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A review of the ecosystem concept — Towards coherent ecosystem design

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ABSTRACT

The ecosystem concept is of increasing significance in the field of the management of technology and innovation. This paper provides an overview of 90 previous studies using the ecosystem concept in this field, all published in leading academic journals, and clarifies their four major research streams. The first stream is the *industrial ecology* perspective, which is based on the concept of industrial ecosystems. The second is the *business ecosystem* perspective. This approach is based on the theory of organizational boundaries. Within the business ecosystem perspective, some influential scholars emphasize *platform management*, which represents the third approach. The fourth approach is the *multi-actor network* perspective, which contributes dynamic behavioral relationship analyses based on social network theory. This perspective expands the range of analysis to include a variety of actors in addition to private companies. As a result of the review, this study presents an integrated model of the existing literature. Furthermore, this paper proposes original definitions of the ecosystem and the concept of a coherent ecosystem. This coherency is the core concept underlying the explanation of the dynamic evolution or extinction of the ecosystem. Finally, this paper discusses the significance of the ecosystem concept and indicates topics for future research.

1. Introduction

In the field of management of technology and innovation, the ecosystem concept is of increasing significance (Adner and Kapoor, 2010; Kapoor and Lee, 2013; Meyer et al., 2005; Pierce, 2009; Teece, 2007), although the term *ecosystem* seems to be used without clear definition or sound theoretical backing. This paper poses three basic questions at the start of the review process. First, what is the definition of the ecosystem in the field of management? Second, what are the main streams of ecosystem research? Third, has the ecosystem concept added new and significant value to management research?

To answer these questions, this paper provides an overview of 90 previous works published in leading academic journals in the management of technology and innovation and clarifies their major investigative research streams.

We found that the definition of the ecosystem was not clear and that there were four major streams of ecosystem research. Each stream has a different theoretical background. However, the fourth stream, the multi-actor network perspective, does not have a clear theoretical background.

Based on the review of the existing literature, as our objective we set out to propose an original ecosystem concept, definition, and concept of a coherent ecosystem. This coherency is the core concept for the explanation of the dynamic evolution or extinction of the ecosystem.

Regarding the third question, we clarified the significance of the ecosystem concept to the management of innovation and technology. Additionally, we indicated the difference between our ecosystem concept and previous related concepts, namely: national innovation systems, supply chain management, and strategic alliance networks.

The essential significance of the ecosystem concept lies in five points. First, the ecosystem concept analyzes organic networks, based not only on their positive aspects, but also on their negative and competitive aspects: ecosystem-level competition, predation, parasitism, and destruction of the whole system. Second, each actor has different attributes, decision-making principles, and purposes. These differences can cause unintended results at the ecosystem level, although each actor's decision-making and behavior is rational at a given point in time. Third, the analytical border of the ecosystem is the product/service system; it is not limited by national borders, regional clusters, contract relations, and/or complementary providers. Within the ecosystem, not only business actors, but also non-business actors are included. Fourth, ecosystem analysis requires longitudinal observation of the dynamic evolution of the product/service system. Fifth, the objectives of ecosystem research are to find patterns of decision-making and

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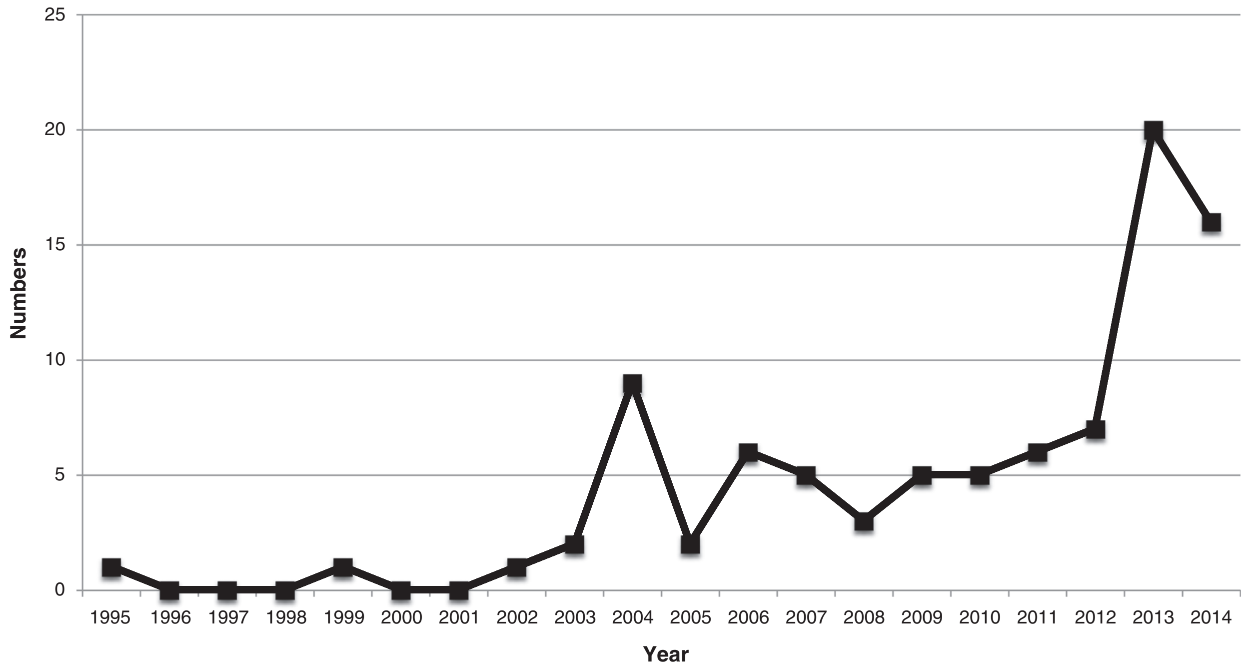

Fig. 1. The number of papers by year.

behavioral chains that strongly affect the growth and decline of the ecosystem under specific boundary conditions.

