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Cyclic dependence, vertical integration, and innovation: The case of Japanese electronics sector in the 1990s

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ABSTRACT

The architecture of a firm's network of transactions in its surrounding business ecosystem may affect its innovation performance. Here we proximate a business ecosystem as a transaction network among firms. Specifically, we analyze how the innovation performances of the firms are associated with their network positions and vertical structures in the transaction network, using the data for the Japanese electronics sector in the early 1990s. The results show that, a firm's participation in inter-firm transaction cycles, instead of sequential transactional relationships, is positively and significantly associated with its innovation performance for vertically integrated firms. Within cycles, vertically integrated firms have better innovation performances than vertically specialized firms. Vertically integrated firms that participate in cycles have the best innovation performances in the Japanese electronics sector. These findings provide strategic implications and guidance for firms to design and manage their vertical structure and transaction network position.

1. Introduction

Depending on their level of complexity, contemporary products are normally made of a few or many interacting components and parts, which are designed and produced by different firms (Hobday et al., 2005; Langlois and Robertson, 1992; Prencipe et al., 2003). These interactions leave a footprint in firms' transaction network, which reveals the web of technological and transactional interdependencies among them (Luo, 2018; Luo et al., 2012). Inter-firm transaction networks are also called "supply networks" (Choi et al., 2001; Pathak et al., 2014) in the supply chain management literature and "production networks" (Saxenian, 1991; Sturgeon, 2002) in the industrial economics literature, and used to proximate "production markets" (White, 2002a, 2002b; Williamson, 1985) in the economic sociology literature and "innovation ecosystems" (Adner and Kapoor, 2010; Iansiti and Levien, 2004; Luo, 2018) in the strategy literature.

Via the transaction linkages, interdependent firms co-create value (Adner and Kapoor, 2010; Jacobides et al., 2006; Luo, 2018). In turn, their heterogeneous architectures of participation in the value chains may influence their individual innovation performances (Baldwin and Clark, 2000; Jacobides et al., 2006; Jacobides and Billinger, 2006). Prior studies have empirically shown that the network positions of firms in alliance networks affect their innovation performances (Basole, 2016; Schilling and Phelps, 2007), that direct pairs of supplying, purchasing and complementing firms in the same value chain affect each other's innovation performances (Adner and Kapoor, 2010), and that firms are embedded in heterogeneous local network structures in the industrial ecosystems for such system products as automobiles and electronics (Luo et al., 2012). However, our understanding is still limited regarding how the architecture of a firm's network of transactions in its surrounding business ecosystem may affect its innovation performance.

In particular, transaction networks have been understood as complex adaptive systems, characterized by the non-linear interdependence relationships among firms having no centralized design, management and control (Choi et al., 2001; Pathak et al., 2007a; 2007b; Surana et al., 2005). Our prior work has shown that firms can be embedded in cyclic transactional relationships (Luo et al., 2012), signaling cyclic dependences to varied degrees in networks, in addition to sequential relationships that have been taken for granted in traditional supply chain or value chain studies (Henkel and Hoffmanna, 2014). Such cyclic structures are key elements of the non-linearity of inter-firm transaction networks, and may have fundamental but implicit impacts on the performance of individual firms that participate in the cycles. Such an impact is by nature difficult to uncover because of the non-linearity of cyclic transaction networks.

In this study, we extend to investigate if the participation of firms in cyclic versus sequential transactional relationships can be correlated to

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their individual innovation performances, and also concern the possible moderating effects of the firms' vertical structures, e.g., vertically integrated or specialized, in the influences. Various prior studies have suggested the benefits of vertical integration for firm innovation (Jacobides and Billinger, 2006; Kapoor, 2013; Strojwas, 2005). A firm can choose its own vertical structure, but its architecture of participation in the network is a collective result of its own choices of transaction partners and the choices of other firms either directly or indirectly connected to it in the network.

Our empirical analysis is based on a sample of 227 firms connected by transactional relationships in the electronics sector in Japan in the early 1990s. We matched data on their transaction network positions with their patenting records indicating innovation performances, and run regression analyses. Our main finding is that, a firm's participation in inter-firm transaction cycles, instead of sequential ones, has a positive impact on its innovation performance for vertically integrated firms. Within cycles, vertically integrated firms also have better innovation performances than vertically specialized firms. Altogether, vertically integrated firms that are also in cycles have the most superior innovation performance in the Japanese electronics sector. Such new understandings provide straightforward implications and guidance for firms to design and manage their own vertical structures and their participatory positions in the surrounding transaction network, for the interest of innovation.

The rest of the paper is organized as follows. Section 2 provides a brief review of relevant literature, leading to theoretical hypotheses. Section 3 describes the data and methodology. Section 4 reports results, followed by a discussion of their implications in Section 5. Section 6 concludes with highlighting limitations of this study and future research opportunities.

