Modelling the network economy: A population ecology perspective on network dynamics

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ABSTRACT

Network platforms are increasingly important in current economic ecosystems. With industries, platforms and organizations integrating in many directions, the difficulties of defining the boundaries of organizational populations increase. Although population ecologists have frequently applied legitimation and competition mechanisms to analyze inside the organizational population, there is little understanding of the transition of such mechanisms across populations and whether competition mechanisms vary in mixed populations. This paper therefore builds on recent work in community ecology and proposes a Platform System Dependence Model, which involves a re-specification of these mechanisms and offers a theoretical framework that is suitable for heterogeneous organizational populations and sufficiently adapted to the dynamic nature of the network economy. Furthermore, in order to describe and analyze how different organizational populations interact within the ecosystem, we expand traditional population and community ecology models to time-related differential equations. This change makes it possible to perform a comprehensive density-trend analysis that can be applied within and across different categories of populations. We furthermore offer a simulation based on this framework, which supports the thesis that the density of a symbiotic organizational population increases rapidly in the initial stage of organizational population growth, while, at the same time, the platform-based organizational population increases gradually. As the density of a symbiotic population decreases and the competitive population density remains stable, the density of the platform-based organizational population decreases after reaching its maximum. We discuss the implications of these findings for research on ecology and on the platform economy.

1. Introduction

Since the foundational work of Hannan and Freeman (1977), theoretical and empirical research on population ecology has focused on the emergence, development, and death of organizational populations over time. From 1977 to early 2000, researchers borrowed metaphors from ecology and biology to refine the concepts and foundational models they used in their theoretical research. In 2007, Hannan, Polos, and Carroll published their landmark formal work on population ecology. In their research, the authors used nonmonotonic logic and fuzzy sets to capture the process of categorization, setting forth a new language for organizational theory-building and developing an “audience-based theory of organizational categories” (Hannan et al., 2007). Following that publication, population ecology theory turned from its original reliance on ecology to sourcing ideas from the social sciences, particularly anthropology, sociology and psychology. Traditionally, population ecology theory defined an organizational population as a bounded set of independent entities that share common forms and compete for common...
resources (Hannan and Freeman, 1977; Hannan et al., 2007, p. 86). Over the years, several theoretical studies on population ecology have attempted to explain the evolution of organizational populations through legitimation and competition mechanisms and on the basis of the density-dependence model (Hannan and Carroll, 1992; Hannan and Freeman, 1993; Carroll and Hannan, 2000). However, the density-dependence model can only be applied to independent populations with clearly demarcated boundaries. Furthermore, there are certain limitations to using the legitimacy mechanism in cross-population studies (Rud, 2004; Van Witteloostuijn and Boone, 2006), as such a mechanism is typically tied to a given homogeneous population. We thus need to expand our understanding of legitimizing processes in mixed populations to “bolster the explanatory power of ecological models” (Lander and Heugens, 2017, p. 1594). More recently, Morin (2020) emphasized that relations between and across populations may be captured in the form of symbiosis, predation, and co-optation. To date, however, little is known about how such processes play out and how legitimation and competition mechanisms work in mixed population settings.

The difficulty of defining the boundaries of populations has hampered theoretical research on population ecology in recent years. With organizations integrating vertically and horizontally, organizational populations are becoming more mixed and varied. Market settings characterized by network or platform-based organizations are one area where the increasing prevalence of mixed and varied populations is salient. Network platforms are playing an increasingly important role in the economic system; 70% of the Global Top 10 companies are based on network platforms (PwC, July 2019 update, due to market capitalization of Top 100 company). Network platforms consist of organizations and individual operators with fuzzy boundaries; different organizations move in and out of the organizational population frequently. To study such settings, it is necessary to document how related populations interact as part of a larger ecosystem. In this regard, Auto (2017) argues that organizations in the same value chain may construct “horizontal competition” through traditional regional agglomeration. Moreover, network platform populations include different suppliers in the same stage of a value chain. Affected by such horizontal competition, the supply side, the demand side, and other platforms jointly construct platform-based organizational populations and compete against traditional industry incumbents vertically. Horizontal competition has evolved into vertical competition, while competition among organizations has evolved into competition among platforms in a growing number of industries.

