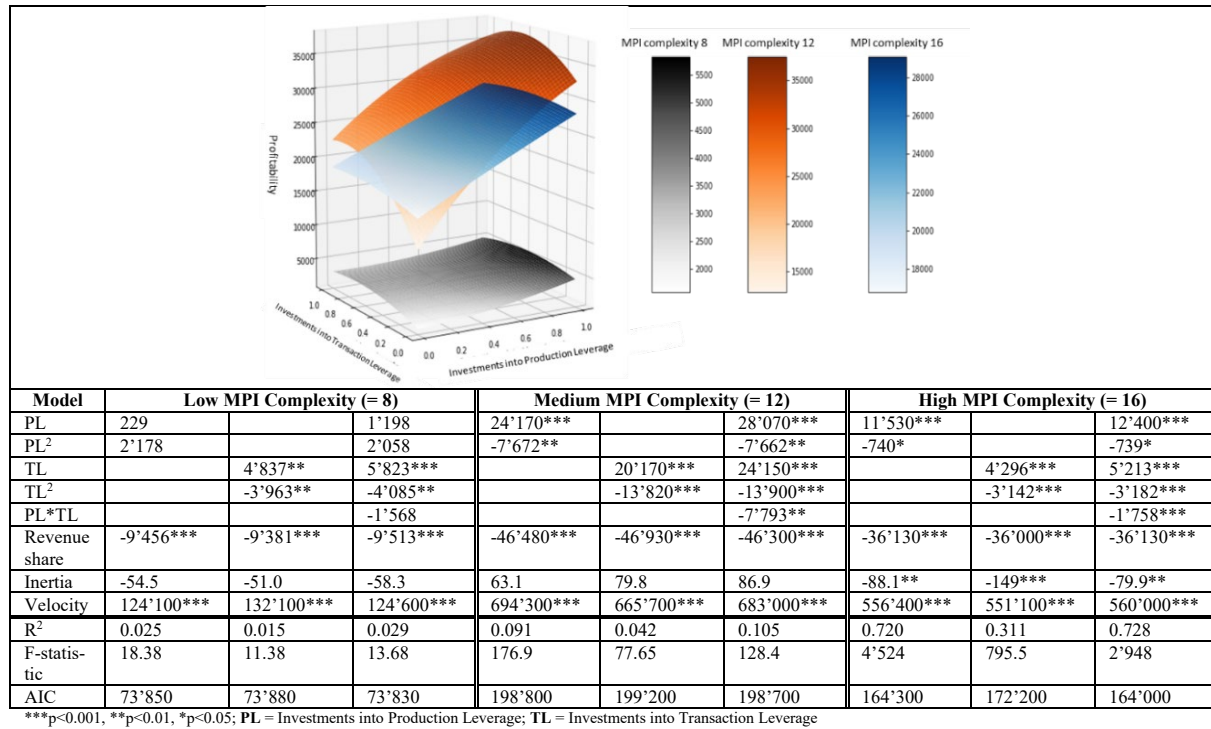


Table 5. Interaction effects of MPI complexity, production leverage, and transaction leverage on profitability (result of Paper E)

The derived theory thus posits that the business ecosystem's region of operation is a major contingency for *whether* and *when* a B2B innovation platform enables partners to tame the challenges of complexity. It also addresses *how* a B2B innovation platform helps partners tame challenges of complexity, revealing non-linear moderation effects on the relationship between MPI complexity and partners' generativity and profitability outcomes. Interestingly, production and transaction leverages are found to negatively interact to attenuate each other's effects on the links between MPI complexity and generativity and profitability outcomes.

Overall, Paper E thus significantly extends on the findings in Paper C and Paper D. It deconstructs the concept of complexity and explains how complexity dynamics unfold in business ecosystems. In turn, it analyses B2B platform leverages' ability to tame complexity challenges and thereby delineates when it is promising to adopt a platform logic.

5 Discussion and outlook

Fundamentally, B2B innovation platforms facilitate innovation amongst multiple partners (Cusumano et al., 2019; Gawer, 2020). They promise to address the challenges faced by firms who engage in complex MPI processes through various mechanisms (e.g., Ceccagnoli et al., 2012) that can be classified as platform leverages (Schrieck et al., 2021; Thomas et al., 2014). However, the circumstances under which the offered B2B platform leverages successfully tame MPI complexity, and a platform organizing logic is particularly promising, are yet to be delineated. Therefore, this dissertation aims to specify B2B platform leverages' ability to tame the challenges of complexity and inform on the critical question of when to adopt a B2B platform organizing logic.

The result of this dissertation emerged from an iterative process of refining a theory-informed ABM and the resulting theory development over the five presented research papers. This section provides a summary of the core contributions of this dissertation, their implications for research and practice, as well as limitations and avenues for future research.

5.1 Contribution

To derive insights on B2B platform leverages' ability to tame the complexity challenges of MPI, the complexity of MPI and platform leverages in business ecosystems first had to be modeled (**RQ1**). Paper A and Paper B contribute in this regard, by iteratively developing a respective ABM. Paper A leverages complexity science to capture and model the complexity of the platform itself. It thus represents a first approach at adopting a complexity perspective to the phenomenon of interest. Paper B extends the focus to the surrounding ecosystem and models the complexity that emerges in business ecosystems, as partners engage in the MPI process to meet customers' requirements. As such, Paper B establishes the process of accounting for the core components of a business ecosystem, conceptually modeling them and their interrelations, and translating this into a computational simulation to model the complexity of MPI and B2B platform leverages in a business ecosystem.

Papers C, D, and E gradually extend on this theory-informed ABM development to generate new theoretical insights and explicate under which circumstances B2B platform leverages help to tame MPI complexity challenges (**RQ2**). Paper C establishes the complexity of the competitive environment as a contingency of platforms' ability to foster

profitability and generativity outcomes. It finds that partners perform better without the aid of a platform when complexity is low, but begin to perform better on the platform, compared to engaging in MPI on their own, as complexity increases further to medium and high levels. Paper D quantifies the effects of MPI complexity and B2B platform leverages on profitability and generativity outcomes. It thereby establishes more precisely B2B platform leverages' ability to tame MPI complexity challenges at different levels of complexity. Paper E refines the concept of MPI complexity and illustrates how different levels of MPI complexity yield different circumstances, i.e., three distinct regions of complexity in a business ecosystem: the region of order, the region of emergent complexity, and the edge of chaos. In turn, B2B platform leverages are found to only tame the complexity challenges of MPI when the business ecosystem operates in the region of emergent complexity. These findings yield several implications for research and practice.

5.2 Implications for research

Existing research recognizes that taming ecosystem-level complexity resulting from MPI motivates firms to opt for a platform organizing logic and invest into platform leverages (e.g., Malgonde et al., 2020; Sandberg et al., 2020). The results of this dissertation posit that for B2B innovation platforms, the level of complexity in the ecosystem presents a contingency, however. More specifically, B2B platform leverages are only found to be effective in taming MPI complexity challenges when a business ecosystem is operating in the region of emergent complexity. In effect, the ecosystem-level complexity and the resulting region of complexity of a business ecosystem can be too low for platform leverages to be attractive, or too high for them to help taming complexity challenges.

This finding may also serve as a potential explanation for opposing findings in broader platform research on the positive and negative profitability and generativity effects of platforms (e.g., Boudreau, 2017; Casadesus-Masanell & Hałaburda, 2014; Ceccagnoli et al., 2012; Cennamo & Santaló, 2019; Kapoor & Agarwal, 2017; Mantovani & Ruiz-Aliseda, 2016). Ecosystem-level complexity is found to be crucial for whether B2B platform leverages have positive or negative effects on profitability and generativity outcomes. Although previous research acknowledges complexity as a source of competitive advantage in platform contexts (Kapoor & Agarwal, 2017), an understanding of the bottom-up emergence of ecosystem-level complexity and its implications for B2B platform leverages was lacking thus far.

Aside from revealing that ecosystem-level complexity plays a crucial role, the presented results also provide insights into how B2B innovation platforms and the respective platform leverages tame the challenges of complexity. The effects of increased investments into platform leverages on innovation outcomes are found to be nonlinear, such that their complexity taming abilities appear to have limits. In addition, results suggest that the returns to investments into production leverage compared to transaction leverage differ. More specifically, results imply that taming the underlying transaction-related challenges of MPI is more difficult than taming the production-related challenges of MPI. Surprisingly, the two leverages are also found to negatively interact to attenuate each other's effects on the links between MPI complexity and generativity and profitability outcomes, rather than having an additive effect.

Overall, these findings complement existing studies in the research stream on the role of platform partners and the relationship between platform owners and partners, and thereby the broader topic of platform governance (Zhang et al., 2022). As a whole, the dissertation addresses the call for research on platforms to leverage computational techniques for theorization (de Reuver et al., 2018; Shree et al., 2021) and shows *why* it is important to consider the surrounding business ecosystem in this regard. It also contributes back to the theoretical foundation of complexity science. Complexity science generally explains why complexity posits challenges (e.g., Anderson, 1999; Cilliers, 1998; Holland, 1995), but not how to tame these challenges. Evidently, B2B innovation platforms can account for the complexity of MPI, and B2B platform leverages are able to tame complexity when a business ecosystem operates in the region of emergent complexity. Lastly, the results of the dissertation reveal how ABM and simulation in general may be leveraged to develop new theoretical insights on complex phenomena.

5.3 Implications for practice

Although the primary contribution of this dissertation is theoretical, the derived findings from the adopted complexity perspective also yield implications for practice. For one, the complexity in the competitive environment of the business ecosystem should be assessed before investing into B2B innovation platforms and the respective platform leverages. The presented results imply that when a business ecosystem is not operating in the region of emergent complexity, B2B innovation platforms do not help to tame the challenges of complexity, and thus are not attractive for prospective platform owners or partners. For practitioners, understanding the level of complexity in their given business ecosystem is thus critical to judge whether adopting a platform organizing logic is

promising or not. Similarly, partners considering joining an existing B2B innovation platform should be aware of the business ecosystem-level complexity. On a broader scale, these results imply that the B2B innovation platforms are not uniformly disruptive in all kinds of competitive environments. Incumbents in business ecosystems that exhibit low complexity may not be under threat of being disrupted by the entry of a B2B innovation platform.

The dissertation's results also have implications for the design and governance of existing platforms. The results imply that platform owners should not expect linear returns from their investments into platform leverages. The presented findings in Paper E even suggest that platform leverages negatively interact to attenuate each other's effects. Costly investments may thus even produce negative returns. As indicated by the results of Paper C and Paper E, this finding may be due to intensified competition on the platform. As platform owners make dedicated investments into platform leverages, more partners are tempted to join and compete on the platform. Thus, the investment decisions by B2B innovation platform owners must be weighed carefully and factors like the competition amongst innovating partners on a platform must be considered.

5.4 Limitations

The research approach pursued in this dissertation, as well as the findings that were generated, have certain limitations and boundary conditions. First and foremost, the constituent papers leverage ABM and simulation as a research method to deduce the presented findings. Although simulation in general, and ABM in particular, is suitable to study complex systems (Davis et al., 2007; Haki et al., 2020; Harrison et al., 2007), the computational modeling of a phenomenon always simplifies real-world instances (Davis et al., 2007; Haki et al., 2020). The limitations of simplification are particularly relevant for agent-based models of human actors, who may be subject to unexpected or irrational behavior that can influence system-level outcomes (Bonabeau, 2002; Haki et al., 2020).

Additional boundary conditions regarding the concrete choice of variables and parameters apply. Most prominently, complexity is modeled with regard to the complexity of customer requirements and the respective MPI, in turn triggering ecosystem-level complexity dynamics. Additional triggers of business ecosystem-level complexity dynamics like regulatory requirements (Davis et al., 2009) were beyond the scope of the developed model. Similarly, although the presented ABM comprises both customers and partners engaged in economic transactions, the main focus lies on innovating partners.

Differences in customer motivations and potential heterogeneity in customer behavior was therefore out of scope.

Lastly, the developed ABM models a particular phenomenon: A single B2B innovation platform within a broader business ecosystem. Therefore, it does not account for situations with multiple competing B2B innovation platforms, or how this platform competition may impact complexity dynamics. Similarly, it does not account for contexts where customers are individual consumers. As for any ABM, the derived theoretical insights from simulation experiments must thus be interpreted with care and with respect to the underlying boundaries and modeling choices (Davis et al., 2007; Haki et al., 2020).

5.5 Future research

The presented findings of this dissertation, as well as their discussed limitations offer several avenues for future research. For one, the foundation of the dissertation (theory-informed ABM development) may be leveraged in its current form to investigate additional aspects of B2B innovation platforms in business ecosystems. Instead of tracking outcomes at the end of simulation experiments, the model may be adapted to investigate the evolution of B2B innovation platforms under different circumstances, to contribute to the respective research stream on platform evolution (e.g., Tiwana et al., 2010).

In addition, future research could consider other established factors that may trigger complexity dynamics in business ecosystems (e.g., Davis et al., 2009) to refine the boundary conditions of the proposed theory. Accounting for competing B2B innovation platforms may also be promising, as multihoming of partners and platform competition becomes increasingly relevant in platform literature (Rietveld & Schilling, 2021). Similarly, the phenomenon of interest could be shifted to consumer-oriented contexts, to enable a comparison of results and add to the discussion on specificities of different platform types (e.g., Blaschke et al., 2019; de Reuver et al., 2018).

Alternatively, the presented research approach can be extended by an empirical data-based approach. The developed theoretical insights and propositions on the role of complexity and competitive circumstances could be empirically tested and validated through individual or multiple case studies. This could serve as a basis for deriving patterns across different contexts and help to translate theoretical insights on the role of complexity into concrete recommendations for practitioners.

Part B – Papers of the Dissertation

Part B of this dissertation comprises the five constituent research papers and corresponding bibliographical information. The papers were re-formatted to ensure a consistent presentation. Next to font styles and sizes, this includes the numbering of figures and tables, the lists of references, and the references to the respective Appendices. The terminology used evolved over the development of the different papers, implying some inconsistencies.

Paper A – Developing design principles for digital platforms: An agent-based modeling approach

Attribute	Value
Title	Developing design principles for digital platforms: An agent-based modeling approach
Authors	Schmid, Marius; Haki, Kazem; Aier, Stephan; Winter, Robert University of St.Gallen, Müller-Friedberg-Strasse 8, 9000 St.Gallen, Switzerland marius.schmid@unisg.ch, kazem.haki@unig.ch, stephan.aier@unisg.ch, robert.winter@unisg.ch
Selected approach for order of authors	Sequence determines credit
Publication outlet	Proceedings of the 15 th International Conference on Design Science Research in Information Systems and Technology (DESRIST 2020), Kristiansand, Norway.
Publication type	Conference Paper
Publication year	2020
Rating (Jourqual 3)	C
Publication status	Published
Acknowledgements	This work has been supported by the Swiss National Science Foundation.

Table 6. Bibliographical metadata on Paper A

Abstract

In the context of digital platforms, platform owners strive to maximize both their platforms stability and generativity. This is complicated by the paradoxical relationship of generativity and stability, as well as associated tensions. To aid B2B platform owners in their design decisions, we aim to derive specific design principles that address the inherent tensions such that generativity and stability are maximized simultaneously. This requires a better understanding of when and to which extent a platforms generativity and

stability are paradoxical, and under which circumstances they can be maximized simultaneously. Thus, we first develop an agent-based simulation model to analyze the effects of an exemplary design decision regarding a tension (i.e., control vs. openness) on a platform's generativity and stability. The developed simulation model enables predictive analyses of varying degrees of control and openness and their effect on generativity and stability. The simulation model must be further refined and applied to other tensions to thoroughly understand the impact of design decisions on a platform's generativity and stability, and ultimately derive design principles.

Keywords

Digital platforms, Complex adaptive systems, Agent-based modeling, Design principles

A.1 Introduction

Despite an increasing research focus on digital platforms, the understanding of reasons for success versus failure remains limited (de Reuver et al., 2018). It is clear, however, that digital platforms must ensure both generativity and stability to survive and prosper (Wareham et al., 2014). We consider generativity as leveraging external resources to satisfy evolving end-user demands (Blaschke et al., 2018), and stability as the ability to yield long-term returns to be financially viable (Wareham et al., 2014). Attaining both outcomes simultaneously is challenging as they are paradoxical (Wareham et al., 2014), resulting from numerous underlying tensions, like aligning individual and collective incentives (Gawer, 2014; Wareham et al., 2014). Optimizing generativity and stability thus primarily requires handling such tensions (Wareham et al., 2014). We aim to support platform owners in the B2B context by deriving design principles (Chandra et al., 2015) to manage tensions in a way that optimizes a digital platform's stability and generativity. Following the first steps of the design science research (DSR) method (Peppers et al., 2007), we present an agent-based simulation model as a preliminary artifact with which we can investigate platform-related tensions and their effects on a platform's generativity and stability. This allows us to better understand how to optimize both outcome variables and thereby paves the way for deriving design principles.

A.2 Research background

A.2.1 Digital platforms

We consider digital platforms as the central building block that provides the technological foundation for other firms to engage and develop complements (Gawer, 2014). Value creation expands across the boundaries of a single firm, as platform owners, partners, and end users form an ecosystem of loosely coupled actors (Blaschke et al., 2018). The platform itself then evolves as a result of interactions between these heterogeneous actors with unforeseen outcomes (Tiwana, 2014; Wareham et al., 2014). Ultimately, it must generate sufficient external innovation to satisfy evolving end-user needs (Blaschke et al., 2018; Ghazawneh & Henfridsson, 2013), whilst remaining financially sustainable and economically viable, so achieve a balance of generativity and stability (Wareham et al., 2014). Attaining this requires an alignment of individual and platform-wide incentives and objectives (Gawer, 2014; Wareham et al., 2014), so yields tensions (Mini & Widjaja, 2019), as every actor in the ecosystem primarily pursues their own interests (Wareham et al., 2014).

A central tension for platform owners is that of control vs. openness (Boudreau, 2010; Karhu et al., 2018; Mini & Widjaja, 2019). In the B2B context for example, where owners, partners, and end users are firms, a platform owner like SAP must decide how much of its core resources to share with partners and how much freedom partners have to collaborate and develop solutions for customers (Huber et al., 2017). Essentially, owners decide how far to ease “restrictions on the use, development, and commercialization of platform technologies” (Boudreau, 2010) (p. 1851), so define the degree of openness. Literature in the B2C context suggests that more openness can foster platform innovation (Boudreau, 2010), but also increases vulnerability (Karhu et al., 2018). Boudreau (Boudreau, 2010), even finds an inverted-U relationship between openness and the development rates of complements. We argue that the degree of openness is not only decisive for a platform’s generativity, but also its financial stability. Thus, we extend existing research (Boudreau, 2010) by considering both generativity *and* stability of digital platforms, as well as the B2B context. For this analysis, we employ complex adaptive systems (CAS) theory as a kernel theory that enables us to capture the components and mechanisms of complex systems.

A.2.2 Complex adaptive systems

CAS are open, non-linear dynamic systems that adapt and evolve in the process of interacting with their environment (Merali, 2006). Effectively, actors in such complex systems adapt their behavior through interactions with one another and the environment, bringing about the emergent properties of the system as a whole that impedes accurate predictions regarding the outcomes of said interactions (Haki et al., 2020; Merali, 2006). Interactions at the local level thus create a system with non-linear characteristics at the global level (Haki et al., 2020). More precisely, CAS comprise agents (as representatives of a system's actors), interactions, and the environment (Nan & Tanriverdi, 2017). Agents attempt to survive in their environment by converting the information obtained into action that will improve their chances of survival, depending on both their own attributes and the defined behavioral rules (Haki et al., 2020; Nan & Tanriverdi, 2017).

In the context of digital platforms, heterogenous actors like partners join and produce unforeseen outcomes as a result of their interactions (Tiwana, 2014; Wareham et al., 2014) in an increasingly complex environment (de Reuver et al., 2018). As is indicative of CAS, interactions among a platform's actors (at the local level) shape the development and delineate the properties of the platform as a whole (at the global level), producing unpredictable outcomes. Chains and cycles of digital platform-related tensions (Mini & Widjaja, 2019) reveal interdependencies and nonlinearity that are also symptomatic of CAS (Merali, 2006; Nan & Tanriverdi, 2017). In this study, we posit that anticipating the emergent outcomes of digital platforms as complex adaptive systems may be feasible with the assistance of a theoretically grounded simulation model as it enables us catering predictive analyses (Haki et al., 2020). Thus, we opt for simulation to develop an agent-based simulation model as a foundational artifact that enables an analysis of design decisions' implications and thereby create a basis for deriving design principles for digital platforms.

A.3 Methodology

To generate this foundational model, we adhere to design science research (DSR) as a research method (see Table 7). DSR has an established history in the context of IS research and revolves around creating IT-related artifacts (Winter, 2008), but also knowledge in the form of design principles (Gregor & Hevner, 2013; Hevner et al., 2004). It suits our context because the study ultimately centers around generating such design principles for digital platforms to maximize their stability and generativity, and

thus utility (Winter, 2008). Currently, we are at the first step of designing a simulation model for an exemplary tension.

Activity (Peppers et al., 2007)	Implementation
Problem: “Define the specific research problem and justify the value of a solution” (p. 52).	Digital platform owners must deal with several design decisions to balance the interests of a plethora of actors (i.e. tensions) to reach the desired generativity and stability in their platforms.
Requirements: “Infer objectives of a solution and knowledge of what is possible and feasible” (p. 55)	The requirements for the design principles are specified based on (Chandra et al., 2015) and the insights into the relation between stability and generativity.
Design: “Create the artifact” (p. 55)	The derived design principles shall be presented in the structure proposed by (Chandra et al., 2015).
Demonstration: “Demonstrate the use of the artifact to solve one or more instances of the problem” (p. 55).	The derived design principles shall be compared to success and failure cases using the case survey method (Larsson, 1993) to demonstrate their utility.
Evaluation: “Observe and measure how well the artifact supports a solution to the problem” (p. 56).	The derived design principles shall be evaluated based on the results of the case survey.

Table 7. Methodology for developing digital platform design principles

A.4 Development of the simulation model

Informed by CAS theory and proven simulation models (Davis et al., 2009; Haki et al., 2020), the agent-based model of a B2B platform ecosystem is developed (using NetLogo software). In such ecosystems, core actors are the platform’s owner, partners, and end users (Blaschke et al., 2019), which thus are considered as agents of the CAS with attributes and behavioral rules (see Table 8).

Conceptual design	Operational design	Literature reference
Partners combine their heterogeneous resources with those of the owner to develop complements, i.e. digital services; the owner thus leverages a community of partners that develop unforeseeable outcomes and defines the degree of openness	Digital services are feature sets with 20-element vectors of 0s, 1s, and ?s (e.g. [0 1 0 0 1 ? 1 0 0 1 ? ? 1 1 0 0 1 1 1 0]), where the first 10 digits represent a partner's resources, the second 10 digits represent the technological codebase provided by the owner, and ?s represent the freedom to improvise (realized as either 1 or 0 with equal probability) or the degree of openness	(Blaschke et al., 2019; Boudreau, 2010; Davis et al., 2009; Gawer, 2014; Haki et al., 2020; Huber et al., 2017; Nan & Tanriverdi, 2017; Tiwana, 2014)
End users are represented by their demands in form of opportunities that arise in the environment of the ecosystem	Opportunities are represented by patches in the environment that have feature sets with 20-element vectors and are updated continuously	(Blaschke et al., 2018; Davis et al., 2009; de Reuver et al., 2018)
Partners interact amongst each other and with their digital services to share information; some partners have more connections than others	Partners can access each other's feature sets to communicate; the number of initial and maximum partner-partner connections are defined by respective parameters	(Blaschke et al., 2018; Haki et al., 2020; Huber et al., 2017)
As learning and utility-based agents, partners execute opportunities by using or building digital services to receive payoffs and maximize their utility; they can use their own or connected partners' digital services	If there are enough matches between a digital service and an opportunity, partners will execute the opportunity and receive the associated payoff; if no matching service is available in the network, partners will build a new digital service if most of their past opportunities could have been executed with a service that has the exact features of the current opportunity	(Ghazawneh & Henfridsson, 2013; Haki et al., 2020; Nan & Tanriverdi, 2017; Wareham et al., 2014)
Building digital services extends the technological core resources of the digital platform, reflecting an adaptation to evolving end-user needs	The initial feature set of the platform owner is augmented by the first 10 digits of any newly built digital service	(Blaschke et al., 2018; Ghazawneh & Henfridsson, 2013; Wareham et al., 2014)
Partners' survival is contingent on receiving more payoffs than the accumulated costs from building and maintaining their digital services	Partners constantly calculate their profitability (payoffs – cost); every x time steps, they check if a participation is profitable and will leave the ecosystem if it is not (x is defined by an adjustable parameter)	(Haki et al., 2020; Nan & Tanriverdi, 2017)
New partners enter the ecosystem to account for low barriers of entry	Every y time steps, a new partner enters the ecosystem (y is defined by an adjustable parameter)	(Wareham et al., 2014)
The dynamic environment is defined by four dimensions of environmental dynamism	Each dimension (velocity, ambiguity, unpredictability, complexity) is realized as an adjustable parameter	(Davis et al., 2009; Haki et al., 2020)

Table 8. Simulation model design

After creating the simulation model of a digital platform ecosystem, it was internally validated and verified following (Beese et al., 2019; Haki et al., 2020) and employed to analyze the effects of varying degrees of openness (from entirely open to entirely closed as a proxy of tension) on a platform's stability and generativity. The output variable generativity is operationalized as the ratio of executed opportunities vs. all opportunities this digital platform was exposed to (Haki et al., 2020), to account for the necessity to satisfy evolving end-user needs (Blaschke et al., 2018; Ghazawneh & Henfridsson, 2013; Wareham et al., 2014). Stability is calculated as the sum of payoffs received by partners in the ecosystem divided by the sum of costs incurred from building and maintaining digital services (Haki et al., 2020), representing a digital platform's economic viability (Wareham et al., 2014). Leaning on a proven model (Davis et al., 2009), 50 simulation runs were conducted for every level (550 runs in total), each comprising 1,000 time steps. Figure 9 illustrates exemplary results of varying degrees of openness, i.e. different manners of handling the control vs. openness tension, on a digital platform's generativity and stability in more and less dynamic environments.

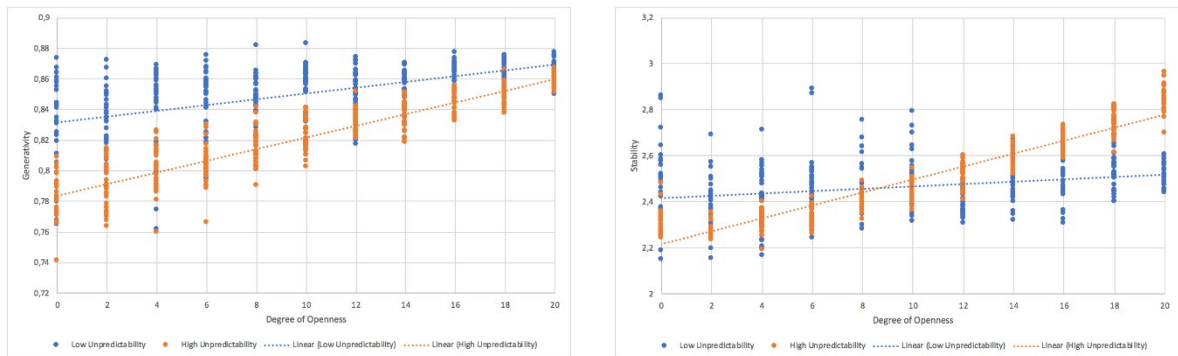


Figure 9. Effect of varying degrees of openness on generativity (left) and stability (right) in environments with low and high unpredictability

A.5 Discussion and outlook

The exemplary illustrations present clear effects of the degree of openness and environment on generativity and stability, but the simulation model evidently requires further elaboration to better capture digital platforms as non-linear CAS. This paper's main contribution is thus a theory-informed simulation model as an extendible instrument to enable predictive analyses of the impact of design decisions on a B2B platform's generativity and stability in different environments. The immediate next step is to further refine the model and extend the investigation to other relevant tensions, like standardization vs. differentiation, or quality vs. variety (Mini & Widjaja, 2019), to analyze the

impacts of associated design decisions on the platform's generativity and stability. This enables us to derive concrete design principles that include materiality, action, and boundary conditions (Chandra et al., 2015), for the effective management of tensions. In the B2B context, platform owners may address the control vs. openness tension by decreasing the control of partners in their development of digital services to optimize generativity in a highly unpredictable environment, for example. After deriving the design principles, we plan to demonstrate and evaluate them by employing a case survey method (Larsson, 1993). For researchers, this would enrich both the extant descriptive knowledge on digital platforms and their governance, as well as CAS on how to harness the unpredictable evolution of complex systems. For B2B platform managers, it would yield concrete actionable advice for different environments.

Paper B – Towards an understanding of the platform phenomenon: An agent-based simulation approach

Attribute	Value
Title	Towards an understanding of the platform phenomenon: An agent-based simulation approach
Authors	Schmid, Marius University of St.Gallen, Müller-Friedberg-Strasse 8, 9000 St.Gallen, Switzerland marius.schmid@unisg.ch
Selected approach for order of authors	Sequence determines credit
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Table 9. Bibliographical metadata on Paper B

Abstract

Despite the omnipresence of platforms and the breadth of related research, predicting the outcomes of platforms remains challenging. To reach a critical mass of complementary partners innovating on their platform, platform owners must foster both generativity and profitability on their platform. The conditions under which these objectives may be achieved have yet to be delineated, however. The study at hand theorizes that the impact of platforms' promised capabilities is delineated by the conditions in the competitive environment. Through simulation, explicitly designed to understand system-level behavior, this theorization can be tested. The developed agent-based simulation model

captures a platform within its surrounding business ecosystem. It accounts for platforms' value proposition to lower search costs and resource costs associated with innovation, as well as related governance decisions faced by platform owners. Importantly, conditions in the competitive environment, namely environmental complexity, may also be adjusted for experimental testing. The simulation model thereby enables a flexible investigation of platform governance decisions and broader environmental conditions. Experimentation results reveal platforms as ineffective at fostering generativity and profitability in low complexity environments, implying platforms to not be uniformly promising or disruptive in all kinds of competitive environments. Thus, this study's main contribution is an agent-based simulation model to help understand and predict outcomes of platforms as complex phenomena.

Keywords

Platforms, Agent-based simulation, Complex adaptive systems

B.1 Introduction

Platforms are becoming increasingly relevant across industries, irrespective of size and domain (de Reuver et al., 2018). Whereas newly established firms like AirBnB or Kickstarter are platform-native, several more traditional companies launch platforms and convert their current businesses into platform ecosystems (Constantinides et al., 2018). Examples of this include General Electric (Constantinides et al., 2018), SAP (Hein et al., 2020; Schmid et al., 2021), and Salesforce (Staub et al., 2021). Naturally, such transitions in organizing logic bring along several challenges.

Managing a platform ecosystem requires the orchestration of a network of complementary third-party innovation to integrate functionalities on the platform and to co-create value with customers who source their services on the platform (Ceccagnoli et al., 2012). The crucial factor for the sustained success of orchestrating a platform ecosystem is the network effect in reaching a critical mass of complementary platform partners to foster innovation (Ceccagnoli et al., 2012; Eaton et al., 2015). Platform ecosystems can be attractive not only for platform partners owing to access to new markets and higher profits, but also for customers due to the access to a wide range of innovative solutions. Platform ecosystems must thus address the need for both creation and capture of additional value (Karhu et al., 2018). In turn, platform owners must orchestrate value creation and value capture in a way that is attractive to both customers and partners.

This orchestration entails several decisive governance decisions. Platform owners must define aspects like revenue sharing arrangements (Karhu et al., 2018), and the level of investments in platform-related capabilities like recommender systems (Malgonde et al., 2020), or modularity (Yoo et al., 2010), for example. Search costs (Benslimane et al., 2005) and resource costs (Alexy et al., 2018) associated with the process of innovation may be decreased depending on the level of such investments. Platform owners may also decide to enter the market of their own platform and thus directly compete with platform partners (Foerderer et al., 2018). Here, research disagrees on whether complementary innovation is positively or negatively impacted (Foerderer et al., 2018). Similarly, there are conflicting findings on whether a higher number of partners is beneficial or detrimental to platforms (Boudreau, 2012; Li & Netessine, 2020; Yoo et al., 2010). Thus, despite the critical role of network effects for the platform logic (Casadesu-Masanell & Hałaburda, 2014; Cennamo & Santaló, 2019; Markovich & Moenius, 2009), it is not entirely clear how to optimize them. Ultimately predicting the success or failure of a platform is thereby still challenging (de Reuver et al., 2018). Fundamentally, we lack insights into the conditions under which platforms are particularly advantageous (Kretschmer et al., 2022) and when additional investments in platforms stop paying off (Hein et al., 2020). This study theorizes that the impact of platforms' promised ability to decrease firms' search costs and resources costs varies in different competitive environments and for different designs of governance mechanisms.

To enable this theorization, simulation is leveraged as a research method that allows to generate large amounts of data and conduct what-if analyses for various scenarios (Nan & Tanriverdi, 2017). Thus, this study presents an extendible agent-based simulation model of a platform and its surrounding business ecosystem. By characterizing platforms and the broader business ecosystems as complex adaptive systems (Anderson, 1999), the simulation model aims to help illustrate and explain the underlying system-level behavior. It enables the testing of governance decisions faced by platform owners, as well as the environmental conditions that apply in the surrounding business ecosystem. The impact of these varying conditions on relevant performance metrics can thus be tested extensively. Thereby, the simulation model allows platform researchers and managers to better understand platforms as complex phenomena and assists the latter in predicting outcomes of platform design decisions.

