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TWO SIDES OF THE SAME COIN: AN E-COMMERCE ECOSYSTEM AGENT-BASED SIMULATION

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TWO SIDES OF THE SAME COIN: AN E-COMMERCE ECOSYSTEM AGENT-BASED SIMULATION

Research Paper

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Abstract. E-commerce is one of the most important sectors of the economy, with an expected global turnover of USD 7.4 trillion in 2024. Leading companies in the industry like Amazon and Alibaba leverage platform business models that orchestrate complex ecosystems of buyers and sellers. These ecosystems are characterized by globally intertwined networks of independent participants and multifaceted interactions, making their development hard to predict. We propose an agent-based simulation approach, following the three-step process of Haki et al. (2020), to predict the behavior of e-commerce ecosystems with a particular focus on the impact of premium subscription services. Simulation models offer the opportunity to tangibly visualize the effects of a participant's actions on the ecosystem level. Our simulation includes the key actors (i.e., buyer, seller, marketplace), their characteristics, and behaviors to draw conclusions about the evolution of the ecosystem and the strategic role of premium memberships in shaping these digital landscapes.

Keywords: E-Commerce Ecosystem, Agent-Based Simulation, Computationally Intensive Theory Construction

1 Introduction

Increasing globalization and tremendous digitalization efforts at the societal, company, and individual level have resulted in complex systems of independent but intertwined actors. Platform business models have enriched many industry sectors because the most valuable companies (e.g., Apple, Amazon, and Alibaba) orchestrate multi-sided markets (Gawer, 2021). These companies form digital business ecosystems with their surrounding participants, which serve (end) customers (Adner, 2017). These business models propel ecosystem complexity with an increased division of labor (Schüßler et al., 2021). Due to increasingly interactive processes and global dependencies, even single actors have the power to influence the overall ecosystem (e.g., supply-chain shortages). Precisely the e-commerce sector builds on these mechanisms of complex systems with independent but intertwined actors and represents the most important economic sector with an expected global revenue of USD 7.4 trillion and 24.5% of total retail sales (Lebow, 2021). As it allows electronically supported retail transactions without spatial and temporal restrictions (Zwass, 1996), e-commerce is likely to be conducted globally in systems of systems (Stallkamp & Schotter, 2021). The most successful organizations in e-commerce operate platform business models exploiting the economic effects of two-sided markets (e.g., matching and subsidizing selected participants) (Parker et al., 2016). These platforms form the center of e-commerce ecosystems, which are surrounded by networks of independent participants such as buyers and sellers (Wulfert et al., 2022). These focal platforms (e.g., Amazon Marketplace, Walmart Marketplace, and Alibaba.com) actively orchestrate ecosystem participants by executing governance rules (Hein et al., 2020). They match supply- and demand-side participants to enable retail transactions involving additional actors (e.g., content providers) (Böttcher et al., 2021; Wulfert et al., 2021). As focal platforms in e-commerce mature, they alter their business models by providing additional (retail-related) services for ecosystem participants (Wulfert et al., 2021). These services aim at differentiating the company from other competing platforms and locking in participants (Cennamo, 2021). A popular means of locking in demand-side participants (i.e., customers) is premium memberships (e.g., Amazon Prime, Walmart+, and Alibaba 88 VIP) that offer privileged services (e.g., free deliveries, exclusive offers, and prioritized order handling) compared to standard members. Membership fees are an important source of revenue for platform owners, although rumors have been raised by recent announcements of price increases for premium memberships (Amazon, 2023; Herrera, 2022; Lee et al., 2018).

Because e-commerce ecosystems are composed of complex and global networks of intertwined but independent participants and a multitude of interacting processes (Jacobides et al., 2018), it is worthwhile investigating their behavior. However, the behaviors and interactions of single participants collectively shape the entire ecosystem, making it challenging to predict the evolution of e-commerce ecosystems in general as a consequence of the behavior of single participants within them (Hannah et al., 2021; Harrison et al., 2007). Therefore, computationally intensive theory construction approaches, such as simulations, can provide a suitable vehicle to address the complexity and dissect the evolution of e-commerce ecosystems and their participants (Miranda et al., 2022). Recent studies in information systems research have shown that agent-based simulations are especially suitable for the analysis of complex adaptive systems (i.e., two-sided markets, ecosystems) by simulating the micro-level behaviors that form the macro pattern (i.e., the system under investigation) (Davis et al., 2007; Schalowski & Barrot, 2019; Schmid et al., 2021). Against this backdrop, we address the following research question:

How can the behavior of ecosystems and their participants in e-commerce be predicted when premium services are introduced?