In the final part of the paper, we indicate important topics for ecosystem research in the near future. Our major contribution in this paper is the theoretical discussion and definition of the ecosystem. The core concept is the coherency of the ecosystem.

2. Review process and basic statistics

2.1. Review process

An ecosystem is defined as "A biological system composed of all the organisms found in a particular physical environment, interacting with it and each other. Also in extended use: a complex system resembling this" (Oxford.English.Dictionary, 2017). This paper applies the extended definition to the field of management of technology and innovation.

Our review process employs the journal-ranking website Scimago Lab. In Scimago Lab, we chose "management of technology and innovation" and "strategy and management" as the subject categories. We set the region/country option to include "all." The span of the period investigated is from the year 1900 to the year 2014.

Following that, we listed the journals classified as Q1, which are in the top 25% of academic journals in their subject categories. In the "management of technology and innovation" category, there are 224 journals, with 56 defined as Q1. In the "strategy and management" category, there are 340 journals, with 85 defined as Q1. Comparing these two lists and after deleting duplicates, we obtained a final list of 95 journals.

In these 95 journals, we searched using the word "ecosystem" or "ecosystems" using the Web of Science™ Core Collection of Thomson Reuters. We placed each word in the topic field and the name of the journal in the publication field. The topic field and the publication field were connected by the "and" condition. Topic Field includes the title, summary, keywords by author, and Keywords Plus®. Keywords Plus® are the original keywords provided by Thomson Reuters. The period of the search was from the year 1900 to the year 2014, corresponding with the database default setting.

We obtained a list of 187 papers as a result. We checked the abstracts and full texts of the 187 papers and isolated the papers that used only the biological definition for the ecosystem concept. Although we collected papers from management-specific areas, the list included 92 papers that were written based on biological ecosystems. Almost all of these papers concerned natural environmental management for a sustainable world. Some of the papers used the concepts of life-cycle assessment, sustainability assessment, and stakeholder management. However, they did not use the extended concept of the ecosystem in the context of management of technology and innovation. Additionally, five papers were reviews of a specific book describing an academic society's directions or retracted directions. We excluded these papers. Consequently, we selected a total of 90 papers for review.

Two intentions were implemented in this procedure. In the field of management of technology and innovation, the word "ecosystem" is used in various formulations such as industrial ecosystem, business ecosystem, digital ecosystem, IT ecosystem, and innovation ecosystem. Because of this diversity, we tried to collect the appropriate papers by using "ecosystem" as a search keyword. This represents the first intention. Second, we gathered samples from Q1 journals; these publications hold leading positions in academia and represent the major discussions of the ecosystem concept.

This process can be classified as a systematic review. A systematic review usually includes a meta-analysis, which requires the researches include the statistical estimation. However, a major part of the reviewed papers adopted qualitative research methods, as explained in the following sections. Consequently, we decided to proceed with the systematic review without the meta-analysis.

2.2. Basic statistics and criteria for classification

This section explains the basic statistics. Fig. 1 shows the number of studies on ecosystems by year from 1995 to 2014.

Fig. 1 shows that the number of papers significantly increased in the years 2004 and 2013. We gathered the papers in October 2014; therefore, the number for 2014 could have increased by the end of the year. This tendency implies that the ecosystem concept was used increasingly after 2004 in the field of management of technology and innovation. The numbers of papers also noticeably increased after 2010. The extended use of the ecosystem concept in this field is not

Table 1
The number of papers by journal.

Title of journal	Range of the publication year	Number of papers
Journal of Cleaner Production	1997–2014	25
Research Policy	1999–2014	8
Technological Forecasting and Social Change	2004–2014	7
Journal of Information Technology	2006–2014	6
Strategic Management Journal	2007–2013	5
California Management Review	1995–2014	5
Technovation	2003–2014	5
Journal of Product Innovation Management	2012–2014	4
MIT Sloan Management Review	2006–2012	4
Organization Science	2005–2014	4
R & D Management	2009–2014	4
Academy of Management Review	2013	2
Management Science	2010–2013	2
Academy of Management Perspectives	2014	1
Business Strategy and the Environment	2011	1
International Entrepreneurship and Management Journal	2013	1
International Journal of Production Research	2013	1
Journal of Business Venturing	2003	1
Journal of International Management	2013	1
Journal of Management Studies	2013	1
Strategic Organization	2013	1
Tourism Management	2011	1
Total		90

new, but was a more active phenomenon in the years following 2010.

Table 1 shows the number of papers by journal.

Table 1 shows that the *Journal of Cleaner Production* published the most papers (25, 27.2%). The second group (each journal published more than six papers) in terms of publication volume is composed of *Research Policy* (9, 9.8%), *Technological Forecasting and Social Change* (7, 7.6%), the *Journal of Information Technology* (6, 6.5%), and *Strategic Management Journal* (6, 6.5%).

The *California Management Review* in 1995 is the first journal to publish ecosystem research in this dataset, with a study of the versatile ecosystem of Silicon Valley being the first paper (Bahrami and Evans, 1995).

In the following sections, we proceed through three stages. First, we categorize the studies into four perspectives based on differences in theoretical background. Second, we present an integrated model of the existing research. Third, we propose an original concept, definition, and concept of a coherent ecosystem.

3. The four perspectives

3.1. Summary of the four perspectives

We found there are four streams among the previous studies. Table 2 shows an overview of the four ecosystem perspectives. We classified each perspective according to five key elements. The main element is the background theory, but we also consider the key concepts, analytical methodology, attributes of actors, and variables between actors. The nature of each perspective and the significance of the findings of previous works are described in the following sections.

3.2. The industrial ecology perspective (IEP)

The first perspective is reflected in research based on the concept of the *industrial ecosystem*, which was introduced by Frosch and Gallopoulos in 1989. The authors used the concept of a natural ecosystem as an analogy for the understanding and transformation of the industrial system. The article stated that "the traditional model of industrial activity—in which individual manufacturing processes take in raw materials and generate products to be sold plus waste to be disposed of—should be transformed into a more integrated model: an industrial ecosystem" (Frosch and Gallopoulos, 1989).