A platform is formed by an interconnected group of organizations and individual sellers. The existing definitions of “organization population” and impact “mechanism” are not fit for the modern platform economy. With that in mind, in this study we concentrate on advancing population ecology theory and identifying mechanisms that capture the nature of network platforms in order to adapt the definitions of key concepts to the current research setting.

The purpose of this paper, in other words, is to propose a platform system dependence model and illustrate how the symbiosis and competition mechanisms function in the platform economy. Generally, population ecology theory and its classic density-dependence model assume that legitimacy and competition can be best captured by time-independent density functions. The existing theory cannot therefore explain the industrial resurgence in mature industries (Box, 2017). Informed by recent writings on multistable and competitive mechanisms from community ecology theory (Zhou and van Witteloostuijn, 2010; Çakmakli et al., 2017; 2020; Boone et al., 2018; García-Díaz et al., 2020; Liu and van Witteloostuijn, 2020), we define the interacting populations in the community that affect an organizational population as a symbiotic organizational population and as a competitive organizational population. Network platforms benefit from related symbiotic industries because symbiotic populations contribute symbiotic energy and resources to platform-based organizational populations. Meanwhile, competitive organizational populations compete with platform-based organizational populations for the similar or even the same resources. We use symbiosis and competition mechanisms to analyze the interactions of network platform-based organizational populations, symbiotic organizational populations, and competitive organizational populations. We express the relevant functions as time-related differential equations; this will help us develop a revised account of population dynamics.

The paper is organized as follows. In Section 2 we present a review of the literature on relevant topics in population ecology theory and discuss how the legitimation and competition mechanisms are defined and applied in research. In Section 3 we describe our methodology. In Section 4 we present our simulation model and in Section 5 we summarize the trajectories of organizational population evolution and the validation results of the simulation model. We conclude the paper with Section 6, where we discuss the findings and limitations of this study and suggest directions for future research.

2. Theoretical background

Since its foundation as a research program in 1977, population ecology theory has focused on how organizational populations evolve and what trends prevail over time. From 1977 to early 2000, population ecology theory drew heavily on insights and similar concepts from the domain of ecology (Hannan and Freeman, 1989; Carroll and Hannan, 2000). Many researchers mined evolutionary models and imported specific statistical methods from that field, such as using event-history analysis to study vital rates. This tradition made some scholars consider this theory as “a seminal line of work in the Darwinian spirit in organization science” (Scholz and Reydon, 2013, p. 995) until recent years.

However, during the 1980s and the 1990s, the logic underlying the theory of population ecology changed as scholars redefined constructs and causal relationships, drawing on sociological concepts such as “legitimacy” and “categories”. Legitimacy strengthens the authority of new organizations in the organizational community and an organization’s ability to provide specific products and services (DiMaggio and Powell, 1983; Oliver, 1991). Population ecology theory underlines factors that “homogenize organizational forms” (Astley, 1985, p. 224). Only when an organization improves the isomorphism with other organizations in the socially constructed system, will it gain the support of legitimacy (Hannan and Carroll, 1992; Suchman, 1995, p. 574).

Hannan et al. (2007, p. 78) defined legitimation as “constitutive legitimation,” which they described as the status of organizations as taken-for-granted elements in a society. The study by Hannan et al. (2007) followed the basic tenets of population ecology theory that Hannan and Freeman (1977) had put forward earlier; namely, that organizational populations are independent entities that share common forms and compete for common resources (Hannan et al., 2007, p. 86). Through organizational form, audiences understand, label and classify organizations; therefore, organizational form represents a cognitive category. Categories help us group organizations, being typical of accepted categories accelerate members to gain value from the affiliation (Zuckerman, 1999; Hsu, 2006). Hannan et al. (2007) offered an audience-based theory to capture organizational categorization.

After 2007, especially in recent years, population ecology theory evolved into a broader sociological theory as scholars merged some of the earlier ecological concepts with other macro-sociological concepts. Pioli and Romanelli (2012) found that constitutive legitimacy can be hindered by fuzziness. The fuzzier the boundary of a category, the lower the possibility of success for an organizational form and the lower entry rate into a category (Pontikes and Barnett, 2015). Heterogeneous categories weaken the mechanism of legitimacy (Haans, 2019). However, clear categorical schemas reduce an audience’s cognitive burden (Lo et al., 2020), which improves the constitutive legitimacy of a population of organizations. Lander and Heugens (2017) proposed that using
institutional variables could enhance the traditional density-dependence model. The authors argued that institutionalism and organizational ecology theory work “better together” (Lander and Heugens, 2017, p. 1573) and can jointly explain population dynamics more effectively.