To address the research question, we conceptualized and developed a multi-agent-based simulation of e-commerce ecosystem (Wulfert et al., 2022), including the key actors, their characteristics, and their relationships, to analyze their behavior. This paper focuses on the analysis and simulation of the two-sided markets involving buyers and sellers (Hagiu & Wright, 2015b; Rochet & Tirole, 2003) and the central service mechanisms of today's e-commerce platforms (Turban et al., 2017).

Specifically, this work establishes the foundation for a computationally intensive theory construction endeavor for e-commerce ecosystems by providing an approach to consider the key players in an e-commerce ecosystem (i.e., buyer, seller, and marketplace), their interaction, and the influencing factor of premium membership. Future research will extend the simulation to an overall ecosystem simulation approach, e.g., by including further approaches of simulating agents via generative agents (Park et al., 2023; Wang et al., 2024). The remainder of this paper is structured as follows. First, we elicit the fundamentals on agent-based simulations and platforms in e-commerce ecosystems. Second, we present our research approach following Haki et al. (2020). Third, we present our results of the e-commerce ecosystem simulation and the impact of platform memberships on ecosystem development. Finally, we briefly summarize our results and provide an outlook for further research and extending our simulation.

2 Theoretical Background

2.1 Agent-Based Simulation

In natural and social sciences (e.g., chemistry, biology, and economics), the methodological approach of simulation is considered a de facto standard (Dong, 2022). The use of simulations, and in particular **agent-based simulations**, continues to increase in information systems research due to their suitability for analyzing complex phenomena (Beese et al., 2019; Davis et al., 2007; Haki et al., 2020). This is especially true for the simulation of complex adaptive systems (Dong, 2022), and deployment scenarios include the role of information technology in organizational learning (Kane & Alavi, 2007), the evolution of information systems architectures (Haki et al., 2020), the examination of market mechanisms in ecosystems (Schmid et al., 2021), and the efficiency-based tuning of human and machine learning (Sturm et al., 2021). Regardless of the individual design, agent-based simulations are founded on three central elements: **agents**, **interactions**, and **environment** (Macal & North, 2014; Nan, 2011).

Agents are the core actors of the simulation and represent a broad variety of different objects ranging from individuals to technological concepts to entire organizational structures, depending on the phenomenon under investigation (Nan, 2011). Similar to real-world entities possessing attributes and behaviors (e.g., human beings), agents also possess attributes that characterize themselves and behavior rules that describe how the attributes change or how agents act based on their perception of their environment (Drazin & Sandelands, 1992; Epstein & Axtell, 1996; Holland, 2003).

Interactions describe bidirectional behaviors of agents within the simulation due to the connections and flows between them (Drazin & Sandelands, 1992; Holland, 2003; Nan, 2011). Connections define relational links within the simulation that describe which agent or rather which attribute-based instance of an agent (e.g., buyer) may interact with which agent instance of the same or another (e.g., seller) attribute base (Nan, 2011). Due to the adaptive and dynamic nature of agent-based simulations, the definition of interactions is one of the key challenges in simulation modeling (Macal & North, 2014). Flow, on the other hand, characterizes the exchange of resources between agents, which can reflect a range of material or immaterial objects (e.g., goods, money, and information) similar to the agents' attributes depending on the scenario (Holland, 2003; Nan, 2011). The exchange of resources between agents serves not only as a realistic representation of real-world phenomena but as fuel for the simulation, keeping it in a stable state and preventing the transition to an entropic state (Anderson, 1999; Nan, 2011).

Environment represents the surroundings and thus the conditions under which the agents behave and interact (Epstein & Axtell, 1996; Haki et al., 2020). The topography of the environment can be modeled by corresponding structures based on the phenomenon under investigation (e.g., valuable resources in a mining simulation). These structures themselves passively influence the simulation through their explicit conditions for the unfolding of actions and interactions (Nan, 2011). A common example is the predator–prey ecosystem, in which the hunter's access to the prey is blocked by a natural structure such as a rock or reef.