After the introduction of the concept of the industrial ecosystem, the term *industrial ecology* (IE) evolved (Basu and van Zyl, 2006). However, the concepts of IE and industrial ecosystem remain unclear (Ehrenfeld, 2000).

Based on a literature review of approximately 150 references, Erkman said that "it is argued that while IE studies the whole of the industrial system material and energy flows and interaction with the environment, as does industrial metabolism, it further seeks to move beyond description and use the model of sustainable ecosystems in unsustainable industrial systems" (Erkman, 1997).

Industrial ecology researchers have contributed to the realization of sustainable industrial systems in the real world. This was the clear objective of researchers in this cluster.

Twenty-five of the researchers in this cluster published articles in the *Journal of Cleaner Production*. A total of 26 papers used the term "ecosystem" in the context of IE. The researchers who used the term "industrial ecosystem" typically focused on the application of the IE concept and/or model to society. Fourteen of the 26 papers (51.8%) used real case studies and/or applications to real projects, eco-parks, regions, and/or industries.

Five papers reported and analyzed the application of IE to real projects. The projects were technology and climate change (CLIMTECH) research in Finland (Korhonen et al., 2004), Singapore's Jurong Island (Yang and Lay, 2004), the Gulf of Bothnia steel and zinc industries (Salmi and Wierink, 2011), and the Guitang Group (Zhu and Cote, 2004). Heeres, Vermeulen, and de Walle analyzed industrial park initiatives in the US and The Netherlands as a comparison (Heeres et al., 2004). Nine papers applied IE to regions, industries, and countries. Among these, six case studies applied the approach at the regional level, one showed an industrial application, and two studies were country-level applications.

The industrial ecosystem concept has thus been applied to real society for a considerable time. IE researchers have undertaken the optimization of energy, material, and monetary networks. Thus, the industrial ecosystem is not just a concept, model, or simulation analysis.

With respect to methodology, most of the existing industrial ecosystem research has used energy and/or material flow analysis. Some researchers created conceptual models of industrial ecosystems (Despeisse et al., 2012; Liwarska-Bizukojc et al., 2009; Ulgiati et al., 2007). Expanding conceptual modeling, researchers applied system dynamics or chemical engineering techniques to optimize the symbiosis, stability, and resilience of the industrial ecosystem (Casavant and Cote, 2004; Timmermans and Van Holderbeke, 2004; Wang et al., 2013). Wu et al. (2012) gathered real data for phosphorus flow in Feixi County in central China and applied a static substance flow analysis model (Wu et al., 2012).

IE theory remains disconnected from business studies and industrial investment (Tsvetkova and Gustafsson, 2012). Three papers from our dataset have addressed this situation. Korhonen (2004) used the concept of strategic sustainable development in connection with industrial ecosystems (Korhonen, 2004). Adamides et al. (2009) adopted the approach of strategic niche management as a key concept of the evolutionary institutional perspective (Adamides and Mouzakitis, 2009). Recently, Tsvetkova and Gustafsson (2012) analyzed the biogas industrial ecosystem, which is composed of complex business constellations involving a variety of business actors unaccustomed to working within one system (Tsvetkova and Gustafsson, 2012). Tsvetkova and Gustafsson (2012) adopted material and energy flow and cash and product/service flow analysis (Tsvetkova and Gustafsson, 2012). This represents one of the novel approaches from the industrial ecosystem stream that we classify in this paper.

The other recent novel approach, particularly concerning

Table 2
Overview of ecosystem perspectives.

Five key elements of perspectives	Industrial ecology	Business ecosystem	Platform management	Multi-actor network
Background theory	Industrial ecosystem	Organizational boundaries Four boundary concepts	Platform leadership Two-sided market	Non-equilibrium and non-linear phenomenon analysis
Key concepts	Optimization Sustainability Symbiosis	Complementary Niche creation	Balance between open and closed Balance between stability and evolvability Hierarchy, layer structure	Embeddedness Resilience Evolutionary
Analytical Methodology	Model simulation Chemical engineering Fieldwork Action research	Case study Survey Statistical test Network analysis Delphi	Case study Network analysis Statistical test Mathematical modeling	Case study Field research Statistical test System dynamics
Attributes of actors	Natural resources Private firms (factory) Consumers	Private firms	Private firms Private developers End-users	Government Private firms Universities Consumers Entrepreneurs Investors
Variables between actors	Material Energy (Money)	Money Complementary goods/services Contract Power	Technological knowledge Contract Money	Power Regulation Historical relationship Money Contract Knowledge
Numbers of Papers	26/90 (28.9%)	27/90 (30.0%)	11/90 (12.2%)	23/90 (25.6%)
Empirical examples	Canal Zone of Zeeland Hai Hua industrial ecosystem Rhine-Neckar region	Semiconductor lithography Automotive leasing US healthcare industry	Free beta applications of Nokia US video game industry Mobile data services in Hong Kong	Deutsche Telekom LEGO Dutch high-tech campus Start-ups in Flanders

methodology, is event sequence analysis (ESA) (Spekkink, 2013). Spekkink (2013) built the original concept of the complex actor network and adopted ESA for the analysis of the canal zone of Zeeland in the Netherlands (Spekkink, 2013).

In Nielsen (2007), a chemist compared natural systems and industrial societal systems to emphasize the considerable differences between them (Nielsen, 2007); and nonetheless hypothesized that industry and society, both in terms of economy and sustainability, would benefit from exploiting these natural principles. We share this insight for our definition of ecosystems in the field of management of technology and innovation.

3.3. The ecosystem consists of business players: the business ecosystem perspective (BEP)

The second and third perspectives mostly feature business players. The IE perspective emphasized the optimization of material and energy flows inside the material flow network. Only a few researchers mentioned the scarcity of business contexts within IE research (Tsvetkova and Gustafsson, 2012). In contrast, researchers using the *business ecosystem perspective* (BEP) concentrate on the business context and set value capture and/or value creation as central variables. The purpose of research in this stream is to reveal the dynamics and patterns of ecosystems and organizational behavior.