A common feature in this line of research is a persistent concern with the legitimation and competition mechanisms, which are fundamental to population ecology theory and to the density-dependence model. The legitimation and competition mechanism can affect the founding rate and death rate of organizations. Both these rates affect significantly the population density (Hannan and Freeman, 1989, p. 133; Hannan and Carroll, 1992; Hannan and Freeman, 1993). With regard to the competition mechanism, previous research indicates that competitive dynamics operate at a “more fine-grained” level (Chen and Miller, 2012, p. 142) and that, as a result, intense competition will lead to the emergence or reinforcement of a niche (Buitzbach, 2016). Although the findings of relevant studies tend to match predictions based on density-dependence models (Simons and Ingram, 2003), legitimacy mechanism can so far only work within a homogeneous organizational population.

Existing legitimation and competition mechanisms cannot deal with the dynamism and heterogeneity of market and industry settings. Population ecology theory has been criticized for suggesting that all organizations in a population contribute equally to legitimacy or competitiveness (Baum and Powell, 1995). Recently, scholars started to emphasize differences within organizational populations (Van Witteloostuijn and Boone, 2006; Bogaert et al., 2016). Fiol and Romanelli (2012) highlighted the importance of systematic heterogeneity and called on researchers to explore organizational evolution theory and measure the fuzziness of boundaries. Lander and Heugens (2017, p. 1575) argued that legitimacy is a “multidimensional concept”, and organizational ecologists should not restrict their analyses to constitutive legitimation.

To explain the emergence and evolution of heterogeneous organizational populations, which consist of fuzzier organizational forms, recent writings and studies in the community ecology literature deserve further attention. “How the links between and among populations affect the sustainability of the community as a whole” is the key concern of community ecology theory (Boone and Van Witteloostuijn, 1995, p.266). Organizational community is “a bounded set of forms with related identities” (Ruef, 2000, p.658), whereby the collective resource base of the community facilitates the emergence of a specific population which may be more heterogeneous and mixed.

According to community ecology theory, mutualistic (also being called as symbiotic) and competitive mechanisms are key mechanisms that exist across different populations in the community. For instance, Ruef (2000) noted that symbiotic relationship may tap into legitimating benefits, which include the socio-political legitimation and cognitive legitimation of an emerging form, and the benefits that are accrued in terms of a resource spillover. The existence of symbiotic organizational populations in an area can accelerate the legitimacy of new organizational forms. When the density of organizational populations that have symbiotic relationships with instruments manufacturers rises, the founding rate of instruments manufacturers will increase. As a result, the density of the organization population in nearby communities may have a mutuality or competitive effect on the founding of the population (Audia et al. 2006). Zhou and van Witteloostuijn (2010) also demonstrated that the competitive or symbiotic impact of the viability of one organizational form on another form is one of the determinants of a population’s subsequent growth. The mutualistic relationship between established and newly emerging hybrid organizational forms is considered as “legitimation spillovers” (Cakmakli et al. 2017). Mutualism may come from ideological similarity when organizational forms do not share key resources, but this mutualism relationship will turn into competition when organizational forms occupy similar or even the same resource space (Boone et al. 2018).

Network platforms are a particularly important setting where the fuzziness is clearly evident. Network platforms represent a new type of organizational population whose role in the current global economic system becomes increasingly important. Industries and platforms integrate in multiple directions; whereby the competition of organizations has become a competition between platforms. Organizations that offer superior products are not necessarily more successful in the marketplace than organizations that sell inferior products as part of stronger network ecosystems (Dougherty and Dunne, 2011).

In light of the above, research should develop theoretical frameworks that are suitable for studying heterogeneous organizational populations through theories and methods that can be adapted to dynamic settings. This does not mean that population ecology theory should at this point be abandoned; it can still be used to explain how a population evolves in conjunction with updated definitions and models. The traditional concepts and models of population ecology theory and community ecology are useful, in that they provide a general picture of different types of organizations and populations.

