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Architecture and evolvability of innovation ecosystems

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ABSTRACT

Prior studies have implied that the architecture of firms' participation in an innovation ecosystem may affect the evolvability of their own ecosystems, thus conditioning firm strategies and performance. However, specific influences are unknown. In this paper, we abstract and model an innovation ecosystem as a network of firms connected by their technological dependences and assess its evolvability in the framework of the *NK* model. Network simulations suggest that although firms' influence diversity promotes ecosystem evolvability, their influence density limits ecosystem evolvability. We also relate these findings to empirically observed differences in the architecture and evolvability of the automotive and electronics ecosystems. Implications from our findings may help firms either to better sense their ecosystems' evolution prospects and adjust their strategies accordingly or to design and manage their technological dependences and the architecture of their ecosystem participation to influence the evolvability of their ecosystem in favor of their strategic intents and capability advantages.

1. Introduction

The design and innovation of contemporary products and technologies are increasingly carried out by many interdependent firms that participate in an innovation ecosystem (Adner, 2006; Baldwin, 2012; Iansiti and Levien, 2004).[1] The architecture of firms' interdependences may shape their value co-creation and co-evolution (Baldwin and Clark, 1997; Jacobides et al., 2006; Jacobides and Winter, 2005, 2012; Teece, 2007; Casadesus-Masanell and Yoffie, 2007; Adner and Kapoor, 2010). This architecture may influence the ecosystem's innovation dynamism and evolutionary prospects (Jacobides and Winter, 2005, 2012), which firms need to continually sense, assess and adjust so that they can adjust their strategies, organization designs, capability and resource positions accordingly (Brown and Eisenhardt, 1997; Eisenhardt, 1989). However, our knowledge of these important influences remains limited.

This paper investigates the impact of the architecture of firms' participation in an innovation ecosystem on the "evolvability" of that ecosystem. We focus on an ecosystem's "evolvability," which is an *inherent ability* that conditions its evolution prospects. For firms embedded in the ecosystem, it is useful to understand their innovation ecosystem's evolvability either to adjust their strategies to the environment (Brown and Eisenhardt, 1997) or to reshape the environment to favor their established advantages (Jacobides and Winter, 2012) by designing and managing their architecture of participation in the ecosystem.

The concept of "evolvability" originated in biology, where it is defined as the capacity to generate heritable phenotypic variations with improvements (Kirschner and Gerhart, 1998). In a Darwinian evolutionary process, variations that promote fitness improvements are most likely to be selected and heritable (Wagner and Altenberg, 1996). By analogy, we define the evolvability of an innovation ecosystem as its inherent ability to generate value-creation variations in the technology configuration of the ecosystem's final products, e.g., smart phones or automobiles. An ecosystem's technology configuration is the combination of design choices for interdependent technologies designed by all ecosystem-participating firms.

As a result of interfirm dependences, individual firms' technology design choices may either positively or negatively influence other firms' technology choices and performance, as shown in historical studies of the steel, airplane, computer, electronics, telecommunications and other industries (Baldwin and Clark, 2000; Casadesus-Masanell and Yoffie, 2007; Constant, 1980; Funk, 2009; Hughes, 1983; Rosenberg, 1963; Tee and Gawer, 2009). As a result, the evolution of industry sectors is conditioned by firms' technological interdependences (Jacobides and Winter, 2012; Malerba, 2002). Interfirm influences propagate throughout an ecosystem of firms (Anderson and Joglekar,

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[1] The notion of innovation ecosystem overlaps with the concepts of "business ecosystems" (Adner et al., 2013; Baldwin, 2012) and "sectors" (Malerba, 2002). For example, the smart phone ecosystem includes firms specializing in system integration, processors, telecommunication chipsets, displays, GPS, camera, audio, etc., the developers of operating systems and application software, and material suppliers. A broadly defined innovation ecosystem may also include agents that do not contribute to technologies, such as government agencies, intermediate organizations, the end-user market, and policy or regulatory actors, but can influence technology innovation in non-technical ways. In this paper, our theoretical framing focuses on (the architecture of) technological dependences between firms; such dependences are often manifested in interfirm transactions.

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2012) in a manner shaped by the architecture of those firms' technological dependences.

Recent research has revealed that an architecture of firms' ecosystem participation can either benefit or constrain their innovation performances (Kapoor, 2013), that firms in different ecosystems are embedded in different architectures (Jacobides et al., 2012; Luo et al., 2012), and that firms may proactively choose to participate in specific architectures that fit their capability advantages (Ferraro and Gurses, 2009; Jacobides and Billinger, 2006; Jacobides and Hitt, 2005; Jacobides and Winter, 2012; Pisano and Teece, 2007). However, little is known about how specifically the architecture of firms' participation may affect the evolvability of their ecosystem in the aggregate. Such knowledge could support firms in designing and managing their participation architectures to their own advantage. That is the goal of this paper.

In this research, we characterize the architecture of participation of firms in an ecosystem in terms of interfirm influence diversity, density and cyclicality. First, influence diversity concerns the variety of the technology dependents of an average firm in the ecosystem in terms of their value chain roles and positions and is the opposite concept of influence specificity. A firm's technology dependents are firms that depend on its technologies and can be technologically influenced by it. Second, influence density concerns how many other firms depend on the technologies of an average firm, i.e., the number of technology dependents of an average firm. This is a reverse indicator of autonomy. Cyclicality concerns the likelihood that an average firm's design influences will be propagated back to itself through other firms participating in the same cycle.[2] These architectural lenses adopt alternative perspectives to characterize the pattern of technological interactions among firms and how they participate in an innovation ecosystem.

