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Modeling collaboration formation with a game theory approach

Jbid Arsenyan [a], Gülçin Büyüközkan [b,*], Orhan Feyzioğlu [b]

[a] Department of Industrial Engineering, Bahçeşehir University, Çırağan Caddesi Osmanpaşa Mektebi Sk. No: 4–6, Beşiktaş, İstanbul 34100, Turkey
[b] Department of Industrial Engineering, Galatasaray University, Çırağan Caddesi No: 36 Ortaköy, İstanbul 34357, Turkey

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ABSTRACT

While collaborative product development (CPD) is adopted by more and more firms as a business strategy, there is still lack of thorough research on the conditions under which the collaboration is formed. This paper proposes a mathematical model integrating trust, coordination, co-learning, and co-innovation dimensions of CPD. These dimensions, as well as additional parameters such as knowledge investment, absorption capability, efficacy, and complementarity enable the observation of the collaboration behavior under various scenarios. An analysis is conducted with Nash Bargaining approach to investigate the effect of various parameters on the collaboration formation as well as the revenue sharing. The analysis summary presents the optimum strategies for each scenario.

1. Introduction

With the increasing market competition and globalization, as well as high product differentiation, collaboration between firms becomes more and more frequent to share product development (PD) costs and to significantly reduce time-to-market. The incentive to collaborate is not limited with the aim of enhancing PD project and the implication of collaboration goes beyond the revenue sharing (Bhaskaran & Krishnan, 2009). It includes the creation and sharing of knowledge about the markets and technologies, setting the market standards, the sharing of facilities, etc. (Goyal & Joshi, 2003). Innovation also is a part of the collaborative product development (CPD) projects.

The benefits of the collaboration efforts can only be exposed by analyzing the conditions which enabled the collaboration formation. Negotiating the collaboration terms holds a strategic importance, and therefore, the strengths and weaknesses of the parties need to be meticulously investigated before establishing the contract. In this respect, a decision aid mechanism is required to choose on the level of investment, knowledge, trust, development cost and innovation revenue, as well as the level of profit sharing and collaboration.

In this paper, we develop a collaboration formation model and analyze it for various scenarios. The following principles are adopted while drafting the model. Not only monetary terms but also other aspects of the collaboration should be included, given that the collaborating firms seek to learn and innovate by joining knowledge and technology, cultivating trust and assuring coordination. It should assist in identifying how collaborative parties should negotiate and interact with each other to improve the total process effectiveness. Accordingly, the mathematical model introduced in this paper is inspired from the conceptual CPD model established by Arsenyan and Büyüközkan (2014). In this conceptual model, successful CPD is assumed to be based on three dimensions: effective partnership, effective collaboration and effective PD. Among those three dimensions, effective collaboration is based on four sub-dimensions including trust, coordination, co-learning, and co-innovation. The importance of the conceptual model dimensions is identified by using axiomatic design method and for software development industry. Here, we integrate the mentioned sub-dimensions within a game theoretical framework in order to observe their effect of on the total of CPD.

Our model reflects a negotiation environment where each party benefits from collaborating, i.e. a win–win situation. The win–win situation is required to balance the contribution of each factor from each party by defining the level of sharing. Game theory is a known tool to model the conflict and/or collaboration between individuals and/or institutions, and its principles are applied in our study to analyze collaboration efforts in PD. In sum, our aim is to provide insight for the product developers on how to negotiate and collaborate under particular conditions by proving the equilibrium solutions.

The paper is organized as follows: the next section introduces collaboration concept with its main dimensions. It also presents briefly the game theory applications in the collaboration literature and Nash Bargaining theory. The following section describes our

* Corresponding author. Tel.: +90 212 227 4480.
E-mail addresses: jbid.arsenyan@bahcesehir.edu.tr (J. Arsenyan), gulcin.buyukozkan@gmail.com (G. Büyüközkan), ofeyzioglu@gsu.edu.tr (O. Feyzioğlu).

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mathematical model for CPD. The numerical analysis section includes several scenarios to illustrate the details of the model and to make inferences. Some remarks and research perspectives are given in the conclusion section.

2. Relevant literature

2.1. Collaboration for product development

CPD is described by various interrelated aspects, often intangible, resulting from the synergy of diverse teams working together and different managerial systems converging. These various aspects are put into a systematic structure and consequently, it is widely accepted that CPD consists of three main processes, which are the partnership process, collaboration process, and PD process (Arsenyan & Büyüközkan, 2014). Aiming to form an analytical basis for collaboration formation, this paper focuses on the collaboration process and integrates its components into a mathematical model.

Collaboration process differs from the partnership formation given that it focuses on collaboration dynamics occurring from the interaction between partners, rather than the characteristics of the partners. According to Chapman and Corso (2005), the stability and effectiveness of a network are strongly dependent on softer issues such as open communication, knowledge sharing, trust and common goals. Accordingly, the four dimensions of the collaboration can be identified as *trust, coordination, co-learning* and *co-innovation* (Arsenyan & Büyüközkan, 2014) and are discussed in more details in this section.