Twenty-seven papers working from the BEP are included from our dataset. Four of these represent theoretical development papers and one represents the development of a framework for a business model and business ecosystem. Twenty-one papers analyzed five different types of ecosystems and one paper focused strongly on specific conceptual relationships.

The five different types of ecosystems are the following: (1) digital ecosystems (eight papers); (2) complementary (sub-industry) ecosystems (eight papers); (3) supplier ecosystems (two papers); (4) business group (M & A) ecosystems (two papers); and (5) global professional human network ecosystems (one paper). The range of ecosystem concepts and definitions used is broad. However, we integrate almost all of the different types of ecosystems into a single framework in the following section.

The theoretical background of the BEP is organizational boundary theory within general strategic management theory (Alexy et al., 2013; Meyer et al., 2005; Santos and Eisenhardt, 2005; Teece, 2007). Santos and Eisenhardt (2005) developed four boundary concepts (efficiency, power, competence, and identity) that have strongly supported and contributed to business ecosystem research, as the authors predicted (Santos and Eisenhardt, 2005).

In addition to these theoretical papers on organizational boundaries, Zott and Amit (2013) clarified the business model theory and described the characteristics of the business ecosystem concept (Zott and Amit, 2013). Following Zott and Amit (2013), Wei et al. (2014) categorized business model patterns and statistically tested the fit between business model types and technological innovation (Wei et al., 2014).

The definition of business ecosystem varies according to each type of ecosystem. The researchers in this cluster focused on business player networks and analyzed the mechanisms behind the networks. The boundary settings differ depending on the objectives of each study.

The largest group within the BEP is composed of eight papers concerning the analysis of digital ecosystems. The studies in this cluster focus on the IT industry. There is no consensus on the definition of a digital ecosystem. However, almost all of the studies on digital ecosystems analyzed IT-based complex relationships among firms in IT industries such as the software sector (Iyer et al., 2006), the application market (Selander et al., 2013), and mobile network operators (Aaltonen and Tempini, 2014). The research in this cluster can possibly be classified under the next perspective (the platform management perspective); however, these studies did not focus on the platform, but on the complex firm relationships in a digital ecosystem, for example, business process ecosystems (Vidgen and Wang, 2006) and strategic hyperlinks (Dellarocas et al., 2013).

The second group, equal in size to the first group, focused on the complementary (sub-industry) ecosystem. Adner and Kapoor (2010) described the generic schema of an ecosystem that consists of the supplier, a focal firm, a complementor, and the customer (Adner and

Kapoor, 2010). Using data from the semiconductor lithography equipment industry, Adner and Kapoor (2010) verified their hypothesis for ecosystem dynamics. Kapoor and Lee (2013) classified the relationships between the focal organization and the complementor and tested the significance of correlations between these classifications and technological investment (Kapoor and Lee, 2013). These two studies pioneered business ecosystem analysis and created a conceptual basis for this approach.

The researchers in this cluster set boundaries at the sub-industry level, including complementors, and focused on the clarification of dynamic patterns. Pierce (2009) focused on shakeouts in the context of business ecosystems and found a relationship between core companies' decisions and niche players' performances using real individual car lease data (Pierce, 2009).

The third group represents the supplier ecosystem approach. The researchers in this group investigated the supplier selection problem (Viswanadham and Samvedi, 2013) and the creation of cooperative and diverse supplier networks (Hong and Snell, 2013). The research in the fourth group considers the ecosystem as an agglomerated company connected by M & A. The researchers analyzed the dynamic changes in business groups and the relationship with economic growth using M & A and patent data (Gomez-Uranga et al., 2014; Li, 2009). A unique paper focuses on the global STEM (science, technology, engineering, and mathematics) human talent network as a source for the global innovation ecosystem (Lewin and Zhong, 2013). This viewpoint has the potential to be expanded by other scholars.

With respect to methodology, the main approaches used are qualitative case studies and multiple-case analysis using an original survey or database. There are proposals that use a qualitative research methodology and/or process. Network visualization and analysis that was executed by specific computer software was applied in three papers (Basole, 2009; Battistella et al., 2013; Li, 2009). Battistella et al. (2013) created a theoretical proposal for the methodology of business ecosystem network analysis (MOBENA) (Battistella et al., 2013). Methodologically, MOBENA has potential applicability to other cases. Hung et al. (2013) combined the Delphi research methodology with ecosystem analysis (Hung et al., 2013). The Delphi approach is effective in achieving a thorough analysis on the basis of reality recognition.

3.4. The ecosystem consists of business players: the platform management perspective (PMP)

Within BEP, there are influential scholars who emphasize the significance of platform management and analyze the mechanism of platform dynamism. We separated these studies into a third perspective: the *platform management perspective* (PMP).

This perspective was introduced by Cusumano and Gawer (2002) in "The elements of platform leadership" (Cusumano and Gawer, 2002). Originally, the authors used the term "industry ecosystem" as a keyword. According to a recent review of platform research studies, there are manifold papers that analyze the platform mechanism (Thomas et al., 2014). Thomas et al. (2014) classified platform research into four streams. Among these, the fourth stream addresses platform ecosystems that are composed of industry-wide networks based on complex correlations between firms. This stream resembles the PMP. This implies that PMP research overlaps a substantial portion of platform research and attempts to clarify the associated complex networks. Additionally, the terms "industrial ecosystem" from the IE perspective and "industry ecosystem" from the PMP perspective are similar, but represent concepts that differ in certain ways.

