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SIMULATION DESIGN IN INFORMATION SYSTEMS RESEARCH: EXAMPLE OF STUDYING IT VALUE COCREATION WITH NK MODEL

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Abstract

As an emerging research method that has showed promising potential in several research disciplines, simulation received relatively few attention in information systems research. This paper illustrates a framework for employing simulation to study IT value cocreation. Although previous studies identified factors driving IT value cocreation, its underlying process remains unclear. Simulation can address this limitation through exploring such underlying process with computational experiments. The simulation framework in this paper is based on an extended NK model. Agent-based modeling is employed as the theoretical basis for the NK model extensions.

Keywords: IT value cocreation, alliance behavior, simulation, complex adaptive systems, agent-based model, NK model, research framework, conceptualization

1 INTRODUCTION

Based on formal modeling, simulation refers to "any modeling effort in which a model is described within a set of computer code" (Carley 2009). Using simulation modeling in social sciences is rather a new idea but one that has quite enormous potential (Gilbert & Troitzsch, 2005). It differs from both quantitative and qualitative empirical approaches. One theoretical perspective of simulation is Complex Adaptive Systems (CAS), which are defined as "systems composed of interacting agents described in terms of rules" (Holland 1995, p. 10), where "the agents adapt by changing their rules as experience accumulates" (Holland 1995, p. 10). Agent-Based Modeling (ABM) is the instrument of CAS (Nan 2011). The reference framework used in this research is NK model. NK model has demonstrated its value in organization science (e.g., Levinthal 1997; McKelvey 1999). One reason why simulation is not widely recognized in social research community might be "a lack of clarity about the method and its link to theory development" (Davis et al. 2007, p. 480). To address this issue Davis et al. (2007) proposed a roadmap for developing theory with simulation methods. In their roadmap, two phases are critically important: creation of computational representation and verification of computational representation. This paper focuses on the former and illustrates the process of designing simulation framework, within an IT value cocreation scenario.

Information technology (IT) value cocreation is a new domain of research. It involves high-level inter-firm structure and value cocreating mechanisms. Related researches began to thrive only several years ago in response to Kohli and Grove (2008). Special issues in *Information Systems Researches* (2010) and *MIS Quarterly* (2012) have pushed this field forward. However, most literature only focuses on identifying antecedents of IT value cocreation (e.g., Chellappa & Saraf 2010; Ceccagnoli et al. 2012). This may be due to the limitations of traditional research methods. Given restrictions such as human resource, money, and time, it is hard to use traditional research methods to address complex and dynamic phenomena. As a result, few cocreation studies involve studies of dynamic processes. Grover and Kohli (2012) called for future studies "focusing on 'process' of IT-based value cocreation". They highlighted the importance of the value cocreation stages and the related conditions. The motivation of this research is to examine the "process" of IT value cocreation.

The concepts of IT value cocreation used in this paper are consistent with the main IT value cocreation literature (e.g., Rai et al. 2012; Grover & Kohli 2012). It comes from resource-based view theory (RBV) (Barney 1991) and its extension - Relational View (RV) perspective (Dyer 2000; Dyer & Singh 1998). According to RBV, the business value of IT is created by developing valuable, inimitable, and non-substitutable IT resources. Such resources are the basis of competitive advantage and superior innovation performance (Barney 1991; Belderbos et al. 2012). IT resources are transformed into business capabilities through resource integration. These capabilities then generate business value of IT (Melville et al 2004; Wade & Hulland 2004; Bharadwaj et al 1999). RV extends the context of in-house IT resources to the context of IT resources simultaneously held by multiple stakeholders (Dyer & Singh 1998). It argues that value can be cocreated within a multi-firm environment. The analysis of cocreation process is extended from Zhang's (2014) conceptual framework. In his framework, IT value cocreation is divided into three stages, which correspond to: alliance formation, alliance cocreation of value and alliance dissolution/continuation.

This research intends to make several contributions. First, it encourages simulation in the IS discipline by offering an example of simulation research design. Second, it develops a set of concepts relevant to the studies of IT value cocreation. Further, a new way to use NK model is suggested.

