A complex adaptive systems agenda for ecosystem research methodology

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A COMPLEX ADAPTIVE SYSTEMS AGENDA FOR ECOSYSTEM RESEARCH METHODOLOGY

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ABSTRACT

Ecosystems have recently emerged as a visible stream in organization and management research. The ecosystem concept promises a broader, systems view of organizational and technological phenomena beyond traditional firm, value chain or network boundaries. However, adopting an ecosystem approach presents a range of methodological challenges for researchers, including how to set boundaries for the ecosystems, as well as how to examine their structure and relationships, as well as to explain the inherent dynamics and co-evolution. Based upon on a complex adaptive systems lens, this study proposes a theoretically grounded but pragmatic approach to address these challenges. The proposed methodological framework facilitates exploration of the conceptual, structural and temporal dimensions of ecosystem research design. An illustrative example is also included to showcase the framework's applicability.

Keywords: Ecosystem, Complex Adaptive Systems, Research Design, Methodology

1. INTRODUCTION

The aim of this study is to reflect critically on the research challenges associated with the increasingly popular topic of *ecosystems*, and to propose a complex adaptive system -based foundation for ecosystem research methodology. The concept was initially introduced by Moore (1993) as a *business ecosystem* – an analogy to a biological ecosystem (Tansley, 1935, p. 299) – extending previous conceptions of value chains (Porter, 1985) to take account of interdependencies and the co-evolution of relevant organizational and institutional actors. The field has since expanded to encompass such issues as interdependencies in technology and innovation (Adner, 2012), knowledge generation (Clarysse et al., 2014; Järvi et al., 2018), as well as digital platform –operated ecosystems (Gawer & Cusumano, 2014; Cennamo & Santalo, 2019). In doing so, ecosystem scholars have been able to explain several important phenomena related to strategy, technology and innovation. These include management and orchestration of ecosystems (Ritala et al., 2013; Williamson & De Meyer, 2012; Wareham et al., 2014), the structure and relationships of ecosystems (Basole et al., 2015, 2016; Clarysse et al., 2014), as well as the emergence of innovation and technologies in an ecosystem context (Ansari et al., 2016; Kolloch & Dellerman, 2018; Dattee et al., 2018). The surge of research on ecosystems are documented in several literature reviews, demonstrating the wide variety of epistemological and ontological approaches adopted by scholars (Aarikka-Stenroos & Ritala, 2017; Tsujimoto et al., 2018; de Vasconcelos Gomes et al., 2018; Suominen et al., 2019).

However, along with the increasing popularity of the concept, there are also critiques of the ambiguous and metaphorical usage of the ecosystem concept, which limits the progression and accumulation of scholarly knowledge (see e.g. Oh et al., 2016; Ritala & Almpanopoulou, 2017; Scaringella & Radziwon, 2018; Ritala & Gustafsson, 2018; Suominen et al., 2019). It could be argued that we are lacking a ‘meta-level’ methodological approach to match the theoretical ambitions of ecosystem scholars, addressing issues such as co-evolution (e.g. Adner and Kapoor, 2010; Kolloch & Dellerman, 2018) or the emergence of organizing (Järvi et al., 2018; Roundy et al., 2018). Indeed, given the lack of a big picture –type background for research designs makes synthesis and cross-study inferences problematic, inhibiting the development of a solid theoretical and methodological base and potentially slowing the progress in the field.

To address this challenge, we argue that ecosystem research would benefit from adopting a better founded theorizing behind the core methodological choices. In particular, we follow the recent calls on the promise of *complex adaptive systems* (CAS) theorizing to address ecosystems (see e.g. Ritala & Gustafsson, 2018; Roundy et al., 2018). We choose to focus on a CAS approach, since ecosystems are literally and phenomenologically ‘systems’, regardless of how they have been previously studied. To this end, we will put forward a complex adaptive systems research agenda and related methodological framework for research designs focused on ecosystems.

The developed framework encompasses three dimensions in this regard—conceptual, structural and temporal—and the paper outlines a research design for each. While these dimensions have previously been identified in systems sciences and related fields (Anderson, 1999; Cilliers, 2001; Holland, 1995; von Bertalanffy, 1968), they are rarely explicitly or exhaustively addressed in ecosystem research. The present study contributes to the field by advocating and demonstrating the utility of complex adaptive systems thinking in designing rigorous methodological foundations for the study of ecosystems.

2. CONCEPTUAL BACKGROUND

2.1 Complex adaptive systems and systems thinking

Since the early conceptualization of organizations as ‘open systems’ (Katz & Kahn, 1978), systems thinking has informed many branches of organization and management research (see Mingers & White, 2010 for a full review). However, complex system definitions and theories generally entail ‘inherent fuzziness’, hindering their wider application (see for instance Prokopenko et al., 2008). To begin, then, it is helpful to briefly review some key concepts and approaches.

Systems are entities with more than one connected or interrelated component (von Bertalanffy, 1956). As the number of components and the relationships between those components increases, the system becomes a complex system, making prediction of cause and effect more difficult (Anderson, 1999), as these parts are also ‘in interaction’ (von Bertalanffy, 1956, p. 19). *Complex adaptive systems* involve many components that adapt or learn as they interact (Holland, 1995) and organize without being controlled or managed by any singular entity (Holland, 1995). In studying systems, Cabrera (2006) identified the need to link our (ontological) knowledge about systems to systems thinking (which is conceptual and epistemological) as one of the key challenges. While knowledge about systems addresses such issues as structure and relationships (as defined above), systems thinking involves adopting multiple perspectives to consider the roles of parts and the whole and the complex interrelationships between them (Cabrera, 2006, p. 63). The present study utilizes both of these approaches.

2.2. Complex adaptive systems as an emerging foundation for ecosystem research

Following its initial appearance in practitioner outlets (e.g. Moore, 1993; Iansiti & Levien, 2004), the ecosystem concept has featured increasingly in leading management and organization journals, including the *Academy of Management Review* (e.g. Alexy et al., 2013; Priem et al., 2013; Dattee et al., 2018); *Organization Science* (e.g. Jacobides & Tae, 2015; Wareham et al., 2014) and *Strategic Management Journal* (e.g. Pierce, 2009; Ansari et al., 2016; Kapoor & Furr, 2015; Jacobides et al., 2018), as well as in technology and innovation journals such as *Technological Forecasting and Social Change* (e.g. Tsujimoto et al., 2018; Walrave et al., 2018) and *Research Policy* (e.g. Clarysse et al., 2014; Järvi et al., 2018). Ecosystem research has highlighted the managerial relevance of viewing organizations and their environments as systems, characterized by interdependence, co-evolution, non-linear behavior and scalable, system-level opportunities and challenges (e.g. Adner, 2012; Moore, 1993; Priem et al., 2013). In contrast to the classical ‘market focus’, ecosystem studies have explored users, complementors and producers in network markets (Frels et al., 2003; Jakobides et al., 2018), identifying the role of ‘platforms’ in creating connectivity between actors (Gawer & Cusumano, 2014; Wareham et al., 2014; Thomas et al., 2014) and examining their emergence and evolution (Ansari et al., 2016; Dattee et al., 2018).

More importantly, ecosystem research expands the boundaries of management research to achieve a more holistic view (Autio & Thomas, 2014), but the field arguably lacks a more coherent methodology to support its further development. Illustrating this deficit, the seminal papers (top 20 cited *business or innovation ecosystem* in the ISI Web of Science), including for example Moore (1993) and Iansiti and Levien (2004), rarely elaborate explicit systems thinking or systems approaches. Recent reflective critiques and reviews (Badinelli et al., 2012; Oh et al., 2016; Ritala & Gustafsson, 2018) have noted the same issues. Badinelli et al. noted that “much of the use of the word “system” in literature merely describe interconnectedness of entities, but do not adhere to systems thinking principles, which often disrupt the traditional thinking” (2012, p. 499). In their overview, Autio and Thomas (2014) found that while many systems-related concepts were used in ecosystem research, there was no explicit reference to systems thinking or methods.