Our dataset has 11 PMP papers. The background theory was built by Cusumano and Gawer (2002) in terms of platform leadership (Cusumano and Gawer, 2002; Gawer and Cusumano, 2008). Following the publication of these studies, substantial research has continued to emerge (Thomas et al., 2014). However, most platform research focuses on platform dynamism and the mechanism of growth and/or decline of the platform itself. The two-sided market concept of microeconomics is one of the background theories of platform research. In the platform research stream, research on industry ecosystems remains limited, although the original researchers focused on industry ecosystems and platform analysis (Cusumano and Gawer, 2002; Gawer and Cusumano, 2008; Gawer and Cusumano, 2014; Thomas et al., 2014). Recently, the original scholars re-theorized the platform approach (Gawer, 2014; Gawer and Cusumano, 2014), clarifying the platform concept and the relationships between the platform and other relevant factors.

In one recent theoretical paper, the original two scholars clearly defined the platform as follows:

> "*We define internal (company or product) platforms as a set of assets organized in a common structure from which a company can efficiently develop and produce a stream of derivative products. We define external (industry) platforms as products, services, or technologies that act as a foundation upon which external innovators, organized as an innovative business ecosystem, can develop their own complementary products, technologies, or services*" (Gawer and Cusumano, 2014).

This definition clearly distinguishes external platforms and business ecosystems. However, the relationship between the external platform and the business ecosystem was not included in this definition.

Almost all of the empirical studies in PMP investigate the IT industry. The platform strategy is observed particularly clearly in the IT industry, because of the technological characteristics of high modularity. However, the platform phenomenon itself is applicable to other industries in accordance with industrial convergence.

Krishnamurthy and Tripathi (2009) analyzed the interaction between open source stakeholders and their platform using financial donation data (Krishnamurthy and Tripathi, 2009). The open source software platform community has a vital role in creating ecosystems (Krishnamurthy and Tripathi, 2009). Weiss and Gangadharan (2010) visualized the huge API (Application Programming Interface) and mash-up ecosystems (Weiss and Gangadharan, 2010). The authors' analysis shows the multilayer structure of the ecosystem. The platform aggregator integrates the existing platform, and other players build the next layer of the platform. A migration mechanism among the platforms is analyzed using consumer survey data of 3G platforms in Hong Kong (Xu et al., 2010).

Winner takes all (WTA) logic based on network externality effects was tested on US game industry data; the results showed that the WTA approach will not be universally successful (Cennamo and Santalo, 2013). Makinen et al., 2014analyzed the adoption of free beta applications, using Gompertz's model and the Bass model comparatively on Nokia's beta test data (Makinen et al., 2014). The study results showed that the adoptive dynamic of free beta products in a co-creation community follows Gompertz's model rather than the Bass model (Makinen et al., 2014).

Thomas et al. (2014) created the concept of "architectural leverage," which integrates the four streams of platform research and effectively explains platform evolutionary dynamics (Thomas et al., 2014).

Wareham et al., 2014focused on the balance between stability and homogeneity variability and heterogeneity of platform-based ecosystems. Through an extensive case study, the authors identified three salient tensions that characterize the ecosystem: standard-variety, control-autonomy, and collective-individual (Wareham et al., 2014).

With respect to methodology, an intensive multi-case study is the predominant method. In case studies, most scholars applied statistical or mathematical tests using empirical data. The network analysis method was also applied (Weiss and Gangadharan, 2010).

3.5. The multi-actor network perspective (MNP)

The *multi-actor network perspective* (MNP) is the fourth perspective identified. This viewpoint was expanded to include various actors

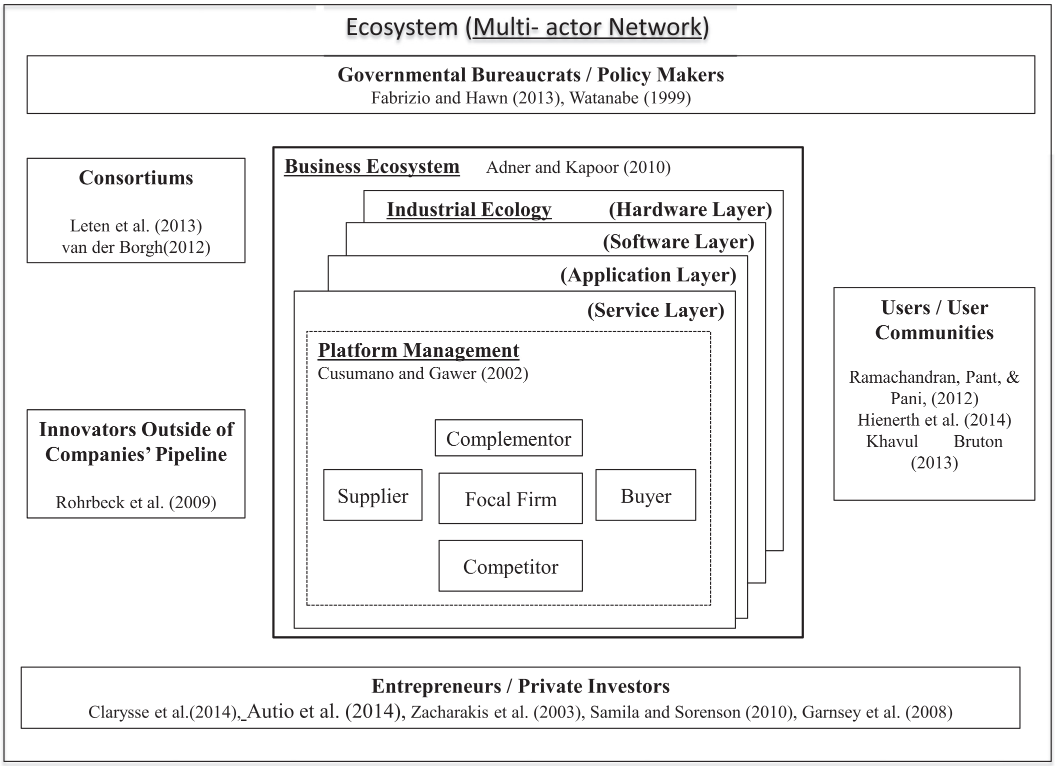

Fig. 2. Integrated model of previous research.