The rest of this paper is organized as follows. First, NK model is described. Next, IT value cocreation is examined with the language of ABM. An extended NK model framework is illustrated. In the end, implications and future work are discussed.

2 TECHNICAL BACKGROUND

NK model is proposed by Kauffman (1993). Its core concept is fitness landscape. Fitness landscape is a mapping of all possible organism structures onto their fitness (adaptive ability) in environment. In NK model, an organism is conceptualized as an *N*-length array. Its fitness calculation is a mapping function $F: R^N \rightarrow R$. Each agent attribute has its individual contribution to fitness and agent fitness is an average of all contributions. Thus, the fitness landscape contains *N+1* dimensions in total, in which *N* dimensions depicting the organism's attributes and the $(N+1)^{th}$ dimension demonstrating adaptive ability in environment. The shape of the fitness landscape is affected by the degree of interaction among attributes, which is denoted by parameter *K*. For instance, when *K=0*, the contribution of one attribute only depends on its own value. The fitness landscape is smooth and contains only one peak. A peak is defined as a location at where organism has higher fitness than all other organisms that have only one different attribute (neighbors). With *K* increasing, fitness landscape will be more rugged and multi-peaked.

Natural selection is used to model environment pressure. Organisms with relatively lower fitness will "die" in natural selection process at beginning of each simulation period. Surviving organisms after natural selection take adaptive behaviors. New organisms will be "born" to replace dead organism, thus ensuring a stable organism number. NK model designs two alternative ways to determine a new organism's attributes. One is replicating existing forms. The other is taking a new random form. The choice is based on average fitness of the organism population. If the average fitness is high, replication can ensure an instant high fitness form. On the contrary, replication seems unreliable and a new organism tends to choose a random form.

The objective of adaptive behavior is to obtain higher fitness. Reflecting on the fitness landscape, all organisms are "climbing" from lower locations to higher ones. NK model also defines two strategies of adaptive behaviors. One is local adaptation, also called "local climbing". An organism using this strategy searches its neighbors for a form with higher fitness. If there is one, it will adopt it. If not, it shows that this organism is already standing at one of the peaks. However, this organism does not know whether this location is a global peak (the highest peak). Then it will take the second strategy – "long jump". By "long jump", an organism randomly chooses a location far away. If new location is higher on the fitness surface, this organism will replicate the agent attributes there.

In summary, NK model is a repetition of competing and evolving processes. It begins with initializing an organism population and a fitness landscape. In each simulation time period, the process of NK model contains three stages. In the first stage, all organisms go through natural selection process. Those organisms with relatively higher fitness survive and go to the adaptation stage. They try "local climbing" first. If "local climbing" is failed, they try one "long jump". In the birth stage, new organisms are born. The initial forms of these organisms are determined in two alternative ways – replication and random birth. The choice depends on the average fitness of agent population. After three stages are finished, new simulation period begins. The circle continues until equilibrium is achieved. Figure 1 illustrates the process of NK model in one simulation period.