Where systems-like approaches are used, they have tended to focus on structure and specific phenomena (Anggraeni et al., 2007). This may in part be due to early research that focused predominantly on the structure of ecosystems and identification of key actors and their roles. Some notable exceptions who take a systems perspective include those approaching them as technical systems (Adner & Kapoor, 2010; Baldwin & Clark, 2000; Gawer & Cusumano, 2014; Kapoor & Furr, 2015) or as economic systems (Jacobides & Tae, 2015). Some studies (e.g. Peltoniemi, 2006; Roundy et al., 2018; Scaringella & Radziwon, 2018) have adopted a broader, complex systems approach, but these remain a minority within the larger body of ecosystem research.

The challenges in studying complex systems (Halinen & Törnroos, 2005; Meyer et al., 2005) and defining their boundaries (Cilliers, 2001; Gibbert & Välikangas, 2004) are well documented, and it has been argued that a lack of context or controls makes development of robust theory more difficult (Davis, 2010). That being so, the aim here is to identify the fundamental dimensions of an ecosystem research design using a complex adaptive systems approach. In particular, we propose a research agenda addressing the conceptual, structural and temporal dimensions of ecosystems (see Table 1), which we will discuss in detail in the following sections.

Table 1. Conceptual, structural and temporal dimensions and their implications

	Conceptual	**Structural**	**Temporal**
	How we think about the system	*What we know about the system*	*How systems change over time*
Systems-theoretic definition	Epistemology and theoretical considerations and implications for scope and design of ecosystem research	Ecosystem components and relationships between them impacting structure and processes	Temporal considerations impacting the dynamics and evolution of the ecosystem
Focus of systems-based inquiry	**Boundaries:** Determining ecosystem type and scope (e.g. business, knowledge, innovation) **Perspectives**: How to address the differing perspectives of actors, ecosystem, and environment	**Hierarchy:** Components (actors) in the ecosystem study, which may include subsystems and individuals **Relationships:** Links (and their nature) between components (actors), driven by actors' processes (schema)	**Dynamics:** Changes over time in the ecosystem, actors, relationships and boundaries **Co-evolution**: Interdependent evolution within the ecosystem *and* environment
Key research design questions	What is the focal issue? What philosophical and theoretical positioning is appropriate? What are the implications for research scope and determining the boundary?	What are the structures? What is the hierarchy (of actors and processes), How are these interrelated? How might these be mapped and studied? What is/are the appropriate level/s of analysis?	What are the underpinning dynamics of the environment, ecosystem and its components? What timeframe and approach are appropriate? How might time impact conceptual and structural considerations?

3. CONCEPTUAL DIMENSIONS—HOW WE THINK ABOUT ECOSYSTEMS

In studying systems, it is crucial to separate what we know—the ontology—from how we think—the epistemology (Cabrera, 2006). The first set of relevant ecosystem dimensions—the *conceptual* considerations—relates to epistemology, building on two common principles of systems thinking: boundary critique (i.e. in order to think about a system, one must identify and explicitly define *boundaries*, however arbitrary); and the need to address the multiple *perspectives* that prevail in any social system (Midgley, 2008).

3.1 Boundaries

Conceptually, a system can be understood as "a complex of interacting components together with the relationships among them that permit the identification of a boundary-maintaining entity or process" (Laszlo & Krippner, 1998, p. 47). To understand a system, one must first distinguish between 'the system and something else' (Luhmann, 2013, p. 44) or, put another way, identify a boundary between the system and its surrounding environment (Cilliers, 2001). For the purposes of systems thinking, the environment is not simply things 'outside' the system but includes everything that affects the system's behavior (Hall & Fagen, 2003).

Social systems with 'open boundaries' (such as ecosystems) see new actors joining as others leave (Anderson, 1999). While this adds to the complexity of defining boundaries, this issue is central in understanding forms of organizing (e.g. Santos & Eisenhardt, 2005) and ecosystem research (e.g. Autio & Thomas, 2014). Scott and Davis (2007) identified three approaches to boundary determination, focusing on *actors* (the 'who'), *social relations* (their 'relatedness and frequency', as for instance in social network analysis) and *activities* or 'processes'. From another perspective, Santos and Eisenhardt (2005, p. 494) proposed boundaries of *efficiency* (transactions within the organization), *influence and power* (domains over which the organization exercises influence), *competence* (the organization's resources), as well as cognitive and emotional *identity* (the dominant mindset or 'who we are'). Several ecosystem scholars have adopted recently the latter approach and studied how ecosystems boundaries are constructed around and evolve in relation to identity, competence, power and efficiency (Phillips & Srai, 2018; Radziwon & Bogers, 2018). In fact, Zobel & Hagedoorn (2018) suggest that recognizing these different system boundaries helps to explain how firms in innovation ecosystems can create and capture value as well as establish effective governance mechanisms.

It can be argued that the system ultimately constructs its own boundaries (Webb, 2013). On the other hand, researchers themselves often determine the boundaries explicitly or implicitly via setting research questions and choosing informants. Thus, to have any confidence in boundary selection, the researcher must engage with the ecosystem and actors in the wider environment to elicit understanding. To reduce any risk of researcher bias or subjectivity, ecosystem actors should be engaged in helping to define or validate any proposed boundary (Doreian & Woodard, 1994). Such a task, however, may become quite large, given the fact that many ecosystems have dozens, if not hundreds of actors, and those actors may also be changing rapidly.

Given these challenges, it is unsurprising that so few ecosystem papers refer explicitly to the boundaries or how these are determined. Drawing analogies from ecology itself, Post et al. (2007) examined the challenges of boundary determination in biological and geomorphological systems and identified two approaches: *population-community* and *process-function*. For example, using a population-community approach, some researchers have determined organizational boundaries based on geography (Korhonen & Snäkin, 2005), a research project (Järvi et al., 2018), boundaries on the focal firm (Adner & Kapoor, 2010) or more broadly on a 'core domain' (Iansiti & Richards, 2006) or industry (Ansari et al., 2016), which can be extended to include identity (Santos & Eisenhardt, 2005). A process-function approach, on the other hand, views systems in terms of their activities. For instance, Valkokari (2015) used 'type of flow' to identify three types of ecosystem: the business ecosystem, the knowledge ecosystem and the innovation ecosystem (see also Clarysse et al., 2014). Additionally, Adner (2017) suggests that an ecosystem consists of actors that need to interact in order for focal value proposition to materialize. Similarly, Jakobides et al. (2018) view ecosystems as involving unique complementarities in the supply and demand side, and the actors involved in the ecosystem are those that participate in facilitating these complementarities. Thus, any actor involved in such processes, would be a part of an ecosystem related to that value proposition or complementarities creation.

In our view, the ecosystem boundary definition will benefit from both population-community and process-function approaches. Focusing only on population-community might miss out important points about the actual value creating processes, and the actors involved. Also, if we adopt a process-perspective, we risk leaving out actors that are important to the ecosystem but are less obvious or visible. The difference between the two approaches echoes the Adner's (2017) distinction between *ecosystem-as-structure* and *ecosystem-as-affiliation*. The former focuses on the most relevant actors and activities in the ecosystem that relate to focal value proposition. The latter, however, relates to a broader set of actors that are affiliated to the ecosystem, and might have a more indirect influence. Thus, depending on the analytical focus of the study, researchers might consider adopting one of these approaches. In any case, it is important to recognize the consequences of including or excluding particular actors.