2. Literature review and hypothesis development

Recently there have been an increasing number of studies that examine the structures of inter-firm transaction networks. For instance, Choi and Hong (2002) mapped the transaction networks of direct and indirect suppliers for the center console of three different car product lines, including Honda Accord, Honda Acura, and DaimlerChrysler Grand Cherokee. Kim et al. (2011) further used social network analysis to investigate the centralities of firms in these three networks. Kito et al. (2014) analyzed the supplier network of Toyota Motor Company, and found that the degree distribution does not follow a power law, i.e. it is not a scale-free network, in contrast to other studies of inter-firm supply networks that suggested a scale-free topology (Nair and Vidal, 2010; Zhao et al., 2011). Recently Park et al. (2016) and Basole et al. (2017) proposed systematic methodologies and strategies for the visual analytics of inter-firm supply networks.

The topological or structural analysis lens, such as centralities and scale-free topologies, which have been applied to analyzing inter-firm transaction networks, were drawn from social network analysis. For instance, Bellamy et al. (2014) found firms' centralities and local clustering in supply networks are positively associated with their innovation performances measured as patent grants. However, social network metrics or topologies were not developed to specifically capture or characterize the unique structures of inter-firm transaction networks. In particular, the nodes, i.e. firms, in transaction networks are heterogeneous, and play different but interdependent or complementary roles in the design and manufacturing of materials, components, subsystems and final end-user systems in the value co-creation process of an ecosystem (Hoffmanna, 2015). Due to the differences and complementarity in roles, firms are embedded in heterogeneous transaction network positions and structures determined by the flows of transactions for materials, components, or parts among them (Luo, 2010).

The prior study of the first author revealed that firms could be embedded in either cyclic or sequential transactional relationships in a transaction network (Luo et al., 2012). Fig. 1 provides a few examples of firms in cycles or sequential transactional relationships. Inter-firm transaction cycles indicate either direct or indirect reciprocal dependences (Thompson, 1967) or information flows among a set of firms. Sequential transactional relationships of firms imply that they take sequentially dependent stages or tasks from upstream to downstream in a value chain (Dalziel, 2007; Henkel and Hoffmanna, 2014; Hoffmanna, 2015; Jacobides, 2005; White, 2002a, 2002b). Specifically, Luo et al. (2012) found that about 40% of the inter-firm transactional relationships are engaged in cycles, whereas the rest are only sequentially organized, in the electronics transaction network in Japan.

Information sharing about technologies and design through inter-firm transactions give rise to firm innovation (Gao et al., 2015). And particularly, cyclic dependences may facilitate feedbacks, design iterations and co-learning among firms in a reinforced manner, because information and knowledge can be circulated back to a firm itself through other firms in the same cycle (Mihm et al., 2003; Smith and Eppinger, 1997a, 1997b; Thompson, 1967). Such iterations and feedbacks are needed to address the uncertainty and the need for experiments in the exploratory innovation process (Jacobides and Winter, 2012). Firms in a cycle may also propagate design changes to every other and back to themselves, and thus synchronize interdependent design choices across firms designing different but interdependent parts of a larger system (Luo, 2018; Sosa et al., 2013), thus enabling each firm to contribute to the innovation of the system together. Taken together, cyclic transactional relationships might increase the innovation potential of firms that are part of the cycle.

In contrast, streamlined sequential inter-firm relationships may imply clear orientation, specialization and control, thus giving advantages for efficiency, productivity and quality (Jacobides et al., 2016; Ulrich and Eppinger, 2001). This gives rise to advantages for exploitation and production. However, sequential transactional relationships do not provide as much reinforcing feedbacks, design iterations, information circulation for the participating firms as cyclic relationships. In fact, for any pair of two firms in sequential transactional relationships, either directly or indirectly, only one depends on or influences the other, because the propagation of influences or information flow is only one-directional.

For the benefits from cyclic interdependences for innovation, innovation-oriented firms are likely to choose to engage in cyclic relationships with other firms. Production-oriented firms, which primarily pursue efficiency and quality maximization and cost minimization instead of innovation, might be less interested in cyclic relationships, but more likely to favor sequential relationships with others. The dominance of sequential transactional relationships has been empirically observed in a number of production-oriented networks (with low innovation dynamism), such as the automobile production networks (Jacobides et al., 2016; Kim et al., 2011; Kito et al., 2014; Luo et al., 2012).

The above literature-based theoretical reasoning suggests the following hypothesis:

H1. *Firms participating in cyclic transactional relationships are associated with better innovation performance than those only engaged in sequential transactional relationships.*

Prior studies have empirically shown that vertically integrated firms may gain advantages in innovation, because the in-house integration of system and component knowledge allows leveraging component-level knowledge and resources for system innovation more efficiently (Luo,