B.2 Conceptual foundation

B.2.1 Digital platforms as enablers of value creation and value capture

Being situated at the center and as the enabler of a platform ecosystem, a digital platform is crucial to the success of the corresponding platform ecosystem. From a sociotechnical perspective, platforms comprise both technical and organizational elements (de Reuver et al., 2018; Ghazawneh & Henfridsson, 2015). It is the technological core, typically provided by the platform owner, that can be extended by autonomous and self-organized third parties (platform partners) to jointly create value in the form of innovations for customers (Ceccagnoli et al., 2012; Eaton et al., 2015; Wareham et al., 2014; Yoo et al., 2010). Apple and Google provide the mobile operation systems of their respective iOS and Android platforms that may be extended to develop apps for customers, for example. Similarly, SAP provides fundamental technologies, data, and processes to enable complementary innovation on its Business Technology Platform. The digital platform thus serves as the basis of a platform ecosystem that comprises complementary platform partners whose resources are bundled to create value in the form of innovative solutions to solve customers' problems. The main platform actors are the platform owner, complementary partners, and customers (Blaschke et al., 2018).

Within platform literature, there is a common understanding that sufficient value creation is a prerequisite for the success of the entire ecosystem (Ceccagnoli et al., 2012; Wareham et al., 2014). Enabling the joint value creation among platform partners represents a platform's generativity (Tilson et al., 2010), which is the "overall capacity to produce unprompted change driven by large, varied, and uncoordinated audiences" (Zittrain, 2006, p. 1980). Put simply, the demand for a given platform increases with the availability and quality of available complements (Markovich & Moenius, 2009). Thus, a platform's generativity for value creation and innovation, to offer a wide range of solutions to platform customers, is vital for platform success.

Next to, and as important as, value creation is the appropriation (capture) of the created value (Jacobides et al., 2006; Karhu et al., 2018) that sustains an economic benefit from innovation (Garcia-Castro & Aguilera, 2015). Platform partners, as third-party innovators, must perceive the participation in the platform ecosystem as beneficial to join and integrate their resources, and remain on the platform over time. If partners cannot appropriate sufficient value from the platform, they will feel free to conduct business off-

platform or offer their resources on rival platforms. Similarly, the platform owner must derive an economic benefit from orchestrating the platform ecosystem. Platform owners must invest significantly and these investments should pay off in terms of value capture (Hein et al., 2020). Platform owners ideally want to maximize value appropriation without limiting generativity as the underlying mechanism of value creation (Wareham et al., 2014). Thus, both value creation and value capture play central roles for the success of platforms.

B.2.2 Platform governance

Governing a platform and its surrounding ecosystem is therefore a challenging task (Gawer & Cusumano, 2002; Halckenhäusser et al., 2020). As an orchestrator of the platform ecosystem, the platform owner typically has a variety of governance mechanisms it can apply to govern the platform and its participants (Halckenhäusser et al., 2020; Tiwana et al., 2010; Wareham et al., 2014). Platform owners may decide to employ a greater degree of openness of their platform to external innovation, for example (Benlian et al., 2015). This may increase the diversity of contributed innovations (Tiwana, 2014) but also may yield a loss of control over the content provided that may result in a lower quality of offerings (Casadesus-Masanell & Hałaburda, 2014). Platform owners typically employ boundary resources, i.e., software tools and regulations, to steer generated innovations (Eaton et al., 2015) and may adjust their policies over time. Although realizing network effects is a fundamental aspect of platforms (Casadesus-Masanell & Hałaburda, 2014; Markovich & Moenius, 2009), it is not clear to which extent an increased number of partners is beneficial. Research suggests both positive attention spillover effects (Li & Agarwal, 2017), as well as negative crowding effects (Li & Netessine, 2020) as a result of an increased number of partners operating on a platform. Platform governance is thus also impeded by the fact that desired outcomes are not entirely clear.

Another central task for platform owners is deciding how to distribute the generated revenue and thereby setting a framework for value capture on the platform (Karhu et al., 2018). Platform owners will typically define a revenue sharing arrangement for transactions on their platform (Ghazawneh & Henfridsson, 2013; Karhu et al., 2018), as Apple does on the App Store (30%) or Salesforce does on its AppExchange (15%), for example. The empirical example of SAP suggests that defining the revenue sharing arrangement may be adapted over time. On its recently launched Business Technology Platform

(BTP), SAP merges existing platform offerings and offers only a single revenue sharing arrangement (Sahasrabudhe, 2021). Platform governance thus entails decisions that may have to be revoked or adapted over time.

B.2.3 The role of search costs and resource costs

Platform literature thus presents contradictory findings on the implications of platform governance decisions. Similarly, empirical examples suggest platform owners continuously adjust their governance mechanisms. Understanding why platforms succeed may thus require expanding the scope to the greater context in which platforms are situated. In broader innovation ecosystems (Ganco et al., 2020), firms have alternatives to organizing around a platform and may decide to interact without the aid of a platform. Following the resource-based view of the firm, resources are assumed to be valuable, rare, and not perfectly imitable or substitutable (Bowman & Ambrosini, 2000). Furthermore, it is generally understood that not all firms are endowed with all resources (Gavetti et al., 2017). In business ecosystems, innovation is typically distributed within a network of upstream and downstream firms (Ganco et al., 2020), searching for and integrating each other's resources.

Search, as a process in itself, is hence an integral part of value creation and innovation that comes at a certain cost (Benslimane et al., 2005). This is where digital platforms and platform ecosystems can contribute in effectively facilitating and optimizing solution and resource matching through their search matching function. Search matching capabilities, in the form of two-sided recommender systems, have been found to improve the performance of platform agents (Malgonde et al., 2020). More specifically, they aid in taming the complex search matching in platform ecosystem settings (Malgonde et al., 2020). Thus, investing in search matching capabilities can reduce the search costs of both platform partners and customers. Such a capability incentivizes both platform partners and customers to conduct their business on the platform, as opposed to alternative organizing logics, and thereby affects the sustained success of a platform ecosystem.

Similar to the search process, creating and maintaining resources is also associated with a relevant cost (Alexy et al., 2018). Here, the level of modularity has direct implications (Yoo et al., 2010). If a platform offers a high degree of modularity, resources can be decomposed and recombined to a greater degree, yielding a higher reusability of resources (Yoo et al., 2010). In effect, this decoupling of resources through investments

in a modular architecture enables a higher flexibility in generating outputs on a platform, stimulating generativity and leveraging economies of scale (Yoo et al., 2010). It is precisely the decrease in resource costs through such reusability that is an inherent part of the value proposition of platforms in general. Even though platforms can evidently lower both search costs and resource costs, joining a platform is a decision associated with risk for potential partners. Partners that consider joining the platform effectively weigh the benefits of reduced search costs and resource costs against the risks such as not getting paid sufficiently, for example.

The sustained success of a platform ecosystem is thus contingent on how much the platform owner invests in search matching and modularity to reduce search costs and resource costs for platform partners and customers. Further, the platform owner can employ revenue sharing as a governance lever to increase the attractiveness of conducting business on the platform for partners, but also adjust the own profitability. Accounting for such factors is vital to understand the fundamental logic of platforms and ultimately why they may fail or succeed. Nevertheless, there are also aspects outside of the control of the platform owner. This study therefore opts for considering the conditions in the surrounding competitive environment, i.e., the broader innovation ecosystem, as well. The aim is to investigate the effect of platform governance decisions in different competitive environments and thereby delineate the conditions under which platforms are particularly promising.

To understand both internal platform factors and external factors in the surrounding environment, the complex adaptive systems (CAS) view is applied as a starting point. Recent studies in platform literature have drawn on CAS theory to characterize and analyze platforms as CAS (Malgonde et al., 2020), or investigate how a product platform transitioned into a platform ecosystem (Sandberg et al., 2020). Thus, CAS theory is evidently suitable to investigating platforms and existing approaches may be complemented by adopting a system-level view that incorporates the surrounding business ecosystem, as elaborated in the subsequent section.

B.3 Research method

B.3.1 Simulation-based research

A research method that lends itself well to understanding system behavior, particularly in the context of complex adaptive systems, is simulation (Nan, 2011; Spagnoletti et al.,

2018). Simulation-based research is established across various fields and has made significant contributions particularly to disciplines like the natural sciences (Beese et al., 2019; Spagnoletti et al., 2018). It is commonly defined as “a method for using computer software to model the operation of real-world processes, systems, or events” (Davis et al., 2007, p. 481). In effect, a simulation is a simplified, computational representation of a world and its central underlying constructs (Davis et al., 2007). Thus, through simulation, researchers create an abstraction of a given phenomenon of interest and translate it into software for experimentation. Importantly, this allows for investigating individual aspects or constructs of a phenomenon in isolation and generating large amounts of artificial data for analysis, which may be difficult or infeasible in empirical contexts (Beese et al., 2019). Although the application of simulation techniques in the field of information systems (IS) is not as widespread as in other fields, recent studies highlight its potential for IS research (Beese et al., 2019; Spagnoletti et al., 2018). Agent-based simulation, as one of the most common simulation techniques, is deemed particularly suitable for analyzing complex systems with emergent properties and nonlinear behavior (Davis et al., 2007; Haki et al., 2020). Thus, this study sets out to develop an agent-based simulation model of the complex system under investigation. The model development process leans on common simulation guidelines (Sargent, 2005) and existing models (Davis et al., 2009; Haki et al., 2020). More precisely, the development process consists of the conceptual development, operational simulation development and validation, and conducting experiments and analysis (Haki et al., 2020).

B.3.2 Conceptual model design

The conceptual model creates the basis for any computational operationalization (Haki et al., 2020; Sargent, 2005). The basic setting at hand is a business ecosystem of partners and customers, within which a digital platform is situated. As discussed, the platform owner typically provides this extendible technological core (Blaschke & Brosius, 2018; Ceccagnoli et al., 2012). Partners and customers may decide to conduct business and source their required services on- or off-platform, depending on which option they perceive to be more beneficial (see solid arrow lines and dotted arrow lines in Figure 10, respectively). For the innovating partners, this means resources for integration to develop new services may be sourced on-platform or off-platform in the broader ecosystem (see solid arrow lines and dotted arrow lines in Figure 10, respectively). To account for the investments into search matching and modularity as an effort by the platform owner to increase the platform’s attractiveness, levels of search costs and resource costs

on the platform may vary. Similarly, the revenue share obtained by the owner depends on the defined revenue sharing arrangement. This basic conceptualization also leans on an existing agent-based simulation of a digital platform (Malgonde et al., 2020) that conceptualizes a multi-sided platform as a complex adaptive business system. The resulting setting is depicted in Figure 10.

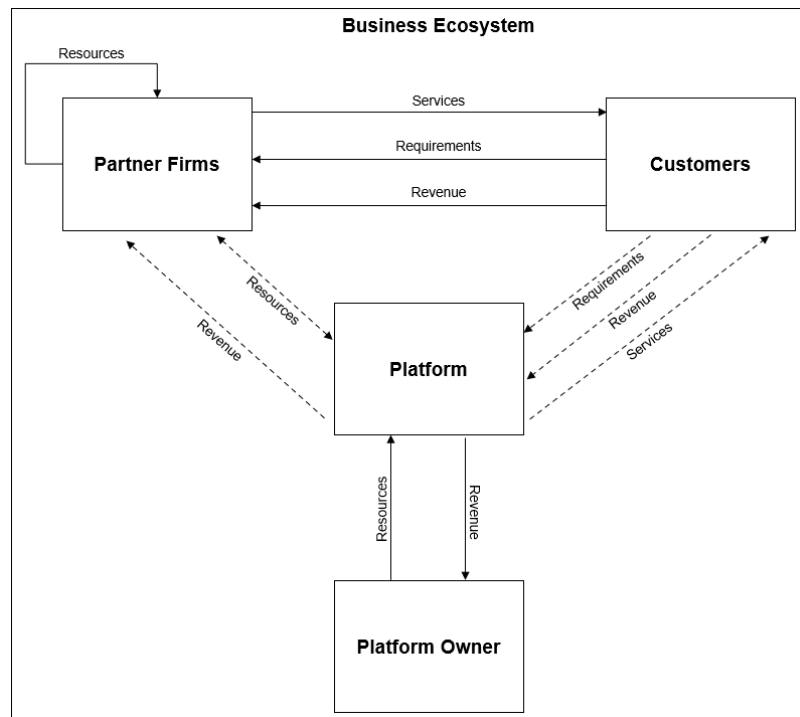


Figure 10. Abstract model design

Operationalizing this basic concept into a simulation model requires a more precise definition of the model components. From a CAS perspective, *agents*, *interactions*, and the *environment* are the critical elements in this regard (Nan, 2011).

B.3.2.1 Agents

Formally, agents may represent different entities, like individuals, groups of individuals, or entire organizations (Nan, 2011). They are equipped with unique attributes and behavioral rules that define their operationalization (Haki et al., 2020; Nan, 2011). Based on the abstract model design, the simulation model contains the platform owner, partners, and customers as central agents, as well as combinable resources and resulting services. As a main attribute, customers are equipped with service requirements for which they search for matching services. This accounts for the fundamental premise that innovations are designed to meet customer demands (Ahuja et al., 2008), be it mobile applications or analytics services. Naturally, aside from meeting the requirements,

services must also be affordable for customers. The services are in turn created by partners that combine and integrate resources (Ganco et al., 2020; Gavetti et al., 2017).

Similarly, the platform owner supplies an extendable core for complementary innovation (Gawer, 2011), i.e., offers core resources as a basis for generating services on-platform. Next to extendable resources, platform owners also make dedicated investments into search matching (Malgonde et al., 2020) and modularity (Yoo et al., 2010) to lower search costs and resource costs on the platform, respectively. Owner, partners, and customers may all be characterized as learning- and utility-based agents that choose to maximize their utility function (Haki et al., 2020; Russel & Norvig, 2009). Customers search for services that they can afford, partners intend to make profits with their generated innovations, and the platform owner aims to orchestrate a platform that fosters both value creation and value capture. Resources and services on the other hand are reflex agents (Haki et al., 2020; Russel & Norvig, 2009) that are designed and used by other actors.

B.3.2.2 Interactions

Importantly, these described agents also interact in different ways. Aside from the agents themselves, interactions in CAS generally comprise the connections or links between given agents and the flows of resources among them (Haki et al., 2020; Nan, 2011). In other words, the premise for interaction among agents is being connected and exchanging something along this connection. In the described conceptual model, interactions are driven by innovation as a search process in the broader business ecosystem (Ganco et al., 2020). Whereas customers search for services that match their requirements, partners search for resources to integrate in order to meet customers' requirements. Following established conceptions of search in other simulation contexts (Ganco et al., 2020; Kauffman, 1993; 1997), the basic search process is divided into local search and distant search. Thus, agents search both their immediate neighborhood (local search) and conduct *long-jumps* beyond their immediate neighborhood (distant search) (Ganco et al., 2020; Kauffman, 1993; Levinthal, 1997) that are associated with higher risk and may therefore be more costly (Levinthal, 1997).

Adopting this logic to the presented setting, both customers' and partners' search may thus be divided into local search and distant search. The immediate neighborhood as a setting for local search is then the existing network of partners and customers, whilst conducting distant search means moving beyond this local network, i.e., searching the

entire business ecosystem of actors. Searching the broader business ecosystem also includes the possibility to search on-platform. Partners that innovate may thus also search for and integrate the resources offered on-platform, and customers may source services on-platform. These interactions may be facilitated through the mentioned investments by the platform owner. Thus, conceptually, partners and customers may also be connected to the platform owner through the platform.

B.3.2.3 Environment

The medium in which these agents interact is considered the environment (Haki et al., 2020; Nan, 2011). Based on Figure 10, the surrounding business ecosystem conceptually presents the environment. However, the conditions in the competitive environment may vary and such variations must be accounted for. Thus, this study leans on existing simulation models (Davis et al., 2009; Haki et al., 2020) to account for environmental complexity as a decisive factor for the conditions in the competitive environment. In effect, the competitive environment is shaped by the complexity of customer requirements. Innovation, that is ultimately designed to meet customer requirements (Ahuja et al., 2008), becomes increasingly challenging as the complexity of these requirements increases, especially when not all firms are endowed with all resources (Gavetti et al., 2017). Therefore, the complexity of customer requirements requires an adaptation by the other agents in the business ecosystem, delineating the conditions in the surrounding competitive environment. With the conceptual model and its constituent components outlined, the focus turns towards the operationalization of the simulation model and experimentation.

B.4 Operationalization and experimentation

B.4.1 Operational model logic

In the conceptual model, partners combine and integrate their resources to form services as the basic process of innovation and can choose to do so on-platform or off-platform. Operationally, the approach from existing studies that use binary vectors of 0s and 1s (Davis et al., 2009; Ganco et al., 2020), as well as “?”s (Haki et al., 2020) is adopted. Ganco et al. (2020) specifically model upstream and downstream firms mixing-and-matching their components, i.e., 5-bit vectors of 0s and 1s to form a product. To account for resource features left open for improvisation (Haki et al., 2020), some features are represented by “?”s and may be improvised to become either a 1 or 0. For example, the

resource [0110?] may be interpreted as [01101] or [01100]. In our digital platform context, the recombination of components is applied so that four resources as 5-bit vectors are combined and integrated to form services as 20-bit vectors. Thus, the resources [1101?], [1100?], [0010?], and [1010?] may be combined to form the service [11010110010010010101].

As the developed innovations must ultimately meet customers' requirements (Ahuja et al., 2008), services must be tested for their fit to given requirements. Again, the operationalization leans on existing models that capture opportunities as binary vectors of 0s and 1s that, if met, yield a random payoff (Davis et al., 2009; Haki et al., 2020). In our setting, opportunities for partners are equated to customers' requirements. If partners meet a given requirement, they receive a payoff for the successful transaction. To enable a comparison of requirements and services, the former are also operationalized as 20-bit binary vectors of 0s and 1s. Importantly, the complexity of customer requirements determines how many matches there must be between a service and a requirement for the service to match the requirement (Davis et al., 2009; Haki et al., 2020). Thus, resources are combined to form services and the resulting services are tested for their match with requirements, leaning on existing approaches (Davis et al., 2009; Ganco et al., 2020; Haki et al., 2020).

B.4.2 Definition of variables and parameters

The computational model is subsequently developed using the agent-based simulation software NetLogo, a software designed particularly to model complex phenomena (Tisue & Wilensky, 2004). After the translation of the described conceptual model, several parameters can be defined and adjusted to test their impact on output variables of interest. Based on the conceptual foundation of platforms, value creation and value capture are vitally important. The modeling context allows making these factors concrete and measurable. The platforms' value creation capacity, or generativity, may thus be measured in terms of the number of services generated on-platform. Similarly, value capture may be captured in the form of platform agents' profitability by considering the revenues generated and costs incurred. Partners' profitability on the platform may be of particular interest in delineating their decision to innovate on-platform versus off-platform in the broader business ecosystem. Thus, profitability and generativity serve as suitable outcome variables.

These outcome variables may be impacted by several factors. The discussed investments into search matching and investments into modularity can be concretized by lowering search costs and resource costs on-platform. This is operationalized as a cost reduction by a factor of 0.00-1.00, respectively. Similarly, the revenue sharing agreement between platform owner and partners may vary. In the simulation model, the platform owner's revenue share can thus be adjusted freely between 0%-100% per transaction. Lastly, the environmental complexity in the broader business ecosystem, induced by the complexity of customer requirements, may be varied between 0-20. In effect, simulation enables an investigation of all of these factors individually and jointly, allowing for a more nuanced analysis of the impact on the outcome variables of interest. How is generativity impacted when the platform owner opts for a revenue share of 50%, compared to 25%? How effective are investments into search matching and modularity when the competitive environment is highly complex? Table 10 summarizes the discussed variables and variations as a basis for a first round of simulation experiments. Table 11 summarizes the remaining initialization parameter settings required for operationalization.

Variable Name	Range	Tested Values	Description
Environmental complexity	0-20	5; 15	More complex customer requirements are more challenging to meet, i.e., require more feature matches with a given service. Customer requirements thus delineate the complexity of partners' competitive environment.
Investments into search matching	0.00-1.00	0.00; 0.50; 1.00	Through dedicated investments into search matching, the platform owner may decrease search costs on the platform by a factor of 0.00-1.00.
Investments into modularity	0.00-1.00	0.00; 0.50; 1.00	Through dedicated investments into modularity, the platform owner may decrease search costs on the platform by a factor of 0.00-1.00.
Owner's revenue share	0%-100%	0%-100% in increments of 5%	The platform owner's revenue share for transactions on-platform may vary.
Generativity	N.A.		As a proxy for value creation, the simulation model tracks the number of unique services developed on-platform.
Profitability	N.A.		As a proxy for value capture, the simulation model tracks partner firms' generated revenues and incurred costs, as well as the resulting profitability.

Table 10. Experiment parameter settings

Parameter	Description	Default Value
Time steps	Each simulation run comprises a defined number of time steps.	1,000
Number of customers	The number of customers and partners in the entire business ecosystem must be defined initially.	1,000
Number of partners		100
Initial platform market share	The model assumes the platform owner providing the technological core to be a significant player in the business ecosystem.	25%
Resources per partner	Each partner is equipped with a number of resources.	4
Owner's resources	The platform owner provides a number of extendable core resources.	30
Resource costs	Resources are costly to produce and maintain and thus associated with a cost.	5-15
Level of improvisation of resources	Resources are assumed to leave some room for improvisation when combining them (i.e., a number of the 5 features is not fixed)	1
Requirement payoff	Each met customer requirement is associated with a payoff.	$\mu=110$, $\sigma^2=10$
Requirement duration	Customers' requirements disappear after a number of time steps in the model.	$\mu=20$, $\sigma^2=5$
Service duration	Services disappear after a number of time steps in the model without being requested by customers.	$\mu=30$, $\sigma^2=10$
Customer-partner links	Customers and partners are assumed to have an existing local network. These links may also disappear after a number of time steps without interacting, i.e., local networks are not infinitely stable.	2
Partner-partner links		1
Life of links		100-150
Search costs	Search costs for resources and services may vary, particularly between local and distant search.	20-80
Renewal of resources	To account for continuous innovation, as well as the possibility to retire existing resources, after a number of ticks, partners renew and replace one of their resources.	100

Table 11. Initialization parameter settings

B.4.3 Experimentation

The definition of the main variables lays the foundation for experimentation. In a first round of experiments, all discussed variables are varied simultaneously to test their impact on profitability and generativity. In total, the defined parameter ranges in Table 10 yield $2 \times 3 \times 3 \times 21 = 378$ unique parameter combinations that were tested 25 each for a total of $25 \times 378 = 9,450$ simulation runs. Each simulation run in turn comprises 1,000 time steps. Figure 11 captures an excerpt of these results, displaying how varying levels of the platform owner's revenue share impact profitability and generativity in low and high complexity environments. To this end, the platform owner's revenue share (for every transaction within one simulation run) is varied across the entire range from 0%-100%

in increments of 5%. Complexity, varying from 0-20, is fixed at a level of 5 (low) and 15 (high). To account for the impact of investments into search matching and investments into modularity, both factors are fixed at medium levels (0.5) in the displayed results. This basic setup helps to understand whether the discussed investments are worthwhile in different kinds of environments.

Evidently, environmental complexity fundamentally impacts profitability and generativity outcomes on-platform. Generativity, i.e., the number of services created, is at or below 3 in low complexity environments, and profitability, i.e., value capture, is accordingly low (aside from a few outliers)¹. In high complexity environments, however, generativity is notably higher, reaching levels of 800 and beyond. Profitability, though not sharing the same curve progression, is also significantly higher. Interestingly, generativity levels are still stable when the platform owner's revenue share is increased to around 50%, where partners' profitability is already significantly decreasing. This may imply that although the value capture capacity for partners decreases on-platform, this does not automatically decrease their value creation capacity. More broadly, these findings suggest investments into search matching and investments into modularity may not be feasible in low complexity environments. In high complexity environments, however, such investments may be promising, even when the platform owner's revenue share increases beyond the discussed empirical examples of Apple (30%) and Salesforce (15%).

Validation of these results and the model in general stems partially from building on existing models (Davis et al., 2009; Haki et al., 2020). In addition, results like partners' profitability decreasing with an increasing platform owner's revenue share or generativity levels maximizing around 15%-35% whilst tapering off at the extremes are intuitive or in line with empirical examples.

¹ Individual services may be highly profitable. This may explain the few outliers displayed for profitability in a low complexity environment, despite low generativity levels.

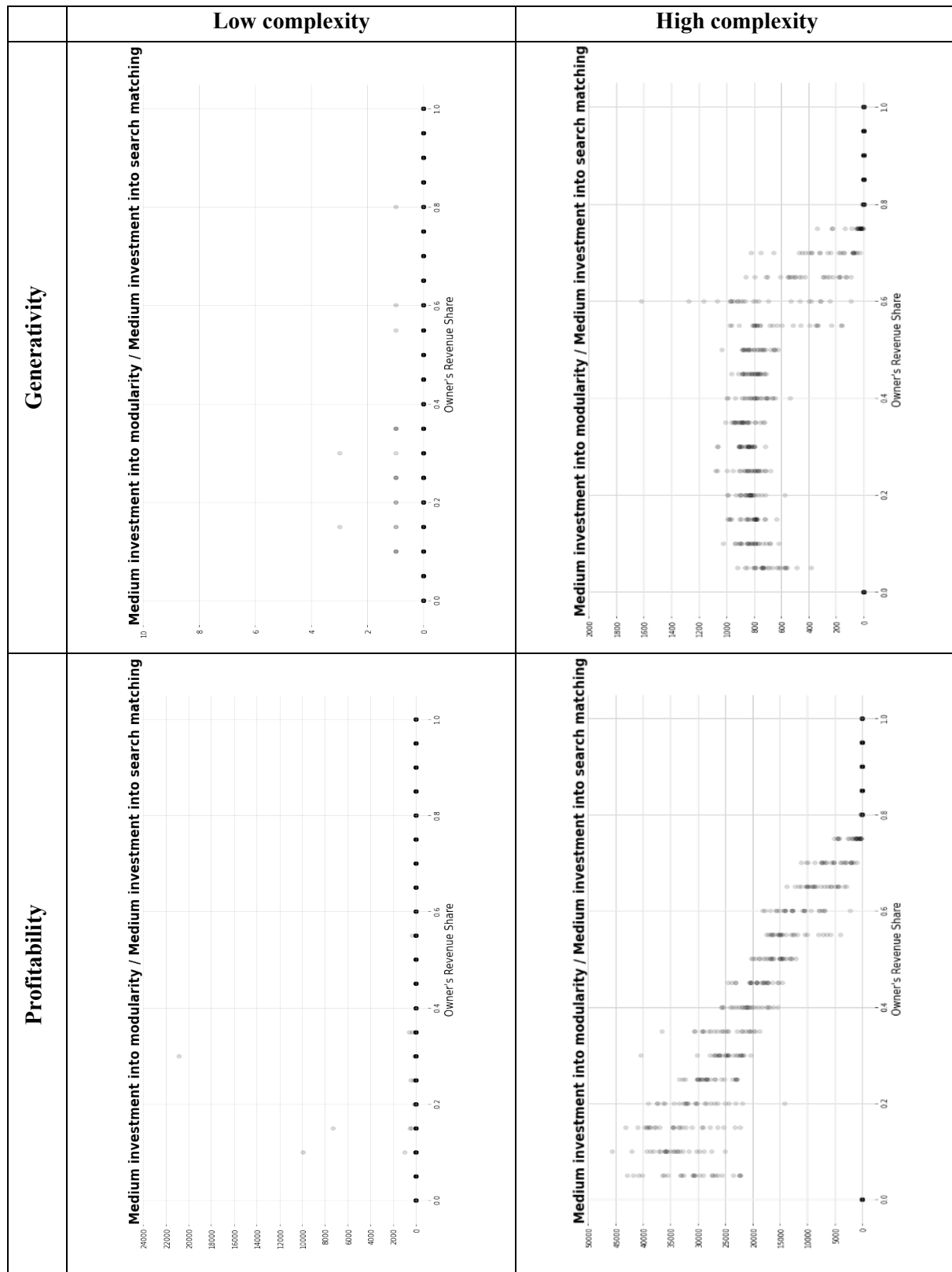


Figure 11. Profitability and generativity in low and high complexity environments

B.5 Discussion and conclusion

The aim of this study was to address some of the timely research gaps in platform literature, particularly contributing to the discussion on why platforms may fail or succeed and delineating the underlying conditions. Current research informs us that attracting a critical mass of complementary partners is critical to foster innovation (Ceccagnoli et al., 2012; Eaton et al., 2015) and so platform owners must orchestrate their platform ecosystem accordingly. Related studies point out that an increased number of partners on a platform may also have negative impacts like competitive crowding, however (Li & Netessine, 2020). Such contradictory findings suggest that there is a lack of understanding for the underlying mechanisms that impact the ultimate success of platforms. This study posits that the external environment plays a non-trivial role. Thus, an extendible agent-based simulation model is developed that enables the flexible testing of governance decisions and environmental conditions in the platform context to better understand why platforms may fail or succeed.

The model itself builds on some of the fundamental premises of platforms, e.g., their ability to decrease participants' search costs and resource costs associated with innovation. The study theorizes that the impact of decreased resource costs and search costs is delineated by platform owners' governance decisions and the competitive environment. Experimentation results indeed suggest that the complexity of the competitive environment significantly impacts relevant performance indicators of platforms. Investments into search matching, which have been found to improve performance in form of two-sided recommender systems (Malgonde et al., 2020), and investments into modularity, which are designed to increase flexibility (Yoo et al., 2010), do not appear to fulfill the desired effect in low complexity environments. Similarly, as the platform owner requires a greater or lower revenue share for the transactions on the platform, partners' performance is clearly impacted. Thus, the developed simulation model helps to delineate under which conditions platforms are particularly advantageous and thereby also assist practitioners in predicting the feasibility of costly platform-related investments.

In its current form, the model may be used to further investigate how value creation (in terms of the number of created services) and value capture (in terms of the profitability levels of platform partners) are affected by governance decisions regarding the investments into search matching and modularity, and at different levels of environmental complexity. In a first step, the parameter combinations may be extended to include

values across the entire range of all main variables. This would serve as a basis for conducting regression analyses on the individual and joint impacts of these variables and thus enable an extension of the developed findings. It would also require further validation efforts, i.e., extending the testing of the initialization parameters outlined in Table 11. Additionally, to compare performance in the broader business ecosystem, generativity and profitability can be tracked off-platform to better understand the ecosystem-level dynamics.

The model may also be extended in several ways. For one, to investigate competition between platforms, additional platforms may be modeled within the broader business ecosystem. This would allow for a deeper investigation of multihoming by platform partners under different environmental conditions, or the implications of different governance decisions for the performance of competing platforms, for example. In addition, the model could be extended by accounting for the explicit entry of a platform owner (Foerderer et al., 2018), through the acquisition of complementors or the integration of certain service offerings, for example. Again, the impact of such strategic decisions on crucial outcome variables like the overall generativity on the platform can thus be tested for different competitive environments. As platform evolution is a central topic in platform literature that needs further research (de Reuver et al., 2018), one may also investigate the impact of adapting these governance mechanisms over time by using the model to collect data throughout simulation runs, rather than at one point in time. In general, the model thus lends itself to several avenues of future research in the platform context.

Paper C – Platform over market: When is joining a platform beneficial?

Attribute	Value
Title	Platform over market: When is joining a platform beneficial?
Authors	Schmid, Marius ¹ ; Haki, Kazem ¹ ; Tanriverdi, Hüseyin ² ; Aier, Stephan ¹ ; Winter, Robert ¹ ¹ University of St.Gallen, Müller-Friedberg-Strasse 8, 9000 St.Gallen, Switzerland ² The University of Texas at Austin, Austin, TX 78705, U.S.A. marius.schmid@unisg.ch, kazem.haki@unig.ch, huseyin.tanriverdi@mcombs.utexas.edu; stephan.aier@unisg.ch, robert.winter@unisg.ch
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Table 12. Bibliographical metadata on Paper C

Abstract

Firms struggle to meet dynamically changing customers' needs. One challenge is to navigate a complex search space to find resources needed for innovations that meet customers' needs. Another challenge is to acquire the resources at lower costs than revenue opportunities to yield profitability. Digital platforms promise to address these challenges

better than the market by providing search matching capabilities and modular, reusable resources. We examine whether platforms improve innovation performance and profitability of firms better than the market, as assumed. Using agent-based modeling and simulation, we find that firms perform better in the market when environmental complexity is low. As environmental complexity increases, firms start to perform better on the platform than in the market, specifically when the platform owner remarkably invests in search matching and modularity capabilities. The study advances our understanding of the environmental conditions under which platforms could be superior or inferior to the market.

Keywords

Platform, Market, Complexity, Generativity, Profitability, Search matching, Modularity

C.1 Introduction

With the rise of the platform economy (Kenney & Zysman, 2016; Parker et al., 2016), we have witnessed not only the emergence of many born-platform businesses, but also the transformation of traditional businesses into digital platform businesses (de Reuver et al., 2018; Sandberg et al., 2020). For a traditional business attempting to transform into a platform ecosystem, a critical success factor is to offer platform capabilities that attract partner firms to develop and offer innovations on the platform rather than in the market. For example, the enterprise software corporation SAP has been trying to transition its on-premise offerings into cloud-based offerings on its SAP Cloud Platform². The success of the platform hinges on SAP's ability to attract independent software developers (ISVs), consulting firms, implementation partners, and training firms to the platform and enable them to develop innovative solutions on the platform. To the extent that the platform's resources and capabilities enable such partners to generate innovations that meet SAP customers' dynamically changing needs, the platform would survive and thrive. If partners choose to continue innovating through the market mechanism, the platform would not take off. In this study, we theorize and test the conditions under which partner firms that innovate on the platform can achieve superior (or inferior) generativity and profitability relative to partners who innovate off the platform through the market mechanism. Specifically, we examine how environmental complexity and

² In January 2021, SAP retired the SAP Cloud Platform brand, but its services are continued as part of the SAP Business Technology Platform.

platform's search matching and modularity capabilities affect generativity and profitability of partners.