3.2 Perspectives

Another key conceptual choice concerns the *perspective* adopted to examine an ecosystem, which may be technological (Adomavicius et al., 2007; Li, 2009; Wareham et al., 2014), holistic (Rong et al., 2013), contextual (Priem et al., 2013), firm or inter-firm (Anggraeni et al., 2007) or theoretical (Thomas & Autio, 2014). Perspectives can be narrow in focus, as for instance in analyzing the system around technological platforms (e.g. Wareham et al., 2014) or around a particular organization (e.g. Adner & Kapoor, 2010). Alternatively, some authors have adopted multiple parallel perspectives where interconnected ecosystems are conceptualized around different domains and contexts (e.g. knowledge, innovation, and business ecosystem; Clarysse et al., 2014). While these perspectives may inform a clear research objective and methodology, it can be argued that they transcend all such objectives and methodologies. These choices are implicit in any ecosystem investigation and have major consequences for how that ecosystem is studied. An informed choice of epistemology helps to move from mere analogy (see Oh et al., 2016) towards a systems-based inquiry beyond specific organizational phenomena.

Snowden and Kurtz (2003) proposed that different perspectives from diverse sources are fundamental to sense making—that is, not only can there be different perspectives, but these differences or divergences can be exploited both by organizations (to identify points of differentiation) and researchers (to identify new insights or explanations). This idea of different perspectives also informs Santos and Eisenhardt's (2005) approach to boundary definition and can be considered integral to any system investigation as a fundamental concept that presents challenges and potentially opens up new possibilities and lines of inquiry or explanation. Ecosystem studies employ multiple prefixes (e.g. business, innovation, platform, knowledge, service), offering some insight into the perspective adopted and helping to identify the relevant epistemology. Additionally, the analytical tools chosen to explore ecosystems and their appropriateness to the system's complexity (Basole et al., 2016) may affect the research perspective.

In order to identify a suitable perspective and identify boundaries of an ecosystem, there are several useful methodologies that we highlight here. As these methods are often qualitative in nature, ensuring clarity in the research setting, sampling procedures, the nature of participants, and documenting interactions with participants, as proposed by Aguinis & Solarino (2019) are valuable to ensure transparency. An approach that seeks to initially explore (diverge) and later confirm (converge) may be particularly useful in poorly defined ecosystems. By initially engaging an 'expert' group (e.g. knowledgeable top managers or industry experts as informants), then using snowballing to expand the search (Rowe & Wright, 2011), and semi-structured interviews to enable different perspectives and unexpected opportunities to emerge, activity and flow mapping (as discussed earlier), and finally confirmatory interviews. This approach provides a 'divergent search' until a 'saturation point' (Aguinis & Solarino, 2019). Analysis of the interviews through coding, mapping flows and activities provides insights for boundary analysis that, when subject to confirmatory reviews by a range of ecosystem informants, improves transparency and rigor as the research 'converges' on an eventual 'boundary proposal'.

Synthesizing these issues, Figure 1 describes how the conceptual dimensions of an ecosystem might be examined.

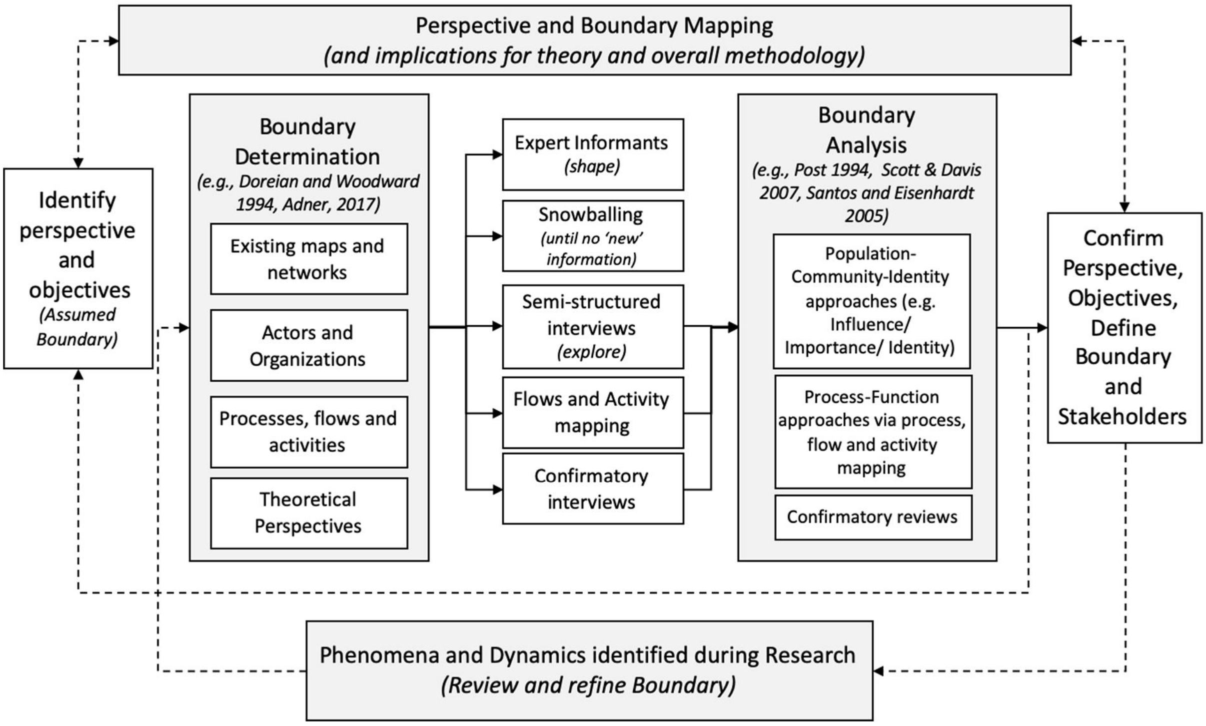

Figure 1. Methodological framework to identify boundaries, perspectives and objectives.

4. STRUCTURAL DIMENSIONS—WHAT WE KNOW ABOUT ECOSYSTEMS

A second relevant dimension relates to the ontology of the ecosystem, i.e. its *structure.* This involves ecosystem's internal *hierarchy* and its *relationships*, together constituting the 'tangible' or 'physical' issues that can also be characterized as the elements of the system (Hall & Fagen, 2003).

4.1 Hierarchy

Defining a complex system in terms of components (actors) and linkages (relationships) implies a structure that can be understood and examined by an external observer. However, the structures of complex systems are not homogeneous (Cilliers, 2001), resulting in some form of *hierarchy* (Holland, 1997). The concept of hierarchy within complex systems, resulting in the formation of subsystems within a wider system, is well established (Simon, 1962). Such hierarchy can be established between actors through differences in influence and contribution (Adner, 2017) or through the creation of subsystems of specialization or as niches (Walgrave et al, 2018) or through their position in value creation (Adner & Kapoor, 2010). Furthermore, complex systems have a known ability to self-organize bottom-up, thus creating structures that are based not only on spatial relations, but on processes generated by interactions over time (Maturana & Varela, 1980). The nature of such structures makes it more difficult to determine causation; as phenomena may result from activity in other subsystems or hierarchies, making observation and analysis challenging. In the existing literature, structure is often simply defined in terms of the roles or names of focal actors. Alternatively, broader structural features are typically investigated by identifying structural network linkages (e.g. Basole, 2009; Basole et al., 2015); by equating the ecosystem with a 'segment' or 'industry' (Jacobides & Tae, 2015; Kapoor & Furr, 2015); or by identifying actors connected to a technological platform (Gawer & Cusumano, 2014; Wareham et al., 2014).

Although many authors refer to systems approaches when examining ecosystem structure, the actual analysis is often reduced—for practical or conceptual reasons—to a simple value network. For example, Lin et al. (2009) examined ecosystem structure from the perspective of a classical supply chain or value network analysis. However, the importance of multilevel understanding is well established in the broader literature (Zappa & Lomi, 2015). For instance, in technological transition studies the multilevel perspective is often advocated where activities of the socio-technical systems are examined between and within levels of analysis (see e.g. Geels, 2004, 2005). Furthermore, discussing innovation at multiple levels of analysis, Gupta et al. noted that "A complete multilevel perspective for theorizing and studying innovation of course requires consideration of both bottom-up and top-down approaches. Few studies have the ability to incorporate both sets of multilevel relationships" (2007, p. 890). We expect these challenges to be pressing for most ecosystem research as well. Indeed, ecosystem scholars are increasingly calling for *multilevel approaches*, where the research design could involve various levels of analysis, as well as recognition of the interaction between these levels. This could include e.g. micro and macro-levels (Meynhardt et al., 2016) or ecosystem actors, ecosystems, as well as their institutional environments (Aarikka-Stenroos & Ritala, 2017).

