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PLATFORM OVER MARKET – WHEN IS JOINING A PLATFORM BENEFICIAL?

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PLATFORM OVER MARKET – WHEN IS JOINING A PLATFORM BENEFICIAL?

Research Paper

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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

1 Introduction

With the rise of the platform economy (Kenney and 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 Platform¹. 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

¹ In January 2021, SAP retired the SAP Cloud Platform brand, but its services are continued as part of the SAP Business Technology Platform.

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 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.

2 Conceptual Foundation

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 (de Reuver et al., 2018; Blaschke 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 et al., 2019; Thomas et al., 2014). Since resources are scarce and not completely imitable or substitutable (Bowman and 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 (Brunswick et al., 2019; Haki et al., 2019; Lusch and 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, 2015; 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 and Santaló, 2019; Eaton et al., 2015; Henfridsson and 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 and 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 (Karhu et al., 2018; Jacobides et al., 2006) that sustains an economic benefit from innovation (Garcia-Castro and 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, 2015; 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.

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 and 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).

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 and 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.

3.1 Simulation Model Design

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

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.

3.1.2 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.

3.1.3 Environment

The environment represents the medium in which agents interact (Nan, 2011; Haki et al., 2020). 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 1 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, affordable service. Partners obtain payoffs when services to	(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

		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.	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; Karhu et al., 2018; Haki et al., 2020)
	<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.	(Constantinides et al., 2018; Ceccagnoli et al., 2012)
	<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 ² .	(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 and 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 1. Simulation Model Components.

3.2 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 environment (Davis et al., 2009) as well as

² 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.

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).

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 2). 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 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 1a and 1b).
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 2 and 3).

Table 2. Experiment Setup (each simulation run comprised 1,000 time steps).

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 1a plots partners' average profitability, Figure 1b 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) levels³. The environmental complexity is fixed at low, 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 1a and 1b). In providing further insights into these observations, Figures 2 and 3 plot the partners' average profitability and generativity on the platform at low, medium, and high levels of complexity, while

³ 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.

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.