2.2 Two-Sided Market Theory in E-Commerce Ecosystems

A **two-sided market** "refers to a market with two distinct sides that benefit from network effects by interacting on a common platform" (Rochet & Tirole, 2003, p. 990). Multi-sided markets describe platforms with more than two independent types of actors (Boudreau & Hagiu, 2009). Transaction platforms orchestrate two (or more) previously distinct market sides and enable (retail) transactions between them (Armstrong, 2006; Hagiu & Wright, 2015a; Rochet & Tirole, 2003). Thus, **transaction platforms** can be seen as synonymous to digital marketplaces. Network effects describe the benefits of actors caused by the number of participants on the same (i.e., direct) or other (i.e., indirect) market side (Rochet & Tirole, 2003; Shapiro & Varian, 1998). These effects can be either positive or negative (Boudreau & Hagiu, 2009).

Two-sided markets require clearly separable market sides and a strict assignment of participants to a market side to successfully exploit network effects (Adner, 2017). However, a single actor can also take on multiple roles in multi-sided markets in subsequent transactions (Wulfert et al., 2021). Eisenmann et al. (2009) identified demand- and supply-side participants as well as the platform owner as archetypal **actors** in two-sided markets. In the context of e-commerce, they resemble the customer and seller (Wulfert et al., 2022). The platform owner's major source of revenue is transaction fees charged for matching participants and enabling retail transactions (Wulfert et al., 2021). The transaction fee depends on the price of the product or service exchanged. Armstrong (2006) identified volume of network effects, payment type, and multi-homing possibilities as determinants of the price structure in two-sided markets.

Focal platforms (i.e., digital marketplaces) in e-commerce ecosystems can be characterized as multi-sided markets (Hagiu & Wright, 2015b; Wulfert et al., 2021). They intermediate between independent ecosystem participants from separate market sides (e.g., advertising partner, developer, or seller) that can be assigned with unambiguous roles (Böttcher et al., 2021). The independent participants form an e-commerce ecosystem with a common goal (e.g., provide final customers with products or services) (Adner, 2017). The platform owner can influence the surrounding ecosystem participants by implementing certain governance mechanisms and providing an interaction structure (Hein et al., 2020; Helfat & Raubitschek, 2018). **E-commerce ecosystems** are digital business ecosystems in the context of e-commerce with focal transaction platforms orchestrating different participants and enabling retail-related transactions between them (Hagiu & Wright, 2015b; Wulfert et al., 2022).

3 Research Methodology

Agent-based simulations can be seen as a "third kind of science" (Axelrod, 1997), besides induction and deduction, that allows us to analyze complex systems, their participants, and the relations among them in a controlled environment. The utilization of such a computationally intensive approach provides us with the methodological groundwork for theory building (Miranda et al., 2022), and the associated achievement of our research goal of predicting the behavior of ecosystems and their participants to pursue. We approach e-commerce ecosystems from a theoretical perspective grounded in the influence of individual actors, the interaction between them, the complex environment, and the dynamic adaptation to this environment as complex adaptive systems (CAS) (Anderson, 1999; Drazin & Sandelands, 1992; Holland, 2003; Nan, 2011; Reuver et al., 2018; Wulfert et al., 2022). Our research process is adapted from the three-phase approach by Haki et al. (2020), which followed Davis et al. (2007) and Sargent (2010) for the development of agent-based simulations (Figure 1).