Facing constant competition for market shares and, ultimately, profit in their given product markets (Porter, 1979) firms engage in innovative search for novel combinations of components or resources (Ganco et al., 2020) to address customers' needs. Firms' competitive environment is thus delineated by the dynamism of customers' requirements. As these requirements become more complex, the challenge to search and integrate resources increases and firms may depend on the innovative (re)bundling of various resources by other firms. A market then comprises a network of interdependent firms that combine their resources in response to customer requirements. Traditionally, firms employ the market mechanism, e.g., in form of bilateral contracts, alliances, or license agreements (Porter, 1985), to search and integrate each other's resources. Alternatively, firms may opt for joining a platform, which can potentially address the challenge of searching and finding affordable resources to create and appropriate value (Ceccagnoli et al., 2012; Wareham et al., 2014).

Platforms invest in search matching capabilities to enable partner firms to navigate the complex search space and modularity capabilities to increase reusability and reduce costs of resources (Malgonde et al., 2020; Yoo et al., 2010). Would such capabilities enable partner firms on the platform to increase generativity of innovations and become profitable? Although we expect such capabilities to be helpful in general, we also posit that their helpfulness could be contingent on the complexity level of the competitive environment. In a relatively simple environment, partner firms may not need sophisticated search matching and modularity capabilities. They may be able to search and find the resources they need affordably through the market mechanism. In more complex environments where it is more challenging to search and find affordable resources, a platform's capabilities could boost partners' generativity and profitability. The potential roles of environmental complexity, search, and modularity in firm performance is recognized (Tanriverdi et al., 2010). However, we do not know yet how these factors interact with each other to affect the generativity and profitability of partners on the platform. We address this gap.

We use an agent-based modeling and simulation method to study these dynamics. We model a platform, its surrounding market, customers who have complex requirements, and partner firms who choose to innovate on the platform or off the platform (i.e., in the market) to seize opportunities to meet the customers' requirements. The platform owner makes investments into modularity to reduce resource costs. As the platform owner

invests more into modularity, resources on the platform become more *reusable* (de Reuver et al., 2018; Yoo et al., 2010), and reusability reduces the average cost of resources available on the platform. The platform owner also makes investments into search matching capabilities to reduce search costs on the platform. The extent of search costs on the platform can vary depending on whether an automated search matching capability such as a recommender system is in place (Malgonde et al., 2020). As the platform owner increases its *investments into search matching*, search costs on the platform decline. Ultimately, partner firms must be able to generate innovations (value creation) that meet customers' requirements, and do so cost effectively, to become profitable (value appropriation) as they navigate dynamically changing customer opportunities in the competitive environments. We track both the *generative capacity* and *profitability* levels of partners on and off the platform as the platform's search matching and modularity capabilities are altered experimentally at low, medium, and high levels of *environmental complexity*. This allows us to observe not just the individual effects but also the interaction effects between environmental complexity, modularity, and search matching.

We find that platforms do not make a noticeable difference in partners' generativity and profitability when environmental complexity is low. In fact, partners innovating through the market mechanism do significantly better than partners innovating on the platform at a low level of complexity—regardless of the platform's investment levels into modularity and search matching. When environmental complexity reaches a medium level, partners innovating on the platform start to significantly outperform partners innovating in the market in both generativity and profitability. As the environmental complexity increases further to a high level, the platform still outperforms the market. However, the profitability levels of partners on the platform taper off to some extent, attesting to the challenges presented by high levels of complexity.

C.2 Conceptual foundation

C.2.1 Platforms' promised capabilities

Our understanding of platforms is informed by the sociotechnical view, considering platforms as a construct that comprises both technical and organizational elements (Blaschke et al., 2018; de Reuver et al., 2018). It revolves around a technological core, typically provided by the platform owner, that can be extended by loosely-coupled and self-organized third parties (platform partners) to jointly create value in the form of

innovation (Blaschke et al., 2018; Ceccagnoli et al., 2012; Eaton et al., 2015; Wareham et al., 2014; Yoo et al., 2010). In other words, the platform serves as a basis for an ecosystem that comprises complementary platform partners whose resources are bundled to co-create value in the form of innovative solutions to solve customers' problems (Blaschke, Riss, et al., 2019; Thomas et al., 2014).

Since resources are scarce and not completely imitable or substitutable (Bowman & Ambrosini, 2000), not all partner firms are endowed with and cannot afford to possess all resources (Gavetti et al., 2017). In complex competitive environments, partner firms might be facing a customer's requirement that requires technical know-how beyond their own possessed resources. Thus, they must search for other partners that can provide the required resources to jointly co-create an affordable and suitable service to meet the customer's requirement (Brunswicker et al., 2019; Haki et al., 2019; Lusch & Nambisan, 2015; Wei et al., 2020). Similarly, a customer might have such a complex or specific requirement that none of its known network of providers can meet, and thus must engage in an elaborate search process to find an affordable and suitable service (Levinthal, 1997; Wei et al., 2020).

Platforms can potentially help address these challenges as their *raison d'être* is built on three types of leverage, i.e., (i) production, (ii) transaction, and (iii) innovation leverage (Thomas et al., 2014). (i) Production leverage is based on the reuse and sharing of a collection of assets in the ecosystem that drive economies of scale and scope. The latter is enabled through *modularity* in the architecture of digital platforms, allowing resources to be decomposed and recombined (Tiwana, 2015a; Yoo et al., 2010) to eventually significantly reduce *resource costs* associated with the creation and maintenance of resources for platform partners (Thomas et al., 2014). (ii) Transaction leverage is based on manipulation of the market mechanism and market access, which drive transaction efficiency and reduce *search costs* in the exchange of services, i.e., driving economies of transaction and search. Digital platforms can contribute to reducing search costs by effectively facilitating and optimizing service and resource matching through their *search matching* function in the form of, for instance, two-sided recommender systems (Malgonde et al., 2020). Lastly, (iii) innovation leverage is also based on the sharing of assets among ecosystem participants (same as the production leverage), but with the goal of driving economies of innovation and complementarity. By providing access to the innovative capacities of a large pool of platform partners, digital platforms foster *generativity* (Cennamo & Santaló, 2019; Eaton et al., 2015; Henfridsson & Bygstad, 2013), which is defined as the platform's capacity to generate complementary

innovations from autonomous platform partners, extending the usage scope and value of the platform to customers (Cennamo & Santaló, 2019). Overall, platforms in general and digital platforms in particular provide easier access to affordable resources that reduce ecosystem participants' resource and search costs and facilitate their generative potential.

The aforementioned modularity (to decrease the resource cost) and search matching (to decrease the search cost) capabilities of digital platforms fostering generativity in the form of innovation are related to the creation of value on the platform. Nevertheless, next to, and as important as, value creation is the appropriation of the created value (Jacobides et al., 2006; Karhu et al., 2018) that sustains an economic benefit from innovation (Garcia-Castro & Aguilera, 2015). Therefore, platform partners, as third-party innovators, must perceive the participation on the platform as *profitable* to join and integrate their resources, and remain on the platform over time.

Existing research has already studied and provided insights into the individual and independent roles of platforms' modularity (Brunswick et al., 2019; Tiwana, 2015a; Yoo et al., 2010) and search matching (Malgonde et al., 2020) capabilities. In respect to the promised, inter-related types of leverage in platforms (Thomas et al., 2014), we still lack insights into the interactive effects of modularity and search matching capabilities as well as their impact on generativity and profitability capacities of a platform. Further, existing research generally acknowledges environmental complexity and assumes the idea of platforms to be uniformly superior to the market mechanism in complex environments (Malgonde et al., 2020; Sandberg et al., 2020). Therefore, in investigating the partner firms' choice to join a platform over conducting business through the market mechanism, we study the interactive effects of modularity and search matching capabilities and their impact on generativity and profitability capacities of a platform in different levels of environmental complexity in the platform ecosystem.

C.2.2 Complex adaptive systems: The theoretical lens

To account for the complexity of platform ecosystems and their surrounding environments, we employ complex adaptive system (CAS) theory as a theoretical lens.

CAS represent systems with emergent properties that result from their constituent participants' interactions and from their dynamic adaptation to an environment (Anderson, 1999; Holland, 1995). CAS are comprised of *agents*, *interactions*, and an *environment* that underlie their emergent behavior (Drazin & Sandelands, 1992; Holland, 1995; Nan, 2011). Agents are people, organizations, or objects that share certain *attributes* and

behavioral rules. Interactions reflect mutually adaptive behaviors by agents, realized through *connections* between and resource *flows* among agents. The environment, in turn, mediates interactions among agents. Platform ecosystems resemble the attributes of CAS as they comprise a multitude of loosely-coupled and self-organized actors that interact in an increasingly complex environment, and thus their properties emerge in an unforeseeable manner (de Reuver et al., 2018; Malgonde et al., 2020; Wareham et al., 2014).

C.3 Research method

Considering the complex nature of digital platforms and their ecosystems due to the engagement of a multitude of heterogeneous actors (e.g., owner, partners, customers), we opt for developing an agent-based simulation model. Simulation in general (Beese et al., 2019; Davis et al., 2007), and agent-based simulation in particular (Haki et al., 2020), is suitable to the study of complex phenomena. More specifically, the simulation method allows us to observe interactions amongst various agents in different scenarios, thereby enabling experimentations and what-if analyses (Nan & Tanriverdi, 2017). In our given setting, platform owners may simultaneously vary the level of investments in search matching and modularity capabilities, whilst customers' requirements may become increasingly complex, for example, fundamentally altering the competitive environment that partner firms navigate. Such decisions and circumstances will impact individual agents differently and yield system-level outcomes that we are interested in. Capturing the simultaneous effect of various variables and the resulting complexity with conventional empirical data may not be feasible, as the collection of data in real-life scenarios may take years and experimentations might be impossible.

The developed simulation model is guided by the empirical example of SAP's Cloud Platform (merely based on secondary data such as papers as well as publicly available articles, whitepapers, videos) and existing simulation models (Davis et al., 2009; Haki et al., 2020), which are relevant to the objectives of our study. Moreover, the research process follows the simulation methodology (Davis et al., 2007; Sargent, 2005) as outlined in this section.

The simulation model captures a market comprising various partner and customer firms that can conduct their economic transactions via market mechanism or via a digital platform. In line with our study's objective to compare the performance of the digital platform and the market under varying environmental complexity, partners and customers can decide to conduct business and source their required services on the platform or in

the market, depending on which option they perceive to be more beneficial. We account for the production and transaction leverage of platforms by implementing the platform owner's investments into modularity and search matching, respectively. Thereby, levels of search costs and resource costs on the platform can be reduced by a factor of 0.00-1.00, respectively (i.e., both costs can be reduced up to 100% compared to the market). As these two capabilities directly impact the value creation on the platform, we track their impact on generativity as the number of services created (reflecting the innovation leverage). Simultaneously, due to the criticality of value appropriation for partners' choice of platform over market, our model also includes partners' obtained profitability. It is noteworthy that the simulation model tracks generativity and profitability both on the platform and in the market to enable a comparison. As such, the simulation model captures the effects of platform owner's investments into modularity and search matching as independent variables on the model's dependent variables of generativity and profitability. Lastly, following existing simulation models (Davis et al., 2009; Haki et al., 2020), our model accounts for the complexity of the environment in which the development of the platform ecosystem occurs, to capture how differently the simulated system behaves under different environmental conditions.

C.3.1 Simulation model design

In line with CAS theory, our simulation model comprises agents, interactions, and the environment.

C.3.1.1 Agents

In general, agents can represent different entities, including organizations (Nan, 2011). They are defined by *attributes* that can change over time and make them distinguishable, and by *behavioral rules* that guide their attributes and behaviors, and thereby the process of improving their fitness in a given environment (Haki et al., 2020; Nan, 2011). The model comprises four types of agents: customers and partners (as learning- and utility-based agents) as well as resources and services (as reflex agents). Customers have requirements from their environment for which they search for matching services that they can afford based on their budget. Partners on the other hand create these services by combining their own and other partners' resources to form the required services and intend to sell them to customers at a profit. To afford a service, customers' budget must exceed the sum of the search cost for finding the service and the cost of purchasing the service. For partners, in turn, transactions are only profitable if the prospective payoff exceeds the sum of resource costs for building and maintaining a service's resources, as

well as possible search costs associated with the search for other partners' resources when they are not able to fulfill the requirement with only their own resources.

C.3.2 Interactions

The model accounts for interactions amongst these learning- and utility-based agents, as well as amongst the reflex agents. In general, interactions in CAS comprise the interacting *agents*, *connections* or relational links among these agents, and *flows* of resources that move amongst the agents (Haki et al., 2020; Nan, 2011). In our model, interactions are driven by the search processes of customers and partners to ultimately generate innovation (Ganco et al., 2020). Customers search for services that match their requirements, whereas partners search for resources to integrate, in order to generate services that meet customers' requirements when they are not able to do so with only their own possessed resources. Thus, the starting point is always a customer's requirement. If an affordable service matching a customer's requirement can be found, the requirement is fulfilled, and partners' search process will not be triggered. If, however, customers' requirements cannot be met by an existing service, customers will signal the need to develop a new service to known partners. The corresponding partners may in turn be able to meet the requirement by recombining their own resources, or engage in a search process for other partners' resources to mix and match with their own (Ganco et al., 2020), attempting to form a new service that matches the customer's requirement. Following Levinthal's (1997) conception of search, both customers and partners first engage in a local search within their immediate neighborhood (customers for services and partners for resources, respectively), before conducting distant search and moving beyond this immediate neighborhood. In our model, local search is conducted within the existing network of customers and partners (captured through existing *connections*), whilst distant search is conducted either in the market or on the platform. Depending on the level of investments into search matching, the associated search costs can be significantly reduced on the platform, increasing the probability of a transaction.

C.3.3 Environment

The environment represents the medium in which agents interact (Haki et al., 2020; Nan, 2011). We adopt the conceptualization of the environment as outlined by Davis et al. (2009), such that the customers' requirements that drive all search processes shape the level of complexity in the environment. In the enterprise software example, a customer may, for example, require a routine update of or a small add-on for its inventory management system. Such low complexity tasks may be solvable by a single partner firm,

meaning resource integration and collaboration amongst numerous firms is not needed. A customer requirement may, however, entail the development and integration of several systems/modules along with corresponding implementation and consultancy services. In this situation, a single firm may not have all resources and must integrate other partner firms' (e.g., industry or technology experts') resources to address the higher complexity customer requirement. Therefore, as the challenges faced by partner firms in their environment, in form of customer requirements, become more complex, interconnectedness and interdependencies amongst resources and firms increase, yielding a higher system-level complexity (Tanriverdi et al., 2010) that must be tamed or harnessed by partner firms.

More concretely, the simulation model captures environmental complexity as the minimum number of features in customers' requirements that need to be successfully addressed by a partner's service (Davis et al., 2009; Haki et al., 2020). Operationally, both services and requirements are defined by 20-bit vectors, or feature sets (e.g., [01100011110001110101]). In a possible transaction, each of the 20 features of a service is compared to the feature in the same position of the requirement (Davis et al., 2009). If, for example, the complexity level is set to 10, at least 10 of the features of services and requirements must match to meet the requirement. The premise behind this is that, as the environment becomes more complex, the difficulty of capturing fleeting opportunities increases (Davis et al., 2009). Complexity thus varies from 0-20 and thereby dictates the competitive environment for all agents.

Table 13 outlines the simulation model's components in more detail, along with literature references for the individual design choices.

Component		Description	Literature
Agents	Customers (learning- and utility-based agents)	Attributes: Customers have service requirements and search for matching services on the platform or in the market. Behavioral rules: When customers have a service requirement, they (1) conduct local search for fitting services in their existing partner network. If successful (enough matches between requirement and service), they choose a random, affordable service, considering both service price and search costs. Otherwise, they (2) conduct distant search on the platform or in the market. If both searches are unsuccessful, customers trigger the partner search process.	(Brunswick et al., 2019; Davis et al., 2009; Ganco et al., 2020; Haki et al., 2020; Levinthal, 1997; Wareham et al., 2014)
	Partners (learning- and utility-based agents)	Attributes: Partners are endowed with particular (random in the model) sets of resources that are combined to create services, on the platform or in the market, to fulfill customer requirements. Behavioral rules: When partners' search is triggered, they (1) recombine their own resources and conduct local search for resources in their known partner network. Of any configurations that match the customer's requirement, a random, affordable resource is integrated, considering both search and resource costs. Otherwise, partners (2) conduct distant search in the market, as well as on the platform, if they are a platform partner. If search is successful, customers can choose a random,	(Blaschke et al., 2018; Brunswick et al., 2019; Ganco et al., 2020; Gavetti et al., 2017; Haki et al., 2020; Levinthal, 1997; Malgonde et al.,

		affordable service. Partners obtain payoffs when services to which they contribute are used and incur costs for building and maintaining resources. Partners join the platform when they receive enough positive signals from their local network and will leave the platform if they perceive to gain more in the market.	2020; Wareham et al., 2014; Yoo et al., 2010)
	<i>Resources (reflex agents)</i>	Resources have a set of features (5-bit vectors of 0s and 1s, e.g., [01100]) and are combined to create services. The feature sets are not entirely fixed and allow room for improvisation by partners. Resources have an associated, randomized costs. To account for innovation and dynamism in the environment, resources are renewed periodically throughout individual simulation runs.	(Ganco et al., 2020; Gavetti et al., 2017; Haki et al., 2020; Karhu et al., 2018)
	<i>Services (reflex agents)</i>	Services are used by customers to fulfill their requirements. Each service consists of four resources (while each resource is a 5-bit vector, see <i>resources</i>) that define its 20 features. On the platform, one of these resources is provided by the platform (i.e., contributed by the platform owner). The other three resource sets are contributed by platform partners. All firms have the possibility to search for and offer their resources in the market as well.	(Ceccagnoli et al., 2012; Constantinides et al., 2018)
	<i>Owner</i>	The owner provides base resources for all services offered on the platform. It incurs costs for maintaining these resources and receives payoffs from services used on its platform, depending on the defined revenue share ³ .	(Karhu et al., 2018; Wareham et al., 2014)
<i>Interactions</i>	<i>Customer - partner</i>	Connection: Customers know partners in their local network. New links are established after a successful customer distant search. Flow: Customers communicate their service requirements to partners; partners share existing services.	(Ganco et al., 2020; Gavetti et al., 2017; Malgonde et al., 2020; Srinivasan & Venkatraman, 2010; Wareham et al., 2014; Yoo et al., 2010)
	<i>Partner - partner</i>	Connection: Partners have an existing local network. New links are established after a successful partner distant search. Flow: Partners share resources and experiences on the platform with known partners in their network.	
	<i>Partner - resource</i>	Connection: Partners create and operate resources. Flow: Partners define and improvise the features of resources.	
	<i>Resource - service</i>	Connection: Combinations of resources yield services. Flow: Combined resource sets define a service's feature set.	
	<i>Partner - service</i>	Connection: One single partner owns each service. Flow: The partner who owns a service provides the main resources and decides when to reconfigure its service.	
	<i>Partner - owner</i>	Connection: The platform owner provides resources for service creation. Flow: Partners on the platform use the owner's resources to create services with or without other partners on the platform.	
<i>Environment</i>		Customers have varying service requirements that delineate the environmental specificities of a platform ecosystem. The environment is shaped by the complexity of requirements.	(Davis et al., 2009)

Table 13. Simulation model components

C.3.4 Validation and experimentation

As part of the simulation model development process, the model requires validation and verification (Davis et al., 2007; Sargent, 2005). These aspects are addressed by building the simulation model on existing, established ones (Davis et al., 2009; Haki et al., 2020). Several design decisions such as the conceptualization and operationalization of the

³ In practice, we observe variations in the owner's revenue share, such as Apple's 30% on the Appstore (Oh et al., 2015), or Salesforce' 15% on its AppExchange. Therefore, we randomize the platform owner's revenue share in the simulation model within a range of 10-30% for each transaction.

environment (Davis et al., 2009) as well as conceptualization and operationalization of agents and their interactions (Haki et al., 2020) build on already validated approaches and models. In addition, we carried out reliability and degeneracy tests that demonstrated the model's internal consistency and robustness (Davis et al., 2007) over more than 3 million simulation runs (for initialization parameters and tested ranges, see Appendix A).

The simulation experiments were designed to test how varying levels of platform owner's investments into search matching (for decreasing search costs, ranging from 0.00-1.00) and modularity (for decreasing resource costs, ranging from 0.00-1.00) affect the platform's generativity and profitability, compared to the market, as the competitive environment's complexity is altered (see Table 14). More specifically, complexity was fixed at low (8), medium (12), and high (16) levels. These thresholds were determined based on the results of degeneracy tests, where complexity was varied across the entire possible range. The selected values revealed meaningful changes in the measures of the tested outcome variables and are operationally feasible for low, medium, and high levels of complexity, respectively (see Section B.4).

Experiment	Descriptions
Individual effects	For each level of complexity (= 3 variations), one of the independent variables was varied from 0.00 to 1.00 in increments of 0.01 (= 101 variations), whilst the other was fixed to low (0.05), medium (0.5), and high (0.95) levels (= 3 variations). Each parameter setting was tested 50 times for a total of $3 \times 101 \times 3 \times 50 \times 2 = 90,900$ simulation runs (see excerpt of results in Figures 12a and 12b).
Two-way joint effects	For each level of complexity (= 3 variations), one of the independent variables was varied from 0.00 to 1.00 in increments of 0.01 (= 101 variations), whilst the other was varied from 0.00 to 1.00 in increments of 0.05 (= 21 variations). Each parameter setting was tested 50 times for a total of $3 \times 101 \times 21 \times 50 \times 2 = 636,300$ simulation runs (see results in Figures 12 and 13).

Table 14. Experiment setup (each simulation run comprised 1,000 time steps)

C.4 Results

In a first step, in analyzing the partners' choice to do business via market mechanism or on the platform, we compare the overall performance of the platform and the market under different conditions. While Figure 12a plots partners' average profitability, Figure 12b captures generativity, both on the platform and in the market. Both figures depict the effects of platform owner's investments into modularity, which attract partners to the platform by reducing their resource costs. Platform owner's investments into search matching, which in turn attract partners to the platform by reducing their search costs, is fixed at medium (0.50) levels⁴. The environmental complexity is fixed at low,

⁴ In testing for the effect of investments into modularity when fixing investments into search-matching at low (0.05) and high (0.95) values, we found very similar patterns.

medium, and high levels. In effect, the analysis revolves around defining the conditions under which partners choose to join the platform over conducting business in the market, and the implications this has for the performance of the platform.

Even though our experiments collected data under various levels of investments into modularity, investments into search matching, and environmental complexity, we observed the effects of environmental complexity to be the differentiating factor for partners' choice to stay in the market or to move to the platform. First, more partners move to the platform as the environmental complexity rises. For example, when environmental complexity is high, on average 71% of all partners join the platform, as opposed to 24% when complexity is medium. Second, both the partners' average profitability and generativity on the platform are considerably below the market in low complexity environments but exceed the market at higher levels of complexity (when comparing the three rows in Figures 12a and 12b). In providing further insights into these observations, Figures 13 and 14 plot the partners' average profitability and generativity on the platform at low, medium, and high levels of complexity, while simultaneously varying the levels of investments into search matching and modularity. In what follows, we provide the main findings and insights of the aggregated analysis, centered around the varying levels of complexity in the competitive environment.

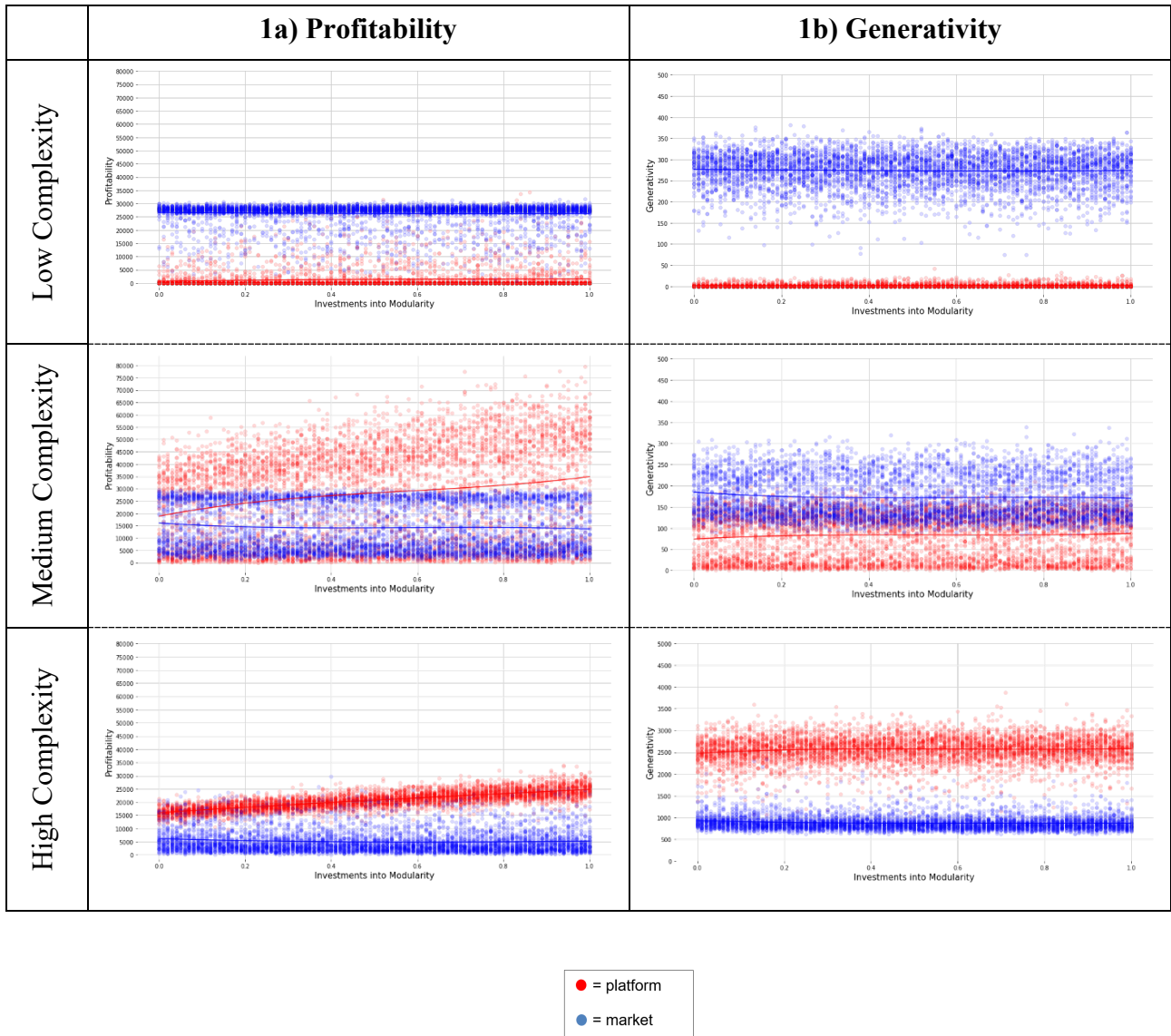


Figure 12. Profitability and generativity effects of platform vs. market

C.4.1 Low complexity environment

In a low complexity environment (green plane, Figure 13), partners' average profitability on the platform is at its lowest level. Even though the relationship between profitability and investments into modularity has a slight positive slope, the impact of investments into modularity on profitability can be considered as negligible. Similarly, we observed that the relationship between profitability and investments into search matching is almost flat. These results indicate that the platform owner's investments into modularity and search matching do not have any noticeable impacts on the partners' average profitability on the platform at a low level of environmental complexity. Contrarily, partners achieve considerably higher profitability in the market as depicted in Figure 12a. At a low level of complexity, generativity alike remains very low on the platform

(green plane, Figure 14) and, compared to the situation on the platform, the market is considerably more generative (Figure 12b). The latter indicates that firms are well equipped in the market to meet customers' needs without the aid of a platform's promised capabilities.

C.4.2 Medium complexity environment

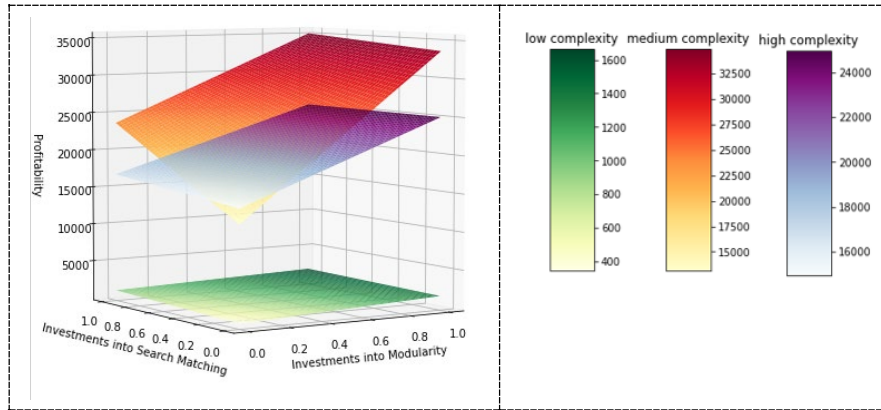


Figure 13. Profitability effects on the platform

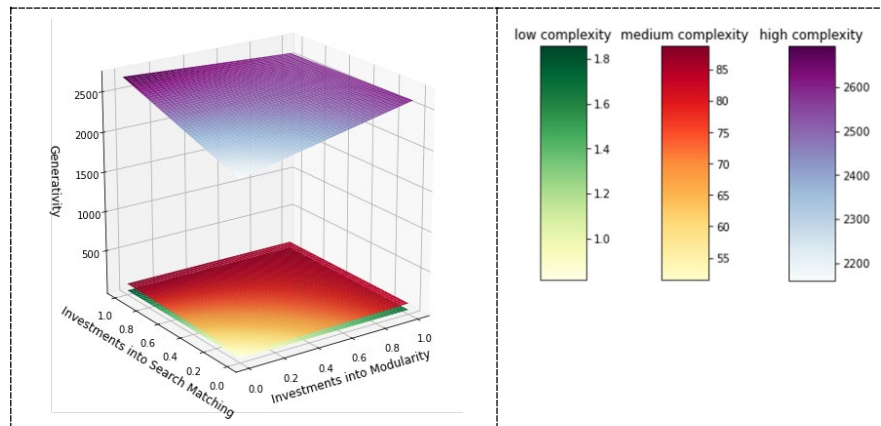


Figure 14. Generativity effects on the platform

C.4.3 High complexity environment

As the complexity in the environment increases further to a high level (violet plane, Figure 13), we observe that partners' average profitability on the platform declines. Partners still obtain profitability, but not as high as the profitability levels obtained under a medium level of complexity (orange plane, Figure 13). In highly complex environments, the variety and changes in customers' needs and requirements increase further. For partners innovating through the market mechanism, it becomes much more challenging to generate innovations that match the fleeting customers' needs. Therefore, to address the aforementioned challenge, significantly more partners are attracted to the platform

(around 71% of all partners, on average) to take advantage of the platform's search matching and modularity capabilities. However, such a mass move leads to crowding on the platform and increases rivalry among the partners on the platform, that in turn reduces partners' profitability. In this situation, the platform's search matching capability provides advantages to partners to innovate and improvise on the platform, but partners concurrently face the challenge of searching and finding affordable resources that might prove useful in meeting the fleeting customers' needs. This is where the platform's modularity capability comes in handy to make resources on the platform reusable and reduces resource costs to foster the generation of more innovations. Thus, the average generativity of innovations on the platform increases significantly at a high level of complexity, as shown in Figure 12b and Figure 14 (violet plane). Even though the production of more innovations increases the chances of matching the variety of customers' needs, partners' average profitability takes a hit because of the costs of the increased generativity and the intensified competition on the platform. As such, compared to a medium level of complexity, a high level of environmental complexity reduces partners' average profitability on the platform, but the platform still outperforms the market, as illustrated in Figure 12a.

In sum, the platform is most effective in improving partners' profitability levels at a medium level of environmental complexity. In addition, at a medium level of environmental complexity, partners' profitability can be maximized when platform owner's investments into modularity and search matching are high.

C.5 Discussion and conclusion

With the phenomenal and sustained success of some digital platforms such as Amazon, Google, Apple, and Facebook, a taken-for-granted assumption in academia and practice is that platforms might outperform the market. The findings of this study challenge this assumption and explain the conditions under which the assumption is valid or not. By modeling partner firms' search process for resources needed to meet customers' evolving requirements under different environmental conditions, we find the platform not to be uniformly superior or inferior to the market. The level of complexity in the environment determines when the platform outperforms or underperforms the market. On average, the platform is superior to the market at a medium level of complexity, in terms of profitability, and at a high level of complexity, in terms of generativity. On the other hand, the platform is found to be inferior to the market, with regards to both profitability and generativity, at a low level of complexity.

C.5.1 Contributions to research

Prior studies have examined how search matching and modularity independently affect generativity and profitability outcomes of firms in platform settings (Brunswick et al., 2019; Malgonde et al., 2020; Tae et al., 2020; Thomas et al., 2014). They also acknowledged that environmental complexity could be an important driver of generativity and profitability outcomes (Malgonde et al., 2020; Sandberg et al., 2020). However, prior studies have not examined whether and how these three variables interact with each other. This study addresses this gap by showing that complexity, search matching, and modularity interact with each other to jointly affect generativity and profitability outcomes. As complexity science suggests, these interactions are non-linear and their outcomes are emergent and non-predictable (Anderson, 1999; Holland, 1995). By examining the average profitability and generativity levels of partner firms on the platform and in the market, we can observe the conditions under which the platform outperforms the market.