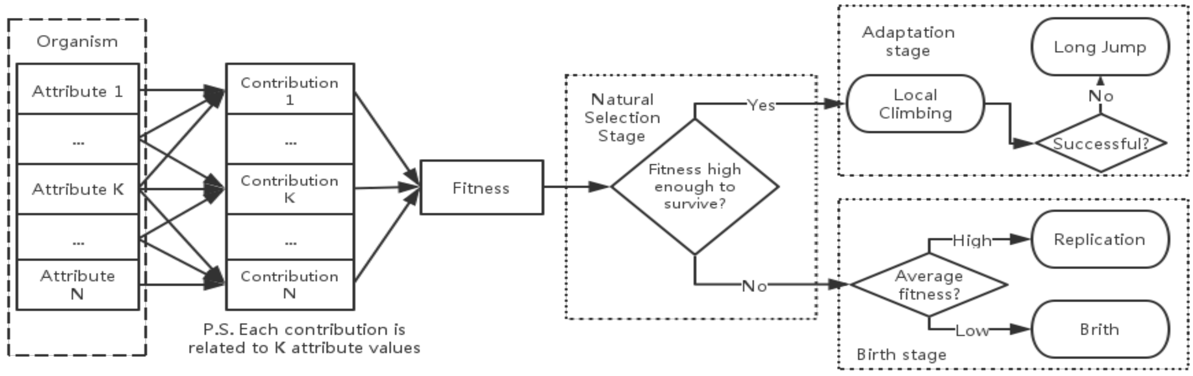

Figure 1. NK model process in one simulation period

3 FRAMEWORK ON IT VALUE COCREATION PROCESS

In this research context, designing simulation framework means mapping concepts of IT value cocreation process and NK model together. The bridge is complex adaptive systems (CAS). On one hand, the process of IT value cocreation can be considered as a CAS. On the other hand, as an agent-based modeling (ABM) method, NK model is a practical instrument of CAS. Thus, concepts from two sides can be both represented in a CAS form. Holland (1995) explained seven components of a CAS. Recent literature condenses them into two major components: agents and environments (e.g. Zhang 2013; Nan 2011). Agents are characterized by attributes, behavioral rules, and behaviors. Environment characteristics include attributes, environment rules, and network structures.

After mapping concepts, next is creating representations. The creating rules are quite different according to type of ABM. Two types are mentioned in previous literature: empirical testing (Burton 2003) and theory building (Davis et al. 2007). In the former case, simulation is used to collect data and elaborate existing theories and models. While for theory building, running simulation is a way to explore. When creating computational representations for empirical testing, all details should be included to best reflect the existing model. In theory building experiments, computational representations need to be general and experimental. The process of IT value cocreation is still vague, so NK model used here is the latter.

Concept mapping and creating computational representations together comprise the process to design a simulation framework. Summary of simulation framework in this research is illustrated in Table 1. Later parts in this section explain the table in details.

CAS	**IT value cocreation**	**Description**	**NK modeling computational representations**
AGENT	Stakeholders	A person, a group, or an organization that independently provides IT resources	A fixed length array.
· Attributes	Structure of agent	Stakeholder characteristics that affect IT value cocreation	X nodes of relational resources, Y nodes of integrated relational resources, and Z nodes of mediating factors.
· Behavioral rules	Stakeholder strategies on cocreation	Decisions to best leverage and develop its resources by considering its relative roles, competitive abilities, and other environmental factors.	A fixed length array containing three parts of strategic decisions.
· Behaviors	Cocreation activities	Individual and mutual stakeholder cocreation activities.	The logics or details of agent attribute dynamics at three cocreation stages.
ENVIRONMENT	Social and organizational contexts	The social and organizational IT value cocreation context where stakeholders cocreate IT values together.	The virtue simulation environment containing all agents.
· Attributes	Structure of social and organizational contexts	Properties of social and organizational contexts characterizing environment.	Properties of virtue simulation environment such as environment capacity, geography settings, and virtual political settings, etc.
Fitness landscape	Collections of cocreated IT value	Manifestation of best cocreated IT values for all possible stakeholder structures.	A virtue surface where stakeholder structure determines location and best cocreated IT value represents height.
Fitness calculation	Ways to cocreate IT value	Mechanisms on how IT value is generated and appropriated.	Mathematical modeling on how locations at fitness landscape determine their corresponding fitness height.
· Environment rules	Rules of social and organizational contexts	Rules stipulating relationships of social and organizational properties and their dynamics.	Functions to model relationships and changing patterns of different environment attributes.
· Network structures	Architectures of stakeholders in social and organizational contexts	Highly integrated stakeholder relationships. Cocreation structure is one special kind of network structures and only cocreation relationships are involved in cocreation structure.	Integrated agents connections. Each connection is one channel or bridge of agent interactions.

Table 1. Mapping IT value cocreation into CAS and NK modeling simulation design

3.1 Agent

Agent is individual actor to take adaptive behaviors in environment. In IT value cocreation context, an agent refers to a cocreation stakeholder. It can be a person, a group, or a firm as long as it provides some relational resources to cocreate IT value[1].