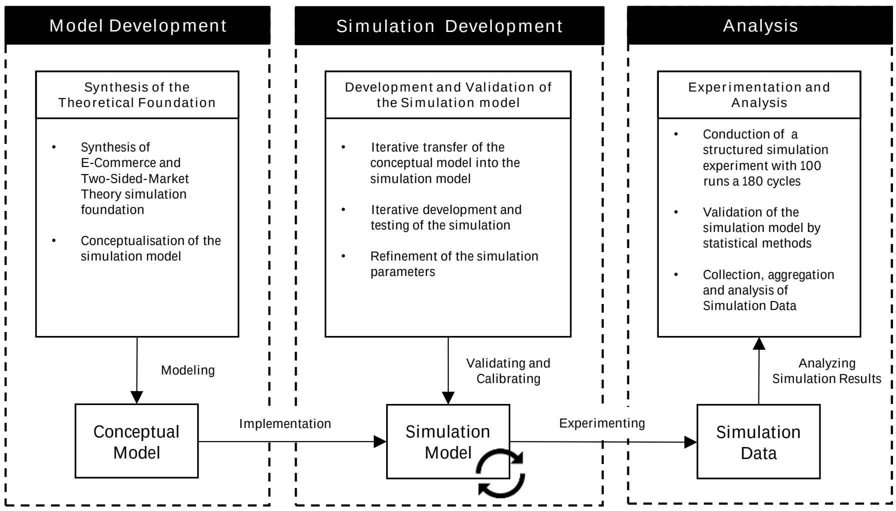

Figure 1. Research Design

Phase 1 – Model Development: The simulation is based on a conceptual model that represents the object of investigation. The starting point of our model development was the synthesis of theoretical foundations from the environment of the object of study (e.g., two-sided market theory) combined with the analysis of real-world scenarios (e.g., Amazon and Walmart) to derive the actors, their behavior, and their relationships. Based on this analysis, we were able to identify key actors (**buyers, sellers**, and **marketplaces**) as agents for the simulation (Table 1).

Marketplaces act as intermediaries between the other agents in the simulation (Hagiu & Wright, 2015b). The central task here is to execute transactions between docked sellers and visiting buyers. If a transaction is successful with the given probability, it is tracked, and the marketplace receives a transaction fee as a share of the transaction price (Wulfert et al., 2021). Primary attributes of the marketplace are the transaction probability in matching buyers and sellers, the number of successful checkouts, and the marketplace's share of transaction fees (Reillier & Reillier, 2017). Here, the sphere of influence in which the marketplace can interact with the buyer or seller is limited but can grow or shrink depending on the turnover of the marketplace, which is simulated by the success of a marketplace. In addition, a special type of marketplace has been defined that offers a subscription for membership to the platform based on typical premium subscriber models (Lee et al., 2018).

Buyers search the ecosystem for products or services that match their requirements (Wulfert et al., 2021). When they find a marketplace, they search it for suitable offers and take them accordingly. At selected marketplaces, buyers can sign up for a premium membership, which will provide them with better conditions and increase their preference for this marketplace. In return, a monthly fee must be paid to the marketplace (Lee et al., 2018).

Sellers offer their products or services on the marketplace (Wulfert et al., 2021). These arise costs, which are estimated per month. If a marketplace becomes occupied by too many other sellers in relation to the number of desired customers, sellers may seek other sales channels (Eisenmann et al., 2009).

Table 1. Simulation Model Conceptualization

Simulation Elements		Description	Sources
Agent	Buyer	*Attributes:* Have the need to purchase products and services.	(Zwass, 1996)
		Behavioral rules: If an interest in buying prevails, searches for marketplaces and offers matching the needs; if matching offer is available, may decide to purchase it; otherwise, continues to search the ecosystem.	(Böttcher et al., 2021; Eisenmann et al., 2009)
	Seller	*Attributes:* Search for opportunities to sell products and services.	(Zwass, 1996)
		Behavioral rules: Is continuously looking to find sales opportunities; if there is a suitable marketplace with buyers, places	(Böttcher et al., 2021; Eisenmann et al., 2009)

		offers; otherwise, searches for other marketplaces.	
	Marketplace	*Attributes:* Act as an intermediary between supply and demand. *Behavioral rules:* Attracts other entities based on their intermediary role; connects supply and demand and creates average price; randomly offers premium membership to buyers.	(Hagiu & Wright, 2015b) (Wulfert et al., 2021)
Interaction	Buyer	*Connection*: Buyer–marketplace *Flow*: Paying energy	(Hagiu & Wright, 2015b)
	Seller	*Connection*: Seller–marketplace *Flow*: Receiving energy	(Hagiu & Wright, 2015b)
	Marketplace	*Connection*: To all entities in the ecosystem *Flow*: Distributing energy and keeping energy (fees)	(Boudreau & Hagiu, 2009)
Environment		E-commerce ecosystem with dedicated marketplaces where buyers and sellers can move freely, disappear but also add new ones	(Adner, 2017)

Phase 2 – Simulation Development: The developed conceptual model was iteratively transformed into a simulation. During development of the simulation, we decided to implement the model in the form of a cellular automaton as a grid. The cellular automata represent one of the five basic topologies for agent-based simulation and enable a structured 2D simulation based on the interaction of the cells with their environment. By integrating a multi-cell grid (i.e., the multiple occupancy of a cell), we were able to represent the immaterial infinity of e-commerce marketplaces. To establish a baseline for the parameterization and in particular to obtain the range of the parameters of the simulation, we looked at existing simulation models from the same subject area as a starting point. We also conducted degeneracy tests following Davis et al. (2007). In line with transparency and knowledge accumulation, the full list of parameters is online available (https://bit.ly/TS0tSCabS). Subsequent work will include comprehensive sensitivity analyses that examine the effect of each selected parameter on the system behavior and ultimately help to gain insights in the emergence of patterns and properties generated in the CAS (Broeke et al., 2016). Further, in the spirit of open science, we plan to publish our simulation, including all code.