In this study, we put forward a platform system dependence model and use the related differential equations to capture the features of interacting organizational populations in the community. Ingram and Simons have shown that there is “mutualism with populations representing similar ideologies” (Ingram and Simons, 2000; Simons and Ingram, 2004: 37). The symbiosis and competition mechanism we specify in this study focuses on the basic requirement of a population—the resources it needs to survive and develop. With these re-specified mechanisms, we aim to advance population ecology theory, reduce its limitations, and increase its flexibility so that reflects the conditions of the platform economy.

3. Methodology

To examine the platform system dependence model and the mechanisms on which we focus in this paper, we construct system-dynamic models to simulate interactions within network platform-based organizational populations, symbiotic populations, and competitive populations. We believe that simulation is an ideal method to test our theory for the following reasons: First, the ability of empirical research to infer the overall and long-term effects of sample-specific differences is limited (Freeman et al., 2012). By contrast, computer simulation is “a third way of doing science” (Axelrod, 1997, p.3). Simulations perform better when it comes to examining the overall characteristics of the organizational population (Lomi et al., 2005) and mining the implicit dynamic behavior of models. Second, simulations can be used to generate integrated and consistent hypotheses (Harrison et al., 2007). Computer simulations provide the possibility of understanding and examining the dynamics and long-term implications of organizational and social systems (Lomi and Larsen’s, 1996; Lomi et al. 2010). The entire process of population evolution can also be modeled through simulation.

System-dynamics theory is a widely used approach to simulating and analyzing the internal dynamic structure and feedback mechanism of a system (Freeman et al., 2012). Platforms have also been recently conceptualized as dynamic systems (Ruutu et al., 2017). System-dynamics (SD) modeling is capable of simulating complex socio-economic issues with long-term and cyclical characteristics. Systems-dynamic modeling can effectively reflect the interactions within and the dynamics across organizational populations. As network platforms and related populations have constructed an integrated ecosystem, simulation is thus an ideal method for a platform economy context.

According to organizational ecology theory, two of the key parameters that affect organizational population density are the founding rate and the death rate of organizations. The founding rate $\lambda(t)$ at time $t$ is affected by the legitimacy of the population ($L_2$) and by competition ($C_i$) within the population: $\dot{\lambda}(t) = a(t) \cdot \frac{\lambda(t)}{C_i}(Hannan and Freeman, 1989, p. 133)$. Legitimacy increases with density but at a decreasing rate,
whereas competition also increases with legitimacy at an increasing rate (Hannan and Freeman, 1989, p. 134). Consequently, the LQ approximation of the organizational founding rate is \( \dot{L}(t) = \frac{1}{t} \exp(\theta_1 N_t + \theta_2 N_t^2) \). The death rate of organizations in age \( u \) is \( \mu(u) = \frac{2 \theta_1}{t} \exp(-\theta_1 N_t + \theta_2 N_t^2) \). Applying a log-transformation (Hannan and Carroll, 1992) to this rate yields \( \ln(\mu(u)) = \ln(\mu(u)) - \theta_1 N_t + 2 \theta_2 N_t^2 \). However, the legitimation mechanism, which is the key concept of density-dependence models, cannot as mentioned, be used across populations.

Initially, Hannan and Freeman (1989, p. 141) used \( \beta_2 \) to capture cross-population competitive effects and build a multi-population model: \( \dot{C}_{12} = \exp(\beta_1 N_1^2 + \beta_2 N_2^2) \). Since then, many organizational ecologists have applied ecology models, such as the Lotka-Volterra competition model (model as the “Lotka-Volterra predator-prey model”) and the NK model in population-ecology research. However, the solution curves of the Lotka-Volterra competition model show that populations evolve periodically, whereas in reality, this rarely occurs. An organizational population needs a long time to recover from the threat of extinction when eager to re-emerge. The NK model (Kauffman and Weinberger, 1989), which aims to optimize solutions in a given setting, assumes that all organizational populations in the same evolutionary systems share common goals (Arthur et al., 2017). Network platforms and related industries are independent in their aims. For this reason, we cannot assume that these populations share a common goal. This implies that the NK model cannot be used in a platform context.