Existing ecosystem literature has identified many instances of hierarchies as well as subsystems. In general, ecosystems may be structured around different clusters of power and legitimacy, which affect the hierarchy of the system (Vargo et al., 2015). For instance, several authors have recognized that ecosystems are structured around key or "hub" actors (e.g. Iansiti & Levien, 2004; Adner & Kapoor, 2010), technologies or platforms (e.g. Cennamo & Santalo, 2013; Gawer & Cusumano, 2014; Ritala et al., 2014) or focal value propositions (Adner, 2017). Within ecosystems, these features often creating a hierarchy among ecosystem actors, such as technology and service suppliers (e.g. Iansiti & Richards, 2006), upstream and downstream actors (Adner & Kapoor, 2010), or focal and peripheral actors (Wareham et al., 2014). Furthermore, the hierarchies might imply e.g. the existence of bottlenecks – locations in the ecosystem where actors can create value by providing services that are otherwise not available, potentially combining more crowded subsystems together (Hannah & Eisenhardt, 2018). Ecosystem hierarchies might also change; for instance, Ritala et al. (2013) discussed changes of 'hub' actors in innovation ecosystems over time. Furthermore, some studies (e.g. Clarysse et al., 2014) have advanced the idea of parallel interlinked, but thematically different ecosystems regarding knowledge, innovation, and business (see also Valkokari, 2015).

These parallel systems might have different structures, and relatedly, different power relations between actors.

Depending on the scope of the study, then, underlying systems might require investigation of multiple roles and levels. A number of research approaches (Klein & Kozlowski, 2000; Kozlowski & Klein, 2000a, 2000b) provide quantitative methods for studying multilevel phenomena that may, in combination, facilitate the multilevel study of ecosystems. However, a critical examination of recent ecosystem studies (Oh et al., 2016) found that structure is typically considered at only one level. Among the potential implications, the researcher may at worst overlook the fundamental mechanisms of causation and organizing in ecosystems. In short, investigating structures without addressing or understanding the consequences of multilevel relationships and processes may compromise research findings.

4.2 Relationships

One of Moore's (1993) drivers for proposing an ecosystem perspective rather than an industrial organization perspective related to the complexity of interactions and collective, co-evolutionary processes of value creation. In any ecosystem study a key step is to understand those relationships; indeed, in complex systems, "the relationships amongst the components of the system are usually more important than the components themselves" (Cilliers, 2005, p. 140). Analysis of the impact of actor ties within an ecosystem needs to consider not just their connectedness but the flow along those ties (Adner & Kapoor, 2010). Those flows and the nature of the relationships in terms of balance of power and influence are determined by rules or schemas (Gell-Mann, 1994), which may themselves adapt and evolve, enacted by the system actors in interaction with their environment (see Giddens, 1984; Geels, 2004). Additionally, interfirm relationships may exhibit 'multiplexity' (Shipilov, 2012), where a firm may have multiple relationships with different and perhaps divergent objectives. Ecosystem scholars have shown in numerous ways that relationships matter for ecosystem outcomes. For instance, Luo (2018) develops a model of innovation ecosystem evolvability, where it is shown that diversity in the actors and their relationships facilitates the systems' ability to generate new innovation. Similarly, Roundy et al. (2018) suggests that individual ecosystem actors' interactions improve the overall adaptability of the ecosystem.

The interconnection between agents may be physical or contractual, or may simply be based on influence (Kadushin, 2012, p. 140). Relationships also exist between system hierarchies, subsystems and the environment, and this large set of simultaneous (and non-linear) relationships evolves over time (Cilliers, 2001). Counterintuitively, the number of an actor's connections does not adequately describe their impact or influence, as confirmed by various authors, both in models (Quax, Apolloni, & Sloot, 2013) and empirical research (Watts & Dodds, 2007). For that reason, structural, network-level measures of centrality (for instance) cannot fully capture how relationships work in complex adaptive systems (Wasserman & Faust, 1994), and other factors (such as quality of relationships) may need to be investigated. One recent critique of network-theoretic structural analysis in network studies (Ghosh & Rosenkopf, 2015) is particularly pertinent to the study of ecosystems, and confining analyses to the main component(s) of a system or network is known to be a risky endeavor, even for higher connectivity networks (Rosenkopf & Schilling, 2007).

Actor (and knowledge) heterogeneity is a further consideration. At the organizational level, the actor is often assumed to be homogeneous. However, network studies have shown that actors are often heterogeneous, and within organizations, that heterogeneity can influence processes, flow and inter-organizational relations (Ghosh & Rosenkopf, 2015), with clear implications for the chosen level/s of analysis. Ecosystem studies, then, might run into a risk of treating all actors as mere “nodes” in a system, even if in reality the role and nature of different actors varies considerably.

Among established systems approaches to exploring the ‘nature of relationships’, *soft systems methodology* (Checkland & Scholes, 1990) inherently recognize connectedness and address the flow of relationships. In simple terms soft systems takes the ‘messy arguments’ of the real world resulting from people having different perceptions and creates defendable and rational models (known as ‘conceptual models’) to help analysis, make judgments or recommendations to the situation or phenomenon. The approach common uses a ‘rich picture’ (Lewis, 2008) to visualise the key elements and relationships between them. They may also be used to visualise and assess interactions in the hierarchy, between and within subsystems. Indeed, soft systems methodology “remains the most widely used and practical application of systems thinking” (Mingers & White, 2010, p. 1151). Network analyses, particularly approaches such as social network analysis (SNA), provide another well-established approach to understand relational concepts where actors and their actions are interdependent and relational ties are channels for ‘flow’ (of knowledge or resources) in a network that provides opportunities and constraints, where the resulting models conceptualize structure as lasting patterns of relations among actors. Typically, the unit of analysis is that of the network level (Wasserman & Faust, 1994). Implicit in developing such an analysis is a degree of stability in the ecosystem, pointing to applications in more developed ecosystems and those with a larger number of actors making simple mapping approaches impractical. Examples of applying network analysis to ecosystems include Battistella et al. (2013), Clarysse et al. (2014) and Basole et al. (2015). Such analyses are often carried out at an one level (e.g. the network of actors in the ecosystem). However, to address the inherent hierarchy and provide an understanding of the interdependence between higher- and lower-level actors, a multilevel analysis (Zappa & Lomi 2015) might often be more appropriate or provide additional insights. Approaches to multilevel analysis are extensively addressed in the literature of Kozlowski and co-authors (Kozlowski et al., 2013; Kozlowski & Klein, 2000a) and Kozlowski & Klein, 2000b) covering application of theory, research design and methods.

To supplement soft systems and network methodologies, relationships may be further investigated using approaches such as stakeholder theory (Freeman, Harrison, Wicks, Parmar, & De Colle, 2010), itself considered a branch of systems theory (Rowley, 1997). This enables analysis of the differentiation of different actors (stakeholders) and power bases. One important consideration is that the actors in any relationship may themselves have a different perspective on the nature of that relationship, with implications for research methodology and learning. Other approaches to understanding ecosystem relationships have proposed the development of a typology of relationships, looking beyond traditional value exchanges to more complex relationship types (Urmetzer, Neely, & Martinez, 2016). Emergent phenomena are often investigated qualitatively, however Kozlowski et al. (2013) describe a framework and recommendations for the empirical investigation of emergence through quantitative methods and modelling.

Given the challenging nature of relationships with the differing perspectives of actors, consideration should be given to taking a multisided view of the relationships and using triangulation or other approaches to help confirm the relevance and validity of *structural* findings. Figure 2 synthesizes suggested approaches to addressing the structural dimensions of an ecosystem.