(entrepreneurs and private investors, innovators who are outside of company pipelines, users/user communities, governmental bureaucrats/policy makers, and consortiums). The BEP and PMP focus on the complex networks and relationships of private companies; however, the research in this cluster analyzes the dynamic networks among actors with different attributes from private firms.

There are twenty-three papers in this cluster. None of the papers offer a theoretical backbone for this approach. However, three articles can be considered as theoretical works. Priem et al. (2013) reviewed the awarded papers in the Academy of Management Review in 2011 and offered an expanded boundary model that includes the demand side, business models, and business ecosystems under the research strategy umbrella (Priem et al., 2013). The open innovation and open business model paradigm also assists in developing the concept of the ecosystem (Chesbrough and Appleyard, 2007). Meyer et al. (2005) presented a logic for the analysis of phenomena that are far from equilibrium and linearity, for example, shifting industrial boundaries, new network forms, emerging sectors, and volatile ecosystems (Meyer et al., 2005).

The directions of expansion of the actor network are diverse. There are five fields into which ecosystem analyses are expanding: (1) entrepreneurs/private investors (eight papers); (2) innovators that are outside of company pipelines (three papers); (3) users/user communities (three papers); (4) governmental bureaucrats/policy makers (three papers); and (5) consortiums (two papers).

The first group is entrepreneurs and private investors. Eight papers focused on entrepreneurial issues. Autio et al. (2014) presented a framework including public and private actors and proposed the scarcity of the context and entrepreneurial innovation (Autio et al., 2014). Two studies concentrated on venture capital (Samila and Sorenson, 2010) and angels: private investors (Zacharakis et al., 2003) as influential actors. Another two studies analyzed the regional clusters of Silicon Valley (Bahrami and Evans, 1995) and Flanders (Clarysse et al., 2014), including various actors. The remaining two papers are case studies of the start-up companies Chez Panisse (Chesbrough et al., 2014) and Acorn-ARM (Garnsey et al., 2008).

The second group looks at innovators that are outside of company pipelines. There are three studies concerning established companies' reconstruction of their innovation ecosystems by opening their innovation processes to others, using approaches such as consortiums and/or hi-tech campuses (Leten et al., 2013; Rohrbeck et al., 2009; van der Borgh et al., 2012).

The third group includes users/user communities in their ecosystem analysis. Hienerth et al. (2014) analyzed the Lego ecosystem and found that synergies between firms, lead users, and user communities affected the creation of a profitable and sustainable ecosystem (Hienerth et al., 2014). The remaining two papers focused on ecosystems including the demand-side view of developing countries, such as BOP (bottom of pyramid) analysis (Khavul and Bruton, 2013; Ramachandran et al., 2012).

The fourth group includes governmental bureaucrats/policy makers. Watanabe (1999) used the ecosystem concept to analyze the policy impact on industrial technology of Japan's Ministry of International Trade and Industry from the 1970s (Watanabe, 1999). Fabrizio and Hawn (2013) gathered data on solar power installations in the US and tested the effects of the solar carve-out policy and the availability of qualified installers (Fabrizio and Hawn, 2013). The authors found that an analysis adopting the ecosystem concept as a cornerstone could reveal the uncertain mechanisms involved through their indirect effects. Groesser (2014) analyzed building code standardization in Switzerland and found an evolutionally dynamic process among voluntary building codes, legal building codes, and standards improvement (Groesser, 2014).

There are two unique analyses addressing community tourism (Ruiz-Ballesteros, 2011) and technological forecasting in areas where there are no historical data available, such as fuel cell cars (Daim et al., 2006). These studies also found indirect, complex, and non-linear relationships among the actors who affect the outcomes.

With respect to methodology, system dynamics is used in two papers (Daim et al., 2006; Groesser, 2014). The main methodology is the case study and/or statistical testing using open data and/or survey data.

There are three papers that we were unable to categorize, although the studies refer to ecosystems. First, two studies analyzed the technological transition process and substitution orbits using the Lotka-Volterra eqs (Watanabe et al., 2003, 2004). Another unique study analyzed the knowledge cluster of service innovation research using a systematic bibliometric approach (Sakata et al., 2013); it found that ecosystem-related research is one of the larger clusters in the service innovation research field.

3.6. An integrated model of existing research

We present an integrated model of the existing research in Fig. 2. This model provides a framework that can include all of the ecosystem studies and shows our basic construction of the ecosystem concept.

There were four streams identified in the literature on ecosystem approaches. The four perspectives are mapped on the Fig. 2 with underlining. Started from the industrial ecology perspective in the hardware layer, business ecosystem perspective provides the analysis of the relationship among the supply chain actors, competitors, and complementors. The platform management perspective focused on the mechanisms of the platform in each layer. The multi-actor network perspective expanded the boundary of the analysis to include the policy makers, consortiums, innovators, entrepreneurs, private investors, and user communities.

The multi-actor network is not static, but dynamic. The network changes moment by moment. The purpose of this ecosystem approach is to clarify the dynamic change mechanism of the multi-actor network and find the specific patterns of evolution and extinction. If we can understand the mechanism, we will be able to design and manage the ecosystem strategically.

The role of ecosystem designers is to create a new entrepreneurial social business and/or revitalize the declining existing ecosystem. In this situation, the ecosystem designers aim to take a leadership position in the ecosystem and orchestrate the whole ecosystem (Gawer and Cusumano, 2014; Hong and Snell, 2013; Leten et al., 2013; Wareham et al., 2014; Wei et al., 2014). On the other hand, it is difficult to visualize and deeply understand the mechanism of the dynamics of the ecosystem for designers. Even so, the integrated model will help the designers as well as managers to orchestrate the ecosystem.

Based on the industrial ecosystem concept, a large number of eco-industrial projects were executed (e.g., Singapore's Jurong island and An Giang province of Vietnam). The business ecosystem concept is focused on the complementors' role when compared with previous strategic management analyses. The platform-based ecosystem concept opened up the fields of IT-based platform management and the ecosystem management of platforms. These are new and significant contributions to the management field that have been produced by the application of the ecosystem concept. On the other hand, we could not recognize strong theoretical support for the multi-actor perspective.