Based on the thinking of community ecology, scholars developed different measurements to capture symbiosis and competition of populations inside a community. Competitive or symbiotic impact of organizational populations is being estimated as a generic density-dependent parameter that affect form emergence (Ruef, 2000). Later, Audia, Freeman, and Reynolds focused on input-output flows to define inter-population relations. They calculated community supplier symbiosis and community purchaser symbiosis as two measures of community symbiosis, taking account the dollar value of inputs and sales between the focal population, purchaser population, and supplier population. But the shortcoming of this method is that it must consider all populations to produce plausible parameters (Audia et al., 2006). By directly measuring geographic proximity between adjacent communities, Zhang et al. (2009) argued that when mutualism takes effect at the low level of geographic proximity, mutualistic benefits will increase with geographic proximity in this circumstance. At the same time, the mutualistic effect will shift to a competition effect at high levels of geographic proximity. Zhou and van Witteloostuijn (2010) used the population interaction coefficient to capture the competitive or symbiotic effect of one population on another population. By considering the heterogeneity in the industry and applying GoM weighted density (weighting by grades of membership) during the form emergence process to measure the impact of this heterogeneity, Çakmakili et al. (2020) contribute to density dependence theory from a more detailed “micro” level.

Models applied in traditional populational ecology theory and community ecology literature tend to contain competitive or symbiotic effect in one equation, making it possible to estimate effects between two populations. But in the context of platform economy, network platforms interact with symbiotic and competitive populations in the ecosystem. Our paper focuses on the population level, uses separate equations to capture the density of the platform-based Organizational Population (the population that make up of platform or enterprise), Competitive Organizational Population (the population that has competitive relationship with platform-based organizational population) and Symbiotic Organizational Populations (the population that has symbiotic relationship with platform-based organizational population), made it clearer to show the evolution of each organizational population. Importantly, platforms are not tightly constrained by geographic distances as traditional companies and industry are. “Geographic proximity” variable need to be replaced by broader and extended concept.

Meanwhile, instead of using the generalized carrying capacity calculation in the conventional way, we develop a specific resource function to constrain available resources in the ecosystem. To capture the dynamics of population evolution and how different populations interact, it is imperative to revise and improve the current models. The platform system dependence model we illustrate in this paper broadens the way of calculating and measuring mixed populations and provides a different, yet complementary perspective on populational ecology and community ecology theory.

Population ecology and community ecology theory have been developed on the basis of advances in biology and natural science. However, potential applications of ecological models in the areas of business and management still need to be explored. Here, we apply the logic of a “two consumers and one resource” model (Dé Roos, 2019, p. 60), changing those parameters that do not fit the business reality and adding platform-related elements to the model. With these changes, we expand the traditional population biological model so that it can be used in a context where three populations consume the same resource. For instance, we use the variable of “available resources” to represent a maximum concentration of resources in the habitat (Tilman, 1981) and the available concentration of resources. Furthermore, we introduce the new concept of “symbiotic population” to the original resource-competition model. This model includes factors that have an impact on the extinction rate of populations but also takes into account the symbiotic energy and resources that each symbiotic population contributes to an organizational population. We expand the resource-constraint function, which corresponds to two populations in the same habitat, into equations that represent three interactive organizational populations in the same community. Overall, these functions are expressed as time-related differential equations. In sum, the extended model makes it possible to capture both the dynamics among interacting populations in the same ecosystem and the factors that affect the evolution of these populations.

4. The model

We use \( g \) to represent the symbiotic energy that each symbiotic population supplies to the organizational population. Below we describe how we capture platform-based organizational populations, symbiotic organizational populations, and competitive organizational populations.

4.1. Capturing the platform-based organizational population

The density of platform-based organizational population \( A_t \) at time \( t \) can be expressed as

\[
\frac{dA_t}{dt} = \alpha [\mu R - (E_t - C_t) - g] - A_t \beta_4 \]

\( (4.1) \)

where \( \mu_t \) stands for the growth rate of an organizational population (Tuma and Hannan, 1984). Here, \( R \) represents a resource that is available to the platform population, symbiotic population and competitive organizational population, whereas \( E_t \) represents the extinction rate of the platform population and \( C_t \) refers to the density of the competitive population. Furthermore, \( B \) stands for the extinction rate that can be attributed to the competitive population, \( G_t \) represents the organizational population density of the symbiotic population and \( \alpha \) the intraspecific competition intensity of the organizational population.