Furthermore, complexity was found to be an important contingency affecting the relationships amongst factors that have been studied in the platform context. For example, existing research provides insights into how generativity is impacted by the number of platform partners (Boudreau, 2012) or changes to platforms' search design (Tae et al., 2020), as well as why limiting generativity may be beneficial (Casadesus-Masanell & Halaburda, 2014), but it does not take into account the role of complexity. Our findings imply that typical antecedents of generativity, such as revenue sharing (Karhu et al., 2018), may perform considerably differently depending on the level of environmental complexity. Our study also has implications to CAS. Although CAS theory provides a solid basis in capturing the constituent components of complex systems and in explaining inherent challenges and properties of complex systems (e.g., Anderson, 1999), it does not elaborate on the means to tame and harness complexity. As such, our study complements existing discussions on complex systems by demonstrating platforms can help firms tame complexity specifically in medium to high complexity environments.

C.5.2 Contributions to practice

One implication of the findings is that platforms may not be uniformly disruptive to all industries. The results suggest that partner firms operating in the market could outperform partner firms operating on the platform in an industry that is characterized by low complexity. For practitioners, this implies that running or joining a platform in a competitive environment characterized by low complexity would yield no benefits as neither

search matching nor modularity capabilities of platforms would be valuable for them. Thus, incumbents may not face a threat of disruption by platforms in low complexity environments and their investments in entering the platform business may not pay off. The latter is an important consideration as more and more incumbents seek to adopt a platform strategy to establish their position in the digital economy.

Platforms do offer a strong value proposition to partners by maximizing profitability in medium to high levels of environmental complexity. In case of the SAP example, independent software developers (ISVs) as platform partners can reap significant profits from taking advantage of the platforms' search matching and modularity capabilities. However, the initial success of a handful of partners could attract significantly more partners to the platform and lead to the decline of profitability on the platform. The platform provides modular resources and search matching capabilities so that ISVs can find and configure resources to meet evolving customer needs. Because of such platform capabilities, ISVs, on average, can be more generative and obtain higher profitability than firms in the market. However, the same platform resources and capabilities are available to a long tail of ISVs. The more ISVs join the platform, the more crowded the platform becomes. The increasing intensity of rivalry puts pressure on the profitability of the ISVs. As a result, profitability declines on average and ISVs experience wide variability in performance outcomes. When partners on the platform outperform the partners in the market, on average, the platform owner, such as SAP, can benefit, on average.

C.5.3 Limitations and future research

The proposed theory and results have some boundary conditions and limitations. First, we theorized and modeled a B2B platform. Whether the proposed theory and results would generalize to B2C platforms would need to be investigated in future work. Second, we incorporated customers into our model by modeling their requirements and presenting them as opportunities to partners on and off the platform. We, however, did not model potential heterogeneity in customer behavior. Future studies could also model differences in customer motivations and behaviors and assess how they might affect outcomes. Similarly, future studies could expand on partners' motivations to join a platform. For theorization purposes, we focus on profitability as the ultimate goal of transacting on a platform, but partners may, as an intermediate step, also attempt to expand their market shares. Lastly, we randomized the platform owner's revenue sharing arrangement with partners as well as partners' responsiveness or agility to seize

opportunities. Due to randomization, these factors are unlikely to pose alternative explanation threats to our results. Future research can assess if platform's revenue sharing arrangement and partners' agility interact with search matching, modularity, and complexity constructs examined in this study.

Paper D – Taming complexity in business ecosystems: Investigating the role of platforms

Attribute	Value
Title	Taming complexity in business ecosystems: Investigating the role of platforms
Authors	Schmid, Marius ¹ ; Haki, Kazem ¹ ; Tanriverdi, Hüseyin ² ; Aier, Stephan ¹ ¹ University of St.Gallen, Müller-Friedberg-Strasse 8, 9000 St.Gallen, Switzerland ² The University of Texas at Austin, Austin, TX 78705, U.S.A. marius.schmid@unisg.ch, kazem.haki@unig.ch, huseyin.tanriverdi@mcombs.utexas.edu; stephan.aier@unisg.ch
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Table 15. Bibliographical metadata on Paper D

Abstract

Successfully innovating in business ecosystems requires firms to tame the complexity in their competitive environment. Firms must be generative enough to meet dynamically changing customer needs and reap profitability from their innovation efforts. Platforms

promise to foster both generativity and profitability through their offered capabilities. Employing an agent-based simulation approach in modeling a platform within its ecosystem, we analyze the effectiveness of platform capabilities under varying conditions. We find complexity in the ecosystems to be a contingency for generativity and profitability effects of platforms. When complexity is low, firms are able to successfully innovate on their own without help from platforms. As complexity increases to medium and high levels, however, firms face higher adaptive tension and platform capabilities become more desirable and effective to generate profitable innovations. We thereby challenge the assumption of platforms being disruptive to all types of environments and delineate under which conditions platforms help taming complexity.

Keywords

Platform, Complexity, Simulation, Generativity, Profitability

D.1 Introduction

Business ecosystems are the venues of innovation in which a multitude of loosely-coupled firms interact with one another (Jacobides et al., 2018). The collaborating firms bundle their complementary resources to co-create and configure customer-facing offerings (Lusch & Nambisan, 2015). The flow of heterogeneous opportunities imposed by customers and the rate at which new opportunities emerge specify the complexity of the environment in which innovation occurs (Davis et al., 2009; Haki et al., 2020). Such a complexity in business ecosystems entails the need for generativity of innovation, to promptly respond to various customers' requirements, and profitability out of innovation, to make the generation of innovation economically sustainable (Ahuja et al., 2008; Jacobides et al., 2006). Due to this and thanks to advances in digital technologies, platforms have become a preeminent organizational logic in business ecosystems (Jacobides et al., 2018; Parker et al., 2016; Thomas et al., 2014) in which, by means of a digital platform, the platform owner orchestrates the curation and integration of resources in the ecosystem to foster both generativity and profitability of innovation (Ceccagnoli et al., 2012; Jacobides et al., 2018; Wareham et al., 2014). The considerable success of digital platforms across various industries (Parker et al., 2016) has propagated the implicit assumption of the platform organizing logic being superior to the traditional off-platform organizing logic for innovation (de Reuver et al., 2018; Gawer & Cusumano, 2008; Yoo et al., 2010). In contributing to this discourse and to allow for a more nuanced discussion on the success of platforms in general, our study challenges the above

assumption by investigating under which conditions platforms' core capabilities serve the purpose of fostering generativity and profitability in business ecosystems.

To this end, we employ an agent-based simulation approach to model a platform logic in its business ecosystem. More specifically, we model an innovation platform (Cusumano et al., 2019) inspired by the SAP's Business Technology Platform (SAP BTP). We conduct a series of simulation experiments to theorize on the conditions under which investments into platform capabilities bring about the expected impact on generativity and profitability. We particularly find the complexity level of the business ecosystem to be a moderating factor for a platforms' production-related and transaction-related capabilities to take effect. Thereby, complexity presents an important contingency for the role of platforms that yields several avenues for future research.

D.2 Research background

D.2.1 A complexity science view on business ecosystems

Within a business ecosystem, innovation is a process of search for novel combinations of resources (Ganco et al., 2020) to ultimately serve market demands (Ahuja et al., 2008). It is viewed as a collaborative, co-creational process in a network of firms, where each firm offers a resource (e.g., physical resource, production knowledge, customer knowledge) or a set of resources that can be combined to create innovative offerings in response to customer requirements (Lusch & Nambisan, 2015). Thus, resource integration among firms is the fundamental way to innovate (Ahuja et al., 2008; Ganco et al., 2020; Lusch & Nambisan, 2015). Building on complexity science, complexity in innovation is a function of the *number of firms* involved in innovation, the *degree of interconnectedness among firms*, and the *environment* in which innovation occurs (Anderson, 1999; Cilliers, 1998; Holland, 1995).

Assuming that not all firms possess all resources required for innovation (Gavetti et al., 2017), resource integration may span across several firms (Ganco et al., 2020; Lusch & Nambisan, 2015). Since resources are costly to imitate or substitute (Wernerfelt, 1984), in their quest for innovation, each firm constantly searches for resources to be integrated with its own resources to generate affordable innovation (Ahuja et al., 2008; Ganco et al., 2020; Gavetti et al., 2017). Naturally, this process is impeded by *transaction costs* in finding firms with the needed resources and establishing trust between the

collaborating firms, as well as *production costs* since creation, acquisition, and maintenance of resources incur cost (Benslimane et al., 2005; Wolter & Veloso, 2008).

Further, firms engage in the exchange of resources among one another to achieve superior performance and synergy (Gavetti et al., 2017; Lusch & Nambisan, 2015). Thus, the co-creation of innovation generates mutual dependencies and raises the degree of interconnectedness among firms (Anderson, 1999; Cilliers, 1998). That is, innovation becomes highly contingent on the resource contribution by each firm and on how effectively resources are integrated (Ganco et al., 2020). As such, interoperability to enable resource integration among firms and to facilitate the interaction of firms becomes the bottleneck of innovation.

Finally, interactions among firms for resource integration occurs in an uncertain and hypercompetitive environment (D'Aveni et al., 2010) delineated by dynamically changing customers' requirements. In such settings, where competitive advantage is no longer sustainable (Nan & Tanriverdi, 2017), firms need to constantly adapt to the dynamism of their competitive environment (Holland, 1995). Therefore, to cope with complexity in the business ecosystem, interacting firms need to enhance their *generative capacity* through constantly re-bundling their resources for continuous innovation.

Complexity science thus offers a basis to understand complexity of innovation in business ecosystems and its inherent challenges due to involvement of a multitude of heterogeneous firms that form mutual dependencies by interacting with one another to serve the dynamically changing customers' requirements. Complexity science does not propose how to tame complexity of innovation and address its associated challenges, however. At high levels of complexity, the outcomes from the innovation process become emergent that are functions of how a firm and its ecosystem of connected, mutually dependent partners behave (Anderson, 1999; Cilliers, 1998; Holland, 1995; Tanriverdi & Du, 2020). The inter-firm relations could be non-linear, innovation could be difficult to decompose into its constituent resources, and outcomes could be unpredictable (Nan, 2011; Nan & Tanriverdi, 2017). These challenges can increase production costs as production of an innovation becomes highly challenging, risky, and costly in more complex environments. Likewise, transaction costs can increase as it becomes challenging, risky, and costly to find, gain trust in, work with, and transact with other firms to bundle and re-bundle the resources required to generate an innovation that meets customer requirements.

D.2.2 Platforms to tame complexity in business ecosystems

Over the past years, platforms have changed the organizing logic of business ecosystems for innovation with their considerable success in various industries (de Reuver et al., 2018; Parker et al., 2016; Sandberg et al., 2020). Cusumano et al. (2019) generally distinguish between transaction platforms that serve as intermediaries or marketplaces for existing products and services, and innovation platforms, where new innovations are generated. In settings of innovation platforms, a platform becomes the nexus of a so-called platform ecosystem through which resources contributed by a focal firm (i.e., a platform owner) are effectively integrated with complementary resources of a plethora of other firms (i.e., platform complementors/partners) for innovation (Cusumano et al., 2019; Wareham et al., 2014). The context of enterprise software ecosystems provides several evidences for change in the organizing logic of ecosystems for innovation, where, for example, market leader SAP has adopted a platform logic with its SAP BTP. In effect, platforms are employed as a means to tame complexity of innovation and to address its associated challenges (Malgonde et al., 2020; Sandberg et al., 2020) thanks to their offered capabilities. These capabilities revolve around three types of leverage that the notion of platforms in general is built upon, namely production, transaction, and innovation leverage (Thomas et al., 2014).

Production leverage is based on the reuse and sharing of a collection of resources in the ecosystem that drive economies of scale and scope (Thomas et al., 2014). After adopting a platform logic, SAP offers its ERP system on a cloud platform and opens the access to the platform to its partner firms. For partner firms this means that, instead of developing extensions that are inextricably intertwined with the core ERP and are customer-specific, they can develop modular software-as-a-service applications and integrate them with the core ERP via APIs. The latter leverages the reusability of developed modules across various customer organizations, which used to be a severe struggle for partner firms to expand their customer base. Therefore, reusability and modularity of applications thanks to the use of standardized interfaces on a platform (Tiwana, 2015a) evidently facilitates compatibility (Ceccagnoli et al., 2012) and decreases *production costs* for partner firms. Existing research on platforms exemplifies platform capabilities related to production leverage by discussing, for instance, standardization of the platform core and interfaces, or modularity and interoperability of platforms to share resources and to facilitate the integration of resources (Boudreau, 2017; Brunswicker et al., 2019; Ceccagnoli et al., 2012; Cennamo et al., 2018; Tiwana, 2015a), as well as platform

owners' subsidizing partner firms' access to the platform (Gawer & Henderson, 2007; Lan et al., 2019).

Transaction leverage is based on the manipulation of market pricing mechanism and market access to drive economies of transaction and search (Thomas et al., 2014). SAP's platform leverages the fast and effective matching of customers' requirements with existing offerings on the platform. More importantly, when the ecosystem is exposed to a new requirement, partner firms can search and find affordable resources, contributed by other partner firms and the platform owner, that can prove useful in developing innovations to meet the evolving requirements of customers. Thus, transaction leverage of a platform considerably decreases *transaction costs* for both partners and customers. Existing research on platforms exemplifies platform capabilities related to transaction leverage by discussing, for instance, platform's search design to focus on customer feedback (Tae et al., 2020), installing two-sided recommender systems (Malgonde et al., 2020), as well as certifying or promoting partners and complements to establish trust among firms (Rietveld et al., 2019; Rietveld et al., 2018).

Innovation leverage is also based on the sharing of resources among firms in the ecosystem, similar to production leverage, but with the goal to drive economies of innovation and complementarity (Thomas et al., 2014). After adopting a platform logic, SAP orchestrates a large pool of resources, contributed by a wide range of partner firms, and leverages their integration with its own resources to foster innovation in response to customers' various and ever-changing needs. In that regard, SAP's platform enables interoperability among firms that in turn facilitates integration of any sub-set of resources through standardized interfaces. Since many resources are contributed that can be effectively and flexibly (re)bundled, considerably more innovation can be expected. The latter is extensively discussed in the existing research on platforms through the notion of *generativity*, representing a platform's capacity to enable complementary innovation by integrating resources of autonomous and heterogeneous partner firms (Cennamo & Santaló, 2019; Wareham et al., 2014). Next to generativity, *profitability* gains of innovation is vital as the generated innovations may not always be profitable, specifically in hypercompetitive environments. After all, innovation is a simultaneous process of value creation (generativity) in response to customers' changing requirements as well as value appropriation (profitability) to gain profit from innovations in the market (Ahuja et al., 2008; Jacobides et al., 2006). As such, profitability becomes an emergent property of

not just what a firm does, but also what the firm's connected and mutually dependent partners do.

D.2.3 The moderating role of complexity

Platform capabilities and their role in taming the complexity of innovation encourage the provider of downstream resources in a business ecosystem (e.g., SAP and its ERP system) to invest into platforms. As opposed to the off-platform organizing logic without any dedicated coordinator of innovation, in the platform organizing logic, the platform owner (i.e., the firm with focal resources that invests into a platform) orchestrates innovation among a plethora of autonomous and heterogeneous firms (Kretschmer et al., 2022). In materializing the platform organizing logic, platform owner makes *production-related investments* (to build production leverage-related platform capabilities) and *transaction-related investments* (to build transaction leverage-related platform capabilities) to deploy a platform and its promised capabilities. Next to platform owner's investments, the establishment of a platform organizing logic hinges on a critical mass of partner firms that contribute various upstream resources to the platform and choose to transact on-platform (Gawer & Cusumano, 2008; Rochet & Tirole, 2003). Partner firms' choice to join a platform is delineated by their interest in sustaining an economic benefit from innovation (Garcia-Castro & Aguilera, 2015), and this interest is met when the platform effectively enables *generativity* (value creation) and *profitability* (value appropriation) from innovation for partner firms.

Therefore, the effectiveness of a platform organizing logic in taming the complexity of innovation in business ecosystems depends on partner firms' choice to join the platform and the platform owner's incentives to provoke partners in transacting on-platform. This topic resides in the existing research on the role of platform partners in platform ecosystems and on the relationship between platform owners and partners, which is one of the major streams of research on platforms (Rietveld & Schilling, 2021). This stream of research provides several interesting insights into why joining a platform is beneficial for partners (e.g., Ceccagnoli et al., 2012; Wareham et al., 2014), how to optimize partners' benefit from platforms (e.g., Brunswicker et al., 2019; Malgonde et al., 2020), how owners can incentivize partners to join the platform (e.g., Boudreau, 2017; Gawer & Henderson, 2007), how owners align partners' resource contributions (e.g., Huang et al., 2018; Tae et al., 2020), and what are collaboration and competition potentials among partners on-platform (e.g., Boudreau, 2012; Rietveld et al., 2019). Therefore, the default

assumption is that platform organizing logic is superior to the traditional off-platform organizing logic and existing research accordingly provides insights into platform logic's associated benefits, potentials, and steering mechanisms. Translated to the context of platforms' role in taming the complexity of innovation, existing research advocates that platform owner's governance interventions in form of *production-related investments* (e.g., investments in modularity and interoperability of a platform) and *transaction-related investments* (e.g., investments in recommender systems on a platform) are likely to improve partner firms' *generativity* and *profitability* outcomes when compared to the off-platform scenario. In complementing existing research, we aim to spotlight the role of *complexity* in a business ecosystem that delineates if at all platform capabilities help taming the complexity of innovation in the sense of improving partner firms' generativity and profitability outcomes.

Concept	Definition	Related Literature
Complexity	Complexity in a business ecosystem denotes the rate and unpredictability of changes in customer requirements. It creates adaptive tension for firms. To meet customer requirements, firms need to search, find, and integrate resources of other firms with their own.	(Anderson, 1999; Cilliers, 1998; Davis et al., 2009; Dess & Beard, 1984; Holland, 1995; Nan & Tanriverdi, 2017; Tanriverdi et al., 2010)
Production-related investments	As a means to realize a platform's <i>production leverage</i> , platform owner's production-related investments seek to foster resource reusability and reduce <i>production costs</i> of partner firms on the platform. Production-related investments manifest in platform capabilities such as standardization of the platform core and interfaces, modularity, reusability, and interoperability of platform resources, and direct subsidies to facilitate platform.	(Boudreau, 2017; Brunswicker et al., 2019; Ceccagnoli et al., 2012; Cennamo et al., 2018; Gawer & Cusumano, 2008; Gawer & Henderson, 2007; Huang et al., 2018; Lan et al., 2019; Thomas et al., 2014; Tiwana, 2015a; Wareham et al., 2014)
Transaction-related investments	As a means to realize a platform's <i>transaction leverage</i> , platform owner's transaction-related investments seek to ease search processes of partner firms on the platform and reduce their <i>transaction costs</i> . Transaction-related investments manifest in platform capabilities such as platform's search design to focus on customer feedback, two-sided recommender systems, and certifying partner firms to establish trust among firms.	(Huang et al., 2018; Malgonde et al., 2020; Rietveld et al., 2019; Rietveld et al., 2018; Tae et al., 2020; Thomas et al., 2014; Wareham et al., 2014)
Generativity	As a proxy of a platform's <i>innovation leverage</i> , generativity constitutes the generative capacity of a platform, reflected in the variety of unique offerings. Generativity represents <i>value creation</i> in a co-creational process of innovation.	(Boudreau, 2012; Casadesus-Masanell & Halaburda, 2014; Cennamo & Santaló, 2019; Thomas et al., 2014; Tilson et al., 2010; Wareham et al., 2014)
Profitability	Profitability is the difference between revenue generated from a service offering on the platform and the cost incurred in generating the service. It represents the <i>value appropriation</i> by platform owner and partners co-creating the service.	(Garcia-Castro & Aguilera, 2015; Jacobides et al., 2006; Karhu et al., 2018; Mantovani & Ruiz-Aliseda, 2016)

Table 16. Study's main concepts

According to complexity science, firms must continuously find a match or fit with the complexity of their environment to survive and thrive (Anderson, 1999; Cilliers, 1998; Holland, 1995). As the degree of complexity in the ecosystem varies, it is reasonable to expect that there should be considerable differences in adaptive capabilities required for survival (Anderson, 1999; Cilliers, 1998). Complexity is defined as the rate and unpredictability of changes in the environment (e.g., Dess & Beard, 1984), represented in the flow of heterogeneous opportunities imposed by customers that delineate the required innovation's characteristics (Davis et al., 2009). Building on complexity science, if the environment is not complex (e.g., the environment is just complicated), the innovation

process becomes predictable and linear and can be handled in a top-down fashion (Anderson, 1999; Cilliers, 1998; Holland, 1995). In this case, the platforms' promised leverages and capabilities for taming complexity may not be relevant. The more complex is the environment, however, the more loosely coupled network of firms are required to engage in innovation process to bundle and re-bundle their resources in response to customers' changing requirements (Ozcan & Eisenhardt, 2009; Uzzi, 1997). That is, complexity in the ecosystem necessitates specialization of firms in contributing particular resources, and that innovation becomes a process of co-specialization among firms (Teece, 1986) to promptly generate offerings that match customers' requirements. In this case, due to the need for bottom-up addressing of customers' changing requirements, the innovation process becomes unpredictable and non-linear, and this is where the platforms' promised leverages and capabilities for taming complexity come in handy. Thus, we posit that the extent to a platform organizing logic (i.e., platform owner's production-related investments and transaction related investments) help taming the complexity of innovation (i.e., improve in partner firms' generativity and profitability outcomes) is contingent on the level of complexity in a business ecosystem. In other words, the superiority of a platform organizing logic to the traditional off-platform organizing logic is delineated by the business ecosystem's complexity in which innovation occurs.

Hypothesis 1: Complexity moderates the link between production-related investments and generativity.

Hypothesis 2: Complexity moderates the link between production-related investments and profitability.

Hypothesis 3: Complexity moderates the link between transaction-related investments and generativity.

Hypothesis 4: Complexity moderates the link between transaction-related investments and profitability.

Table 16 provides definitions and supporting literatures of the constructs in these hypotheses.

D.3 Research method

We choose an agent-based modeling and simulation (ABM) method for the following reasons. Complex systems entail a large number of diverse and adaptive elements that

interact with each other in non-linear ways to create bottom-up emergence and make the system-level outcomes unpredictable (Anderson, 1999; Cilliers, 1998; Tanriverdi & Du, 2020). ABM allows us to model diverse and adaptive elements, non-linear interactions among them, and nudge the complex system to observe resulting outcomes at the system level (Hedström & Manzo, 2015; Nan & Tanriverdi, 2017). ABM makes it feasible to experimentally manipulate the independent variables and controls of the study to an extent that would not be feasible in conventional empirical settings (Nan & Tanriverdi, 2017). Following existing ABM-based studies (Haki et al., 2020) and common recommendations for simulation-based research (Davis et al., 2007; Sargent, 2005), we developed the simulation model through an iterative process shifting between conceptual model development, actual simulation development, as well as validation, experimentation, and analysis. The mentioned steps are outlined in detail below.

D.3.1 Conceptual model design

The simulation model captures the complex setting of innovation within a business ecosystem (Ganco et al., 2020). In this setting, firms may engage in bundling their resources with resources of the other firms to design innovative services either on-platform, using platform's production leverage-related and transaction leverage-related capabilities, or off-platform on their own. Since the resulted innovations (from bundling of resources) are designed to address customer requirements, the dynamically evolving customer requirements delineates the *complexity* in the ecosystem (see next sub-section on how environment is modeled). Depending on complexity as well as the platform's production leverage-related and transaction leverage-related capabilities, partner firms will adapt their choice of innovating on- or off-platform, and customers may adjust their decision to source services on- or off-platform.

Building on platforms' premises to tame the complexity of innovation, platform capabilities, which are materialized through platform owner's *production-related investments* and *transaction-related investments*, are supposed to significantly reduce firms' associated production and transaction costs in innovation. In the simulation model, both production costs and transaction costs can be reduced by a factor of 0.00-1.00 on-platform (i.e., both costs can be reduced up to 100% compared to innovating off-platform), representing the platform owner's governance interventions through its level of production-related and transaction-related investments. Then, the simulation model captures the impact of production-related investments and transaction-related investments in

various levels of complexity on firm's *generativity* (value creation) and *profitability* (value appropriation) levels both on- and off-platform. The simulation model tracks generativity in form of the number of generated services (through bundling of resources) and traces profitability as the difference between partners' generated revenue and costs incurred. The quality of innovations is captured by tracking whether an innovation meets a customer's requirement and successfully completes a transaction. As such, the simulation model's independent variables are production-related investments, transaction-related investments, and complexity (as moderator) whose impact are tracked on the model's dependent variables of generativity and profitability.

In addition, we control for the revenue sharing arrangement between platform owner and platform partners, partner firms' inertia, as well as stability in the environment. Revenue sharing is generally considered as a means to extract value for platform owners (Karhu et al., 2018) that impact partner firms' motivation to join the platform. Since revenue share varies across platforms (e.g., Apple's 30% on iOS, Salesforce' 15% on AppExchange), we randomly alternated this variable between 10-30% in simulation runs. Further, the likelihood of partner firms adhering to the platform logic and choosing to adapt their business model to transact on-platform is delineated by their level of inertia in innovation research (Hannan & Freeman, 1984; Kelly & Amburgey, 1991). The latter has also been discussed in the platform context by heterogeneity among partner firms (e.g., Boudreau, 2012; Ceccagnoli et al., 2012; Wareham et al., 2014). We account for partner firms' inertia as a form of heterogeneity by randomly assigning different levels of resistance to change in adopting the platform organizing logic. Lastly, next to complexity of the ecosystem, previous simulation models inform us on the importance of the rate of change in the environment (Davis et al., 2009; Haki et al., 2020). Thus, we track the stability in the environment to account for the arrival rate of requirements and control for its effects.

D.3.2 Operational model design

As demonstrated in the research background, complexity in innovation is a function of the number of firms involved in innovation, the degree of interconnectedness among firms, and the environment in which innovation occurs (Anderson, 1999; Cilliers, 1998; Holland, 1995). Our agent-based model accounts for these system specificities by capturing agents, their interactions, and the surrounding environment (Haki et al., 2020; Nan, 2011).

D.3.2.1 Agents

Fundamental to any complex system are agents that can represent different entities such as firms, resources, and services (Nan, 2011). Each agent is defined by individual *attributes* that may change over time and guided by *behavioral rules*, generally aiming to improve their fitness in a given environment (Haki et al., 2020; Levinthal, 1997; Nan, 2011). Our model comprises customer and partner firms as learning and utility-based agents, who aim to improve their fitness in the environment. Customers search for affordable services to meet their requirements, whilst partner firms bundle their own and other firms' resources to develop such services (Blaschke et al., 2018; Ceccagnoli et al., 2012; Yoo et al., 2010). Therefore, the simulation model also captures resources and services as reflex agents, which are just the contributions or byproducts of learning agents.

Operationally, the model captures innovation as a search process as presented in existing simulation models (Ganco et al., 2020; Gavetti et al., 2017; Levinthal, 1997) that has also been applied to the platform context (Brunswick et al., 2019). Accordingly, search processes are divided into local and distant search. Customers first engage in a local search for services in their immediate network of known partner firms. In case any of known partner firms can meet the requirements, and provided that the transaction is affordable for customers and profitable for partners, a requirement is met. If the search is unsuccessful, customers engage in a distant search in the ecosystem (comprising both known and unknown partner firms), either on- or off-platform. If no existing services that meet the requirements can be found, partner firms engage in a search process by mixing and matching resources (Ganco et al., 2020) that are contributed by partners and the platform owner (in the case of on-platform search) in an attempt to meet service requirements. First, partners search within their own organization and in the local network of known partners, and, if unsuccessful, expand to distant search in the ecosystem. Partner firms' resources are operationalized as 5-bit binary vectors (e.g., [01100]), leaning on Ganco et al.'s (2020) implementation of firms' components, and typically applied in the modeling context (e.g., Brunswick et al., 2019; Davis et al., 2009; Gavetti et al., 2017). Building on Ganco et al. (2020), resources are then combined to form services that can be offered to customers. Our simulation model necessitates four resources to form a service (e.g., [01100 10010 11100 01101]), resulting in a 20-bit vector for each service, and representing resource integration among firms as the fundamental way to innovate (Ahuja et al., 2008; Ganco et al., 2020; Lusch & Nambisan, 2015). The number

of requirement contingencies that must be met for a service to meet customers' requirements, also operationalized as 20-bit vectors, is in turn determined by the level of complexity (Davis et al., 2009), as outlined further below.

D.3.2.2 Interactions

As for any complex system, interactions among the modeled agents are central to our model, where interactions are defined by the *connections* between agents and the *flows* of resources among them (Haki et al., 2020; Nan, 2011). All interactions in our model revolve around innovation as a search process (Ganco et al., 2020), i.e., the need for innovations to meet customers' requirements. Fundamentally, customers signal requirements to partner firms, partners signal needs for resources to other partners, and ultimately, partners offer services to customers. To closely account for the role of platform owner, the search processes can be facilitated depending on the availability of platform capabilities offered by the owner. The latter capabilities are represented by the platform owner's level of production-related and transaction-related investments on-platform, if customers search for services or partners search for complementary resources on-platform. Aside from production-related and transaction-related investments, the platform owner also provides own extendible resources to build upon and create services (Blaschke et al., 2018; Ceccagnoli et al., 2012). In fact, all services generated on-platform must contain resources provided by the platform owner. Any service offering in the SAP Store uses the infrastructure provided by SAP, for example. Thus, partners that join the platform are also connected to the platform owner.

D.3.2.3 Environment

All interactions among agents take place in an environment (Haki et al., 2020; Nan, 2011) that is in our case the business ecosystem. Adopting Davis et al.'s (2009) conceptualization of the environment, the customer requirements triggering innovative search in the model shape the level of complexity in the ecosystem. In the enterprise software ecosystem example, an SAP customer from the automotive sector may require a software module to provide after sales support to auto buyers. The customer contacts an SAP consultant within the local network who recommends a standard service from Salesforce.com to meet the need. The consultant then directly helps the customer to integrate the service and neither party is in need of sophisticated platform leverages. The mentioned auto manufacturer may however also decide to extend its enterprise IT such that it connects to all sold vehicles with autonomous driving features. The customer

intends to collect vehicles' data on the road conditions in real-time and perform analytics on the data such that updated self-driving guidance can be provided. Such higher complexity requirements may likely not be met by a single firm. It requires collaboration in form of resource integration among several partner firms, including, for instance, experts on sensory technologies, telematics/telecommunications, and real-time data analytics (Tarafdar & Tanriverdi, 2018). Searching for and finding these numerous partners is challenging and thus the customer may benefit significantly from the platform leverages provided by SAP BTP.

To capture complexity in the model, we lean on existing models' operationalization of complexity as the number of contingencies that must be successfully addressed to meet a customer requirement (Davis et al., 2009; Haki et al., 2020). Recall that both customer requirements as well as partners' offered services are operationalized as 20-bit vectors. The complexity parameter then defines how many elements in a 20-bit vector service must match those in the 20-bit vector requirement to be successfully met. Complexity thus varies from 0-20. For a customer requirement with complexity 12, for example, at least 12 bits of the 20-bit vector of the corresponding requirement and service must match for the requirement to be met. In general, as complexity increases, it becomes increasingly difficult for partner firms to capture the fleeting opportunities in the ecosystem (Davis et al., 2009). Table 17 summarizes this and other components in more detail.

Component		Description	Literature
Agents	Customers (learning- and utility-based agents)	Attributes: Customers have service requirements and search for matching services on- or off-platform. Behavioral rules: When customers have a service requirement, they (1) conduct local search for services in their existing partner network. If successful (enough matches between the requirement and service), they choose a random, affordable service. Otherwise, they (2) conduct distant search on- or off-platform. If both searches are unsuccessful, partners' search is triggered.	(Brunswick et al., 2019; Davis et al., 2009; Ganco et al., 2020; Haki et al., 2020; Levinthal, 1997; Wareham et al., 2014)
	Partners (learning- and utility-based agents)	Attributes: Partners are endowed with particular (random in the model) sets of resources that are combined to create services, on- or off-platform, to fulfill customer requirements. Behavioral rules: When conducting search, partner firms (1) recombine own resources and conduct local search for resources in the known partner network. Of any configurations that match the customer's requirement, a random, affordable resource is integrated, considering both transaction and production costs. Otherwise, partners (2) conduct distant search (for both known and unknown partners) off-platform, as well as on-platform. If successful, services are offered to customers. Partners obtain payoffs when services to which they contribute are used and incur costs for building and maintaining resources. Partners join the platform when they receive enough positive signals from their local network and will leave the platform if they perform better on their own.	(Blaschke et al., 2018; Brunswick et al., 2019; Ganco et al., 2020; Gavetti et al., 2017; Haki et al., 2020; Levinthal, 1997; Malgonde et al., 2020; Wareham et al., 2014; Yoo et al., 2010)

	<i>Resources (reflex agents)</i>	Resources have a set of features (5-bit vectors of 0s and 1s, e.g., [01100]) and are combined to create services. The feature sets are not entirely fixed and allow room for improvisation by partners. Resources have an associated, randomized production cost. To account for innovation and dynamism in the environment, resources are renewed periodically throughout individual simulation runs.	(Ganco et al., 2020; Gavetti et al., 2017; Haki et al., 2020; Karhu et al., 2018)
	<i>Services (reflex agents)</i>	Services are used by customers to fulfill their requirements. Each service consists of four resources (while each resource is a 5-bit vector, see <i>resources</i>) defining its 20 features. On-platform, one of these resources is provided by the platform (i.e., contributed by the platform owner). The other three resource sets are contributed by platform partners. All firms have the possibility to search for and offer their resources off-platform as well.	(Ceccagnoli et al., 2012; Constantinides et al., 2018)
	<i>Owner</i>	The owner provides base resources for all services offered on-platform. It incurs production costs for maintaining these resources and receives pay-offs from services used on its platform, depending on the defined revenue share.	(Karhu et al., 2018; Wareham et al., 2014)
<i>Interactions</i>	<i>Customer - partner</i>	Connection: Customers know partners in their local network. New links are established after a successful customer distant search. Flow: Customers communicate their service requirements to partners; partners share existing services.	(Ganco et al., 2020; Gavetti et al., 2017; Malgonde et al., 2020; Srinivasan & Venkatraman, 2010; Wareham et al., 2014; Yoo et al., 2010)
	<i>Partner - partner</i>	Connection: Partners have an existing local network. New links are established after a successful partner distant search. Flow: Partners share resources and experiences on-platform with known partners in their network.	
	<i>Partner - resource</i>	Connection: Partners create and operate resources. Flow: Partners define and improvise the features of resources.	
	<i>Resource - service</i>	Connection: Combinations of resources yield services. Flow: Combined resource sets define a service's feature set.	
	<i>Partner - service</i>	Connection: One single partner owns each service. Flow: The partner who owns a service provides the main resources and decides when to reconfigure its service.	
	<i>Partner - owner</i>	Connection: The platform owner provides resources for service creation. Flow: Partners on-platform use the owner's resources to create services with or without other partners on-platform.	
<i>Environment</i>		Customers have varying service requirements that delineate the environmental specificities of an ecosystem. The environment is shaped by the complexity of requirements and the rate of change, i.e., environmental stability.	(Davis et al., 2009; Haki et al., 2020)

Table 17. Simulation model components

D.3.3 Validation and experimentation

To ensure the validity of the simulation model, we first built the model on the existing validated models, specifically with regard to the conceptualization and operationalization of agents, interactions, and the environment (Davis et al., 2009; Haki et al., 2020; Malgonde et al., 2020). Further, we followed recommendations for model validation and verification (Davis et al., 2007; Sargent, 2005) and conducted more than three million simulation runs for reliability and degeneracy tests to establish the model's internal consistency and to define parameter ranges for boundary conditions (Davis et al., 2007) (see Appendix B for details). As for experimentations and to test the research hypotheses,

we varied the three independent variables (i.e., production-related investments, transaction-related investments, and complexity) simultaneously across the entire possible range, as specified in Table 18, to track their impact on dependent variables (i.e., generativity and profitability). Control variables were randomized within predefined ranges. That is, the range for the revenue share follows empirical examples (between 10-30% as justified previously), inertia leans on Malgonde et al.'s (2020) conceptualization of signals from the local network attracting partners to the platform, and environmental stability is adapted from existing models (Davis et al., 2009; Haki et al., 2020). More specifically, environmental stability is modeled as a threshold of time steps after which new requirements arrive. Each unique parameter setting of independent variables was tested 20 times, yielding $21 \times 21 \times 21 \times 20 = 185,220$ total simulation runs.