Phase 3 – Analysis: In total, the simulation was run as a structured experiment 100 times in a row with 180 cycles each. In the process, 10 million individual data points were collected and aggregated, and the corresponding average for each attribute was formed for each cycle as the basis for the evaluation of the results. To confirm the soundness of the simulation results, we statistically evaluated our data by conducting a multiple linear regression analysis. The regression analysis allowed us to test whether independent variables have a significant effect on a dependent variable. The goal was to investigate the impact of premium memberships and membership fees on e-commerce ecosystem level. Thus, the regression analysis examined the focal platform effect (i.e., the platform type) on economic success. Furthermore, we introduced a premium membership subscription as a second independent variable and assessed how membership fees affect the overall economic success.

The regression was conducted to evaluate if the platform type and price of a premium membership had a significant effect on the marketplace energy. The results revealed that the simulation model was statistically significant, $F(2, 432044) = 211.847$, $p < .001$, $R^2 = .001$. The marketplace energy had a positive and significant coefficient in relation to the platform type, i.e., premium or non-premium ($\beta = 109.34$, $p < .001$), and also a positive and significant coefficient in relation to the membership price ($\beta = 37.554$, $p < .001$). Therefore, a premium focal platform will lead to a 109.34 times higher energy than a standard platform, and the energy will increase 37.553 units for each unit increase of the membership price. This indicates that our simulation showed the expected results, mimicking the competitive advantage of a premium focal platform with membership fees (i.e., higher energy equals more revenue).

4 Results

The execution of our structured simulation experiment with 100 runs of 180 cycles in a 20 by 20 grid with four randomly positioned marketplaces resulted in the distribution of demand-side (i.e., buyers) and supply-side (i.e., sellers) actors depicted in Figure 2a. Further evaluations (e.g., checkouts, data points) are additionally available online (https://bit.ly/TS0tSCabS).

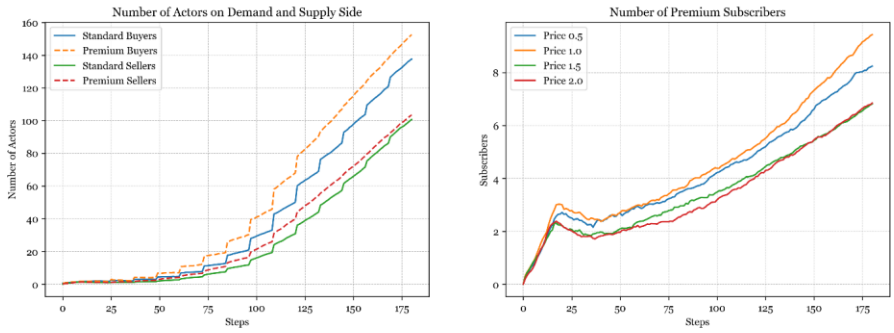

Figure 2. Number of (a) Actors and (b) Premium Subscribers

In contrast to the average of the three standard platforms (solid blue and green curves), the premium platform attracted more participants (dotted orange and red curves). The number of participants indicated the amount of retail transactions orchestrated by each platform per period. While the premium platform orchestrated 4,429 transactions, the other platforms only reached 3,610 participants on average. This orchestration was monetarized by the platforms with commission fees. Hence, the premium platform generated 5,823 fees in total compared to 4,055 by the average of other platforms.

The shape of the curves in Figure 2 resembles a hockey stick form, described in the literature as the typical shape of participants in platform business models exploiting network effects (McAfee & Brynjolfsson, 2017; Parker et al., 2016). A tipping point—when the minimum threshold of participants required for network effects to occur—was reached around 10% of the number of total participants after the 89th iteration. A typical tipping point in platforms with network effects has been conceptualized and reflected in previous research (Evans & Schmalensee, 2010, 2016; Steur & Bayrle, 2020). All four platforms in our simulation were able to capture network effects and monetize them. Sharp increases in the number of actor curves occurred every 12 iterations (i.e., every year) and resembled the holiday season (Figure 2a). Moreover, our algorithm then calculated whether the reach of a platform had to be increased because of the number of participants. This behavior reflects the effects of word of mouth among participants and was part of the direct network effects (Cheung & Thadani, 2012).