4.2. Capturing the competitive organizational population

Specific types of physical stores and other network platforms in the ecosystem can be competitive organizational population to the platform-based organizational population. The density of competitive organizational population \( C_t \) is given by (4.2).

\[
\frac{dC_t}{dt} = \alpha [\mu R - (E_t - C_t) - g] - A_t \beta_4 \]

\( (4.2) \)
According to Equation (4.3) below.

\[
\frac{dG_i}{dt} = (\mu_i R - E_i)G_i
\]  

Here, \( \mu_i \) stands for the growth rate of organizational population and \( E_i \) represents the extinction rate of the competitive organizational population.

### 4.3. Capturing symbiotic organizational populations

A symbiotic population establishes a mutual beneficial relationship with the platform-based organizational population. For instance, Walmart’s home-order Gross Merchandise Volume on China’s e-commerce platform JD.com increased by more than 30 times in 2017 compared to 2016, when these two companies started to cooperate. As a result, JD.com was also able to reduce its delivery time to 30 min (NetEase Tech, 2019). This example illustrates how bricks-and-mortar stores can interact symbiotically with a platform-based organizational population.

We calculated the symbiotic organizational population at time \( t \) according to Equation (4.3) below.

\[
\frac{dG_i}{dt} = (\mu_i R - E_i)G_i
\]  

Here \( G_i \) represents the symbiotic population density at time \( t \) while \( \mu_i \) is the growth rate of the symbiotic population. While symbiotic populations contribute symbiotic energy to the platform population, they also suffer a loss of resources. We use \( E_i \) to represent the resource loss of a symbiotic population that contributes to the organizational population. Here, \( E_i \) is the extinction rate of the symbiotic population.

Every environment has a specific carrying capacity. A platform may use both online and offline resources; however, these resources are limited. A platform-based organizational population needs to share resources with a competitive organizational population and a symbiotic organizational population in the community. The function below constrains the resources that are available to a platform-based population, a competitive population, and a symbiotic organizational population:

\[
\frac{dR}{dt} = F^* R - Q^*_t A_t - Q^*_E C_t - Q^*_C G_t
\]  

Here, \( F^* \) represents the supply rate of resources, \( R \) indicates the available resources, \( Q^*_t \) reflects the resources that each population requires, and \( A_t \) represents the platform-based organizational population while \( G_t \) stands for the symbiotic organizational population. Furthermore, \( \mu_{E_t} \), \( \mu_{Q_t} \), and \( \mu_{g} \) denote the growth rate of the platform population, the competitive organizational population, and the symbiotic population, respectively.

The causal loop diagram and the stock-flow diagram of the platform system dependence model in Figs. 1 and 2 illustrate these calculations. Tables A.1 and A.2 in the Appendix provide more details on the variables we have included in the simulation model. In Fig. 1, the “+” sign indicates that the effect between the two variables is positive, while the “-” sign indicates that this effect is negative. For instance, the higher the density of a symbiotic population, the greater the amount of symbiotic energy it can supply to the platform population, which in turn increases the density of that population. This shows that there are positive effects to be expected among a symbiotic population, symbiotic energy and a platform’s organizational population density. The stock-flow diagram in Fig. 2 shows the input and output flow variables of key stock variables. The stock variables we focus on are symbiotic population density, competitive population density and organizational population density.

### 5. Results

#### 5.1. 1 trajectories of organizational population evolution

We used the Vensim software to run the simulation model. To obtain the simulation results shown in this paper, we ran the Euler integration. Figs. 3–5 below illustrate the trajectories of symbiotic, competitive, and platform-based organizational populations (Time Step = 0.0625, Final Time = 600 months). As shown in Figs. 3 and 4, the density of symbiotic populations and competitive populations will increase at first. In the early phase, there is a limited competitive organizational population and platform-based organizational population, as resources are sufficient inside the ecosystem. The increase of the available resource space leads to the sudden rise of a symbiotic population density, kick starting the further evolution of a symbiotic organizational population. After 1.0625 months the symbiotic population will start decreasing, while the competitive population will remain stable in the same period. Fig. 5 shows how a platform-based organizational population develops over time. The density of the platform-based organizational population rises in the early phase and reaches its peak after 300 months. After that point, the density of the platform-based organizational population begins to decline. Fig. 6 shows the density of the platform-based, symbiotic, and competitive organizational population at the same timing.