Variable	Range	Tested Values	Variations
<i>Production-related investments</i>	0.00-1.00	0.00-1.00 in increments of 0.05	21
<i>Transaction-related investments</i>	0.00-1.00	0.00-1.00 in increments of 0.05	21
<i>Complexity</i>	0-20	0-20 in increments of 1	21
<i>Owner's revenue share</i>	0%-100%	10%-30%	randomized
<i>Partners' inertia</i>	>0	20-50	Randomized
<i>Environmental stability</i>	>0	Poisson distribution, $\lambda = 30$	

Table 18. Simulation experiment

D.4 Results

We use ordinary least squares regressions to examine how complexity affects the links between platform characteristics and generativity and profitability outcomes. To account for potential non-linear relations in a complex system (Anderson, 1999), we include both linear and quadratic terms of the variables (Table 19).

We first examine the main effects of our moderator and independent variables on generativity and profitability outcomes. As Table 19 shows, both linear and quadratic terms of these variables have significant effects on the generativity and profitability outcomes, supporting the non-linearity of the relationships. Increasing complexity significantly increases generativity as indicated by the positive and significant linear ($\beta=646.1046$, $p<0.001$) and quadratic terms ($\beta^2=268.9339$, $p<0.001$). Complexity has an inverse U-shaped relation with profitability, as indicated by the positive linear term ($\beta=6,142.2427$, $p<0.001$) and the negative quadratic term ($\beta^2=-6,023.7247$, $p<0.001$). Initially, profitability rises with the increasing level of complexity. As complexity increases, more unique service offerings are generated on the platform due to particularities of customers' requirements (i.e., more matches are required between a specific

requirement and a specific service), However, as complexity increases further, profitability tapers off and starts to decline. The capacity to reap profits from the generated innovations is increasingly impeded.

Platform's production-related investments and transaction-related investments also have significant inverse U-shaped relationships with generativity ($\beta = 15.9382, p < 0.001$; $\beta^2 = -7.2020, p < 0.05$ and $\beta = 18.6645, p < 0.001$; $\beta^2 = -17.0378, p < 0.001$, respectively), and profitability ($\beta = 1,585.6485, p < 0.001$; $\beta^2 = -85.4595, p < 0.05$ and $\beta = 432.9804, p < 0.001$; $\beta^2 = -315.0978, p < 0.001$, respectively) outcomes. Thus, the impacts of platform owner's investments into production leverage- and transactions leverage-related capabilities do not uniformly improve generativity and profitability. While these investments improve generativity and profitability of partners on the platform, the benefits taper off at high levels of both production-related and transaction-related investments.

	Dependent Variables	
	Generativity	Profitability
Intercept	481.6862***	17,730***
Complexity	646.1046***	6,143.2427***
Complexity ²	268.9339***	-6,023.7247***
Production-related investments	15.9382***	1,585.6485***
Production-related investments ²	-7.2020*	-85.4595*
Transaction-related investments	18.6645***	432.9804***
Transaction-related investments ²	-17.0378***	-315.0978***
Revenue share (owner)	-2.1725	-969.6209***
Revenue share ² (owner)	-1.3294	-158.1401***
Inertia (partners)	-7.8321**	-329.2217***
Inertia ² (partners)	-97.5681***	-535.2724***
Environmental stability	2.6465	-19.6811
Environmental stability ²	-54.7306***	-419.4151***
Complexity×Production-related investments	18.7937***	887.2634***
Complexity×Transaction-related investments	22.5060***	138.5117***
R ²	0.276	0.314
F-Statistic	5,037	6,056
AIC	3,142,000	4,025,000

Notes: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; standardized coefficients in the cells.

Table 19. Regression analyses of on-platform results

When we interact our moderator variable with independent variables, we find that interaction terms are significant. Complexity and production-related investments have a positive interaction effect on both generativity ($\beta = 18.7937, p < 0.001$) and profitability ($\beta = 887.2634, p < 0.001$). Similarly, complexity and transaction-related investments have a positive interaction effect on both generativity ($\beta = 22.5060, p < 0.001$) and profitability ($\beta = 138.5117, p < 0.001$). For ease of exposition and interpretation of interactions effects,

we use 3D surface plots. Figure 15 illustrates how complexity, production-related investments, and transaction-related investments interact with each other to affect the generativity and profitability outcomes of partner firms on the platform. As we manipulate complexity level from 0 to 20, we observe that notable fluctuations in the generativity and profitability outcomes emerge in moderate and high levels of complexity. At complexity levels below 10, 3D surface plots on generativity and profitability are comparably flat, indicating that the hypothesized platform investments do not make any noticeable differences in the outcomes at low complexity levels, in comparison to medium and high complexity levels. As the complexity level increases beyond 10, we start seeing notable increases in generativity and profitability levels, but these effects taper off and start to decline at very high levels of complexity, as shown by the various 3D planes capturing different levels of complexity in Figure 15. These findings provide support for our hypotheses on the moderating effects of complexity. While production-related investments and transaction-related investments have significant effects on both generativity and profitability (see regression results in Table 19), these relations are significantly moderated by the level of complexity in the business ecosystem. Complexity moderates how production-related investments impact generativity (H1) and profitability (H2). It also moderates how transaction-related investments impact generativity (H3) and profitability (H4), as confirmed by the regression results in Table 19.

Maximum profitability is achieved at medium levels of complexity (see 3D surface for complexity=14). At those levels of complexity, partner firms appear to benefit especially from production-related investments that make resources for integration affordable on-platform. However, when transaction-related investments are simultaneously increased to facilitate partners' search for resources as well as customers' search for services, the positive effects of production-related investments are slightly dampened. This may indicate the negative crowding effect on platforms found in other studies (e.g., Li & Netessine, 2020) as more partner firms would join the platform (i.e., move from off- to on-platform) that in turn restrains profitability gains of existing platform partners.

Conversely, generativity is maximized at high levels of complexity (see 3D plot for complexity level=18). Both production-related investments and transaction-related investments appear to considerably foster generativity at high levels of complexity. Nevertheless, simultaneously increasing production-related investments and transaction-related investments beyond a certain threshold appears to be detrimental for the generative capacity of firms, as indicated by the dampening surface. Again, these findings may be

indicative of competitive crowding effects on the platform, which have been found to reduce individual partners’ innovation incentives (Boudreau, 2012).

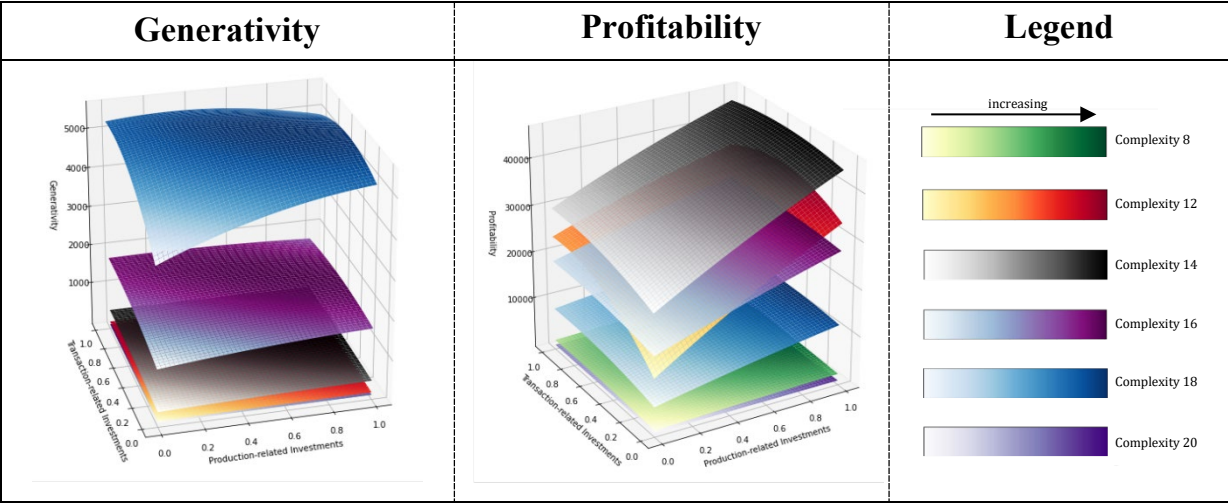


Figure 15. Interaction effects on generativity and profitability

Referring back to Table 19, the results on control variables are also insightful. Platform owner’s revenue sharing requirement (10% to 30% cut of partner firm’s revenues) does not have a significant effect on generativity, but it has a negative effect on the profitability of the partner firms. This is interesting in that asking partner firms to share lower percentages of their revenues with the platform owner does not seem to promote any improvements in generativity on the platform. As the partner firms are asked to share higher percentages of their revenues with the platform owner, there is also a negative and significant hit on the partners’ profitability levels on the platform. Furthermore, organizational inertia of partner firms has significant effects on both generativity and profitability. Firms that have more inertia in moving to the platform have exponentially less generativity and profitability, as indicated by the negative and significant linear and quadratic terms. Finally, the negative and significant quadratic terms of environmental stability indicate that the profitability and generativity of partner firms on the platform decline rapidly in more stable environments. This finding reinforces the support for our thesis that platforms are most useful in complex, rapidly changing environments.

D.5 Discussion and conclusion

Business ecosystems are venues of innovation whose complexity can be characterized by a constant process of bundling and re-bundling resources of a multitude of heterogeneous firms in response to changes in customers’ requirements. From the view of complexity science, as customer requirements become more complex, firms face more

adaptive tension to meet the requirements. Firms' own resources may not have the requisite variety to match the variety in customer requirements. Thus, firms must source missing resources from other firms. This yields higher interrelatedness and interconnectedness among firms in the ecosystem and increases the complexity dynamics and the resulting challenges in the business ecosystem (Anderson, 1999; Cilliers, 1998). Generativity and profitability of firms become emergent outcomes that are beyond the control of any single firm. They become functions of not just what a focal firm decides to do, but also what all the interconnected and mutually dependent firms decide to do. Prior research argued the platform organizing logic can enable firms to tame the challenges of complexity (Malgonde et al., 2020; Sandberg et al., 2020; Thomas et al., 2014). However, prior research did not examine how the platform performs in different levels of complexity. Our study addresses this gap to show that the platform organizing logic is beneficial in certain ranges of complexity. Specifically, we find that a platform does not have any noticeable effects on generativity or profitability at low levels of complexity, compared to higher levels of complexity. The benefits of platform emerge and sustain in medium to high levels of complexity. The benefits taper off and decline at very high levels of complexity.

D.5.1 Contributions to research

Our study contributes to the platform literature by explaining the conditions under which a platform owner's investments into production leverage- and transaction leverage-related capabilities are effective in generating innovations and profitability. Contrary to the assumptions of prior studies (e.g., Malgonde et al., 2020; Thomas et al., 2014; Tiwana, 2015b), these platform leverages do not have linear effects on generativity and profitability. Rather, they have inverse U-shaped, non-linear effects, which initially foster generativity and profitability but later slow down and decline.

The generativity and profitability effects of platforms' production leverage and transaction leverage are also significantly moderated by the level of complexity in the ecosystem. Contrary to the received wisdom, these leverages have negligible effects on generativity or profitability outcomes at low levels of complexity, compared to higher levels of complexity. When complexity is low, the adaptive tension for innovating firms is also low. Firms are able to rely on their own resource endowments as well as their own search and integration capabilities to successfully generate innovations that meet customer expectations. That is, firms are able to search, find, acquire, and integrate other firms'

complementary resources on their own to meet a customer requirement profitably. At low levels of complexity, our findings show that platform owners' investments into production leverage- and transaction leverage-related capabilities do not yield any substantial changes in partner firms' generativity and profitability. The platform leverages deliver the claimed generativity and profitability benefits only in medium to high levels of complexity. When complexity increases to medium or high levels, the adaptive tension increases for firms. Innovation becomes increasingly challenging and costly, in terms of production costs and transaction costs (Benslimane et al., 2005; Wolter & Veloso, 2008). Firms' own resource endowments as well as their search and integration capabilities prove insufficient to meet the variety in customer requirements cost effectively and profitably. Under these conditions, platform leverages enable firms to navigate the complex environment in finding collaborators, and working with them effectively to integrate each other's complementary resources in ways to reduce the production and transaction costs of innovations. However, when complexity increases to very high levels, even the platform leverages prove insufficient in taming the challenges of complexity, as indicated by the tapering off and the decline of generativity and profitability benefits (Figure 15). These results advance the platform literature by showing that the generativity and the profitability effects of the platform are contingent on the level of complexity in the ecosystem.

Our study also contributes to existing discourse in complexity science. Although complexity science enables us to understand why complexity arises and presents many wicked challenges (e.g., Anderson, 1999; Cilliers, 1998), it does not explain how to tame the complexity and address the associated challenges. In this study, we explain how a platform's production and transaction leverages might serve as *taming mechanisms* for the wicked generativity and profitability challenges faced by firms in medium to high levels of complexity.

D.5.2 Contributions to practice

Challenging the assumption of platforms' superiority as an alternative organizing logic has also implications for practice. In many industries, platforms are seen as a disruptive force and threat to incumbents (de Reuver et al., 2018). Our results suggest that the disruptive force of innovation platforms may only apply in competitive settings characterized by moderate to high levels of complexity. When the adaptive tensions faced by firms in a business ecosystem is low and the environment is characterized by low

diversity and interconnectedness among firms (Page, 2009), the threat of an incumbent being replaced by a platform may therefore be negligible. For potential platform owners, it means that costly investments in platform capabilities may not pay off if the competitive environment is not characterized by moderate or high complexity. Similarly, firms contemplating to join a platform may want to refrain from this risky decision (Cecagnoli et al., 2012) in such environments. Our findings thereby indicate when investments in platform-related capabilities to adopt the platform organizing logic may be promising.

D.5.3 Limitations and future work

Despite these findings, some boundary conditions apply to our findings. For one, the presented setting was catered to investigating complexity's moderating effect on platforms' capabilities in general, by comparing the on-platform and off-platform innovation alternatives. Therefore, we only modeled one platform within its business ecosystem. Our findings may be extended by, for example, investigating how inter-platform competition is affected by complexity, or how complexity delineates platform owners' governance decision to enter the market and directly compete with or complement their platform partners (Foerderer et al., 2018). Similarly, the developed agent-based simulation model revolves around an innovation platform. Future simulation studies may compare our results to other types of platforms, for instance transaction platforms that serve as a marketplace for exchanging *existing* goods and services (Cusumano et al., 2019), rather than a foundation for developing *new* innovations. Furthermore, although we account for heterogeneity among partners in form of endowed resources and inertia, we model customers in form of requirements. Future research may extend on this by, for instance, accounting for customer behavior heterogeneity under different conditions. Lastly, because of the employed method, we quantified various levels of complexity ranging from 0 to 20. We have provided examples in the context of SAP BTP how low and high levels of complexity manifest in practical examples. Nevertheless, we call for in-depth case studies to provide more delicate examples of customer requirements with regard to their various complexity levels and provide empirical accounts for their role on realization of platforms' capabilities and leverages.

Paper E – Taming complexity of multi-partner innovation: The roles of B2B platform leverages

Attribute	Value
Title	Taming complexity of multi-partner innovation: The roles of B2B platform leverages
Authors	Schmid, Marius¹; Haki, Kazem²; Tanriverdi, Hüseyin³; Aier, Stephan¹; Winter, Robert¹ ¹University of St.Gallen, Müller-Friedberg-Strasse 8, 9000 St.Gallen, Switzerland ²Haute école de gestion de Genève, Rue de la Tambourine 17, 1227 Carouge, Switzerland ³The University of Texas at Austin, Austin, TX 78705, U.S.A. marius.schmid@unisg.ch, kazem.haki@hesge.ch, huseyin.tanriverdi@mcombs.utexas.edu; stephan.aier@unisg.ch, robert.winter@unisg.ch
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Table 20. Bibliographical metadata on Paper E

Abstract

We develop a new theory to explain if, when, and how a B2B innovation platform tames challenges of complexity in multi-partner innovation (MPI). When a new service requirement calls for the integration of specialized resources of multiple partners, MPI becomes complex. If partners can generate the required service, MPI complexity can serve as a source of competitive advantage. However, MPI complexity presents partners with transaction and production challenges, which could inhibit generativity and profitability of innovation. Partners face transaction challenges in finding collaborators who can provide complementary resources, gain trust in, collaborate with, and resolve any conflicts. Partners also face production challenges in integrating disparate resources of multiple collaborators. We use agent-based modeling (ABM) and simulation to study if, when, and how a B2B innovation platform's transaction-related and production-related leverages might tame these challenges. Results suggest that MPI complexity determines whether a business ecosystem operates in the region of order, the region of emergent complexity, or at the edge of chaos. Partners are not attracted to the platform in the region of order or at the edge of chaos. In the region of emergent complexity, however, the platform attracts partners as the platform's leverages moderate the links between MPI complexity and generativity and profitability outcomes. Interestingly, the platform's transaction and production leverages negatively interact to dampen each other's effects on these outcomes. We frame the insights emerging from the ABM simulations as testable propositions.

Keywords

Multi-partner innovation (MPI), Complexity, B2B innovation platform, Transaction and production leverages, Generativity, Profitability, Agent-based modeling (ABM), Simulation

E.1 Introduction

The practitioner motivation for this study is to inform executives if, when, and how they can tame the challenges of complexity in multi-partner innovation to increase generativity and profitability of innovations.

Multi-partner innovation (MPI) is defined as the development of an innovation by two or more firms (Davis, 2016; Furr et al., 2016). Increasingly, customers have new service requirements calling for the integration of many complementary resources. No single firm might have all the required resources to configure an innovation that meets the requirement. Thus, multiple partner firms seek to collaborate to integrate each other's specialized and complementary resources to generate the innovation (Ozcan &

Eisenhardt, 2009; Uzzi, 1997). As more partners become mutually interdependent in integrating each other's resources, the MPI process becomes more complex. The increasing MPI complexity can also lead to the bottom-up emergence of business ecosystem-level complexity, which is defined as the number of interconnected and mutually dependent firms in the ecosystem (Nan & Tanriverdi, 2017).

If partners can successfully generate it, a complex MPI can serve as a source of superior performance (Kapoor & Agarwal, 2017). However, generating a complex MPI is not easy. The MPI complexity, and the ecosystem-level complexity it triggers, present many transaction-related and production-related challenges for partners collaborating on the innovation. In transactions, partners struggle to search and find collaborators in the business ecosystem who can bring in complementary resources to the innovation process. Assessing the quality of the resources and gaining trust in the collaborators also present challenges (Krishnan et al., 2006). During the collaboration process, partners face dilemmas in how much to share their intellectual property (IP) with each other and how much to protect the IP (Jarvenpaa & Majchrzak, 2016). When collaborators behave opportunistically, partners also struggle to resolve the ensuing disputes and conflicts (Madhok & Tallman, 1998). MPI complexity also creates production-related challenges for partners. A complex MPI is not easy to decompose into well-defined resources that can be sourced from various partners. Lack of resource compatibility and interoperability, well-defined interfaces, and common development kits across multiple partners presents challenges and increases production costs to inhibit the innovation process (Wolter & Veloso, 2008). Such transaction and production challenges can negatively affect the generativity of innovation and the profitability of partners. We posit that a B2B innovation platform can potentially tame the challenges created by MPI complexity.

A B2B innovation platform is defined as a digital technology foundation on which partner firms can jointly develop new innovations to meet customers' service requirements (Cusumano et al., 2019). The owner of a B2B innovation platform (e.g., SAP) seeks to attract partners to the platform (e.g., SAP application developers, SAP implementation partners, SAP consultants, SAP training partners). The platform owner designs the platform in ways to tame challenges of partners and enable them to generate innovations that meet customers' (e.g., Nestlé) needs profitably (Ceccagnoli et al., 2012; Schrieck et al., 2021).

The IS literature on platform mechanism design seeks to address the aforementioned transaction and production challenges (e.g., Ceccagnoli et al., 2012; Malgonde et al.,

2020; Tiwana, 2015b). Some IS studies focus on platform mechanisms that address the transaction-related challenges such as search-matching and recommender systems, customer and partner review systems, and partner certification programs (e.g., Huang et al., 2018; Malgonde et al., 2020; Rietveld et al., 2019). Strategy research classifies all such transaction-related mechanisms as platform's *transaction leverage* (Thomas et al., 2014). Some IS studies focus on platform mechanisms that address the production-related challenges such as software development kits, standardized interfaces, modularized resources, and boundary resources (e.g., Boudreau, 2017; Brunswicker et al., 2019; Ceccagnoli et al., 2012). Strategy research classifies all such production-related mechanisms as platform's *production leverage* (Thomas et al., 2014).

There are three major theoretical gaps in the IS platform literature that provide the academic motivation of this study. First, the IS platform literature has not theorized how, in the context of MPI, the platform's transaction and production leverages affect the partner's generativity and profitability outcomes. Second, the IS platform literature has not theorized how the two platform leverages affect the partners' generativity and profitability outcomes under different levels of MPI complexity. Third, the IS platform literature has not theorized whether and how, in the context of MPI, the platform's transaction and production leverages interact with each other. We seek to address these gaps by developing a new theory that explains if, when, and how a B2B innovation platform's leverages can tame the transaction and production challenges of MPI complexity and improve partners' generativity and profitability.

Theoretically, we build on the foundations of complexity science as our theory development approach (Benbya, Nan, Tanriverdi & Yoo, 2020). Methodologically, we use agent-based modeling (ABM) and simulation. We experimentally manipulate MPI complexity to trigger customer-partner and partner-partner linkage dynamics, which in turn, are likely to lead to bottom-up emergence of the business ecosystem-level complexity and aggravate the aforementioned transaction and production challenges (Anderson, 1999; Cilliers, 1998; Holland, 1995). We also experimentally manipulate the platform owner's investments into transaction and production leverages of the platform to observe if, when, and how the B2B platform leverages tame MPI's complexity challenges both independently and jointly. We frame the insights emerging from these experiments as a set of testable propositions that can guide future empirical research.

We find that complexity dynamics do not yet emerge in the business ecosystem-level at very low levels of MPI complexity. The business ecosystem operates in “the region of

order” (Boisot & McKelvey, 2013; Tanriverdi & Lim, 2017) and the two platform leverages do not attract partners to the platform. As we increase MPI complexity further, the business ecosystem starts to operate in “the region of emergent complexity” (Boisot & McKelvey, 2013; Tanriverdi & Lim, 2017). In this region, challenges of complexity emerge and partners start joining the platform. The platform’s leverages moderate the links between MPI complexity and the partners’ generativity and profitability outcomes. As we increase MPI complexity to very high levels, the business ecosystem moves to “the edge of chaos” (Boisot & McKelvey, 2013; Tanriverdi & Lim, 2017). At the edge, the challenges of complexity are so high that the platform’s leverages are not able to ease them. Thus, partners leave the platform. These results indicate that B2B innovation platform leverages effectively tame the challenges created by MPI complexity only in the ecosystem’s region of emergent complexity. In this region, transaction and production leverages negatively interact with each other to reduce each other’s generativity and profitability effects.

E.2 Research background

E.2.1 The problem setting: Challenges of complexity in multi-partner innovation

Customers’ multifaceted requirements require innovative solutions. Within a business ecosystem, innovation is a process of search for novel combinations of resources (Ganco et al., 2020) to ultimately serve customer requirements (Ahuja et al., 2008). It is a collaborative, co-creational process in a multi-partner constellation, where each partner offers a resource (e.g., a physical resource, production knowledge, customer knowledge) or a set of resources that can be combined to create innovative offerings in response to customer requirements (Lusch & Nambisan, 2015).

When customer requirements are relatively simple, partners can rely on their internal resources to generate the innovations. The innovation process is not complex yet. It is somewhat predictable and linear and can be handled in a top-down fashion (Anderson, 1999; Cilliers, 1998; Holland, 1995). Customers can also search in their local environment to find partners who offer innovations that match their requirements.

When customer requirements become multifaceted, they necessitate the MPI process and, in turn, trigger complexity dynamics at the business ecosystem-level (Nan & Tanriverdi, 2017). Partners may no longer be able to meet the requirements with their

internal resources. Thus, they are likely to increase local and distant searches (Levinthal, 1997) to find collaborators who can bring in complementary resources (Nan & Tanriverdi, 2017). The larger the loosely-coupled network of partners required to generate an innovation that meets the requirements, the more complex the MPI process becomes (Ozcan & Eisenhardt, 2009; Uzzi, 1997). MPI complexity necessitates the specialization of partners in contributing particular resources, and innovation becomes a process of co-specialization among partners (Teece, 1986) to promptly generate offerings that match customer' requirements.

Establishing more partner-partner linkages could lead to bottom-up emergence of business ecosystem-level complexity (Nan & Tanriverdi, 2017). Similarly, when customer requirements are multifaceted, customers may not be able to find local partners who meet the requirements. They may have to resort to distant searches (Levinthal, 1997) to find partners who can meet the requirements. The establishment of customer-partner linkages could also contribute to the bottom-up emergence of business ecosystem-level complexity.

Building on complexity science (Benbya et al., 2020), if a system (a business ecosystem) has many nodes (customers and partners), interconnections (partner-partner and customer-partner linkages), and mutual dependencies (resources shared in multi-partner collaborations), it becomes more complex. In the context of our study, the business ecosystem-level complexity generates four properties: non-decomposability, nonlinearity, emergence, and non-predictability (Anderson, 1999; Cilliers, 1998; Holland, 1995; Tanriverdi & Du, 2020). The non-decomposability property implies that a customer's innovation requirement may not be easily decomposed into well-defined resources (Cilliers, 1998). Not knowing which specific resources are needed to generate the innovation, partners may not know which collaborators in the ecosystem might have the resources needed by the innovation. The nonlinearity property implies that partner-partner and customer-partner relationships are nonlinear and that major resources brought in by collaborators may have only negligible effects on the MPI outcomes and waste resources; or seemingly minor resources may generate major breakthroughs (Cilliers, 1998). The emergence property implies that the MPI outcomes would not be deterministic. Partners may have to generate many different innovation configurations in hopes that one of them might meet the customer's requirements. Resource integration and re-configuration processes can unfold serendipitously to generate unexpected, surprising MPI outcomes (Anderson, 1999; Cilliers, 1998; Holland, 1995). The non-predictability

property implies that it is impossible for partners to predict if and when the MPI process would generate an innovation and whether it would yield profitability (Nan, 2011; Nan & Tanriverdi, 2017).

The four ecosystem-level properties of complexity can increase *transaction costs* of partners, such as costs incurred in searching for and finding other partners with complementary resources; establishing trust with and between the partners; governing the collaboration and resolving any conflicts; and addressing IP and revenue sharing issues among the engaged partners (Jarvenpaa & Majchrzak, 2016; Krishnan et al., 2006; Madhok & Tallman, 1998).

The ecosystem-level properties of complexity can also increase *production costs* of partners, such as costs of acquiring resources from other partners; configuring and ensuring the compatibility and interoperability of the acquired resources to generate innovations; and maintaining the possessed resources (Wolter & Veloso, 2008). As such, there is an irreducible uncertainty as to whether an innovation would be generated successfully by a consortium of partners, whether the generated innovation would meet a customer requirement, and if it would, whether the transaction would conclude profitably (Anderson, 1999; Cilliers, 1998; Holland, 1995; Tanriverdi & Du, 2020).

E.2.2 A potential solution: B2B innovation platforms' leverages to tame challenges of complexity in multi-partner innovation

To *tame* (not solve) the challenges of MPI complexity, some incumbent firms, which are the provider of a focal resource in their ecosystem, opt for innovation platforms (Stonig et al., 2022). They shift the locus of MPI *on-platform* and turn their traditional business ecosystems to platform-based ecosystems (Sandberg et al., 2020; Thomas et al., 2014; Yoo et al., 2010). That is, going beyond the provision of a focal resource to which partners add their complementary resources for generating innovations, these incumbent firms offer their focal resource as an open platform and actively orchestrate MPI in their ecosystem.

For example, SAP traditionally provided the on-premise core ERP (as the focal resource) in its business ecosystem. In this ecosystem, many partners were engaged in developing customer-specific extensions to SAP's ERP, filling the white spaces in the ERP system and fulfilling customers' requirements (beyond the core ERP). Due to the on-premise and product-based architecture (*off-platform*), SAP partners dealt with the challenges of searching and finding, gaining access to, reusing, and integrating the

extensions developed by other SAP partners (Ng & Gable, 2010; Sarker et al., 2012). Partners had to develop similar extensions on their own and incur all the costs of new development. To address these challenges, as of 2012, SAP offered its core ERP on a B2B innovation platform and provided open access to partners (*on-platform*). Instead of developing extensions that are inextricably intertwined with the core ERP, partners develop modular software-as-a-service extensions and integrate them with the core ERP and with other partners' extensions via APIs (Benlian et al., 2018; Ceccagnoli et al., 2012). SAP's B2B innovation platform works as a foundation upon which a plethora of partners' resources are more conveniently integrated into innovative services and offered as integrated solutions to meet customers' requirements.

Currently, SAP's *business ecosystem* is the venue where a multitude of SAP partners co-create services both *off-* and *on-platform* in response to customers' ever-changing requirements (Ceccagnoli et al., 2012). SAP customers have the choice to supply their required services, and SAP partners have the choice to do business in the SAP's business ecosystem, off- or on-platform. SAP's *platform ecosystem* is a portion of the business ecosystem where SAP partners co-create services using SAP's platform technology (*on-platform*). To let the platform to take off, SAP needed to incentivize its existing partners in the business ecosystem to join the platform. When transacting on-platform, the engaged partners are considered as platform partners and they need to share part of their revenue from the incurred services with SAP. The more SAP's partners join the platform, the other partners would be encouraged to join as well, creating a critical mass of partners on-platform (Ceccagnoli et al., 2012). As the platform owner, SAP designs certain mechanisms on its platform to tame MPI's complexity challenges in its ecosystem, and to attract partners to the platform.

IS literature on digital platforms discusses various platform mechanisms such as standardization of the platform's core and interfaces, and compatibility and interoperability of partner's resources with the platform's core to reduce the cost of generating innovations (Ceccagnoli et al., 2012; Tiwana, 2015b); boundary resources (e.g., APIs, SDKs) to cultivate the development of innovations by partners (Ghazawneh & Henfridsson, 2013); multi-sided recommender systems to tame challenges of search-matching in platforms (Malgonde et al., 2020); and building trust to the platform and its partners by granting certification to partners and by fostering knowledge sharing among partners (Ceccagnoli et al., 2012; Huang et al., 2018). While the discussion of platform mechanisms in IS literature is somewhat fragmented and not yet well-organized conceptually,

strategy scholars organized these mechanisms under three *platform leverages*: production, transaction, and innovation leverages (Thomas et al., 2014)—a structure that we adopt as an organizing framework for our study.

Production leverage aims to reduce *production costs* of innovations on-platform by building a repository of reusable resources on-platform and driving economies of scale and scope in the generation of innovations (Thomas et al., 2014). The platform owner makes investments into production leverage through, for instance, standardizing the platform's core and interfaces; modularizing resources contributed to the platform by partners to foster reusability; and increasing compatibility and interoperability of resources to ease sharing and integration (Boudreau, 2017; Brunswicker et al., 2019; Ceccagnoli et al., 2012; Cennamo et al., 2018).