3.1.1 Agent attributes

The concept of *attributes* delineates structure of an agent. Each attribute is a critical factor affecting adaptive behaviors. In IT value cocreation context, firm relational and integrated relational resources belong to such factors. From relational view perspective, value cocreation is a process of combining and developing of multi-firm relational resources. There are four types of relational resources: relation-specific investments; interfirm knowledge-sharing routines; complementary resources endowments; and effective governance (Dyer & Singh 1998). Through integration, another three integrated relational resources are formed: positive IT-based cocreation cycle, IT-based cocreation dependencies, and cocreation platform (Grover & Kohli 2012)[2]. Although relational resources are direct determinants, other mediating factors may affect the IT value cocreation process as well. One of them is the role of a firm. A firm's role may be a supplier, a consumer, or a competitor. Other critical factors are firm size and its performance. It has been proved that value appropriation is greatly influenced by bargaining power of alliance firms (Lavie 2007; Lee et al. 1999; Sarker 2012). These mediating factors are not independent of relational resources. For instance, if one firm has huge amount of technological resources (relational resources) and a dominating industry IT platform (integrated relational resources), it should have a relatively big firm size (mediating factor).

Representing this agent structure in NK modeling, this research uses block design (e.g. McKelvey 1999), as illustrated in Figure 2. Block design means using a bunch of attributes as basic building blocks, thus designing agent by a multi-level structure. Configurational theory may provide justification for this designing method. It suggests organizations should be understood as coherent cluster of distinct attributes that commonly occur together (Miller 1986; Mintzberg & Lampel 1999; Fink 2010). In this simulation framework, agent attributes are divided into three blocks, respectively representing relational resources, integrated relational resources, and mediating factors. Arrows in Figure 2 represent the relationships of blocks. Within each block, relationships among homogenous attributes are modeled by attribute interaction degree (recall parameter *K*).

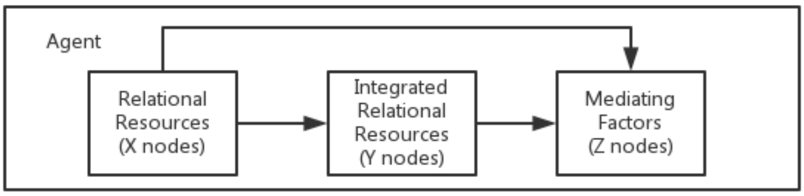

Figure 2. Agent design for IT value cocreation stakeholder

3.1.2 Agent behavior rules and behaviors

Behavior rules are rules that govern agent *behaviors* (Nan 2011). The process of IT value cocreation is a set of sequential cocreation activities. These activities contain individual and mutual firm behaviors, which are guided by firm strategies. Firm strategy refers to the regulation or plan for achieving a long-term or overall firm performance. Fink (2010) has demonstrated profound influence of firm strategy on inter-organizational performance. Firm strategies here contains: 1) relationship evaluating criteria; 2) cocreation plans and governance mechanisms; 3) partner finding policies. This research defines firm strategies as agent behavioral rules and cocreation activities as agent behaviors. The process of cocreation behaviors is illustrated in Figure 3. In alliance dissolution/continuation

[1] As firm is the most common case, this paper uses firm covering other kinds of stakeholder without explanation later.
[2] Because the two kinds of resources are similar, the concept of relational resources is used covering the concept of integrated relational resources later.

stage, a firm evaluates its current cocreation relationships. Based on the evaluation, this firm decides to continue or withdraw from current cocreation relationship. Alliance cocreation stage includes value generation and value appropriation. Main value cocreation behaviors happen here, including co-investment, creating capabilities, creating values (Barney 1991), and value appropriation (Durand et al. 2008). Most previous cocreation researches fall into this stage. Alliance formation stage contains the partner-finding process. Sub-processes are variation, selection, retention and negotiation (Zhang 2014). Variation identifies possible target alliances and relationship forms. Selection evaluates identified solutions. Retention executes selected alternatives. Negotiation addresses value appropriation mechanisms. Generally, a firm's negotiation power is negatively associated by degree of dependence on alliance relationship (Pfeffer & Salancik 1978). Lavie (2007) suggests two factors – relative partner profitability (firm performance) and relative partner alternatives – as the determinants for relationship dependence, mediating by bilateral and multilateral competition.