We also find an interesting result when exploring what type of outcomes would be produced in different scenarios. When the growth rate of the symbiotic organizational population increases while the settings

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Fig. 1. Causal loop diagram representing the platform system dependence model.
of all the rest parameters remain the same, the simulation results of the density of symbiotic organizational population, competitive population and platform-based population are shown in Fig. 7. Fig. 7 proves that symbiotic organizational population plays an important role in the evolution of platform-based organizational population. As the needs of the resource symbiotic organizational population rises, resources for the competitive population decrease, hindering the further development of the competitive organizational population. Hence, platform-based organizational population appear to benefit from the growth of the symbiotic organizational population instead and our results show that it will keep growing in this scenario.

Fig. 8 shows the simulation results for Time Step = 0.25 and Final Time = 1000 months. In this simulation, the trend of the symbiotic population density becomes smoother and grows in a similar direction as that of the competitive population. Fig. 9 depicts the trend of the platform population density for 1000 months and 2000 months respectively. Within the context of the simulation, as this figure shows, the density of the platform population increases and may reach almost 90 billion at 1000 months and 170 billion at 2000 months. These figures show that in the longer term, the platform-based organizational population increases while the symbiotic and competitive populations become gradually stabilized.

5.2. Tests and validation

5.2.1. Extreme-conditions test

The model behaves as expected when we set the variables to extreme conditions. The amount of symbiotic energy equals 0 when the density of the symbiotic population is also 0. The model also shows verisimilitude when parameters change simultaneously in the Monte Carlo experiment.

5.2.2. Multivariate sensitivity simulation

In order to improve the reliability of the simulation model, we performed a multivariate sensitivity simulation (MVSS, also known as a "Monte Carlo simulation") in the DSS version of Vensim. This allowed us to test the impact of uncertainty on the platform system dependence model. We set the number of simulations to 2000 and 20000 times for the purposes of the sensitivity analysis. The software automatically creates random sample values for parameters according to a defined...
distribution and settings. The diagram presents the confidence-bound regions, within which the population density might occur with 50, 75, 95, and 100 per cent probability.

Fig. 10 shows the results of the MVSS that we performed to calculate the density of platform-based organizational populations when the growth rate and the extinction rate of the competitive population and the platform-based organizational population change randomly according to a Random Uniform Distribution [0,1]. When the symbiotic energy and the supply rate of available resources change randomly according to the Random Uniform Distribution, the sensitivity graph that depicts the population density of platform-based organizations is the same as the graph in Fig. 9. In Fig. 10, the narrow confidence bounds suggest that the dynamics of the density of platform-based populations do not change when the values of the input variables varied. Therefore, we can conclude that the model is stable and robust.

6. Discussion and conclusions

The network economy is becoming increasingly important in the current business ecosystem. Platform settings are complex and require further analysis with regard to the heterogeneous organizational populations with fuzzy boundaries that they host. However, there is a lack of research on this type of dynamic setting. The existing mechanisms and methods that are applied in population ecology theory are not adequate for studying how related populations interact within the larger ecosystem. For that reason, in this paper we re-specify the definitions of interacting populations in a larger community or eco-system. Consistent with community ecology theory (Boone and Van Witteloostuijn, 1995; Ruef, 2006; Audia et al., 2006; Zhang et al., 2009; Zhou and van Witteloostuijn, 2010; Çakmakli et al., 2017; 2020; Boone et al., 2018; García-Díaz et al., 2020; Liu and van Witteloostuijn, 2020), we furthermore emphasize a symbiosis and competition mechanism, and
revise existing equations to capture adequately the current setting of the network economy. The symbiosis and competition mechanisms we propose in this paper can be used not only in the context of network platforms, but also in the context of organizational populations that interact in the same community. The equations of the platform system dependence model can be used to analyze three related populations that coexist in the same environment and draw on the same resource base.