Transaction leverage aims to reduce *transaction costs* of innovations on-platform by easing the search- and transaction-related challenges in the generation of innovations (Thomas et al., 2014). MPI complexity creates many challenges for transacting partners and customers. Partners, for instance, face challenges in identifying which new customer requirements are emerging in the ecosystem and how they are evolving over time; what kinds of resources would be needed to meet the customer requirements; which partners in the ecosystem would possess the required resources; how they could assess the credibility and reliability of potential collaborators; how they could contract with the collaborators and govern the collaborations; and how they could resolve potential conflicts (Krishnan et al., 2006; Madhok & Tallman, 1998). The platform owner can invest into transaction leverage to ease these challenges through, for instance, developing multi-sided recommender systems to enable more effective search and matching processes on-platform (Malgonde et al., 2020); developing customer feedback, ratings, and reputation measurement systems to enable partners on-platform to see which customers and partners are reputable, credible, reliable (Tae et al., 2020), and trustworthy (Rietveld et al., 2019; Rietveld et al., 2018); and developing platform procedures to help resolve any conflicts in customer-partner and partner-partner relationships (Wareham et al., 2014).

Innovation leverage builds on a repository of reusable resources on-platform similar to production leverage. However, instead of reusability to achieve economies of scale and scope, innovation leverage aims to foster innovation on-platform by driving economies of innovation and complementarity (Thomas et al., 2014). The platform owner seeks to attract a large number of autonomous and heterogeneous partners who can contribute a variety of complementary resources to drive economies of innovation on-platform, i.e.,

innovation through complementarity (Thomas et al., 2014). The size of the resource base and the complementarity of the resources can create network effects and have positive spillover effects for partners innovating on-platform (Foerderer et al., 2018; Li & Agarwal, 2017). Hence, a platform's innovation leverage manifests itself in the *generativity* of innovations on-platform (Cennamo & Santaló, 2019; Wareham et al., 2014) due to easing the process of finding and integrating complementary resources for partners to generate innovations that address customers' ever-changing requirements.

Aside from the generativity of innovations, which is the proxy of platform's innovation leverage, *profitability* of innovations on-platform is another key objective of the platform owner. After all, innovation is a simultaneous process of value creation (generativity) in response to customers' changing requirements, and value appropriation (profitability) to gain profit from the innovation (Ahuja et al., 2008; Jacobides et al., 2006). In the context of our study, both generativity and profitability are MPI outcomes on-platform thanks to easing the process of finding (transaction leverage) and integrating (production leverage) complementary resources. Hence, the platform owner invests into production and transaction leverages to foster generativity of innovations and to gain profitability from the generated innovations. Table 21 provides definitions along with empirical illustrations from the SAP example for all the constituent constructs of our study.

Concept	Definition	Current Discourses in Platform Literature	SAP Example
Complexity of multi-partner innovation (MPI)	Complexity of MPI is defined as the number of different resources, contributed by various partners, that need to be integrated with each other to generate innovations demanded by the customer (Anderson, 1999; Cilliers, 1998; Holland, 1995).	Complexity of the generated innovation: ▪ <i>Innovation complexity</i> (a platform architecture perspective): More complex platforms are associated with higher integration costs (Cennamo et al., 2018). ▪ <i>Innovation complexity</i> (an ecosystem perspective): As innovation complexity increases, partners need to account for a greater number of interactions between their complements and other components within the ecosystem (Kapoor & Agarwal, 2017).	▪ <i>Low MPI complexity</i> manifests when few resources from few partners are integrated: an automotive industry customer of SAP needs a new software to provide after sales support to auto buyers. This requires the standard module of Salesforce (a partner) and a consultant (another partner) to integrate Salesforce's module to the customer's core SAP system. ▪ <i>High MPI complexity</i> manifests when many resources from various partners are integrated: The same customer needs to digitally extend its enterprise IT to make connections to all sold vehicles that have autonomous driving features. This requires the integration of many resources from various partners, such as sensory technologies, telematics, Cloud, real-time data analytics, and AI/ML (Tarafdar & Tanriverdi, 2018).
Production leverage	"Production leverage is based on (re)use of a collection of assets and the interfaces and standards that enable sharing these to drive economies of both scale and scope" (Thomas et al., 2014, p. 206). Production leverage aims to reduce <i>production costs</i> of partners on-platform.	Various platform mechanisms that a platform owner can invest into for realizing production leverage: ▪ <i>Standardization of the platform core and interfaces</i> (e.g., app decoupling and app interface standardization) to foster multi-partner innovation and to reduce costs of generating innovations (Tiwana, 2015b; Wareham et al., 2014). ▪ <i>Interoperability and compatibility of partners' complements</i> to lower the cost of co-creating innovations and the cost of selling innovations (through faster and more efficient reach to costly-to-build platform's installed base) (Ceccagnoli et al., 2012; Mantovani & Ruiz-Aliseda, 2016). ▪ <i>Boundary resources</i> (e.g., APIs, SDKs) to cultivate development of innovations by partners and to overcome compatibility challenges among partners' complements (Boudreau, 2017; Ghazawneh & Henfridsson, 2013). ▪ <i>Subsidizing platform entry for partners</i> through, for instance, sharing IP with partners (Gawer & Henderson, 2007).	▪ <i>Boundary resources, and standardization of the platform core and interfaces</i>: SAP offers an SDK environment on the platform that grants partners a set of standardized choices when selecting the best-suited programming language for configuring their services. Further, SAP provides its partners with a dedicated tool for API management, organizing defined exchange protocols that allow to deliberately configure services. ▪ <i>Interoperability and compatibility of platform resources</i>: by accessing SAP's platform, partners develop modular software-as-a-service applications on-platform that can be seamlessly integrated with SAP's ERP core and with the applications developed by other partners. The modules become available for all SAP partners to reuse the already developed applications and to reduce the production costs of innovation on-platform. Benefits over a three-year period of using SAP platform's production leverage: over 90% reduction in the cost of internal application development, over 85% reduction in the time-to-value from business applications, and over 60% reduction in the costs of outsourcing application development (Forrester, 2020; Morel, 2020).
Transaction leverage	"Transaction leverage [...] is based on the manipulation of the market pricing mechanism and market	Various platform mechanisms that a platform owner can invest into for realizing transaction leverage: ▪ <i>Searching and matching technology such as two-sided recommender systems</i> to tame complex search matching	▪ <i>Certifying partners to establish trust</i>: SAP offers a certification center that works as a quality management means certifying SAP partners' resources. All the certified resources are listed on a directory, giving certified partners exposure to a large set

	access, which drives transaction efficiency and reduces search costs in the exchange of goods and services” (Thomas et al., 2014, p. 207). Transaction leverage aims to reduce <i>transaction costs</i> of partners on-platform.	of customers and partners and to reduce their search costs (Dinerstein et al., 2018; Malgonde et al., 2020). ▪ <i>Customers’ feedback to rank partners</i> (perceived quality of partners) to guide prospective customers’ search and to improve financial performance of platform owner and partners (Tae et al., 2020). ▪ <i>Selective promotion of partners through granting certifications</i> (requiring a series of quality specifications in the design of innovations) <i>and rewards to partners</i> to be perceived by potential customers as a quality signal for partners’ complements and to make partners’ complements more easily accessible to customers (Ceccagnoli et al., 2012; Rietveld et al., 2019; Rietveld et al., 2018). ▪ <i>Establishing trust</i> to the platform and among platform partners through, for instance, <i>knowledge sharing and seeding</i> (via e.g., online communities) (Huang et al., 2018; Perrons, 2009; Sampler, 2018; Zhang et al., 2022).	of customers. Further, SAP provides guidelines for partners’ step-by-step platform onboarding, competitive pricing incentives, and partnership policies (e.g., revenue share with partners, IP, ownership, license agreements, conflict resolution). Transacting on SAP platform leads to ease multifaceted and complex revenue share models, contracts, and fee structures for partners. ▪ <i>Searching and matching technology and recommender systems</i>: SAP platform’s recommender systems help partners search for and find the relevant resources, and help customers search for and find services relevant to their requirements. The so-called Partner Finder, for instance, allows customers to identify the right partners without needing an in-depth knowledge of SAP technology. Additionally, SAP’s App Center works as a B2B marketplace giving customers access to a wide range of the platform’s offerings. It also allows partners to reach SAP’s global customer base without investments in a sales network (Sahasrabudhe, 2021). Benefits over a three-year period of using SAP platform’s transaction leverage: improved collaboration among partners and brought revenue generated by applications forward in time by 14 months (Forrester, 2020; Morel, 2020).
Generativity	Representing the variety of unique offerings on-platform, generativity is defined as “the ecosystem’s capacity to foster complementary innovation from autonomous, heterogeneous firms” (Cennamo & Santaló, 2019, p. 617). Generativity is the proxy of platform’s <i>innovation leverage</i> and represents <i>value creation</i> in a co-creational process of innovation (Ceccagnoli et al.,	Opposing generativity outcomes of platforms: ▪ <i>Positive generativity effects</i> (spillover and network effects): more generativity reinforces a partner’s positive perception about the prospects of the platform’s user value and the incentives of other partners’ participation in the ecosystem (Boudreau, 2017; Cennamo & Santaló, 2019). ▪ <i>Negative generativity effects</i> (freeriding and crowding effects): partners’ enjoying of the benefits of a shared asset (i.e., platform leverages) to which they do not contribute and crowding of similar innovations that both diminish partners’ incentive to contribute to the ecosystem (Boudreau, 2017; Casadesus-Masanell & Hałaburda, 2014; Cennamo & Santaló, 2019).	Offered mechanisms of SAP’s platform brought about incentivizing more than 22,000 partners to join the platform that contribute to generating over 1,800 services on-platform. The variety of offered services motivates customers to move to and opt for the offered services on-platform. According to a SAP customer in the retail industry “<i>In close to two years, we’ve built and rolled out 24 applications. Without SAP Platform [...], we would not have gotten to half that number.</i>” (Forrester, 2020; Morel, 2020).

	2012; Thomas et al., 2014).		
Profitability	Profitability is defined as the difference between revenue generated from a service offering on-platform and the cost incurred in generating the service (Oh et al., 2015). Profitability represents <i>value appropriation</i> by platform owner and partners in a co-creational process of innovation (Ceccagnoli et al., 2012; Oh et al., 2015) .	Opposing profitability outcomes of platforms: ▪ <i>Positive profitability effects</i>: joining a platform ecosystem is associated with an increase in profitability of partners specifically when partners have greater IP rights or when the creation of innovations requires unique bundling of partners' complements (Ceccagnoli et al., 2012; Kapoor & Agarwal, 2017). ▪ <i>Trapped profitability effects</i> (prisoner's dilemma): when the ecosystem is saturated with innovation, fostered coordination among partners does not necessarily translate into greater profitability (Mantovani & Ruiz-Aliseda, 2016).	Offered mechanisms of SAP's platform brought about fostering revenue for the partners that adopted the SAP's platform. In the beginning of the SAP platform's launch (2012-2014), it was predicted that until 2016 approximately 25 percent of partners' revenue will be based on generated services on-platform (sap.com, 2020). In 2021, almost 60 percent of an SAP partner's revenue came from services that it generated on top of the SAP's platform. This figure is expected to reach almost 70 percent in 2024, a grow into a \$260 billion market up from \$141 billion in 2021 (sap.com, 2020). Given the revenue opportunities and the effects of SAP's platform leverages in reducing both production and transaction costs of generating services, profitability gains are expected for partners transacting on-platform.

Table 21. Study's main concepts

E.2.3 Research gap: Whether and how B2B platform leverages tame challenges of complexity in multi-partner innovation

In incumbent firms' arduous effort to shift the locus of MPI on-platform, achieving both generativity and profitability outcomes hinges on platform owners' efforts to attract a critical mass of partners that contribute various resources to the platform and choose to transact on-platform (e.g., Gawer & Cusumano, 2008; Rochet & Tirole, 2003). This topic resides in the existing research on the role of partners and on the relationship between platform owners and partners, which is one of the major streams of research on platforms (Rietveld & Schilling, 2021). As summarized in Table 22, this literature stream focused on explaining why joining a platform might be beneficial for partners (e.g., Ceccagnoli et al., 2012; Wareham et al., 2014), how owners could incentivize partners to join the platform (e.g., Boudreau, 2017; Gawer & Henderson, 2007), how partners' benefits from the platform could be optimized (e.g., Brunswicker et al., 2019; Malgonde et al., 2020), how owners could align partners' resource contributions (e.g., Huang et al., 2018; Tae et al., 2020), as well as collaboration and competition dynamics among partners on-platform (e.g., Boudreau, 2012; Rietveld et al., 2019).

Research sub-streams	Major research topics	Fundamental insights	Literature
Partners interest to join	Benefit of joining a platform ecosystem for partners	- Access to resources as a basis for creating and appropriating value - Lowered costs associated with search for and development of resources - Access to installed base of customers, i.e., indirect network effects - Individual partner's benefit may vary (e.g., due to presence of IP rights or competitive aspirations)	(Casadesus-Masanell & Halaburda, 2014; Ceccagnoli et al., 2012; Gawer & Cusumano, 2008; Gawer & Henderson, 2007; Karhu et al., 2018; Rietveld et al., 2019; Wareham et al., 2014)
	Performance of partners on a platform ecosystem	- Shaped by platform's architectural design (e.g., degree of constraints or presence of recommender systems) - Delineated by competition on-platform, i.e., market thickness (positive direct network effects and negative competitive crowding effects)	(Boudreau, 2012; Brunswicker et al., 2019; Cennamo et al., 2018; Dinerstein et al., 2018; Foerderer et al., 2018; Geva et al., 2019; Li & Agarwal, 2017; Malgonde et al., 2020; Rietveld et al., 2018; Tae et al., 2020; Tiwana, 2015b)
	Multihoming of partners on several platforms	- Depends on platforms' technological complexity and technical adaptation costs - Indicative of partners' potential to adapt to changes in the competitive environment more easily - Having partners who multihome may be detrimental to an individual platform	(Boudreau, 2012; Cennamo et al., 2018; Cennamo & Santaló, 2019; Ghazawneh & Henfridsson, 2013; Rietveld et al., 2019; Tae et al., 2020; Tiwana, 2015b)
Owner-partner relations	Owner's means to incentivize partners to join a platform ecosystem	- Lowered barriers to entry through subsidies (e.g., by sharing IP or providing core technological infrastructure) - Establishing trust in the platform (e.g., by ensuring quality through certification of partners and offerings) - Active selection of partners	(Boudreau, 2017; Casadesus-Masanell & Halaburda, 2014; Ceccagnoli et al., 2012; Gawer & Cusumano, 2008; Gawer & Henderson, 2007; Geva et al., 2019; Ghazawneh & Henfridsson, 2013)
	Owner's means to stimulate partners' innovation and to align partners' portfolio of complements on a platform ecosystem	- Definition of participation requirements (e.g., requesting fees or transparency on sensitive information) - Definition of architectural design (e.g., decoupling platform components or altering partners' design decision rights) - Definition of incentivization logic (e.g., emphasizing customer feedback or promoting certain kinds of offerings) - Entry in platform market (may lead to attention spillover effects or crowd out innovation) or explicitly refraining from entry	(Boudreau, 2017; Brunswicker et al., 2019; Dinerstein et al., 2018; Foerderer et al., 2018; Gawer & Henderson, 2007; Ghazawneh & Henfridsson, 2013; Huang et al., 2018; Li & Agarwal, 2017; Malgonde et al., 2020; Rietveld et al., 2019; Rietveld et al., 2018; Tae et al., 2020; Tiwana, 2015b)
Partner-partner relations	Collaboration among partners	- Enables unintended outcomes, i.e., generativity - Can be directly impacted by platform owner (e.g., by developing own offerings or installing dedicated partner-finding capabilities) - May be inhibited by competitive crowding	(Ceccagnoli et al., 2012; Cennamo & Santaló, 2019; Huang et al., 2018; Wareham et al., 2014; Zhang et al., 2022)
	Competition among partners	- Delineated by individual partners' competitive aspirations and general market thickness - Can be directly impacted by platform owner (e.g., by altering customers' search metrics or through selective promotion)	(Boudreau, 2012; Brunswicker et al., 2019; Dinerstein et al., 2018; Geva et al., 2019; Rietveld et al., 2019; Rietveld et al., 2018; Tae et al., 2020; Zhang et al., 2022)

Table 22. Current research on relationship between platform owner and partners

In complementing these studies, our study seeks to theorize on whether (if at all) and how platform leverages in the context of B2B innovation platforms tame MPI's complexity challenges. While existing research and practice generally promote platform technology, manifested by the omnipresence of platforms in numerous industries and by their impact in changing the fabric of incumbent firms (e.g., Cennamo & Santaló, 2019; 2018; Rietveld & Schilling, 2021; Thomas et al., 2014; Tilson et al., 2010), we investigate if, how, and when platform leverages are effectual in taming MPI's complexity challenges.

Despite a nascent and burgeoning body of empirical research on platform leverages, there is currently no theory on the roles of platform leverages in MPI. Thus, we opt for a theory development approach in this study. We build on complexity science as our theoretical lens to guide the process of developing a theory on platform leverages because, as summarized above, MPI is a complex phenomenon and platform leverages promise to tame the challenges of complexity. As shown in Table 21, instantiations of platform owner's investments into *platform leverages*, expected *generativity* and *profitability* outcomes on-platform, and *complexity* are well-recognized constructs in platform literature. When considering the relations among these constructs, our study aims to bridge three gaps in the existing research.

First, existing research lacks an investigation of both transaction and production leverages' effects on partners' generativity and profitability outcomes. There are some fragmented studies that generally acknowledged the increase in profitability of partners if they join a platform ecosystem (Ceccagnoli et al., 2012) or studies that demonstrated the increase in profitability of partners through a specific instantiation of one platform leverage (e.g., customers' feedback as an instantiation of transaction leverage) (Tae et al., 2020). Nonetheless, we lack knowledge on the effects of both transaction and production leverages on generativity and profitability outcomes, as well as their interaction effects, i.e., whether platform leverages amplify or dampen one another under different levels of MPI complexity. Second, existing research testified opposing generativity and profitability outcomes of platforms. While some studies established the positive generativity or profitability effects (Boudreau, 2012; Ceccagnoli et al., 2012; Cennamo & Santaló, 2019; Kapoor & Agarwal, 2017), others proved negative generativity or profitability effects (Boudreau, 2012; Casadesus-Masanell & Halaburda, 2014; Cennamo & Santaló, 2019; Mantovani & Ruiz-Aliseda, 2016). Therefore, extant body of knowledge lacks a theory explaining the circumstances under which B2B platform leverages affect the

generativity and profitability outcomes of partners on-platform. Third, existing research merely focused on innovation complexity as a function of the number of interdependent and unique components of the generated innovations (Cennamo et al., 2018; Kapoor & Agarwal, 2017). It has not studied the bottom-up emergence of ecosystem-level complexity as partners engage in complex MPI, and how the ecosystem-level complexity in turn generates top-down challenges for the transaction and production processes of MPI. We seek to generate insights on whether, when, and how B2B platform leverages tame MPI's complexity challenges to affect partners' generativity and profitability of innovations on-platform.

E.3 Research method

As described above, MPI complexity triggers ecosystem-level properties of non-decomposability, nonlinearity, emergence, and non-predictability (Anderson, 1999; Cilliers, 1998; Holland, 1995; Tanriverdi & Du, 2020). A simulation-based methodological approach, particularly agent-based modeling (ABM), is suitable to model and study complex systems (Bonabeau, 2002; Kiesling et al., 2012; Railsback et al., 2006) and is commonly employed for theory development (Beese et al., 2019; Davis et al., 2007; Dong, 2022). ABM allows us to model diverse and adaptive elements of a complex system, nonlinear interactions among them, and nudge the complex system to observe resulting outcomes at the system level (Nan & Tanriverdi, 2017). In the context of our study, ABM makes it feasible to experimentally manipulate the variables of interest (MPI complexity and platform leverages) to observe if and how they interact with each other in affecting the emergence of generativity and profitability outcomes (Nan & Tanriverdi, 2017).

Following existing ABM-based studies (Haki et al., 2020) and common recommendations for simulation-based research (Davis et al., 2007; Sargent, 2005), we developed the simulation model through an iterative process shifting between conceptual model development, operational model development, as well as validation, experimentation, and analysis.

E.3.1 Simulation's conceptual and operational models

We model the complex setting of MPI within a business ecosystem (Ganco et al., 2020). Partners may engage in bundling each other's resources to design innovative services either on-platform, employing the platform's production and transaction leverages and

in return share parts of their revenue with the platform owner, or off-platform on their own. In both cases, the generated innovations must meet customer requirements. Depending on MPI complexity, partners may adapt their choice of innovating on- or off-platform, and customers may adjust their decision to source services on- or off-platform. Partners' choice of innovating and customers' choice of sourcing services on- or off-platform may also be impacted by platform's production and transaction leverages to help them tame MPI's complexity challenges. Therefore, the simulation model's independent variable is MPI complexity, whose effects on generativity and profitability outcomes might be moderated by platform owner's investments into production and transaction leverages. Figure 16 depicts the conceptual model and relations among the variables of interest. In what follows, we further introduce our model's independent, moderating, dependent, and control variables.

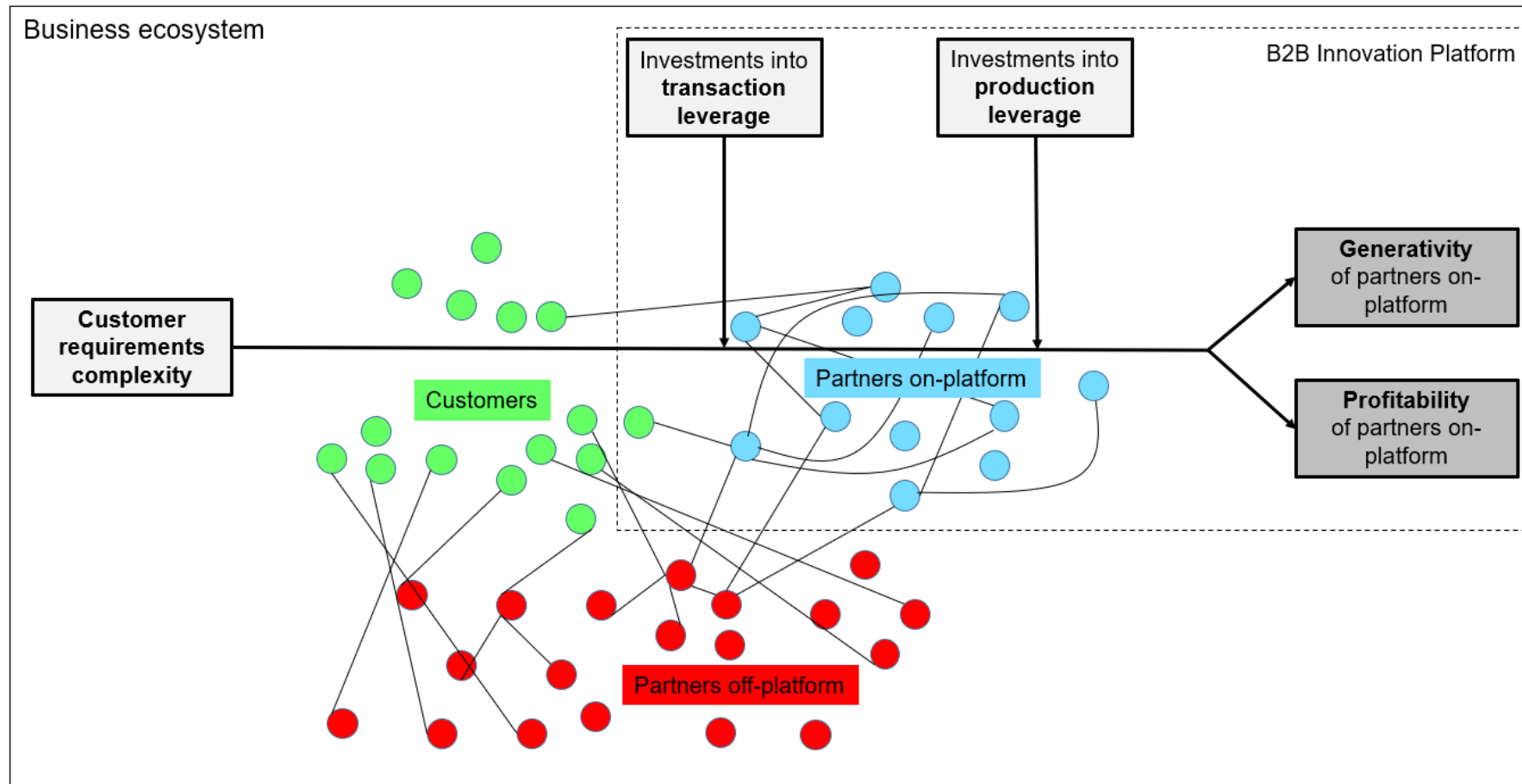


Figure 16. Simulation's conceptual model

E.3.1.1 Independent variable

Building on existing simulation models (Davis et al., 2009; Haki et al., 2020), our model captures *MPI complexity* as the number of contingencies (resources and features) that must be addressed to meet a customer requirement. Each customer requirement is operationalized as a 20-bit vector (Davis et al., 2009). MPI complexity thus varies from 0-20.

E.3.1.2 Moderating variables

Building on platforms' premises to tame MPI's complexity challenges, the platform owner's *investments into production leverage* and *investments into transaction leverage* are supposed to significantly reduce partners' production and transaction costs in innovation. The latter is the reason why partners choose to transact on-platform (instead of the off-platform alternative) to tame MPI's complexity challenges. In return, partners on-platform must share parts of their revenue with the platform owner as a compensation for using platform resources. In the simulation model, both production costs and transaction costs can be reduced by a factor of 0.00-1.00 on-platform, with increments of 0.05, depending on the platform owner's level of investments into production and transaction leverages. When the investment in a leverage is maximized, the associated costs of transaction or production can be reduced by up to 100% compared to innovating off-platform.

E.3.1.3 Dependent variables

When changing the level of platform owner's investments into production and transaction leverages, the simulation model captures the impact of various levels of MPI complexity on partners' *generativity* (value creation) and *profitability* (value appropriation) outcomes both on- and off-platform. The simulation model tracks generativity in form of the number of generated services (through bundling of resources) and traces profitability as the average profit partners make on-platform. Although generativity is a quantitative measure of innovation, the quality of innovations is captured by tracking whether an innovation meets customers' requirements and successfully completes a transaction.

E.3.1.4 Control variables

We control for the *revenue sharing* arrangement between platform owner and partners, *partners' inertia* in joining the platform, as well as *velocity* in the ecosystem. Revenue

sharing is a means for platform owner to appropriate value from partners' innovations on-platform (Karhu et al., 2018). Since revenue share varies across platforms (e.g., Apple's 30% on iOS, Salesforce' 15% on AppExchange), and even within platforms, we randomly alternated this variable between 10-30% in simulation runs. Further, the likelihood of partners adopting the platform technology and choosing to adapt their business model to transact on-platform is delineated by their level of inertia in innovation research (Hannan & Freeman, 1984; Kelly & Amburgey, 1991). Heterogeneity of partners is a commonly studied subject in the platform context (e.g., Boudreau, 2012; Ceccagnoli et al., 2012; Wareham et al., 2014). We account for partners' inertia as a form of heterogeneity by randomly assigning different levels of resistance to change in adopting the platform technology. Lastly, previous simulation models inform us on the importance of the rate at which new customer requirements occur in the ecosystem (Davis et al., 2009; Haki et al., 2020). Thus, we track environmental velocity to account for the arrival rate of customer requirements and control for its effects.

Relying on the underlying premises of complexity science, business ecosystem-level complexity is a function of the number of partners involved in MPI, the degree of interconnectedness among partners, and the environment in which innovation occurs (Anderson, 1999; Cilliers, 1998; Holland, 1995). In the operational model development step, we thus built our ABM upon these specificities by capturing agents (platform owner, partners, customers, resources, and services), the interactions among agents, and the surrounding environment in which interactions occur (Haki et al., 2020; Nan, 2011). Table 23 describes the simulation model's components and Figure 17 depicts the model flow leaning on Kaul et al. (forthcoming). Appendix C.1 also provides the details on how the simulation model's components are operationalized.

Component		Description	Literature
Agents	Customers (learning-agents)	Attributes: Customers have service requirements and a budget; they search for matching services on- or off-platform. Behavioral rules: Customers conduct both local distant searches to meet their requirements. If neither search is successful, customers trigger the partner search process (Figure 17).	(Brunswick et al., 2019; Davis et al., 2009; Ganco et al., 2020; Haki et al., 2020; Levinthal, 1997; Wareham et al., 2014)
	Partners (learning-agents)	Attributes: Partners are endowed with four random resources that they combine to create services, on- or off-platform. Behavioral rules: Partners conduct search to recombine resources and create profitable services that match customer requirements (Figure 17). Partners gain revenue when services to which they contribute are used, and incur costs for building and maintaining resources. Partners join the platform if they receive enough positive signals, and leave the platform if they receive enough negative signals about the platform from their local network (Table 24).	(Blaschke et al., 2018; Brunswick et al., 2019; Ganco et al., 2020; Gavetti et al., 2017; Haki et al., 2020; Levinthal, 1997; Malgonde et al., 2020; Wareham et al., 2014; Yoo et al., 2010)
	Resources (reflex agents)	Each resource has a set of features. Several resources are combined to create a service (Table 32). Resources have an associated, randomized production cost.	(Ganco et al., 2020; Gavetti et al., 2017; Haki et al., 2020; Karhu et al., 2018)
	Services (reflex agents)	Each service is used by customers to fulfill their requirements (Table 32). Services disappear from the ecosystem if unused for a certain number of time steps (see “life of services” in Table 36).	(Ceccagnoli et al., 2012; Haki et al., 2020)
	Owner	The owner provides core resources for all services generated on-platform. The owner incurs production costs (randomized) for maintaining these resources and gains revenue from services used on its platform, depending on the defined revenue share.	(Karhu et al., 2018; Wareham et al., 2014)
Interactions	Customer - Partner	Connection: Customers have certain partners in their local network. New links are established after a successful customer distant search, when a customer transacts with a partner that was previously not in the local network. Flow: Customers communicate their requirements to partners in the local network; partners communicate existing services to customers in the local network.	(Ganco et al., 2020; Gavetti et al., 2017; Malgonde et al., 2020; Wareham et al., 2014; Yoo et al., 2010)
	Partner - Partner	Connection: Partners have an existing local network. New links are established after a successful partner distant search. Flow: Partners share resources and experiences on-platform with partners in their local network.	
	Partner - Resource	Connection: Partners create and operate resources. Flow: Partners define and improvise the features of resources.	
	Resource - Service	Connection: Combinations of resources yield services. Flow: Combined resources define a service’s features.	
	Partner - Service	Connection: One single partner owns each service. Flow: The partner, who owns a service, provides the main resources and decides when to reconfigure its service.	
	Partner - Owner	Connection: The platform owner provides resources for service creation. Flow: Partners on-platform use the owner’s resources to create services with or without other partners on-platform.	
Environment		Next to MPI complexity and the rate of customer requirements’ arrival (i.e., velocity), the environment is open in that partners’ resources are renewed at a defined rate (Table 36). The number of partners and customers is fixed throughout simulation runs. Links amongst those agents are, however, not fixed, and links may die if agents do not interact for too long (Table 36).	(Davis et al., 2009; Haki et al., 2020)

Table 23. Simulation model components

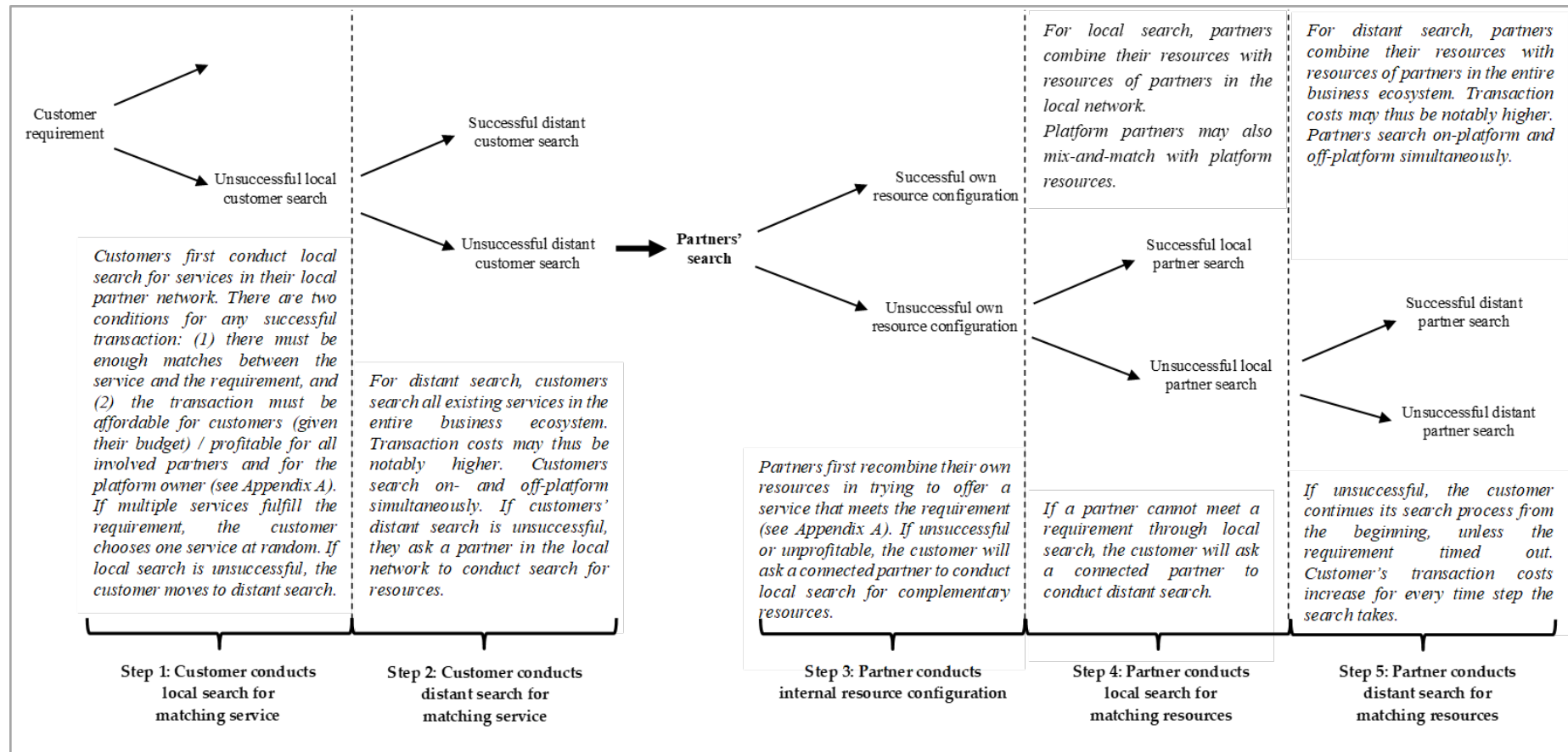


Figure 17. Simulation's operational model flow

E.3.2 Validation and experimentation

To ensure the validity of the simulation model, we first built the ABM on existing models, specifically regarding the conceptualization and operationalization of agents, interactions, and the environment (Davis et al., 2009; Haki et al., 2020; Malgonde et al., 2020). Further, we followed recommendations for model validation and verification (Davis et al., 2007; Sargent, 2005) and conducted more than three million simulation runs for reliability and degeneracy tests to establish the model's internal consistency and to define parameter ranges (details on model's sensitivity analyses appear in Appendix C.2). For experimentations, we varied all independent and moderating variables (MPI complexity as well as investments into production and transaction leverages) simultaneously across the entire possible ranges (Table 24) to track their impact on dependent variables (generativity and profitability). Control variables were randomized within the predefined ranges (Table 24). Each unique parameter setting of independent and moderating variables was tested 20 times, yielding $21 \times 21 \times 21 \times 20 = 185,220$ total simulation runs.