Following the research of Wen and Lin (2017) on the optimal price for a membership fee (including free shipping) for platforms in e-commerce ecosystems, we applied our agent-based simulation to determine an optimal price for our premium marketplace. We tested premium prices from 0 to 2 in intervals of 0.1 and plotted the number of premium subscribers for the membership fees of 0.5, 1.0, 1.5, and 2.0 (Figure 2b). The membership fee reduced the total buying power of the demand-side participants, which started at a value of 100 when a new buyer was generated.

The simulation runs revealed that a membership fee of 1.0 resulted in an average of 9.4 premium subscribers after 15 years. Premium membership fees above this threshold seemed too expensive for demand-side participants compared to the benefits of premium memberships and resulted in a decline in the number of premium memberships. Interestingly, the curves for a price of 1.5 and 2.0 converged after 15 years of simulation so that the fees could be increased more dramatically. Amazon's announcements regarding increasing their premium membership fee could be analyzed using these simulation results (Herrera, 2022). Premium subscriptions have proven to be an important and effective loyalty program in e-commerce (Kumar & Reinartz, 2018). On average, premium subscribers spend more money and buy more often compared to non-premium buyers (Ramadan et al., 2021). Additionally, premium subscribers have a higher behavioral loyalty toward the preferred platform, so multi-homing is more unlikely for them (Ashley et al., 2016). However, premium memberships with free shipping scenarios decreased the number of articles per purchase.

5 Conclusion, Limitations, and Outlook

E-commerce ecosystems are among the most successful business models and the leading companies in this sector, such as Amazon, Walmart, and Alibaba, exert a global influence. Building on the multi-layered interconnectedness of the individual players and the network of globally acting independent actors, these ecosystems can hardly be analyzed with classical methods, let alone their development predicted. However, computationally intensive approaches such as multi-agent simulation provide an approach to address these limitations.

Building on this premise, our paper provides a first approach for simulating e-commerce ecosystems based on their key actors (e.g., buyers, sellers, etc.), their characteristics and dependencies in a two-sided market. We applied our simulation approach to predict the impact of a premium membership platform with demand-side and supply-side participants and determine an optimal membership fee. Simulations are necessary in e-commerce ecosystems because of their complex nature with regard to processes and interactions. Hence, we provide a first tool for guiding actors within these ecosystems. The owners of focal platforms in e-commerce ecosystems can use this simulation to test governance rules (practical contribution). We contribute to existing research on e-commerce ecosystems with a novel approach simulating an excerpt of an e-commerce ecosystem's development at the level of single actors in a two-sided market.

Aside from our contribution to e-commerce research, our work is not without limitations. Currently, the simulation focuses on the key players (e.g., marketplaces, buyers, and sellers), first order within the e-commerce ecosystems. In a next step, we plan to integrate further actors including their behavior and relationships to the already modeled actors into the simulation. On the supply side, manufacturers play an important role by providing the ecosystem with products and services (Mishra & Tripathi, 2020). Supporting actors such as service providers offer value-adding transaction services to other participants (Kaoud et al., 2020) and platform providers supply the necessary software for digital platforms (Aulkemeier et al., 2016). Actors from the surrounding environment such as investors or the government can also have a far reaching impact on all actors by providing necessary monetary foundation for certain participants (Kwak et al., 2019) or enforcing trade and tax laws (Aulkemeier et al., 2017). Modeling the distinct attributes and actions of each additional participant and their relations among each other allows us to investigate and validate our simulation model, for instance under the aspect of premium memberships or the introduction of external constraints (e.g., trade laws). By expanding our current work with further actors, relations, and actions, we aim at a holistic computationally intensive approach towards simulating the behavior of e-commerce participants and constructing theory regarding our research goal.

Besides the integration of further actors, the integration of additional market and ecosystem mechanisms (e.g., openness etc.) plays a central role in creating a holistic simulation approach. In addition to the simulation of dedicated scenarios at the operational level, this would enable the longitudinal simulation of ecosystems starting from the foundation to the evaluation of different ignition strategies. Detached from the e-commerce context, it would also be conceivable to transfer the simulation to other ecosystem domains such as the topic area of data ecosystems and associated problems such as data sharing. In conclusion, this paper provides another building block for simulation-based analysis and modeling of complex systems in information systems research.

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