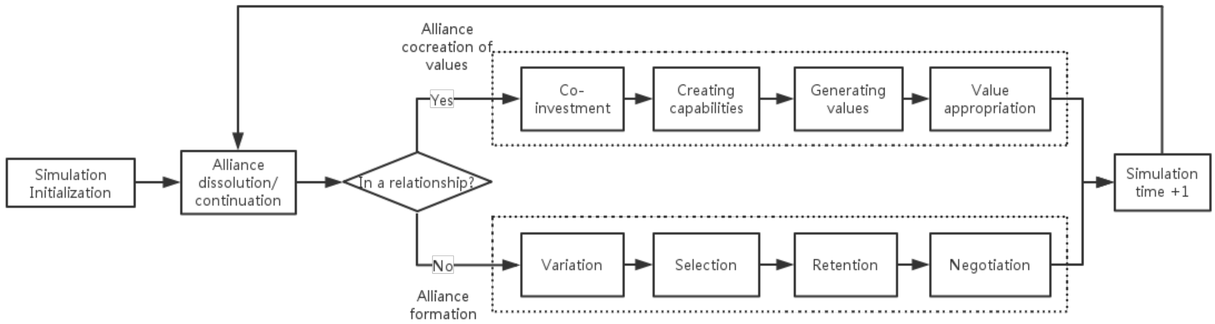

Figure 3. Simulation process of extended NK model

3.2 Environment

Environment is the simulation context where agents interact with each other. In IT value cocreation situations, environment refers to social and organizational contexts. It has been proved that value cocreation circumstance has significant impact on organizational performance (e.g. Miranda 2005).

3.2.1 Environment attributes

Environment attributes illustrate the environment structure. Each environment attribute is an environment property. Original NK model only has one environment attribute – population size, which shows capacity of environment. While in IT value cocreation context, environment attributes should be extended. For example, Madhavan et al. (2004) point out that the geographic factors have significant impact on cocreation relationship formation. Miranda and Kavan (2005) argue that environment resources, institutional conditions, and geographies of time and space serve as mainly external constrains to govern cocreation process. Zimmermann et al. (2013) suggest that political, cultural and organization structural issues lead to vicious and virtuous circles of relational behaviors.

3.2.1.1 Fitness and fitness landscape

Fitness refers to agent performance in simulation environment. The agent fitness then refers to firm performance (i.e. cocreated values). However, participating in different cocreation groups, the same firm structure may have different firm performance. Thus, this research defines a fitness landscape as a collection of best firm performance for each possible firm structure. It indicates that a firm can be positioned not only on the fitness landscape but also "under" the fitness landscape. To acquire a better performance, a firm can change its form or change its cocreation relationships. *Fitness calculation* means the way to cocreate IT values. According to RBV, there are two levels of IT value generation: how joint relational resources transfer to cocreation capabilities, and how these capabilities generate IT cocreation values. After value generation, the third level value appropriation finally determines cocreated value. All three levels are under the guidance of joint mediating factor set (joint agent behavioral rules set). The fitness calculation process is shown in Figure 4.