To quantitatively analyze interfirm influence diversity, density and cyclicality, along with their impact on the evolvability of ecosystems in the aggregate, we abstract and model an innovation ecosystem as a network of firms connected by their technological dependences. The model is then used to simulate many samples of networks resulting from variable influence diversity and density. The evolvability of these networks is further assessed in the framework of the *NK* model and the fitness landscape (Kauffman, 1993; Levinthal, 1997). We further relate the simulation-based findings to the established empirical knowledge on the architecture and evolvability of the automotive and electronics ecosystems, and also discuss strategic implications for firm strategy and management.

2. Evolvability and architecture of innovation ecosystem

2.1. Ecosystem evolvability

Enormous studies have indicated, reasoned or evidenced that different industrial ecosystems exhibit varied innovation dynamism and evolutionary prospects. For instance, the early literature on "technology regime" suggests that firms in the same ecosystem share a coherent set of incentives, goals, problems and knowledge bases that determine their innovation pattern and evolutionary trajectory (Dosi, 1982; Malerba and Orsenigo, 1997; Winter, 1984). Thus, the varied "technology regimes" of different ecosystems lead to different innovation constraints and opportunities and varied technology dynamism and evolution prospects (Malerba, 2002). As a result, different innovation ecosystems exhibit varied "clock speeds" (Fine, 1998), i.e., the rates of change in products, processes and organizations, or environmental "velocity" (Brown and Eisenhardt, 1997; Eisenhardt, 1989).

[2] For example, if firm A's technology choice influences firm B's technology choice and performance, which influences those of firm C, which in turn influence firm A, then firms A, B and C form a dependence cycle. With a dependence cycle of a set of firms, there is always an influence or dependence path between each firm in the set.

In turn, properly perceiving, sensing and interpreting the dynamism and evolution prospects of the ecosystem in which a firm is embedded is necessary to guide the firm in continually reconfiguring its strategies, organizational designs, and capability and resource positions to fit the degree of environment dynamism (Helfat and Peteraf, 2003; Teece et al., 1997; Tushman and O'Reilly, 1996). Teece (2007) considers a firm's ability to properly sense and characterize the evolution dynamism of its ecosystem a fundamental element of dynamic capabilities that may affect the firm's later success or failure.

To characterize an ecosystem's evolution prospects, the lens of analysis used in this paper is "evolvability." Literally, evolvability is an ecosystem's inherent ability to evolve beyond its status quo. At the firm level, Jain and Kogut (2014) defined the evolvability of an organization as its ability to create new and valuable functions. Ethiraj and Levinthal (2004b) considered evolvability of an organization as the efficiency of its search for optimal organizational architectures, and Frenken and Mendritzki (2012) analyzed it as the speed of finding the optimum in organizational searches. Modularization (Ethiraj and Levinthal, 2004a; Frenken and Mendritzki, 2012), hierarchy (Ethiraj and Levinthal, 2004b) and decoupling (Ethiraj and Levinthal, 2004b; Levinthal, 1997; Simon, 1962) of organizational units have been the most commonly studied mechanisms that affect organizational evolution. In contrast, the "evolvability" of an innovation ecosystem has not been formally defined.

The concept of "evolvability" originates from biology. One formal definition of biological evolvability is "an organism's capacity to generate heritable phenotypic variations" (Kirschner and Gerhart, 1998). Another definition is the "ability of a population to both generate and use genetic variation to respond to natural selection" (Colagrave and Collins, 2008). Wagner and Altenberg (1996) consider evolvability as "the ability of random variations to sometimes produce improvement." Luo (2014) synthesized these views to define the evolvability of a food web or ecological ecosystem as its "capacity to allow random but heritable variations of the species which produce improvements from the status quo." These definitions and many others similarly emphasize variations with some level of heritability of prior configurations and the selection of competing new variations to inherit in future generations according to their levels of fitness for the environment (Ziman, 2000). In other words, a variation with higher fitness is more likely to be inherited. By analogy, we define the "evolvability" of an innovation ecosystem as its ability to generate heritable value-creating (i.e., fitness-improving) variations in the technology configuration of the ecosystem.

Furthermore, studies in biology have suggested a few mechanisms that de-constrain phenotypic variations to give rise to evolvability, such as flexible versatile proteins, weak regulatory linkage, exploratory mechanisms, genomic and spatial compartmentation (Kirschner and Gerhart, 1998). In particular, the biology literature has linked modularity to evolvability (Hansen, 2003; Wagner and Altenberg, 1996). These mechanisms provide analogous inspirations about what promotes or limits the evolvability of innovation ecosystems.

2.2. Architecture of ecosystem participation

Empirical studies of the evolution of airplane, steel, electronics, and other industrial sectors have shown that interfirm technological interdependences may either drive or hinder the co-evolution of interdependent technologies and firms (Baldwin and Clark, 2000; Constant, 1980; Funk, 2009; Hughes, 1983; Rosenberg, 1963). Recently, Adner and Kapoor (2010) empirically showed that greater innovation challenges in suppliers' components increase the benefits to technology leaders in the focal segment of semiconductor lithography equipment, whereas greater downstream innovation challenges in complements may erode those benefits. Although the architecture of firms' participation clearly affects their performance, value co-creation and co-evolution in the ecosystem (Jacobides and Winter, 2012; Jacobides et al., 2006), the architecture of interdependences itself has seldom been a variable of analysis.