Building open and trust-based relationships is the key to successful partnership development (Trim & Lee, 2008), and different parties have to seek trusting relationships among many partners and rely on the social control mechanism in the system composed of networks (Yong, NengSheng, & Hong, 2008). In fact, recognizing the role of *trust* in the collaboration may increase the probability of achieving a successful business-to-business implementation and helps to build a productive long-term relationship (Lederer-Antonucci, Greenberg, zur Muehlen, & Ralph, 2003). In a recent study, Hou, Xiong, Wang, and Liang (2014) study the effects of trust on supply chain partnerships and they state that extensive collaboration based on trust can benefit partners. Therefore, trust is the first dimension of the collaboration to investigate.

Coordination is another key factor for collaboration given that various teams from different organizations and at different sites are engaged for the same purpose and their development efforts must be synchronized. Technological infrastructure, information and communication technologies, integration mechanisms and systems that assure interoperability help to coordinate the collaborating teams. Clearly, this dimension of the collaboration requires a major investment and the involvement of all parties.

Identifying the relevant knowledge inputs from the various partner organizations involved in CPD should be considered as mandatory (Trim & Lee, 2008). Improved learning is partly the result of the effective use of communication and information distribution systems, both within and between organizations (Barlow & Jashapara, 1998). Thus, *co-learning* consequently emerges as an important issue in collaboration. Meanwhile, there is an increasing need for sharing information in a global networked economy, and thus information leakage becomes a major problem for collaboration (Yong et al., 2008). Essentially, knowledge is accumulated both through internal capacities of a firm, and through the direct and indirect connections that allow to have access to others' knowledge (Carayol & Roux, 2005). As a result, information sharing emerges as an important aspect of collaboration that needs to be balanced.

The pressure for sustainable development compels firms to innovate in order to maintain competitive advantage. Thus, firms seek to form partnerships with other firms, in order to support systematic innovation (Trim & Lee, 2008). Therefore *co-innovation* is an integral part of the collaboration. The search for an agreement on the innovation applies to both internal and external people to the company (Roffe, 1998) as knowledge is accumulated both internally and externally. Carayol and Roux (2005) state that expected number of innovations is a function of accumulated knowledge. This constitutes a link between co-learning and co-innovation, which cannot exist separately from trust and coordination in collaboration.

2.2. Game Theory for collaboration formation

Forming groups and collaborations is an essential problem in game theory (Goyal & Joshi, 2003). Introduced by von Neumann and Morgenstern (1944), game theory is an applied mathematics branch used in many domains such as economics, politics, management and organization, etc. (such as Barari, Agarwal, Zhang, Mahanty, & Tiwari, 2012; Hernández, Barrientos, & del Cerro, 2014; Sadeghi & Zandieh, 2011; Tsai, Liu, & Wang, 2011; Xiaohui, Feng, Xuehai, Jingbo, & Nana, 2014). There exist various applications of the game theory in the collaboration formation domain. Early studies date back to the appearance of strategic ventures in 1990's. Literature covers interactions such as alliances, strategic partnerships, supply chains, etc. A recent study by Kundu, Jain, Kumar, and Chandra (2014) emphasize that Game Theory is the preferred method for relational/behavioral analysis in supply chain. These analyzes include information sharing decisions, revenue sharing problem, and supplier buyer relation management. These behavioral analyzes also offer a basis for CPD partnerships. However, CPD literature is much more limited when considering game theory studies. Table 1 displays a summary of game theory literature with an emphasis on the focus and the employed approach.

Recent revenue sharing literature focuses mainly on supply chain networks. Palsule-Desai (2013) analyzes revenue-dependent and revenue-independent revenue sharing contracts over multiple periods in the movie industry supply chain. A new perspective is brought to supply chain coordination given the product in question. Another revenue-sharing study by Mafakheri and Nasiri (2013) investigates revenue sharing in reverse logistics. Adopting a system dynamics approach, they seek to improve the environmental performance of the supply chain and they state that changing the leader shows a significant increase in environmental performance. Another reverse logistics revenue sharing study is proposed by Govindan and Popiuc (2014). Their findings suggest that the profits of the supply chain actors keep improving under coordination, with both manufacturer-retailer and manufacturer-distributor-retailer settings. Zhang, Karimi, Zhang, and Wu (2014) study the platform innovation ecosystems with a focus on the collaborative development of supporting product. Making use of game theoretical principles, they study the effect of resource complementarity and analyze CPD mechanism of supporting products in the platform.

Even though these studies form a basis for CPD modeling, they do not fully cover the collaboration dimensions introduced in the previous section. Game theoretical studies generally have a one-dimensional focus, which is either monetary revenue or knowledge. Similarly, revenue-sharing papers investigate the monetary dimension of partnerships. This paper, on the other hand, attempts to combine the revenue sharing literature with CPD dynamics literature and puts forward a multi-dimensional mathematical model that investigates not only the monetary revenue, but the effects of other dimensions such as trust, knowledge investment, and knowledge complementarity on collaboration. Similar