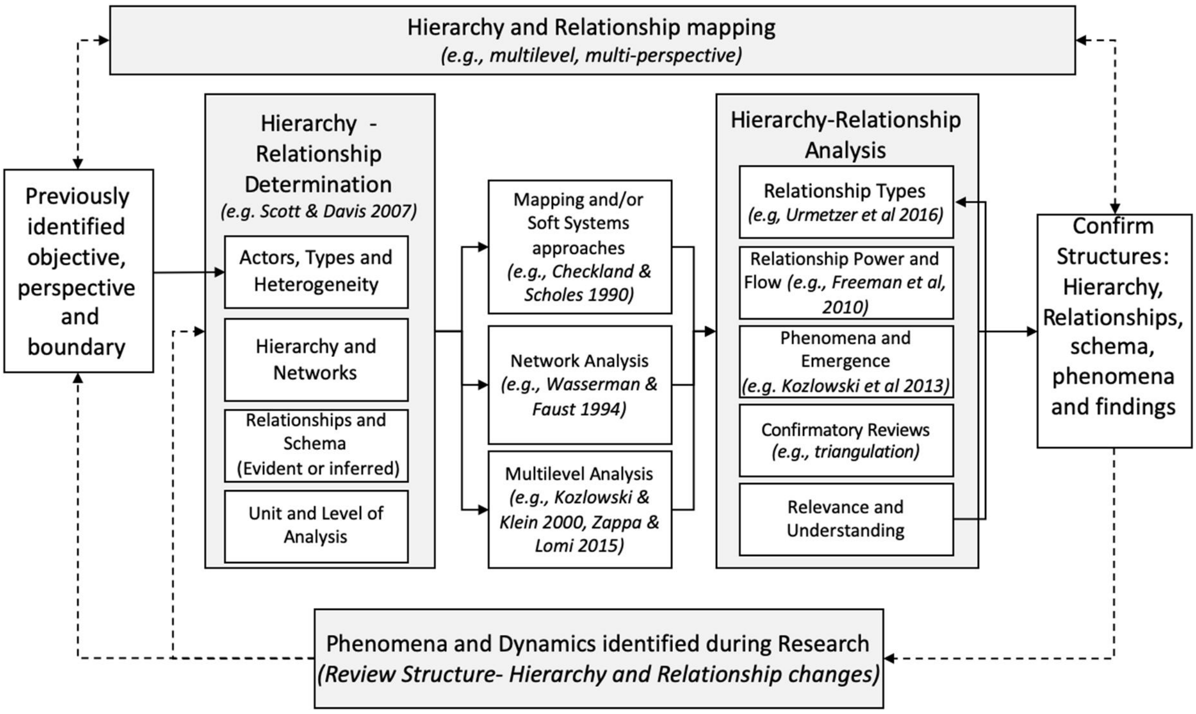

Figure 2. Methodological framework to address system structural dimensions (hierarchy and relationships).

5. TEMPORAL DIMENSIONS—HOW ECOSYSTEMS CHANGE OVER TIME

The third set of *temporal* dimensions arises from 'interaction' and the inherently dynamic nature of complex systems, which evolve over time (Anderson, 1999). Ecosystem scholars have also identified *dynamics* and *co-evolution* as central elements of ecosystems (Moore, 1993; Thomas & Autio, 2014; Aarikka-Stenroos & Ritala, 2017), and recently called for more attention to the dynamics and interactions in the ecosystem, rather than focusing on its structure within a certain point of time (Rong et al., 2018a).

5.1 Dynamics

System *dynamics* refer to the interaction of agents within a system over time (Forrester, 1971). By its very nature, any complex system is dynamic, and non-linear dynamics are common (Boisot & McKelvey, 2011), resulting in unexpected effects. Based on a recent review by Aarikka-Stenroos & Ritala (2017), the inherent feature of all ecosystems is that there is constant change in the system, but what varies is the pursuit of a level of stability or instead to facilitate change and renewal. Furthermore, the locus of change differs: it might take place in the structures and relationships of the ecosystem itself, or in the way that the ecosystem creates value for customers and other stakeholders. Thus, any ecosystem examination should pay close attention to where the dynamics are, and to which extent the ecosystem pursues retention of stability or instigates change.

In examining the dynamics, it has been suggested that the nature of change differs based on the ecosystem lifecycle phase: in early phases, the rate, volume, and direction of change is highly variable, and in the latter phases as the ecosystem is relatively stable as the boundaries, structures and relationships are more explicitly determined (Phillips & Srai, 2018). These life-cycle dynamics have implications for how the ecosystem boundary may be considered or determined. Furthermore, it has been shown that during the different stages of ecosystem evolution, ecosystem structure develops in sync with the focal business models, which has implications for the necessary capabilities to steer the evolution (Rong et al., 2018b).

In summary, dynamics exist in all ecosystems, in that they are meta-stable, and the rate of change is influenced by the lifecycle and the type of the ecosystem. Furthermore, given the complexity and related nature of ecosystems, the dynamics and changes have potentially wider impacts and in the end result in *co-evolution* – where a change in one component in the system leads to changes in other components and the ecosystem itself (cf. Peltoniemi, 2006). We discuss the co-evolution aspects in more detail in the following section.

5.2 Co-evolution

Ecosystem studies often conceive of their target phenomena as controllable and manageable (typically by a focal actor), designing and conducting research accordingly. While it is accepted that ‘keystone’ actors (Iansiti & Levien, 2004), ‘orchestrators’ (Gawer & Cusumano, 2014; Walrave et al., 2018) or ‘kingpins’ (Jacobides & Tae, 2015) are all highly influential, they do not control the system *per se*. Just like the analogous biological systems (O’Neill, 2001), business ecosystems are fundamentally complex, involving a number of components or levels of connectedness that collectively make prediction of cause and effect more difficult (Anderson, 1999). These challenges relate to the fact that systems are inherently dynamic and involve the co-evolution of actors and their environment (see Moore, 1993). In fact, in reviewing the ecosystem literature, Aarikka-Stenroos & Ritala (2017) concluded that the distinctive feature of ecosystem studies is their focus on interdependence and co-evolution among actors, technologies and institutions. From systems theory standpoint, *co-evolution* occurs as a result of the interaction between a system and its environment, influencing the evolution of both (McKelvey, 1999). Indeed, ecosystem scholars have noted that ecosystems co-evolve in alignment with their socio-technical environment (Walrave et al., 2018).

By virtue of their dynamics, complex adaptive systems exhibit *emergence* (Holland, 1997)—a set of properties not found in any one of their components (or actors)—driven by the inherent non-linearity of complex system structures, processes and relationships. Emergence can be understood as the macro-level patterns that arise in systems when agents interact at a meso- or micro-level. For example, a system may appear stable at the macro-level while there is highly dynamic and changing behavior at lower levels. These changes are constant and interdependent (Sull & Eisenhardt, 2012), a result of mutual causality and feedback. Ecosystem scholars have recently pinpointed that ecosystems exhibit *self-organization*, where the order emerges without a particular controlling entity (Roundy et al., 2018). More broadly, it has been noted the "degree of organizability" varies markedly depending on the organizational form of the ecosystem (Järvi et al., 2018). Some ecosystems might be so loosely coupled that most of the organizing is emergent, while other ecosystems could be steered more clearly by a focal actor. In practice, we expect to see both emergence and control to different degrees in any ecosystem over time.

Systems involve internal co-evolution, but additionally, they also co-evolve with their external environment (Kauffman & Johnsen, 1991); as originally identified by Moore (1993) as a key feature of business ecosystems. Co-evolution with the external environment is an important feature of any ecosystem investigation, as the success of the ecosystem is contingent on its external legitimacy and its ability to interact with the broader environment e.g. when launching new product and innovations (Ansari et al., 2016; Snihur et al., 2018). Post et al.'s (2007) review of ecosystem approaches in biology identified that external processes are likely to dominate in the early lifecycle. This is likely to work similarly in the organizational context. For instance, as business ecosystems develop, the early success of them is very much related to how external actors perceive them, while as they grow in size and legitimacy, they start to have a greater effect on the environment (see e.g. Snihur et al., 2018).