This integrated model will help ecosystem researchers, designers, and managers to understand the elements of the ecosystem. If they describe the actor network and use this model as a lens, they will be able to clarify the borders, elements, and dynamics of the ecosystem that they attempt to analyze, design, and/or manage.

As a result, we propose an original definition to create a firm foundation for ecosystem theory and the concept of a coherent ecosystem.

4. Original definition and concept of a coherent ecosystem

In this section, we propose our original definition and concept of a coherent ecosystem. First, we need the boundary-setting criteria for the ecosystem. The boundary of an ecosystem can be set by the consumers' product/service system evaluation range. Consumers evaluate the whole product/service system; the boundary of the ecosystem can be set by the consumers' perception of the product/service system.

For the next step, we need a basic consensus of the ecosystem definition. The ecosystem concept includes all actors inside the ecosystem boundary. Consumers should be included. If there is an actor that has a strategic intention to design the whole ecosystem, the actors in the ecosystem tend to be selected by the designing actor. If not, the ecosystem is formed autonomously. The ecosystem can be managed strategically if managers understand the mechanisms underlying the ecosystem dynamics.

Actors that have different attributions have different decision-making and behavioral principles. As a simple example, the central principle of policy makers is not necessarily profit gains, while the main principle of companies is clearly profit maximization. In some cases, unintended results are caused by the differences in the principles of the various actors.

An actor's decision and behavior affect the decisions and behaviors of the other actors. These dynamic behavioral chains realize the ecosystem's expansion or decline. The actors connect with each other by means of various relationships: visible and/or invisible resource flows, contracts, trust, and vision sharing.

Integrating this basic concept, we define the objective of the ecosystem in the field of management of technology and innovation as follows:

> "*To provide a product/service system, an historically self-organized or managerially designed multilayer social network consists of actors that have different attributes, decision principles, and beliefs.*"

This definition implies significant five analytical viewpoints. First, the term "historically" indicates the requirement of a longitudinal span of data collection. Second, the term "self-organized" suggests that an ecosystem is a complex system. We cite the self-organization idea from the following previous studies. Nielsen, who is an ecologist, examined the self-organized structure of societal ecosystems based on a comparison with natural ecosystems (Nielsen, 2007). Nielsen carefully discussed the similarities and differences between natural ecosystems and industry-societal ecosystems. Similarly, Ulgiati et al. (2007) discussed the self-organized human-dominated system for zero-emission communities using model simulation (Ulgiati et al., 2007). Moreover, social scientists also used the self-organization concept to analyze and understand the societal ecosystem (Battistella et al., 2013; Meyer et al., 2005; Ruiz-Ballesteros, 2011). We follow these researchers and adopt the idea of self-organization for the ecosystem definition. Though the ecosystem is a complex system, some actors seem to succeed or try to manage the ecosystem level network strategically, e.g., Intel, Google, Apple, Microsoft, Twitter, and Nintendo. Third, "multilayer" signifies that there are hierarchical levels and/or separate layers in the ecosystem. This could be an obstacle to understanding the decision principles and beliefs of other actors in the different layers. Fourth, "social network" implies that the relationships among the actors are not confined to the business context. For example, cliques, regulations, and religions could be variables underlying the relationships. Fifth, and most important, "actors have different attributes, decision principles, and beliefs," suggesting that actors' behaviors might not be mutually understood without conscious analysis.

This last characteristic will occasionally produce unintended results. The indirect causal relationship is expected to bring new insights and significance to the field of the management of technology and innovation from an ecosystem perspective. These indirect causal patterns are frequently repeated and produce pathological social situations without intention. If researchers find the complex indirect causal relations, they can propose solutions to these problems.

The underlying concept and definition of the ecosystem is the basement of the ecosystem theory building. Expanding the analysis to ecosystem level phenomena, new mechanisms of social dynamics will be found. For example, unintended policy effects, equilibrium without profitability, and the sources of social system resilience can be discussed using this approach. Moreover, ecosystem creation, expansion, and management are critical issues for both practitioners and academia.

Those actors that have the intention to design and manage the ecosystem do not always succeed in designing and realizing a healthy working ecosystem. How can we manage ecosystems that will evolve? The key concept is *coherency*. The coherency of the ecosystem means, "*The proportion of the actors whose behavior is naturally fit to their decision-making and behavioral principles in an ecosystem.*"

We can check the level of fitness by observing the variety of decision options and behaviors that can be selected by the specific actor group. This implies that for an ecosystem that has high-level coherency, there is a simple linkage of the behavioral selection by actors in the ecosystem. We can measure the level of coherency by checking the proportion of actors whose decision-making principle fits the ecosystem requirement.

The coherency changes according to the time series; at a specific point in history, the behavior of all the actors is based on their own decision-making principles. The rationality of these decisions will sometimes be lost, depending on the sequencing of events. As we described above, the chain of rational decisions and behaviors of the various actors can cause unintended results. This requires dynamic management to maintain a high level of coherency in the ecosystem.

The level of coherency has strong correlations with the sustainability and resiliency of the ecosystem in both positive and negative directions. If there is no designer of the ecosystem, an ecosystem autonomously evolves and high-level coherency accelerates both positive and negative performance without intention. This mechanism can cause both unstable performance and resiliency. Otherwise, if there are ecosystem designers, they can manage to maintain a positive correlation between high-level coherency and sustainable high-level performance and resiliency in the ecosystem.

5. Discussion

5.1. Significance of the ecosystem concept

Regarding the third research question, the authors have attempted to clarify the significant contribution of the ecosystem concept and research to the field of the management of innovation and technology.