Variable	Range	Tested Values	Variations
Investments into production leverage	0.00-1.00	0.00-1.00 in increments of 0.05	21
Investments into transaction leverage	0.00-1.00	0.00-1.00 in increments of 0.05	21
Complexity of multi-partner innovation	0-20	0-20 in increments of 1	21
Platform owner's revenue share	0%-100%	10%-30%	randomized
Partners' inertia	>0	20-501F1F ⁵	randomized
Environmental velocity	>0	Poisson distribution, $\lambda = 302F2F$ ⁶	

Table 24. Simulation experiments

⁵ Inertia is operationalized as the number of signals a partner needs to join or leave the platform. If, for instance, a partner is initially off-platform and has an inertia value of 20, it will need to receive 20 positive signals about the platform to decide to move on-platform. Partners receive a positive signal about the platform each time a partner in their local network has a successful transaction on-platform. If a partner is initially on-platform and has an inertia value of 20, it will need to receive 20 negative signals to decide to move off-platform. Partners on-platform can always choose to also transact off-platform. Partners receive a negative signal about the platform each time they successfully transact off-platform. If a partner has higher inertia, it is less likely to make radical changes in strategy and structure (Hannan & Freeman, 1984), and will need more positive or negative signals to make the strategic move of joining or leaving the platform.

⁶ Velocity defines the interarrival time of customer requirements in time steps. It is operationalized as a Poisson distribution with $\lambda = 30$. The higher the value, the lower the rate of arrival of requirements (e.g., when velocity = 35, new requirements arrive every 35 time steps).

E.4 Results

We first assess if and how the experimental manipulation of MPI complexity would lead to the bottom-up emergence of business ecosystem-level complexity. For different levels of MPI complexity, we examine changes in the search patterns of customers and partners as well as the number of linkages formed among partners. We also compare the situation off-platform vs. on-platform with regard to the number of partners and the number of completed business transactions. We then assess in which regions of complexity in the business ecosystem the platform leverages promise to tame MPI's complexity challenges and attract partners to the platform.

E.4.1 Platform leverages in different regions of ecosystem complexity

We observe that changes in MPI complexity lead to changes in both search and relationship formation patterns in the business ecosystem. As Figure 18 shows, at very low levels of MPI complexity, customers primarily engage in local search to find the services they need. They rarely do distant searches. Partners also primarily focus on the configuration of their own internal resources to create the innovations needed by the customers (Figure 18). Partners rarely, if at all, conduct local or distant searches for complementary resources of other partners (Figure 18), implying that partners may have little or no need for multi-partner collaborations to generate the needed innovations. As Figure 19 shows, the number of partner-partner linkages in the business ecosystem remains close to zero, further suggesting that partners may not need multi-partner collaborations. Thus, platform leverages are not able to attract partners on-platform. As Figure 20 shows, at very low levels of MPI complexity, partners choose to stay (Figure 20a) and conduct business transactions (Figure 20b) off-platform.

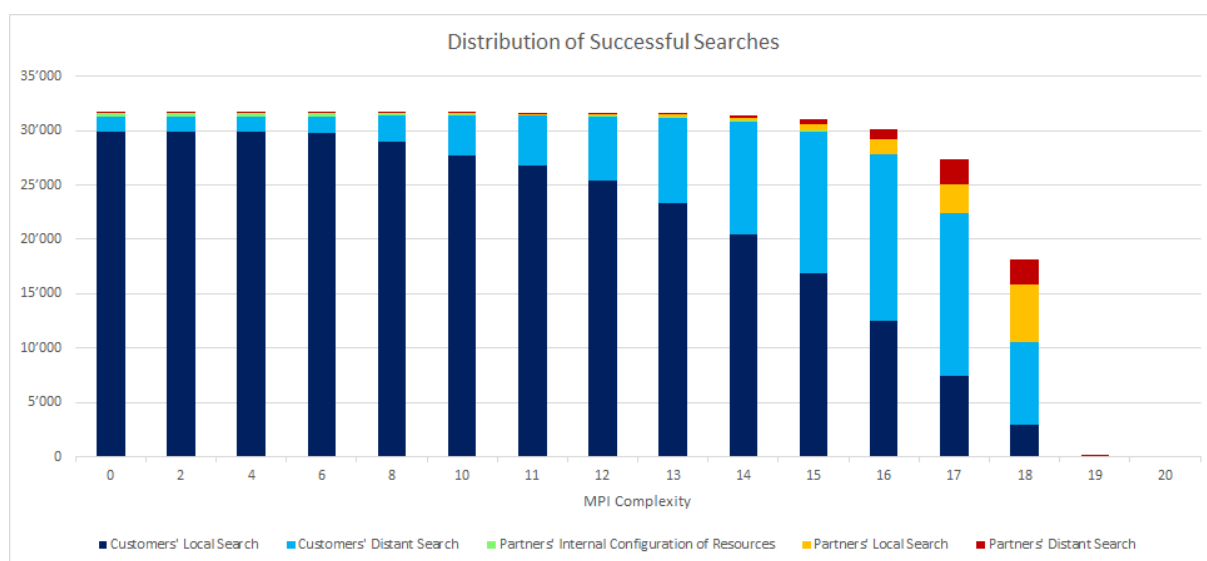


Figure 18. Distribution of successful searches in the business ecosystem

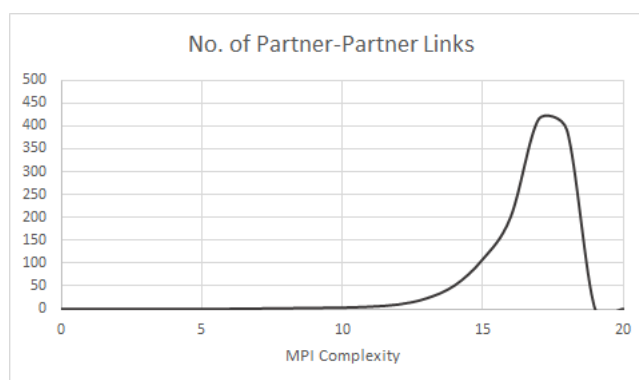


Figure 19. Partner-partner links in the business ecosystem

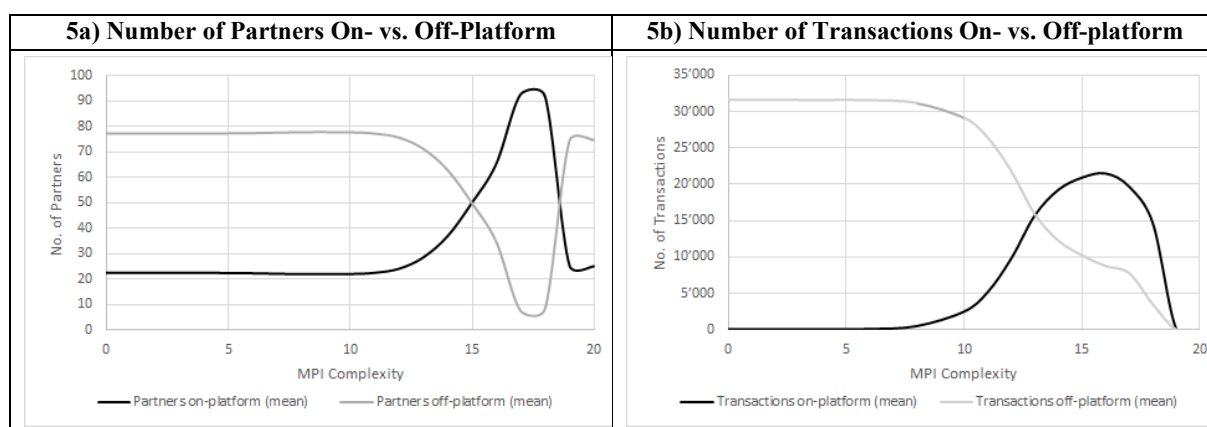


Figure 20. Number of partners and business transactions on-platform vs. off-platform

Collectively, these patterns indicate that the business ecosystem is operating in “the region of order” (Boisot & McKelvey, 2013; Tanriverdi & Lim, 2017). When there is order in the business ecosystem, partners do not face the challenges of complexity. Thus, they do not have a compelling need to join the innovation platform and use its leverages.

P1: *At very low levels of MPI complexity, business ecosystem operates in the region of order, where it is feasible for partners to configure their own resources to generate innovations that meet customers’ needs. In the region of order, innovation platform’s leverages are not likely to attract partners to the platform.*

When MPI complexity increases, customers struggle to find services to their needs with local searches. They start conducting searches in distant parts of the business ecosystem (Figure 18). Partners also struggle to develop innovative services on their own. Partners increase both local and distant searches to find collaborators who can bring in complementary resources (Figure 18). Partner-partner linkages in the ecosystem increase (Figure 19), indicating that the need for multi-partner collaboration increases. These patterns imply that the business ecosystem starts operating in “the region of emergent complexity.” In this region, the ecosystem operates away from equilibrium and likely to have properties of complexity such as nonlinearity, emergence, and non-predictability (Boisot & McKelvey, 2013; Tanriverdi & Lim, 2017). The innovation platform’s transaction and production leverages promise to help partners better address these challenges. To tame MPI’s complexity challenges, partners start migrating from off-platform to on-platform (Figure 20a). They use the platform’s leverages to find collaborators and integrate their resources. Accordingly, both the number of partners on-platform (Figure 20a) and the number of transactions completed on-platform increase (Figure 20b).

P2: *At low to high levels of MPI complexity, business ecosystem operates in the region of emergent complexity, where the innovation platform’s leverages attract partners to the platform to tame MPI’s complexity challenges.*

When we increase MPI complexity to very high levels, the complexity dynamics in the ecosystem increase dramatically. Customers do more distant searches than local searches as they struggle to find services to their needs (Figure 18). Partners increase both local and distant searches to find collaborators who can bring in the complementary resources (Figure 18). MPI is so complex that partners are not able to form collaborations that can bring together and configure the resources needed for a complex innovation. Thus, partner-partner linkages in the business ecosystem drop sharply (Figure 19). The platform’s leverages are no longer able to tame this level of MPI complexity.

Partners start migrating from on-platform to off-platform. Accordingly, the number of partners on-platform (Figure 20a) and the number of transactions completed on-platform decline sharply (Figure 20b). These patterns suggest that the business ecosystem hits “the edge of chaos” at very high levels of MPI complexity. At the edge of chaos, existing structures, roles, and relationships dissipate or collapse (Prigogine & Stengers, 1984; Tanriverdi & Lim, 2017). Partners who migrate from on-platform to off-platform are not able to complete transactions off-platform either at the edge of chaos.

P3: *At very high levels of MPI complexity, business ecosystem operates at the edge of chaos, where MPI’s complexity challenges are too high to be tamed by the platform’s leverages, and hence, partners leave the platform.*

To identify the boundaries of the business ecosystem’s three regions of complexity, we statistically test if and when the overall distribution of the partner-partner linkages in the business ecosystem first rise and first fall significantly. Specifically, we analyze the mean values of partner-partner links at every increment of MPI complexity, compare them pairwise, and use the Kolmogorov Smirnov test (Lee et al., 2010) to identify at what levels there are significant changes. As the Kolmogorov Smirnov tests in Table 25 show, the distribution of partner-partner linkages starts rising significantly at MPI complexity level 5. Before this level, there are no significant changes in the distribution of the partner-partner linkages in the business ecosystem. Thus, we mark MPI complexity range 0-4 as “the region of order” and level 5 as the start of “the region of emergent complexity.” As MPI complexity level increases further, the distribution of partner-partner linkages keeps rising significantly at each increment of complexity until reaching the level of 18, where there is a sharp and significant drop in the linkages. Thus, we mark level 18 as the end of the region of emergent complexity and define range 19-20 as “the edge of chaos.” Table 25 (upper part) depicts the three regions of complexity in the business ecosystem.

MPI Complexity						
Very low MPI complexity				Low MPI complexity		Medium MPI complexity
						High MPI complexity
						Very high MPI complexity
0	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
Region of order				Region of emergent complexity		Edge of chaos
Regions of the Ecosystem						
	MPI complexity range		Partner-partner links			
	From complexity	To complexity	Changes in partner-partner links		Kolmogorov Smirnov Test	
			Absolute	%	Test	P-value
Region of Order	0	1	0.00	66.61%	0.00	1.00
	1	2	0.00	-27.98%	0.00	1.00
	2	3	0.00	100.00%	0.00	1.00
	3	4	0.02	394.39%	0.01	0.99
	4	5	0.05	270.23%	0.02	0.02
Region of Emergent Complexity	5	6	0.18	238.85%	0.08	0.00
	6	7	0.46	183.52%	0.23	0.00
	7	8	0.80	110.90%	0.39	0.00
	8	9	0.72	47.65%	0.22	0.00
	9	10	0.86	38.27%	0.21	0.00
	10	11	2.00	64.83%	0.35	0.00
	11	12	4.70	92.29%	0.56	0.00
	12	13	13.39	136.72%	0.84	0.00
	13	14	28.30	122.03%	0.91	0.00
	14	15	57.04	110.80%	0.93	0.00
	15	16	93.38	86.04%	0.91	0.00
	16	17	215.09	106.53%	0.94	0.00
	17	18	-24.53	-5.88%	0.13	0.00
Edge of Chaos	18	19	-392.23	-99.94%	1.00	0.00
	19	20	-0.24	-100.00%	0.01	0.57

Table 25. Regions of complexity in the business ecosystem

We then examine whether and how the platform leverages tame MPI's complexity challenges in the region of emergent complexity (5-18) for the following reason. The region of emergent complexity is where the business ecosystem is neither at a stable equilibrium nor deteriorating (Boisot & McKelvey, 2013; Tanriverdi & Lim, 2017), and transaction and production challenges induced by complexity are significant to be tamed by platform leverages. We first test if the experimentally manipulated independent (MPI complexity) and moderating (investments into transaction leverage and investments into production leverage) variables have linear or quadratic relationships with dependent variables (generativity and profitability). We find that both the linear and the quadratic terms of these variables have significant effects on generativity and profitability outcomes. Thus, in the rest of the analyses, we use both their linear and quadratic terms.

To track the three-way interactions of the three quadratic variables, we employ the following approach. We use three levels of MPI complexity: low (Mean – σ = level 8), medium (Mean = level 12), and high (Mean + σ = level 16). Within each of these levels of MPI complexity, we examine the individual and two-way interaction effects of investments into transaction leverage and investments into production leverage.

E.4.2 Moderating effects of platform leverages on generativity

Table 26 presents regression results on how production leverage, transaction leverage, and MPI complexity have individual and joint effects on generativity. It also uses a 3D surface diagram to visualize the results. An examination of the three surface diagrams reveal that the generativity outcomes are different at the three levels of MPI complexity. At low level of MPI complexity, partners have limited generativity, while at medium level, generativity slightly increases. At high level of MPI complexity, however, partners achieve the highest level of generativity. For generativity, the sweet spot is then at high levels of MPI complexity, where generativity benefits of the platform leverages for partners are maximized.

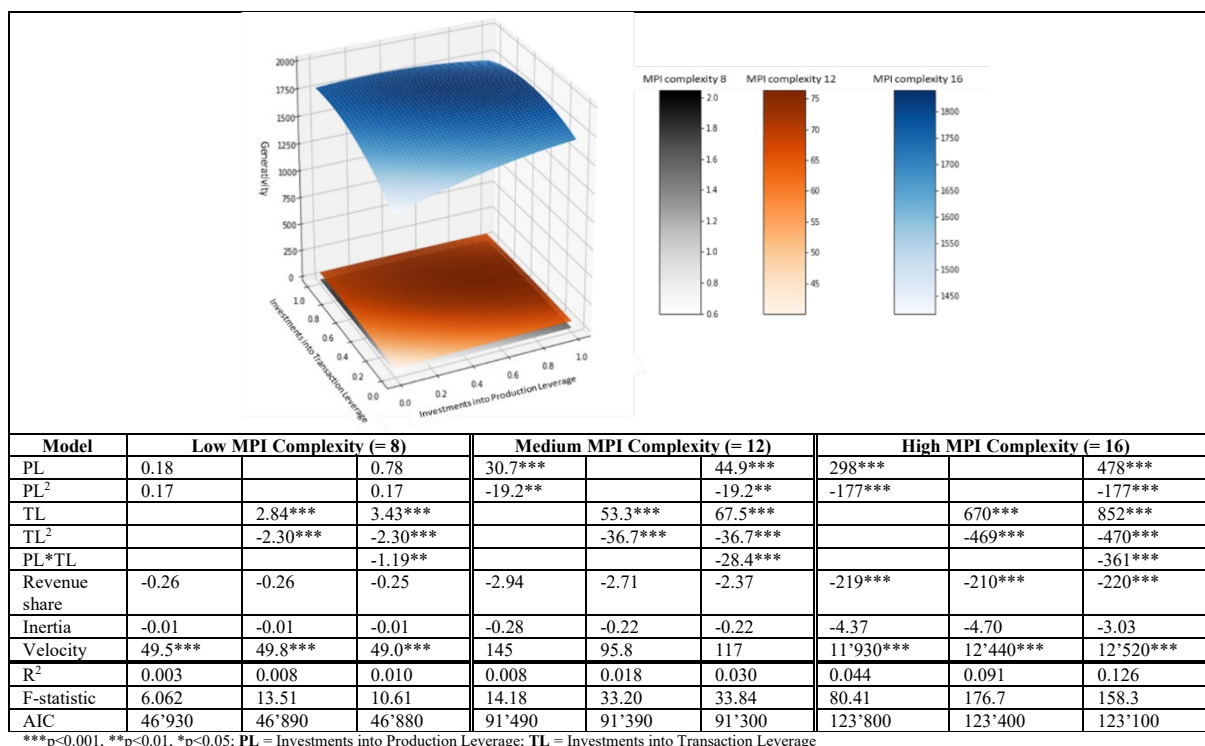


Table 26. Interaction effects of MPI complexity, production leverage, and transaction leverage on generativity

Our analyses also reveal that both production leverage and transaction leverage moderate the link between MPI complexity and generativity. The regression results in the first column of each level of MPI complexity show how production leverage interacts with MPI complexity to affect generativity. At a low level of MPI complexity, production leverage has no significant effect on generativity. At medium and high levels of MPI complexity, production leverage has significant quadratic relations with generativity. Platform owner's investments into production leverage initially increase generativity and then taper off. These results provide support for the moderating role of production leverage on the relationship between MPI complexity and generativity. The regression results in the second column of each level of MPI complexity show how transaction leverage interacts with MPI complexity to affect generativity. Transaction leverage has significant quadratic relationships with generativity at all three levels of MPI complexity. Platform owner's investments into transaction leverage initially increase generativity and then taper off. These results indicate that partners on-platform are able to use the platform leverages to tame MPI's complexity challenges and obtain generativity benefits. However, we also observe that the production and transaction leverages negatively and significantly interact with each other to attenuate each other's effects on the link

between MPI complexity and generativity (the third column of each level of MPI complexity). Based on these insights, we frame the following propositions:

P4: *In the ecosystem's region of emergent complexity, platform leverages moderate the link between MPI complexity and generativity of partners on the platform.*

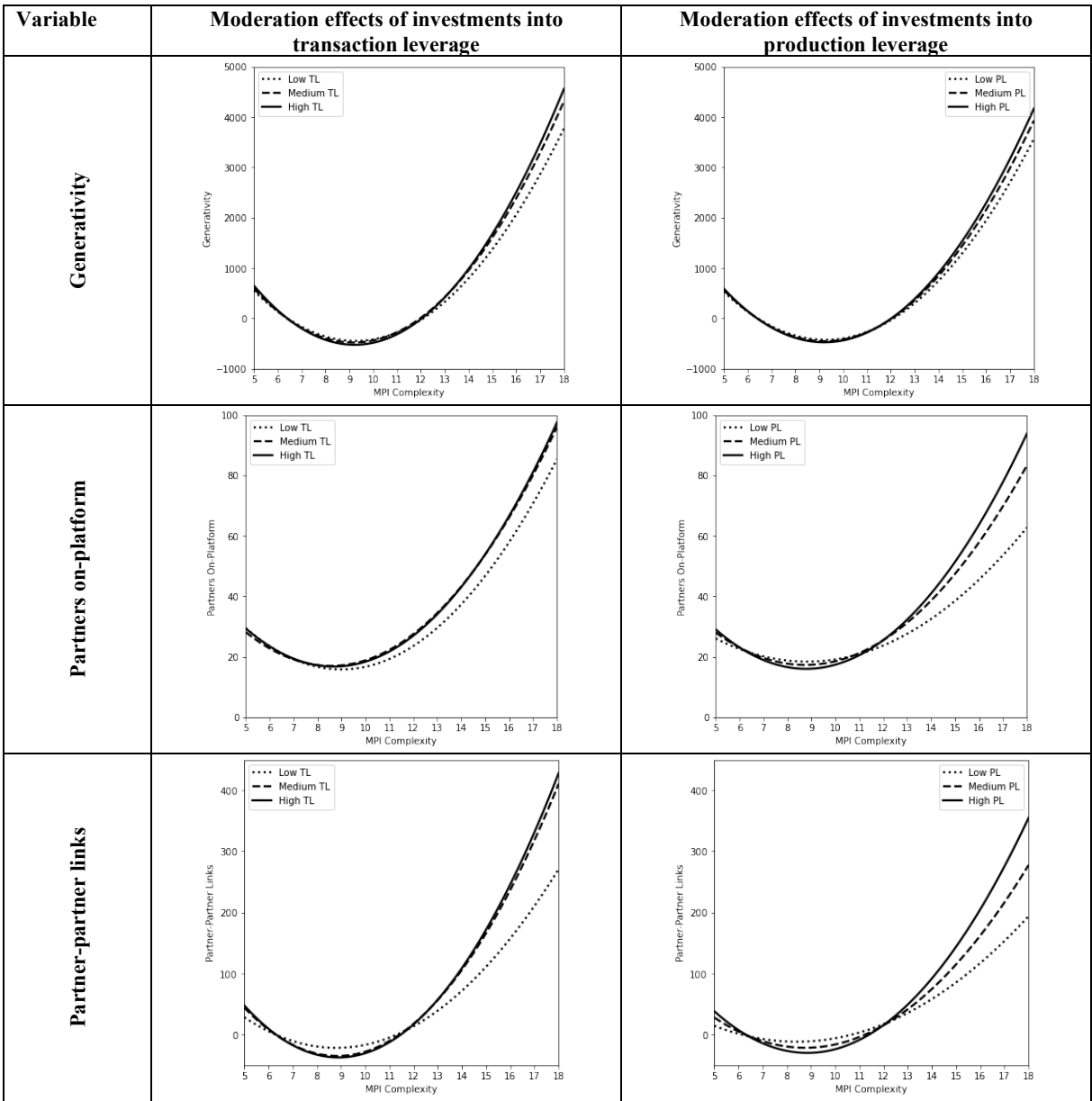
P4a: *Transaction leverage moderates the link between MPI complexity and generativity of partners on the platform.*

P4b: *Production leverage moderates the link between MPI complexity and generativity of partners on the platform.*

P4c: *Transaction and production leverages interact negatively to attenuate the effects of MPI complexity on generativity of partners on the platform.*

To further understand by which means the two leverages affect the generativity outcomes, we probe how the leverages affect intermediate determinants of generativity (numbers of partners on-platform and partner-partner linkages). In Table 27, the first column of 2D diagrams fixes production leverage at a level of 0 to examine how transaction leverage interacts with MPI complexity to affect generativity and its intermediate determinants. Likewise, the second column fixes transaction leverage at a level of 0 to examine how production leverage interacts with MPI complexity to affect generativity and its intermediate determinants⁷.

⁷ We vary the leverage of interest between low (Mean – σ = 0.2), medium (Mean = 0.5), and high (Mean + σ = 0.8).



PL = Investments into Production Leverage ; TL = Investments into Transaction Leverage

Table 27. Moderation effects of platform leverages on the links between MPI complexity and intermediate determinants of generativity

An examination of the generativity graphs in the first row indicates that MPI complexity has a nonlinear relationship with generativity and that both platform leverages moderate this relationship. Until a certain level of MPI complexity (level 9), both leverages struggle to attract partners on-platform and establish partner-partner linkages. Thus, the generativity level of partners on-platform declines slightly in this range of MPI complexity. However, as the MPI complexity level increases to a certain level (level 10) and goes beyond, both leverages significantly increase the number of partners on-platform and partner-partner linkages to significantly increase partners' generativity.

A major difference between the generativity effects of the two leverages is that there are limited returns to the generativity benefits of the transaction leverage. The production leverage does not have such a limitation. The medium and high levels of transaction leverage have almost identical effects on generativity, and on the intermediate determinants of generativity. Finding partners who have complementary resources and integrating their resources is challenging in a complex, dynamically changing ecosystem. Transaction leverage is an outward-looking capability of the platform that seeks to enable partners to do long jumps in the business ecosystem to find distant partners and tame the challenges of complexity entailed in working with them. However, the four properties of ecosystem-level complexity (non-decomposability, nonlinearity, emergence, non-predictability) can inhibit the ability of transaction leverage to complete the searches successfully. Indeed, the results indicate that there are limited returns to increasing the level of investments into transaction leverage from medium to high levels. In comparison, increasing production leverage from low through medium to high levels always yield higher generativity benefits by increasing the numbers of partners on-platform and partner-partner linkages. Production leverage is an inward-looking capability of the platform. As such, its operation is not as dependent on the four properties of ecosystem-level complexity. Production leverage standardizes platform's core and interfaces and modularizes resources to tame the interoperability and compatibility challenges in multi-partner resource integration on-platform. More standardization and modularization of the platform resources increase the reusability and re-configurability of the resources to enable partners on-platform to generate more innovations.

P4d. *There are limited generativity returns to the transaction leverage of the innovation platform. Moderate level of transaction leverage fosters the most generativity. Investing further into high levels of transaction leverage does not yield more generativity.*

P4e. *There are increasing generativity returns to the production leverage of the innovation platform. Investing into low through medium to high levels of production leverage yields increasing levels of generativity on the platform.*

E.4.3 Moderating effects of platform leverages on profitability

Table 28 presents regression results on how production leverage, transaction leverage, and MPI complexity have individual and joint effects on profitability. The 3D surface diagrams indicate that low, medium, and high levels of MPI complexity have different effects on the profitability of partners on-platform. At low level of MPI complexity, partners have limited profitability. At medium level of MPI complexity, partners achieve the highest profitability. At high level of MPI complexity, however, profitability tapers off (compared to medium level). For profitability, the sweet spot is then at medium levels of MPI complexity, where profitability benefits of the platform leverages for partners are maximized.

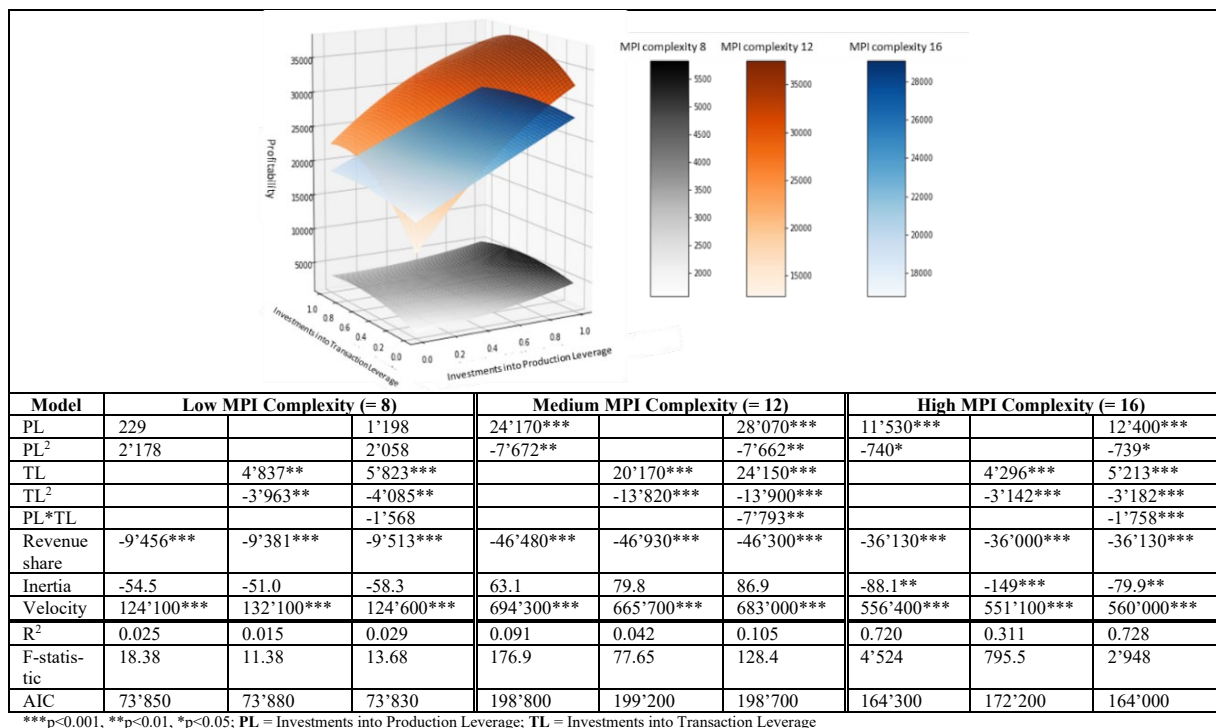


Table 28. Interaction effects of MPI complexity, production leverage, and transaction leverage on profitability

Our analyses also reveal that the platform leverages moderate the link between MPI complexity and profitability. The regression results in the first column of each level of MPI complexity show how production leverage interacts with MPI complexity to affect profitability. At a low level of MPI complexity, production leverage has no significant

effect on profitability. At medium and high levels of MPI complexity, production leverage has significant quadratic relations with profitability. Platform owner's investments into production leverage initially increase profitability and then taper off. These results provide support for the moderating role of production leverage on the relationship between MPI complexity and profitability. The regression results in the second column of each level of MPI complexity show how transaction leverage interacts with MPI complexity to affect profitability. Transaction leverage has significant quadratic relationships with profitability at all three levels of MPI complexity. Platform owner's investments into transaction leverage initially increase profitability and then taper off. These results indicate that partners on-platform are able to use the platform leverages to tame MPI's complexity challenges and obtain profitability benefits. However, the two leverages are not additive. They negatively and significantly interact with each other to attenuate each other's effects on the link between MPI complexity and profitability (the third column of each level of MPI complexity). Thus, we posit:

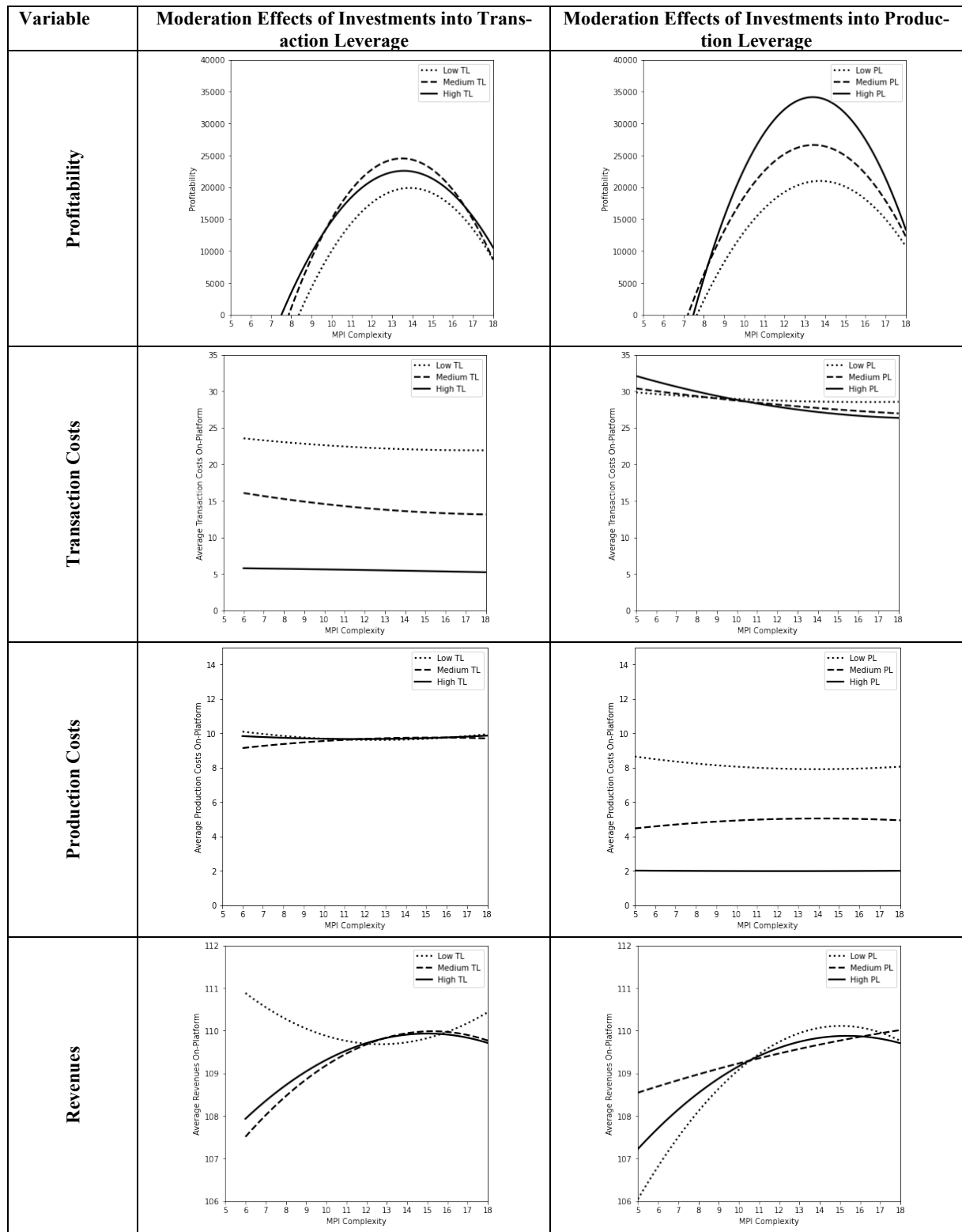
P5: *In the ecosystem's region of emergent complexity, platform leverages moderate the link between MPI complexity and profitability of partners on the platform.*

P5a: *Transaction leverage moderates the link between MPI complexity and profitability of partners on the platform.*

P5b: *Production leverage moderates the link between MPI complexity and profitability of partners on the platform.*

P5c: *Transaction and production leverages interact negatively to attenuate the link between MPI complexity and profitability of partners on the platform.*

To further understand by which means the two leverages affect the profitability outcomes, we probe how the leverages affect intermediate determinants of profitability (transaction costs, production costs, and revenues, see model details in Appendix C.1). Similar to Table 27, Table 29 depicts how one platform leverage interacts with MPI complexity to affect intermediate determinants of profitability when the other platform leverage is fixed at a value of 0.