To address the challenges posed by dynamics and co-evolution, an explicitly temporal perspective—both conceptual and empirical—is required. An understanding of ecosystem history and past key events is suggested as a minimum requirement; longitudinal studies, event sampling or modelling afford greater opportunities. As an example, to understand evolution or emergence, approaches that map elements of the conceptual or structural dimensions over time can be useful to help visualize the nature and characteristics of such changes (see e.g. Phaal et al., 2011). Applying such ‘mapping’ approaches can help identify key milestones or events or structural changes that give rise to transitions or specific phenomena.

Using various methods, a number of studies have investigated the nature of ecosystem evolution (Ansari et al., 2016; Rong et al., 2013). However, contrary to the prevalent steady evolution view (see for example Korhonen & Snäkin, 2005, Figure 1), the evolution of complex adaptive systems is more likely to involve non-linearity, discontinuities, and abrupt periods of change and stability (Bak & Chen, 1991). This is implicit in the analysis of ‘industry patterns’ as identified by Geels (2005) but could equally be applied to ecosystems. While case studies are useful (Eisenhardt, 1989), investigating dynamics requires multiple ‘snapshots’ or a longitudinal research design (Eisenhardt & Graebner, 2007). Drawing on suggestions from innovation research, a contemporaneous investigative approach may be appropriate to understand the subtle nuances of agency (Garud et al., 2013), particularly where the rate of change is significant.

Another useful approach to understanding dynamics is modelling, which Kozlowski et al. (2013) proposed as the best means of illuminating the mechanisms of emergence (see also Sterman, 2000). In this regard, Martinez-Mayano and Richardson (2013) outlined a number of best practices for system dynamics modelling, which are applicable to ecosystems. Other variants include agent-based models (den Hartigh et al., 2005; Marin et al., 2007), but such studies benefit from being grounded in socially constructed and curated data (Basole et al., 2015). Where modelling is not feasible, well established approaches such as soft systems methodology (Checkland & Scholes, 1990) based on case study, ethnographic or observation data may offer a better understanding of underlying mechanisms and dynamics.

Figure 3 synthesizes approaches to understanding the temporal features of an ecosystem, including the dynamics and co-evolution.

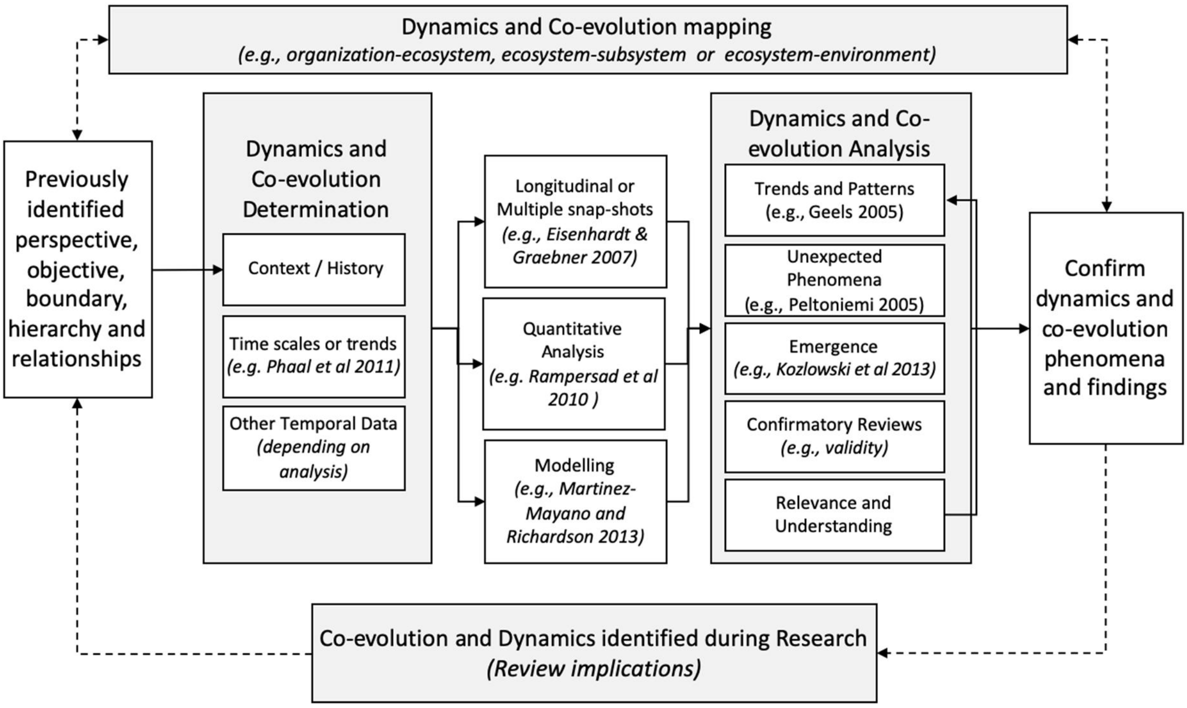

Figure 3. Methodological framework to address system dynamics and co-evolution.

6. APPLYING THE FRAMEWORK: A RESEARCH DESIGN EXAMPLE

Thus far, we have provided ecosystem research design framework based on a complex adaptive systems approach, focusing on conceptual, structural and temporal dimensions. To exemplify how this could be applied in practice, in this section we provide a brief case illustration of ecosystem research using these principles. In particular, and similar to many ecosystem investigations (e.g. Adner & Kapoor, 2012; Ritala et al., 2013; Luo, 2018; Dattee at al., 2018), we have selected a case where a loosely coupled collective of actors (i.e. an “ecosystem”) is pursuing the generation of new technologies and innovation.

The illustrative example considers research to explore the phenomena of convergence or cross-industry innovation (Enkel & Gassmann, 2010; Stieglitz, 2003) involving the combination of biomedical science, novel and nano-materials, digital and information technologies to offer new opportunities for innovation in healthcare technologies. Based on the accounts of the actors involved, the study sought to understand the processes of cross-industry innovation. Given the emergent and evolving nature of the studied ecosystem and the need to explore nuanced organizational capabilities, a qualitative approach was considered appropriate (Anteby, Lifshitz, and Tushman, 2014; Yin, 2014). The research was conducted in two phases, first exploring the wider ecosystem, then later studying several firm-based innovation ecosystem cases. To understand the wider ecosystem an exploratory approach was used. The wider ecosystem was eventually defined as constituting all actors, technologies and institutions (corresponding with the definition by Aarikka-Stenroos & Ritala, 2017) related to the development of medical technologies. Thus, it could be conceptualized as the convergent medical technology (CMT) ecosystem, which includes hierarchy related to aspects such as funding, knowledge generation, as well as regulation. Furthermore, it involves several firm-level innovation ecosystems in a lower level of analysis, structured around the value propositions that the firms were developing regarding particular medical technologies. This multilevel research was conducted from 2014 to 2016, which we briefly describe here.