Obviously, the ecosystem concept is generated in the biological research arena. There are numerous research achievements and insight in that field. Some researchers have compared and discussed the similarities and differences between biological ecosystems and societal ecosystems (Battistella et al., 2013; Despeisse et al., 2012; Garnsey et al., 2008; Kraemer-Mbula et al., 2013; Nielsen, 2007). This exercise sheds light on the management of innovation and technology from different angles. There are many stimulating concepts in biological ecosystem studies, for example, predation, parasitism, symbiosis, decomposition, circulation, trophic level, multiplier effect of chain reactions, and destruction of the whole system.

Ecosystem researchers have continuously expanded the boundaries of their analyses. This is seen in the studies classified in the MNP stream. Studies in the field of the management of innovation and technology tend to focus on private companies. However, the phenomena that relate to such management have become increasingly complicated in terms of actor networks. We should consider the behavior of business actors and non-business actors at the same time. For example, if we attempt to analyze and manage renewable energy, autonomous driving, digital payment, and smart cities in the management of innovation and technology context, we should not focus on causal relationships that are too narrow, because the effectiveness of the analysis for such purposes is limited.

As mentioned previously, some ecosystem researchers have emphasized self-organizing mechanisms (Battistella et al., 2013; Lewin and Zhong, 2013; Meyer et al., 2005; Nielsen, 2007; Ruiz-Ballesteros, 2011; Ulgiati et al., 2007). On the other hand, many researchers set ecosystem design as a research topic in their papers (Gawer, 2014; Gawer and Cusumano, 2014; Hienerth et al., 2014; Khavul and Bruton, 2013; Wareham et al., 2014; Wei et al., 2014). Ecosystem research might be at its strongest when the analyst applies a hybrid view of biological systems and industrial engineering systems at the same time.

In an ecosystem, each actor has different attributes, experiences, and beliefs. This path dependency creates inertia. The differences in decision principles can cause unintended results at the ecosystem level, even though each actor's decision-making and behavior is rational at a given point in time. If we find repeated patterns in the behavioral chain at the ecosystem level, we may be able to find ways to avoid or reinforce the pattern as required.

Finally, ecosystem level design is a significantly ambitious research topic in the management of innovation and technology. We must consider the technological inevitability, path dependency, actor network, chain reaction structure, function, and utility of the whole ecosystem. Obviously, the business ecosystem is a complex living entity, but it is also an artifact at the same time. Humanity can design the artifact.

5.2. The relation to the adjacent concepts

Regarding the third research question, we clarify the differences between our ecosystem concept and previous related concepts, namely: the national innovation system, supply chain management, and strategic alliance network approaches. Moreover, we propose the significance of analysis based on the ecosystem concept. In the final part of this paper, we indicate important research topics for ecosystem studies in the near future.

The concept of the national innovation system (NIS) has spread widely among academic studies (Nelson, 1993). Nelson (1993) produced a well-known comparative analysis of 15 countries' innovation systems. The framework naturally included international relationships. However, the baseline of the comparative analysis is at the national level and the border of the analysis is nearly equal to the national borders involved. This means that the NIS is a concept based on systems at the national level. Moreover, the actors share the purposes of the NIS: to be more innovative, realize economic growth, and gain industrial competitiveness. On the other hand, the concept of the ecosystem sets the border of the system via the overall product/service system; and the purposes of all the actors are not always shared and unified.

The concept of supply chain management (SCM) is also a major academic and practical research area. Studies in the SCM field are classified as operations research, business engineering, and logistics management. The focus of SCM research is the optimization of logistics networks; these networks are described by their distribution relationships. Strategic alliance network (SAN) analysis is another research area that has recently begun to expand rapidly. Numerous investigations into the business alliance relationship show the underlying mechanism of the SAN approach, which is based on the analysis of actual business contracts and transactions.

Compared with the SCM and SAN studies, ecosystem research includes the non-physical, non-business, informal, and invisible relationships contained within the actors' network relationship description. For example, bureaucrats are among the most important actors in the ecosystem analysis; they affect the other actors through the use of regulations and non-official behavior. Thus, NGOs, NPOs, consortiums, and user communities might all affect the other actors in the ecosystem.

6. Conclusion and future research

The essential significance of the ecosystem concept is generated from the analysis of organic networks, based not only on a positive view of their functioning, but also the negative and competitive aspects: ecosystem-level competition, predation, parasitism, and destruction of the whole system. Each actor in the ecosystem has different attributes, decision-making principles, and purposes. These differences cause unintended results at the ecosystem level, although each actor's decisions and behavior may be rational at any specific point. The analytical border of the ecosystem is the product/service system, and is not limited to national borders, regional clusters, contractual relations, and complementary providers. Within the border, not only business actors, but also non-business actors are included. Naturally, the ecosystem analysis requires the longitudinal observation of the product/service system's dynamic evolution or extinction.

The objectives of ecosystem research are to find the decision-making principles and behavioral chains that strongly affect the growth and decline of the ecosystem under specific boundary conditions. Viewing the ecosystem as a complex actor network, each actor has a different background and attributes. The decision-making principle means the mechanism and priority of the decision may be very different among actors in ecosystem. For example, the decision priorities of policy makers are national security and development in macroeconomics. However, in the same ecosystem, the priority of private companies at the same time is obviously their profits. The actors all behave under their own rationality and decision principles. When we analyze the behavioral chain, we may find patterns that have repeated many times in the longitudinal event history of the ecosystem. Such patterns may occur without the recognition of actors and generate unintended results. Moreover, these patterns sometimes affect ecosystem growth and decline.

Consequently, we propose important research topics for the ecosystem research in the near future. These issues also show the limitations of this paper.

We need to build specific ecosystem research theory for MNP research in particular. We assume that social network theory, neoinstitutional theory, and decision-making theory will provide a theoretical base for the ecosystem approach. Based on these theoretical foundations, we need to create schemes and processes to research, manage, and design/redesign both new and existing ecosystems. Regarding methodology, the development of a measurement of the coherency of ecosystems is critical in evaluating the efficiency of the ecosystem. Moreover, action research to participate in the building of new ecosystems will be useful, for example, in creating renewable energy systems, medical information systems, and full-control mobility systems.

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Appendix A. Supplementary data

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