PL = Investments into Production Leverage ; TL = Investments into Transaction Leverage

Table 29. Moderation effects of platform leverages on the links between MPI complexity and intermediate determinants of profitability

As the first row of Table 29 shows, MPI complexity has a nonlinear relationship with profitability of partners on-platform. The two platform leverages both moderate this relationship, but their moderation effects are different. The sweet spot for maximizing the effect of MPI complexity on the profitability of partners on-platform is the medium level of transaction leverage. Increasing transaction leverage to a high level diminishes the effect of MPI complexity on profitability. In contrast, a high level of production leverage is needed to maximize the effects of MPI complexity on the profitability of partners.

P5d. *There are diminishing profitability returns to the transaction leverage of the innovation platform. Moderate level of transaction leverage fosters the most profitability. Investing further into high levels of transaction leverage diminishes profitability.*

P5e. *There are increasing profitability returns to the production leverage of the innovation platform. Investing into low through medium to high levels of production leverage yields increasing levels of profitability on the platform.*

As for the determinants of profitability, the two leverages affect the costs (production costs and transaction costs) and revenues differently (Table 29). Transaction leverage reduces the transaction costs whereas production leverage reduces the production costs. The emergent effect, however, is that production leverage also moderates the effect of MPI complexity on the transaction costs (second row on the right). Increasing the production leverage reduces transaction costs in increasing levels of MPI complexity. More modular and reusable resources on the platform reduce the transaction costs of finding and integrating complementary resources. However, the transaction leverage does not have a symmetric moderation effect on the link between MPI complexity and production costs on-platform (third row on the left). At medium to high levels of MPI complexity, production costs on the platform remain flat no matter how much the investments into transaction leverage are increased. At this range, transaction leverage finds collaborators from distant parts of the ecosystem. Those collaborators' resources are not yet compatible and interoperable, and hence, they can increase the integration costs to neutralize cost reductions achieved by production leverage to flatten the net production costs.

An examination of the revenue diagrams in the last row of Table 29 reveals that the two leverages have different effects on the revenues obtained from completed transactions on-platform. The most salient difference is at low levels of MPI complexity and the leverages, where production leverage increases revenue whereas transaction leverage decreases it.

E.5 Discussion and conclusion

As prior studies find (Kapoor & Agarwal, 2017), and our results also confirm, innovation complexity is a source of superior performance on-platform. However, it is challenging to generate a complex MPI due to the transaction and production challenges entailed. Building on the extant IS platform literature, which suggests that platform's mechanisms (leverages) could be designed to tame the challenges of complexity (e.g., Ceccagnoli et al., 2012; Ghazawneh & Henfridsson, 2013; Huang et al., 2018; Malgonde et al., 2020; Tiwana, 2015b), this study investigated and theorized the conditions under which a B2B innovation platform could tame MPI's complexity challenges. The proposed theory addresses three gaps in the extant IS platform literature and provides guidance for practice.

E.5.1 Contributions to research

The first gap in the IS platform literature addressed by the proposed theory is *whether and when* a B2B innovation platform tames the challenges of complexity. The proposed theory reveals the business ecosystem's region of operation as a major contingency.

IS research acknowledges that the quest to tame ecosystem-level complexity motivates firms to adopt a platform and invest into platform leverages (e.g., Malgonde et al., 2020; Sandberg et al., 2020). Yet, IS research has not theorized whether and when the platform's leverages attract partners and tame the challenges of complexity. In the broader management literature, some studies find that a platform has positive profitability and generativity effects while others find negative effects (e.g., Boudreau, 2017; Casadesus-Masanell & Halaburda, 2014; Ceccagnoli et al., 2012; Cennamo & Santaló, 2019; Kapoor & Agarwal, 2017; Mantovani & Ruiz-Aliseda, 2016). Our ABM simulations and the theory we propose explain that the business ecosystem's region of operation determines whether and when the platform's leverages increase or decrease partners' generativity and profitability outcomes.

In the region of order, customer requirements are not yet challenging-enough to require MPI. Accordingly, complexity challenges do not emerge in the business ecosystem, and partners do not perceive value in joining the platform as there is no complexity to tame. At the edge of chaos, however, MPI's complexity challenges become too high to be tamed by the platform leverages, and the ecosystem becomes sluggish. Partners are not able to generate innovations to meet customer needs. Hence, existing platform partners decide to leave and new partners do not join the platform. Only in the ecosystem's region

of emergent complexity, partners perceive value in joining the platform and using its leverages to tame complexity.

The second gap in the IS platform literature addressed by the proposed theory is *how* a B2B innovation platform's leverages attract partners, tame the challenges of complexity, and foster partners' generativity and profitability in the business ecosystem's region of emergent complexity.

In the region of emergent complexity, the two platform leverages moderate the link between MPI complexity and partners' generativity and profitability outcomes on-platform. However, they do not uniformly tame MPI's complexity challenges. The moderation relationships are also non-linear with negative quadratic terms, suggesting limits to the complexity taming abilities of the leverages. Up to a certain level of MPI complexity, platform leverages tame the challenges of complexity and increase partners' generativity and profitability outcomes. Beyond that level, the benefits of the leverages taper off and start reducing the generativity and profitability outcomes. Profitability is maximized at medium MPI complexity whereas generativity is maximized at high MPI complexity. Our results have nuanced implications for IS platform mechanism design literature, confirming that platform mechanisms can tame challenges of complexity, but they also draw attention to the limits of those taming mechanisms. Further scrutiny reveals differences in how the production and transaction leverages affect partners' generativity and profitability outcomes differently.

There are increasing returns to platform owner's investments into production leverage on both generativity and profitability outcomes. More investments into production leverage keep amplifying the relationship between MPI complexity and partners' generativity and profitability outcomes. Thus, investing into platform leverages such as standardization of the platform's core and interfaces, boundary resources, and interoperability of partners' resources (e.g., Boudreau, 2017; Ghazawneh & Henfridsson, 2013; Tiwana, 2015b; Wareham et al., 2014) yields an increasing return on partners' generativity and profitability on-platform.

We observe a different pattern for returns to platform owner's investments into transaction leverage. After reaching moderate levels of investments into transaction leverage, further investments do not further amplify the relationship between MPI complexity and outcomes. Beyond a moderate level of investments, investing more into transaction leverage such as recommender systems, online communities to provide free technical support, or certifications (e.g., Dinerstein et al., 2018; Malgonde et al., 2020; Rietveld et

al., 2019) does not foster additional generativity and profitability for partners on-platform.

The findings on the two platform leverages suggest that the transaction-related challenges created by MPI complexity are much more difficult to tame than the production-related challenges. At high levels of MPI complexity, partners face non-decomposability challenges (Anderson, 1999; Cilliers, 1998; Holland, 1995; Tanriverdi & Du, 2020). They may not be able to decompose the complex innovation into its constituent resources. If they cannot know which resources to search for, they may not be able to use the transaction leverage effectively. Partners can engage in trial and error in (re)configuring resources of other partners to generate innovations, but trial and error can prove costly and reduce the profitability of the resulting innovations.

The third gap in the IS platform literature addressed by the proposed theory is *how* the two platform leverages *interact* with each other to jointly affect partners' generativity and profitability outcomes on-platform. The extant literature discussed only the independent effects of the two platform leverages in isolation of each other (e.g., Ceccagnoli et al., 2012; Tae et al., 2020).

Interestingly, we find that the production and transaction leverages negatively interact to attenuate each other's effects on the links between MPI complexity and the generativity and profitability outcomes. This is a brand new insight, which challenges the implicit assumption that the two leverages would have additive effects (Thomas et al., 2014) on generativity and profitability of innovations. Our results suggest that simultaneously increasing investments into production leverage and transaction leverage would decrease partners' generativity and profitability on-platform. The intuition for this finding is as follows. Production leverage tries to improve generativity and profitability of innovations by making on-platform resources modular and reusable. In contrast, transaction leverage makes it easier for partners to search for collaborators in distant parts of the ecosystem, and tap into their resources, which may not yet be compatible with the resources that the production leverage previously modularized and made reusable. When partners attempt to bundle the resources of the newly found collaborators, they are likely to face compatibility, interoperability, and integration problems, which would negatively affect the generativity and profitability outcomes.

Finally, the proposed theory also contributes back to the complexity science (e.g., Anderson, 1999; Cilliers, 1998; Holland, 1995) upon which we built our theorization. Complexity science argues that ecosystem-level complexity creates wicked problems

for participants of the ecosystem and poses considerable challenges due to the non-decomposability, nonlinearity, emergence, and non-predictability properties (Anderson, 1999; Cilliers, 1998; Holland, 1995; Tanriverdi & Du, 2020). However, complexity science does not offer taming mechanisms for the wicked problems of complexity. It only offers generic principles for coping with the challenges of complexity such as: the quality of relationships among participants in a complex ecosystem can lead to better outcomes (Clarke & Stewart, 1997). Our study identifies B2B innovation platform's production and transaction leverages as two specific mechanisms for taming the ecosystem-level complexity challenges. The B2B innovation platform's leverages improve the quality of relationships between the engaged partners in MPI, by enabling them to find what they are searching for, gain trust in each other, enter into contractual relationships to collaborate, integrate each other's resources, share the value created, and resolve any conflicts or disputes.

E.5.2 Implications for practice

Our findings suggest that platform owners should assess a business ecosystem's region of operation before making investments into production and transaction leverages. If the ecosystem is in the region of order, investing in the leverages is unlikely to attract partners to the platform. If the ecosystem is in the region of emergent complexity, there are increasing returns to investing into production leverage. The higher the production leverage is, the higher the generativity and profitability benefits will be. However, investing into transaction leverage is beneficial only up to a moderate level. Moreover, the two leverages negatively interact with each other. Transaction leverage reduces the effects of production leverage on generativity and profitability outcomes. Thus, platform owners may need to carefully weigh the pros and cons of increasing investments into transaction leverage. At the edge of chaos, platform owners should not invest in the leverages as challenges of complexity are too high to be tamed by them. Similarly, partners contemplating to join a platform may not see notable benefits of the platform leverages outside the region of emergent complexity.

Our findings also inform executives of incumbent firms in an industry ecosystem whether and when the entry of a B2B innovation platform could prove disruptive by rewiring their customers and partners to the platform. Such a possibility keeps executives up at night because the entry of some platforms such as mobile (e.g., Apple's iOS), ride-sharing (e.g., Uber, Lyft), and lodging (e.g., Airbnb) platforms proved disruptive to incumbents (de Reuver et al. 2018). We suggest that such a possibility is remote in industry ecosystems that operate in the region of order

or at the edge of chaos. But, it is real in ecosystems that operate in the region of emergent complexity.

E.5.3 Boundary conditions and future research

The proposed theory has some boundary conditions. First, it focuses on MPI complexity as the trigger of complexity dynamics in a business ecosystem. Other factors that may trigger complexity dynamics such as regulatory requirements (Davis et al., 2009) were out of scope and may be accounted for by future research. Second, the theory is likely to be valid only in an ecosystem's region of emergent complexity (Boisot & McKelvey, 2013; Tanriverdi & Lim, 2017). We have not theorized the roles of platform leverages at the edge of chaos where the existing structures and relationships in the ecosystem collapse and brand new ones are likely to emerge (Tanriverdi & Lim, 2017). Further theorization is needed to explain how innovation platforms may adapt and survive the challenges of very high complexity levels at the edge of chaos.

As the third boundary condition, our theory focuses on a business ecosystem with only one B2B platform. Competition among multiple platforms, each trying to attract partners (and customers) to its own platform, could change complexity dynamics in the ecosystem. Further theorization is needed to understand whether and how, in the context of MPI, competition among multiple platforms and multihoming of partners would affect complexity dynamics and generativity and profitability outcomes.

A fourth boundary condition of our theory is the focus on a B2B innovation platform. Further work is required to test if the theory would apply to B2C innovation platforms (e.g., B2C mobile ecosystems). Finally, the proposed theory generated a set of testable propositions. Empirical testing of the propositions is required to validate the theory.

Appendix A: Paper B

Parameter	Range tested	Default value	Results
Time steps	1000–2,500	1,000	The model’s behavior is stable throughout the tested ranges.
Number of customers	20–5,000	1,000	The number of customers and partners was derived from publicly available information on SAP’s Cloud Platform, detailing a ratio of 10:1. Increasing beyond this threshold significantly impedes the speed of the simulation model.
Number of partners	20–500	100	
Initial platform market share	15%–60%	25%	SAP created its Cloud Platform with an existing base of partners and customers.
Resources per partner	1–4	4	Partners are initially embedded with 4 resources, enabling them to create services by themselves.
Owner’s resources	5–50	30	The platform owner provides a range of resources that serve as a basis for partners to integrate their resources on the platform.
Revenue share owner	0–100%	10–30%	The platform owner receives a random share of the revenue of every transaction within the predefined range.
Resource costs	5–30	5–15	The cost of resources is randomized within a predefined range, and in relation to the payoffs from requirements and search costs.
Level of improvisation of resources	0–5	1	To allow for some improvisation in configuring individual resources for service requirements, 1 of 5 elements in the resource sets can be improvised to become <i>either</i> a 0 or 1.
Responsiveness of partners	1–100	20–50	To account for heterogeneity amongst partners, their responsiveness to signals and experiences urging them to leave or join the platform varies within the predefined range.
Requirement payoff	Random distribution	$\mu = 110$, $\sigma^2 = 10$	Adopted from Davis et al. (2009) and Haki et al. (2020), adjusted as part of the parameter calibration.
Requirement duration	Random distribution	$\mu = 20$, $\sigma^2 = 5$	
Requirement arrival rate	Poisson distribution	$\mu = 30$	
Service duration	Random distribution	$\mu = 30$, $\sigma^2 = 10$	This parameter defines how long services stay in the ecosystem without being used. It was set to roughly outlast the average search process for services and is renewed after every usage.
Customer – partner links	1–10	2	Partners and customers have the chance to create new links amongst each other, but both types of links will also disappear after a certain number of time steps without interacting. We chose initial settings that roughly represent the mean values of the aggregate number of respective links throughout the simulation runs.
Partner – partner links	1–10	1	
Life of links	30–200	100–150	
(Local) search costs	0–50	20–40	Search costs in the market range between the given values. On the platform, search matching investments by the owner can decrease these costs by a factor of 0.00-1.00.
(Distant) search costs	30–100	40–60	
Renewal of resources	50–200	100	To account for continuous innovation, partners are periodically endowed with a new resource set, replacing one of the existing ones.

Table 30. Tested parameter ranges of initialization parameters

Appendix B: Paper C

Parameter	Range tested	Default value	Results
Time steps	500–2,500	1,000	The main relations tested in the model are stable throughout the tested ranges.
Number of customers	100–2,000	1,000	The ratio of customers to partners was adopted from an empirical example (SAP BTP). Higher numbers of partners and customers amplify effects, but the moderating effect of complexity remains stable. At the lowest levels tested, the dynamics barely unfold, as there are simply not enough partners in the ecosystem.
Number of partners	10–200	100	
Initial platform market share	5%–80%	25%	Our model assumes the platform owner to be a significant player in the business ecosystem. Results are impacted, but complexity's moderating effect is stable.
Resources per partner	1–4	4	Partners are initially embedded with 4 resources, enabling them to create services by themselves.
Owner's resources	5–50	30	Varying the number of resources provided by the platform owner does not impede complexity's moderating effect.
Production costs	5–30	5–15	Production costs are randomized within a range and can be lowered on-platform through production-related investments and must be set in relation to payoff levels.
Level of improvisation of resources	0–5	1	1 of 5 elements in the resource sets can be improvised to become <i>either</i> a 0 or 1. Complexity's moderating effect remains stable across the tested range.
Requirement payoff	Random distribution	$\mu = 110$, $\sigma^2 = 10$	Adopted from Davis et al. (2009) and Haki et al. (2020). Since payoffs are decisive for profitability levels, they must be adjusted to cost levels. Requirement duration variations did not impact complexity's moderating effect.
Requirement duration	Random distribution	$\mu = 20$, $\sigma^2 = 5$	
Service duration	Random distribution	$\mu = 30$, $\sigma^2 = 10$	This parameter defines how long services stay in the ecosystem without being used. It was set to roughly outlast the average search process for services and is renewed after every usage. Complexity's moderating effect was upheld in the tested ranges.
Customer – partner links	1–10	2	Partners and customers create new links among each other, but links will disappear after some time without interaction. When the number of partner-partner links is very high in relation to the number of partners in the model, both generativity and profitability levels are lower on-platform, as partners in the ecosystem essentially know every other partner. However, complexity still moderates effects.
Partner – partner links	1–10	1	
Life of links	30–200	100–150	
Transaction costs	10–80	20–40; 40–60	Transaction costs are randomized within a range for local and distant search, respectively, and can be lowered on-platform through transaction-related investments. Transaction costs must also be adjusted to payoff levels.
Renewal of resources	50–200	100	To account for continuous innovation, partners are periodically endowed with a new resource set, replacing one of the existing ones. Variations had no notable effects.

Table 31. Simulation model initialization parameters

Appendix C: Paper E

C.1. Operational model details

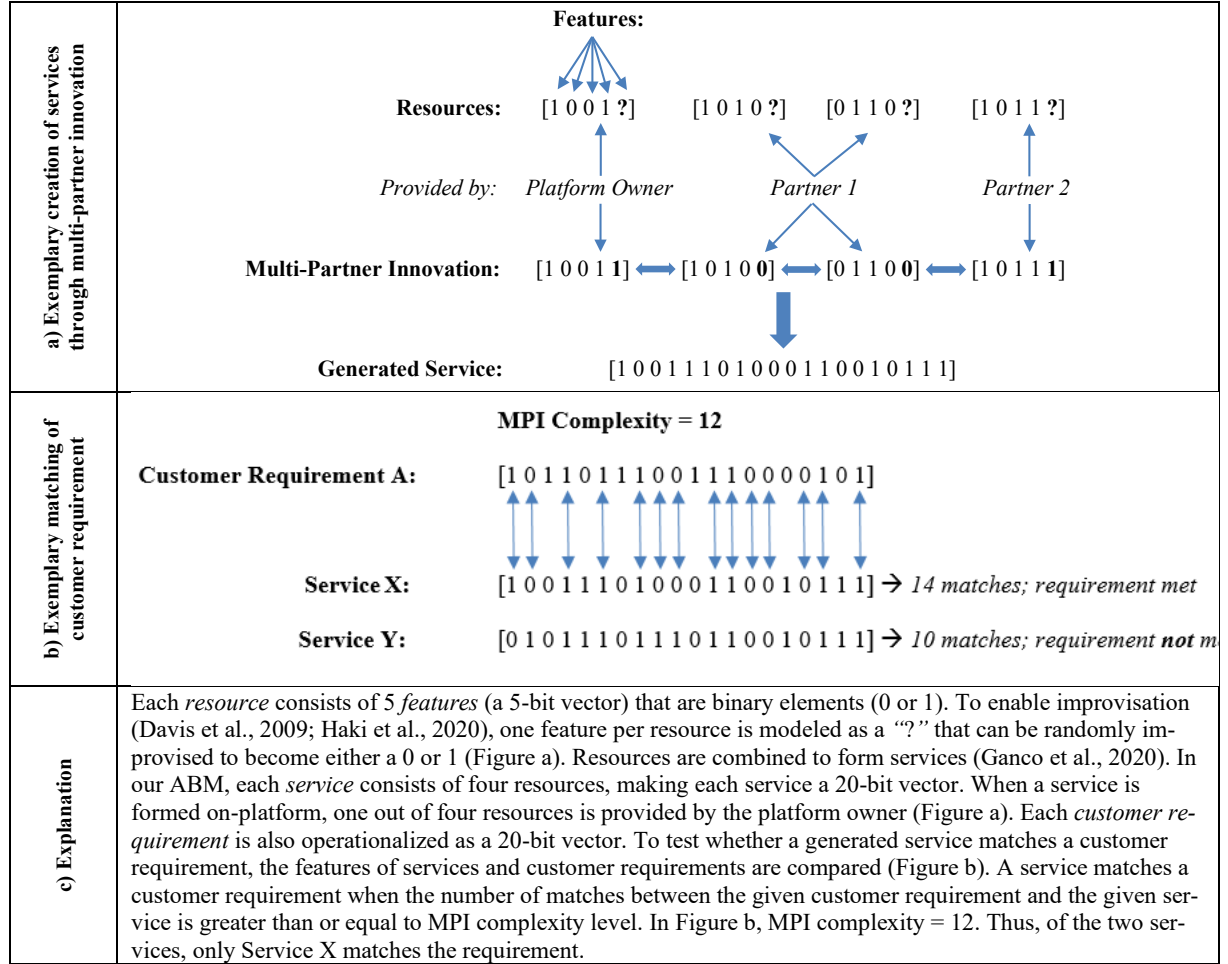


Table 32. Multi-partner innovation and matching of requirements

Steps	Creation of Service		Revenue Distribution	
	On-platform	Off-platform	On-platform	Off-platform
1	N.A. (service exists)	N.A. (service exists)	The platform owner receives 10-30% of revenue. Platform partners receive shares of remaining revenue depending on how many resources they contribute (i.e., 1/3, 2/3, or 3/3 of remaining revenue).	Partners receive shares of revenue depending on how many resources they contribute (i.e., 1/4, 2/4, 3/4, or 4/4 of total revenue).
2	N.A. (service exists)	N.A. (service exists)		
3	N.A. (service is provided off-platform)	Partner recombines its own 4 resources.		
4	Partner combines 3 of its resources with 1 platform owner resource.	Partner combines 3 of its resources with 1 resource of a partner in the local network.		
5	Partner combines 2 of its resources with 1 platform owner resource and 1 platform partner resource.	Partner combines 2 of its resources with 2 resources of partners beyond the local network.		

Table 33. Creation of services and revenue distribution per model step (from Figure 16)

Customers	Platform Owner	Partners	
		On-platform	Off-platform
Customers must be able to afford services. Thus, customers' budget (Table 36) must exceed the total cost of a service. Costs are a sum of customers' (local or distant) transaction costs associated with the search for a service, and partners' production costs. Customers' search also becomes more expensive with duration (i.e., every time step): $b > \sum pc + tc + 2*ts$	The platform owner only engages in profitable transactions. Its revenue share for a given transaction must thus exceed its production costs (for the resource it provides to any on-platform service). Its profit is calculated as: $p = b*rso - pc$	Partners only engage in profitable transactions. Partners' share of the customer budget must thus exceed their costs, for a transaction to take place. The partner that searches for a resource also incurs transaction costs. Partners' profit is calculated as: $p = b - rso - pc - tc$	Off-platform, partners receive the entire customer budget. Transactions must still be profitable. The partner that searches for resources also incurs transaction costs; other contributing partners only incur production costs. For each involved partner, its share of the revenue must exceed its share of the costs. Partners' profit is calculated as: $p = b - pc - tc$

where b = customer budget; p = individual transaction profit; pc = individual production cost; tc = individual transaction cost; ts = time steps; rso = revenue share of platform owner (%)

Table 34. Profitability / affordability calculations for individual transactions

Variable	Type	Calculation / Explanation
On-platform		
Revenues	Intermediate	$R = \frac{\sum_{i=1}^n b_i}{n}$
Production costs	Intermediate	$PC = \frac{\sum_{i=1}^n pc_i}{n}$
Transaction costs	Intermediate	$TC = \frac{\sum_{i=1}^n tc_i}{n}$
Profitability	Dependent	$P = \frac{\sum_{i=1}^n p_i}{n}$
Generativity	Dependent	$G = \sum_{i=1}^n S_i$
Partners on-platform	Intermediate	Number of partners in the business ecosystem that are on-platform at the end of each simulation run.
Ecosystem-level		
Partner-Partner Links	Intermediate	Number of partner-partner links in the business ecosystem at the end of each simulation run.
Customer-Partner Links	Intermediate	Number of customer-partner links in the business ecosystem at the end of each simulation run.

where b = customer budget; pc = individual production cost; tc = individual transaction cost; p = individual transaction profit; R = revenues; P = profitability; PC = production costs; TC = transaction costs; G = generativity; S = services

Table 35. Calculation / explanation of dependent and intermediate variables

C.2. Model validation

To come up with a baseline scenario and initialization parameters, we built on existing simulation models (e.g., Davis et al., 2009; Ganco et al., 2020; Haki et al., 2020). We then conducted additional sensitivity analyses to demonstrate our model's consistency and investigate its boundaries.

Model Parameter	Description	Model's Baseline Value	Other Tested Values	Justification
Simulation Runs				
Time steps	Each simulation run has a defined number of time steps (ticks).	1000	500, 2'500	The applied value was adopted from an existing ABM (Haki et al., 2020). At the lower end, complexity dynamics do not fully unfold in the simulation. At the higher end, outcomes remain consistent but are proportionally higher.
Business Ecosystem				
Number of customers	The number of customers and partners is fixed in the entire business ecosystem and throughout the simulation runs.	1'000	100, 2'000	The ratio of customer to partners was adopted from SAP Cloud Platform. 1'000 agents has been perceived sufficiently large in the simulation context (Brunswick et al., 2019). At the minimum tested values (10 partners; 100 customers), complexity dynamics do not unfold. At the maximum tested values (200 partners; 2'000 customers), results are generally stable but proportionally higher.
Number of partners		100	10, 200	
Customer budget	Each customer requirement is associated with a random budget. This budget value equals the revenue that engaged partners can gain by fulfilling the given requirement (through generating a matching service)	$\mu = 110$, $\sigma^2 = 10$	$\mu = 50$, $\mu = 150$	Budgets follow a normal distribution as in existing ABMs (Davis et al., 2009; Haki et al., 2020). The mean values are the results of parametrization efforts with regard to cost levels (see production and transaction costs).
Customer requirement duration (time steps)	Customer requirements disappear if not met after the defined number of time steps.	$\mu = 20$, $\sigma^2 = 5$	$\mu = 5$, $\mu = 50$	The applied value is adopted from existing ABMs (Davis et al., 2009; Haki et al., 2020). Results at the lower and upper tested boundaries are stable.
Platform's initial market share in the business ecosystem	In the business ecosystem, a given share of all partners is on-platform at the initialization.	25%	5%, 50%, 80%	When launching its initial cloud platform, SAP already managed to incentivize some partners to transact on-platform (Schreieck et al., 2021). Our model thus accounts for an initial market share of the platform in its respective business ecosystem. Sensitivity analyses on the lower boundary revealed that a critical mass of initial partners is needed for dynamics to unfold.
Renewal of partners' and platform owner's resources (time steps)	This rate determines after how many time steps each partner and the platform owner replaces one of its resources with a new resource.	100	50, 200	We account for firms renewing their resource base (Ambrosini & Bowman, 2009). Accordingly, partners and the platform owner replace their resources regularly throughout the simulation. The rate of innovation increases when resources are replaced more frequently and decreases when resources are replaced less frequently. Results are generally stable in both cases.
Life of services (time steps)	A service will disappear if it is not used in a transaction after the defined number of time steps.	$\mu = 30$, $\sigma^2 = 10$	$\mu = 15$, $\mu = 60$	Leaning on an existing ABM (Haki et al., 2020), unused services are removed after a certain number of time steps. At the lower boundary, the need for innovation increases. Complexity dynamics still unfold at both tested boundaries.
Agents				
No. of platform owner resources	The platform owner offers a defined number of core resources. All services generated on-platform must integrate one core resource.	30	5, 15, 50	Platform owners like SAP offer core resources (e.g., APIs, SDKs, the extendable codebase of the platform) for partners to extend on (e.g., Schreieck et al., 2021). Sensitivity analyses on the lower boundary revealed that a minimum

				number of platform owner resources is necessary to make the platform attractive.
No. of resources per partner	Each partner is endowed with a certain number of resources with random features.	4	1-4	Partner firms are endowed with resources (Ahuja et al., 2008). In our model, four resources are needed to generate one service. Thus, each partner is endowed with four unique resources.
Level of improvisation	Partners are able to improvise in each of their resources (i.e., certain features of the 5-digit vectors are not fixed as 0/1)	1	0-5	Leaning on existing ABMs (Davis et al., 2009; Haki et al., 2020), partner firms are able to improvise in their combination of resources. While improvisation enables more flexibility in innovation processes, results remain stable at the lower and upper boundaries.
Interactions				
Initial no. of partner-partner links	Each partner is initially linked with a defined number of other partners.	1	1, 10	As in other ABMs (e.g., Haki et al., 2020; Malgonde et al., 2020), agents are connected to other agents through links. For both partner-partner and customer-partner links, parameters were stable. At the lower and upper boundaries, the number of links stabilized after the first unused links were removed.
Initial no. of customer-partner links	Each customer is initially linked with a defined number of partners.	2	1, 10	
Life of partner-partner links (time steps)	A partner-partner link will disappear if no transaction happens among the respective partners after the defined number of time steps.	$\mu = 150$ $\sigma^2 = 5$	$\mu = 50$, $\mu = 250$	Building on an existing ABM (Haki et al., 2020), unused ties between actors decrease in strength over time. Our ABM captures this as the number of time steps after which a link disappears entirely without any transaction between the given agents. At the upper boundary, the overall number of links increases, and decreases at the lower boundary. In general, complexity dynamics still unfold at both tested boundaries. The life of links is renewed every time the connected agents interact.
Life of customer-partner links (time steps)	A customer-partner link will disappear if no transaction happens among the respective customer and partner after the defined number of time steps.	$\mu = 100$ $\sigma^2 = 5$	$\mu = 50$, $\mu = 250$	
Costs				
Production cost	Each resource is associated with a random production cost within the predefined range.	5-15	4-6, 19-21	The model assumes that creating and maintaining resources is associated with a cost (Alexy et al., 2018). Similarly, transactions are assumed to be costly (Wolter & Veloso, 2008). Distant search is more risky (Levinthal, 1997) and thus more costly. Production costs are always incurred by partners and the platform owner. Transaction costs are incurred by the agent who searches. The applied values and ranges of costs are the result of parametrization efforts between production cost levels, transaction cost levels, and budget levels.
Transaction costs (local search cost)	Each local search is associated with a random transaction cost within the predefined range.	20-40	5-15, 55-65	
Transaction costs (distant search cost)	Each distant search is associated with a random transaction cost within the predefined range.	40-60	15-25, 75-85	

Table 36. Sensitivity analyses of initialization parameters

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Curriculum Vitae

Name	Marius Schmid
Date of birth	28.12.1994
Place of birth	Munich, Germany
Nationality	German

Education

2020-2022	University of St.Gallen (HSG), St.Gallen, Switzerland Ph.D. Program in Management (Business Innovation)
2017-2019	University of St.Gallen (HSG), St.Gallen, Switzerland Master of Arts (M.A.) in Business Innovation
2013-2017	University of St.Gallen (HSG), St.Gallen, Switzerland Bachelor of Arts (B.A.) in Business Administration
2015-2015	Columbia University, New York City, U.S.A. Exchange Program
2011-2013	Munich International School, Starnberg, Germany International Baccalaureate (IB)

Professional Experience

2020-2022	IWI-HSG, St.Gallen, Switzerland Research Associate
2017-2018	Steelcase AG, Munich, Germany Working Student Product Marketing
2016-2016	goetzpartners Management Consultants GmbH, Munich, Germany Intern Management Consulting
2015-2015	KPMG AG Wirtschaftsprüfungsgesellschaft, Munich, Germany Intern Transaction Services