The initial research phase aimed to address *conceptual* aspects, including *ecosystem boundaries* and the key issues and *perspectives* of ecosystem actors. Following initial interviews with a small expert group (in this case a diverse group, from different organizations, including the CEO of an innovation incubator, an entrepreneur, an investor and the director of an innovation start-up), snowballing was used to extend the search for participants for semi-structured interviews. These took place with senior leaders in academia, innovation companies, multi-national pharmaceutical and medical technology companies, medical regulators, healthcare providers and investors. The interviewees were also selected to span the emerging ecosystem to ensure that this exploratory phase involved a sufficiently wide search. The interviews were supplemented by observations at ten industry events and a range of secondary documentation. Interview data were continually mapped until, after 23 interviews, it was clear that only limited new information was emerging (i.e. 'saturation point', see Aguinis & Solarino, 2019). By mapping the ecosystem suggested in each interview, a preliminary map was developed, which evolved and provided an indication the ecosystem's *structure* (i.e. *hierarchy* and key *relationships)*. Several analyses were then undertaken to examine stakeholder influence, focused on impact and identity, helping to determine the system's boundary and stakeholders' perspectives (i.e. taking a population-community-identity approach). These were then summarized and verified by interviewing four diverse ecosystem informants. This first phase analysis provided insights into a wider CMT ecosystem, which provided the context and environment for individual firm-focused case studies. By mapping at different levels (i.e. investigating hierarchy) it became evident that there were issues that were not apparent at the wider scale. For example, although there was a well-established and vibrant funding and investment community in healthcare, a more in-depth analysis identified gaps in the funding which could directly impact innovator firms in this domain.

The follow-on research involved longitudinal case studies of five firm-focused innovation ecosystems. Each case was selected from different domains in the wider CMT ecosystem, and using criteria to ensure they were early phase in their lifecycle with wide access to data and had diversity in terms of scale and products. Each was viewed as an early stage ecosystem in itself. However, to ensure contemporaneous understanding of any wider ecosystem influences, further interviews at the wider CMT ecosystem were continued alongside the case studies, resulting in a total of 39 interviews at this level.

Each case was researched using a combination of contemporaneous interviews (total 62), ecosystem-based observations (e.g. at innovator or partner organization) and documentation in the form of company business or project plans. In this way, case ecosystems were mapped at several levels to produce an overall map and more detailed maps that addressed hierarchy (for example knowledge generation and investment funding) and specific issues. Stakeholder analyses and soft systems approaches were used to achieve a better understanding of relationships within and between hierarchies and their implications. As the ecosystems and innovation activities continued to evolve, regular case interviews and mapping updates provided several ‘snapshots’ over the research period, offering some measure of evolution and dynamics, thus providing the basis for a simple *temporal analysis*. More in depth analyses using multiple coding methods (e.g. both pattern and thematic coding and later, gerund-based coding, Saldaña, 2013) investigated specific phenomena, such as how these influenced firm and leadership decisions, how partners were identified, how alliances were formed and governed, how they integrated internal and external knowledge, how they managed risk, provided insights into the innovation practices within each ecosystem. Then, consistent with multiple case study research (Yin, 2014; Anteby, 2014), cross case analyses were conducted.

Table 2 summarizes the key methodological issues as well as adopted research approaches for our illustrative example.

Table 2. Illustrative example of ecosystem research design using complex adaptive systems approach

Dimension	Key methodological issues	Research approaches
Conceptual (boundary and perspectives)	Ecosystem boundaries are often ill-defined or diffuse. There is rarely a 'common view'. The ecosystem was nascent and poorly understood, with limited existing data on the issues and key actors. Different actors used different language and labels to discuss the same topic or phenomena, so there was no common vocabulary or lexicon. Issues were viewed differently by different actors. Perceptions of the boundary by actors changed over time.	To support transparency: the research setting, sampling procedures, the nature of participants, and interactions with participants were all fully documented. Multiple approaches and diverse stakeholders helped to determine boundaries, refine research goals and key issues. A population-community-identity approach was used, initially with an expert group to identify potential interviewees and then snowball interviews to extend search and diversity of inputs. Observations and secondary data were used to support initial findings and to consider alternative boundaries. Ecosystem boundaries were refined by using stakeholder analysis to focus on key actors' interests, influence and identity. Confirmatory interviews were then conducted to verify the initial boundary and key issues. The ecosystem boundary was revisited several times later in the case research to understand changes.
Structural (hierarchies and relationships)	Structures are hierarchical and not homogeneous. Relationships may be perceived differently by different actors. Mapping at a company level was inadequate to understand the real issues. For example, is was necessary to research the investment and knowledge generation in more depth to understand issues in development of wider ecosystem. Entirely new hierarchy also emerged. Different groups within an organization had different views on relationships. Partnerships were regularly made and broken. The nature of relationships between actors also evolved rapidly.	Starting with an overall map (based on boundary determination), more detailed maps of specific hierarchy were developed (e.g. venture funding, knowledge creation and digital technology suppliers). Simple mapping approaches were used with interviews and other data to develop an understanding of ecosystem actors, hierarchy and key processes. A mixture of stakeholder mapping and soft systems approaches was used to identify key relationships (e.g. contractual, influential), types of relationship between agents and hierarchy. For case firms, multiple sources were used to understand relationships (e.g. interviewing both parties in a relationship) and relationship 'quality', mixing interviews, observations and documentary sources. Interviews also identified key processes used by actors.
Temporal (dynamics and co-evolution)	The actors, ecosystem and environment are constantly evolving. Dynamics may vary across the ecosystem (i.e. the pace of change varies across the ecosystem actors). The boundary changed over the research period driven by a combination of actor interventions and wider ecosystem evolution. The ecosystems were nascent, and so undergoing significant and rapid change as new actors and issues emerged. Different parts of the ecosystem perceived the change differently.	Wider ecosystem interviews were continued during the case study phase to inform environmental changes that might impact the cases. Further interviews and multiple 'snapshots' of each case over the research period helped to understand ecosystem dynamics and any changes in boundaries, illustrating the evolution of the overall ecosystem and of each case ecosystem. Key trends were also mapped over time (using simple 'roadmaps'). The use of longitudinal case studies helped in understanding ecosystem dynamics and changes; as phenomena were identified, further investigations (focused interviews) and analysis were conducted to better understand causation.

This example illustrates one way in which the conceptual, structural and temporal dimensions of ecosystems can be incorporated in the analysis. By adopting an exploratory approach (in phase 1) to determining ecosystem boundaries and engaging widely with stakeholders, insights were obtained that influenced boundary definition, as well as the research perspective and other key issues. It is important to note that this approach may be of greater relevance in studying nascent or highly dynamic systems. By mapping ecosystems at multiple levels, these insights helped to explain aspects of the case firms' behavior that were not apparent at the 'macro-level', such as access to investment funding being limited by structural issues. Furthermore, the nature and quality of relationships could only be determined by more detailed, lower level mapping.

As the case research was conducted in the early life-cycle of each innovation ecosystem, other issues emerged, for example, the lack of a common lexicon and understanding created significant problems in one case, where early attempts to identify potential partners initially failed. So, conceptual issues were impacting the structural development of the ecosystem. As another example, it was only after the innovator company had themselves used snowballing to identify other academic groups and also identified a major gap in the research funding that the innovator firm developed a viable knowledge generation capability. Furthermore, these ecosystems changed markedly over the research period, so without taking a temporal perspective, these insights in the ecosystem evolution may have been lost. More importantly these events changed the perspective of the innovator firm and the strategic approach, so structural issues resulted in conceptual and structural changes over time. As another example, the use of multiple snapshots to understand system dynamics made it possible to map the evolution of the ecosystem and hierarchies within it, illuminating how firms developed their value propositions and business models in these nascent ecosystems.

This is not to say that exploring all three dimensions (conceptual, structural, temporal) is the only way to research ecosystems. However, by doing so, we believe that the likelihood of researchers discovering evidence and implications that might otherwise be missed or misinterpreted is increased. Importantly, the suggested methodology aligns with established approaches to investigating complex adaptive systems (Mingers & White, 2010).