Our simulation results show that the density of symbiotic organizational populations and of competitive organizational populations increases rapidly in the initial stage of organizational population growth, while the platform-based organizational population grows more gradually over the course of 25 years. We also observe that the platform-based organizational population increases when the density of the symbiotic population rises. A symbiotic organizational population cooperates with platform-based organizational populations so that both can gain mutual benefits. Furthermore, a symbiotic organizational population contributes symbiotic energy to the platform-based organizational population. Our results show that the competitive organizational population and intra-specific competition will decrease the density of platform-based organizational populations. As the density of a symbiotic population decreases but the density of the competitive population remains stable, the density of the platform-based organizational population begins to decrease after reaching its maximum numerical value.

Our research makes three main contributions to the literature. First, this study proposes a revised theoretical framework that aims to fill the gap between population ecology theory, community ecology theory and the study of network platforms. Our study reframes population ecology theory and community ecology theory to make these relevant in the context of the current business environment, particularly regarding the
platform-based economy. Industries and platforms are currently blending into each other, and organizations and populations are integrating in multiple directions. This paper seeks to sketch a preliminary agenda for exploring how population ecology and community ecology theory can be applied in the practices that are associated with platform-based businesses. We hope that this paper will deepen the understanding of population dynamics in the new economy, provide references for traditional industries and accelerate further research on organizational population evolution.

Second, our study proposes specific mechanisms that could be used in a revised version of the most frequently used density-dependence model in population ecology. We expand the legitimation and competition mechanisms of typical density-dependence models into a symbiosis and competition mechanisms. These new mechanisms will help capture the features of interacting organizational populations in the community. In contrast to previous research, we put forward new mathematical functions to capture key variables of platform-based organizational populations, symbiotic organizational populations and competitive organizational populations. To develop this new mechanism, instead of using time-independent density functions, we used
time-related differential equations. This change makes it possible to perform a comprehensive density-trend analysis that can be applied in different industries. In light of the fact that populations become increasingly varied and network platforms include organizations and individuals with fuzzy boundaries, we emphasize the definition of a symbiotic organizational population that as part of our platform system dependence model stretches across categories of populations.

Third, in addition to offering new solutions to formal modelling and extending the boundaries of the existing density-dependence model, we also test the newly specified mechanism through simulation. More specifically, we use System Dynamics modeling and the simulation software Vensim to model the mechanisms we put forward in this paper as well as the dynamics of the network economy.

This research has some limitations that may open avenues for further research. From a theoretical perspective, population ecology theory focuses on the macro-level of analysis, which makes it difficult to include firm-level details in the target model. To enable a consistent focus on the population level, we did not integrate the implementation mechanism into the current paper. Inspired by work of García-Díaz, van Witteloostuijn, and Pêti, we believed that agent-based modelling (ABM) techniques provide an opportunity to further connect macro-level research with micro mechanisms. García-Díaz, van Witteloostuijn, and Pêti (2008) built an agent-based computational model to study how the change of product variants in the product space affect the performance of large-scale and small-scale firms. Moreover, they developed a simulation model of interacting economic agents to integrate firm-level decision making rules into an industry-level approach (García-Díaz et al., 2015). Recently, García-Díaz et al. (2020) presented an agent-based computational model of firm competition, describing the co-evolution of the product space and the firms with and without scale economies (García-Díaz et al. 2020). Future research may build on the use of such ABM tools to further explore the impact of different resource features to the evolution of a population and whist doing so may add more organization level details into our proposed platform system dependence model. Also, future studies could try to apply further boundary conditions to our model to optimize its explanatory power. Empirical research could also use operational data of the platform industry to test the exact effect of related variables mentioned in our model but in a field setting.

GoM concept (Çakmakli et al., 2020) may applied as a measure of symbiotic energy. For instance, if symbiotic organizational population and platform-based organizational population share a common mission or corporate initial, then the symbiotic energy between symbiotic organizational population is roughly divided among the symbiotic and platform-based organizational population. Competitive organizational population and symbiotic organizational population is roughly divided and defined in our study. Future research may, however, apply machine learning in discriminant analysis to refine the process of classification and distinguish fuzzy categories more efficiently.

Declaration of competing interest

None.

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Appendix A. Supplementary data

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References