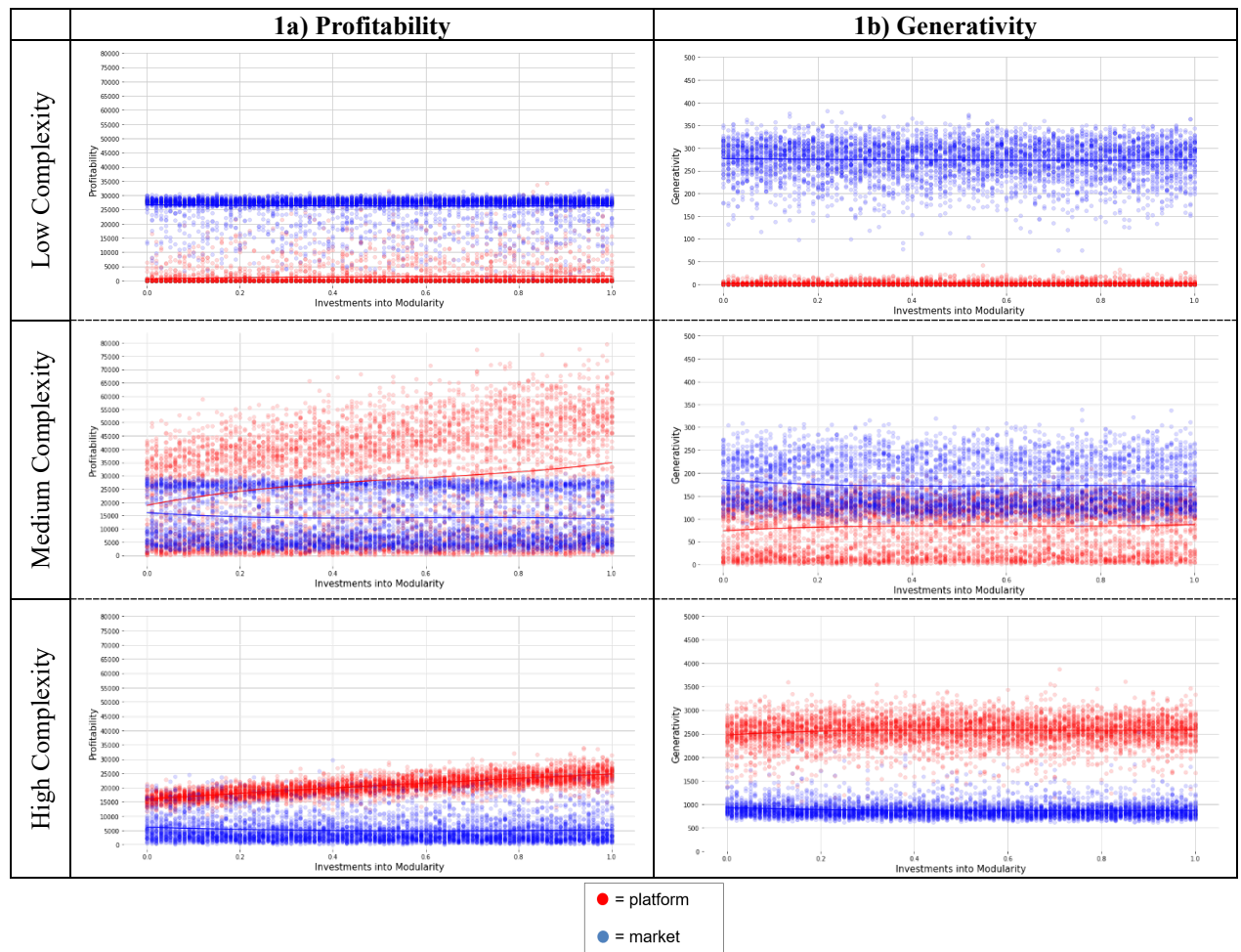


Figure 1. Profitability and Generativity Effects of Platform versus Market.

4.1 Low Complexity Environment

In a low complexity environment (green plane, Figure 2), 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 1a. At a low level of complexity, generativity alike remains very low on the platform (green plane, Figure 3) and, compared to the situation on the platform, the market is considerably more generative (Figure 1b). The latter indicates that firms are well equipped in the market to meet customers' needs without the aid of a platform's promised capabilities.

4.2 Medium Complexity Environment

At a medium level of environmental complexity (orange plane, Figure 2), however, the partners' average profitability on the platform increases significantly. The platform owner's investments into modularity and search matching each improve the partners' average profitability independently. They also interact with each other to jointly reinforce the profitability effects. In fact, under such an environmental condition, there is a higher variety in customers' needs and requirements. Partners face the challenge of searching and finding the resources that might help them to produce the innovations that match the customers' requirements. The search matching capability of the platform can enable partners to effectively find the resources they need whereas the platform's offered modularity capability can reduce the costs of acquiring the found resources. Thus, partners are attracted to the platform and innovate on the platform to increase their chances of matching the customers' needs profitably. In comparison to profitability effects, Figure 3 (orange plane) indicates that generativity on the platform increases only slightly in a medium complexity environment. This implies that only a few partners switch from the market to the platform (on average, around 24% of all partners) to exploit the platform's search matching and modularity capabilities to generate innovations and to achieve high levels of profitability.

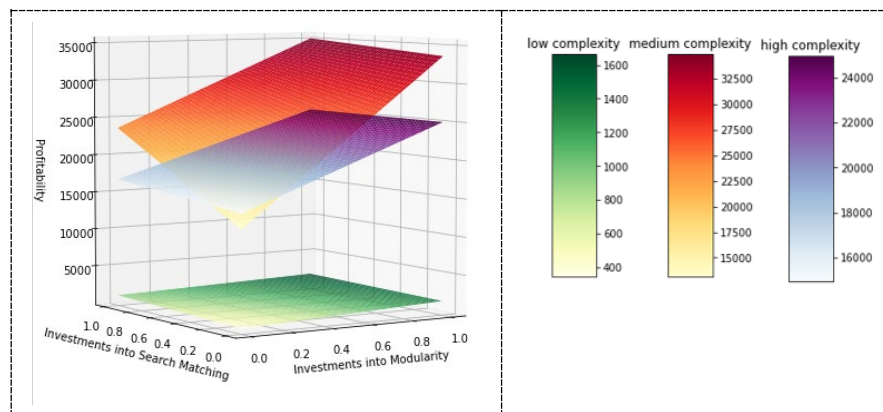


Figure 2. Profitability Effects on the Platform.

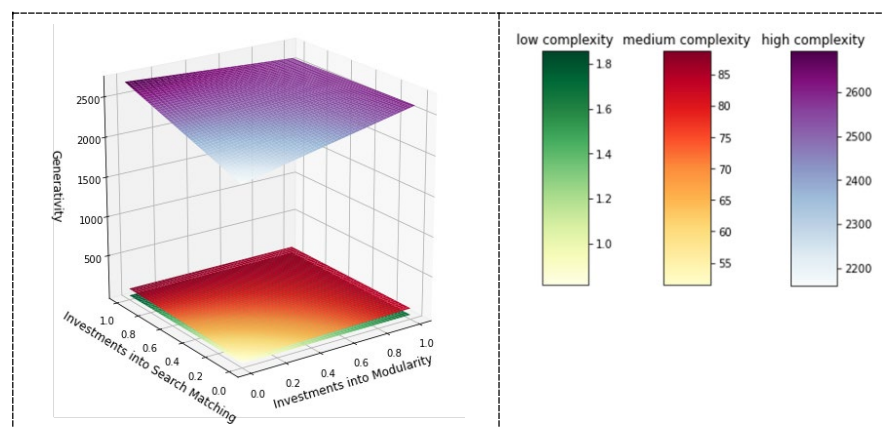


Figure 3. Generativity Effects on the Platform.

4.3 High Complexity Environment

As the complexity in the environment increases further to a high level (violet plane, Figure 2), 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 2). 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 1b and Figure 3 (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 1a.

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.

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.

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 (Sandberg et al., 2020; Malgonde 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 and 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.

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.

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.

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Appendix

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 3. Tested Parameter Ranges of Initialization Parameters.

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