7. DISCUSSION AND CONCLUSIONS

The concept of an *ecosystem* is rapidly gaining in popularity among management, innovation and technology scholars (see e.g. Aarikka-Stenroos & Ritala, 2017; Tsujimoto et al., 2018; Scaringella & Radziwon, 2018; Suominen et al., 2019). The success of a concept semantically associated with the systems perspective is unsurprising in light of the broader trend in organization and management studies to focus on interorganizational linkages, networks and interdependencies (Ahuja et al., 2012; Dyer & Singh, 1998; Owen-Smith & Powell, 2004; Provan et al., 2007). In this regard, an increasingly vocal research community advocates the investigation of organizational phenomena through the lenses of systems thinking, complexity theory and complex adaptive systems (Allen, 2001; Anderson, 1999; Brown & Eisenhardt, 1997; Chiles et al., 2004; Eisenhardt & Piezunka, 2011; Girod & Whittington, 2015; Meyer et al., 2005; Thietart & Forgues, 1995). While the application of systems thinking is apparent in many related fields, explicit recognition of such approaches has been largely absent from ecosystem research despite the rapid rise in usage of the concept. Only recently have a few ecosystem scholars started to suggest ways to incorporate systems thinking and complex adaptive systems approach (Ritala & Gustafsson, 2018; Roundy et al., 2018; Scaringella & Radziwon, 2018).

7.1 Towards a complex adaptive systems approach to ecosystem research design

Thus far, ecosystem research has adopted a wide variety of approaches to understand the increasing connectivity of the contemporary business and innovation environment. According to several authors, this has led to fragmentation and ambiguity in the usage of the ecosystem concept, limiting the potential to accumulate scholarly knowledge (e.g. Oh et al., 2016; Adner, 2017; Ritala & Almpanopoulou, 2017; Suominen et al., 2019). These challenges are both conceptual as well as methodological. In the current study, we have particularly focused on the methodological aspects of ecosystem research from a *complex adaptive system* (CAS) perspective, in an effort to provide an integrative and broad-based foundation for ecosystem research design. In doing so, we seek to put forward systems-based methodological approaches to address common challenges in ecosystem research. These include the need to take a holistic view of the diverse interacting elements across the ecosystem, to recognize that the hierarchy can create different issues at different levels and that these may also interact, that as socio-technical systems' actors will act from differing perspectives and purposes, that the relationships between these actors are often more important than hierarchy in determining behavior, and that all of the above will evolve over time in ways that may be unexpected.

The proposed methodological framework encompasses the conceptual, structural and temporal dimensions of an "ideal" ecosystem research design from CAS perspective. The conceptual dimension addresses issues concerning the boundary definition and the differing perspectives of actors (and of the researcher) in the ecosystem. The structural dimension considers the ecosystem hierarchy and relationships between actors and processes, across and within structures. The temporal dimension considers changes over time resulting from system dynamics, and the co-evolution of actors and the ecosystem. We argue that in combination, these three dimensions provide a means to answer the three fundamental questions regarding any ecosystem. First, "How we think about the system?" refers to the epistemological considerations about what the ecosystem actually is, and which actors are involved in it. Second, "What we know about the system?" refers to the ontology – that is – how the ecosystem is structured and how it and its components interact in order to achieve particular goals. Finally, "How systems change over time?" relates to how the epistemology and ontology change over time. In developing this framework, we have tried to balance parsimony and completeness, and to ensure consistency with a systems-theoretic approach. The framework can be applied to different degrees using both qualitative and quantitative methods, and with many existing tools such as interviewing, observations, network mapping, temporal mapping, modelling, soft systems methodologies and stakeholder analysis. By integrating these views, it supports a more systemic approach and addresses the research gaps identified earlier.

Although a particular study may be concerned only with an ecosystem's outputs, its relationships, its evolution, or with the activities of a single actor, we suggest that a broader assessment of key dimensions is nevertheless useful to scope, position and justify the study. As far as is practicable, then, it is important to address *all three* considerations (conceptual, structural and temporal) as within the research design. For instance, if a study focuses only on the structure of ecosystem actors' relationships, it can certainly provide information of which actors are more central and potentially more influential. However, such an examination misses the justification of the boundaries (why and how some actors belong to ecosystem while others do not) as well as an assessment of dynamics and co-evolution (how does the structure change over time, and how does that matter).

Some would argue that attempting to define a framework such as the one proposed here is itself constraining and inconsistent with a systemic view. While we acknowledge that no single approach is adequate in studying a complex system, we believe that the proposed approach and investigative framework, which is designed to accommodate multi-methodology research designs, can provide greater consistency of approach, integrating well-established tools and contributing to a more rigorous approach. We do not claim to provide a complete description of all potential approaches; instead, we present a viable set of practical measures to ensure consistency in studies of ecosystems and other systems-based forms of organizing. It is further suggested that rather than the individual approaches or tools, which can be tailored to the specific research project, the key concept here is the holistic view of ecosystems, incorporating conceptual, structural and temporal dimensions in the research design. We believe that this combined approach offers a framework for investigating that is more systematic and consistent with complex adaptive systems thinking, contributing further to the ecosystem research agenda both theoretically and methodologically.

7.2 Future research directions

Given the promise of CAS thinking for ecosystem research (see e.g. Ritala & Gustafsson, 2018; Roundy et al., 2018), and based on our methodological developments in this paper, we can identify several promising research areas for ecosystem scholars.

From the conceptual point of view, looking more closely to how boundaries are created is a fascinating empirical question. Ecosystem scholars have tied the ecosystem definitions around focal value proposition (Adner, 2017), shared institutional logic (Vargo et al., 2015), as well as around a variety of other boundary determinants (see e.g. Phillips & Srai, 2018; Radziwon & Bogers, 2018;

Zobel & Hagedoorn, 2018). These studies have shown that the choice through which the boundary is determined has major implications of what the outcomes of the inquiry are. The boundary choice is often made by the researcher; in that case a solid justification of such a choice is in order. Beyond this, examination of the determinant of the boundary might be a topic of an investigation in itself. For instance, is the ecosystem determined via affiliations to a focal technology or a platform (e.g. Thomas et al., 2014), or via their input to a value proposition (Adner, 2017), or perhaps via other types of organizational or institutional linkages and affiliations? Furthermore, recognizing that different ecosystem actors have different perspectives to even what the ecosystem is and what it does provides another fruitful avenue for inquiry. Indeed, it has been recognized that ecosystems are not 'complete organizations', but something that are only organizational to some degree (Järvi et al., 2018).

From the structural point of view, there are already a host of studies focusing on how ecosystems are structured, often using network analysis methods to do so (e.g. Clarysse et al., 2014; Basole et al., 2015). Beyond this, we advocate studies focusing on hierarchies of relationships as well as subsystems within ecosystems, as well as studies examining the linkages between different ecosystems. In practice, very few actors belong explicitly to just one ecosystem, but they are actually intertwined in a web of relationships that span multiple and continuously morphing ecosystems. Studying such phenomena is very challenging but may uncover important and so far, hidden features of how structure and relationships within and across ecosystems unwind. Furthermore, the classic systems theoretical concept of emergence and self-organizing has been discussed in some ecosystem studies (Aarikka-Stenroos & Ritala, 2017; Roundy et al., 2018), but a broader and more detailed examination of emergence is a promising future research avenue.

From a temporal perspective, there are still many issues about co-evolution in ecosystems that remain uncovered. While co-evolution remains a widely referred topic and is a central feature of ecosystems, empirical studies rarely track the actual interdependencies across actors and their activities over time. Such investigation, again, is extremely challenging. However, scholars might consider developing methodologies that could document activities within the ecosystem, and how these activities contribute in facilitating and constraining other activities over time. For instance, Dattee et al. (2018) examine the early phases of innovation ecosystem creation and distinguish how the process unfolds in an interaction between the focal actor and emerging ecosystem.

Overall, we expect that adopting a complex adaptive systems foundation for an ecosystem research design will facilitate empirical studies that are able to address the analogous promise of the concept itself. Such as in the biological domain, the systems-based features of organizing involve subtle and complex dynamics, which benefit from holistic viewpoints. For pragmatic reasons, scholars have mostly focused on narrower designs when examining ecosystems. However, taking more clearly justified positions regarding conceptual, structural and temporal features of ecosystems, could increase explanatory power of individual studies, but could also lead to greater transparency and generalization of findings across different studies and empirical contexts. Our hope is that the current study helps to instigate more broad-based and ambitious scholarship from a systems perspective in this regard.

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