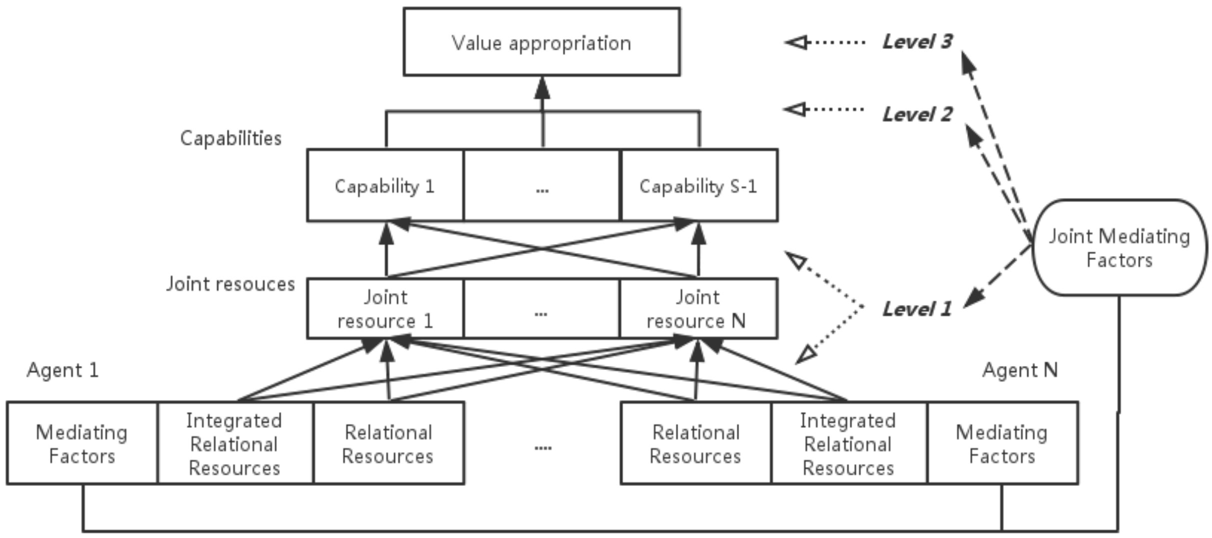

Figure 4. Fitness calculation process

One design for the three-level calculations is followed. In the first level, the attribute values of joint resources are determined by highest values of homogeneous co-invested attributes. From joint resources array to capabilities array, the original NK modeling fitness calculation method is used. That is, value of each capability is assigned a random number from 0 to 1 for a certain type of *K+1* joint relational resources. At the second level, a random number from 0 to 1 is assigned as weight for each capability for each capability interrelationship set (a *k* attribute group). The fitness contribution of this capability is the sum of value of related capability multiplying its weight (equation 1). Finally, overall fitness is the average of each attribute' contribution (equation 2).

$$F_i(d_i; d_{i1}, d_{i2}, \dots, d_{ik}) = \sum_k d_{ik} \cdot \theta(d_i; d_{i1}, d_{i2}, \dots, d_{ik})_k \qquad (1)$$

$$F(d) = \frac{1}{N} \sum_i F_i(d_i; d_{i1}, d_{i2}, \dots, d_{ik}) \qquad (2)$$

In the third level, value is appropriated according to the ration of firm size. A firm size is modeled by the sum of all relational and integrated relational resources.

3.2.2 Environment rules

The relationships and dynamic of environment attributes are affected by *environment rules*. For example, one environment rule for original NK model is that environment is static so its attributes never change. Applying to IT value cocreation context, environment rules need revisions and development. For instance, Moore's law tells frequent technology revolution. Besides, political changes are not rare nowadays. They definitely have a great effect on the fitness calculation process.

3.2.3 Network structure

Network structure refers to an integration of agent relationships. An agent relationship can be understood as agent tie or agent connection. Agent connection is the channel or bridge of interactions. In IT value cocreation context, the most important firm connection is cocreation connection. A cocreation structure refers a network structure only including cocreation connections. Zhang (2014) proposes a typology of number-centric IT value network structure, which contains both cocreation connections and normal connections. Belderbos et al. (2012) defines two types of collaborative alliance: vertical and horizontal. Vertical relationship is collaboration existing in suppliers and consumers, and horizontal relationship is collaboration between competitors. This paper proposes typology of common cocreation structures combining these two methods, which is shown in Figure 5.

Two properties - the degree of cooperation and the degree of competition - are used to characterize a relationship between two firms (Zhang 2014). Each firm relationship has both cooperation and competition properties. Here the two properties are independent and not related to each other.

Cooperation is the manifestation of firm subjective motivation to cocreate values while competition reflects passive status of firm relative roles. As cocreation relationship naturally is a collaboration relationship, cooperation degree in all coreation connection is relatively high than normal connection. In comparison, degrees of competition for different kinds of cocreation relationship may vary. Yet, vertical relationships generally have lower competition degree than horizontal relationships.

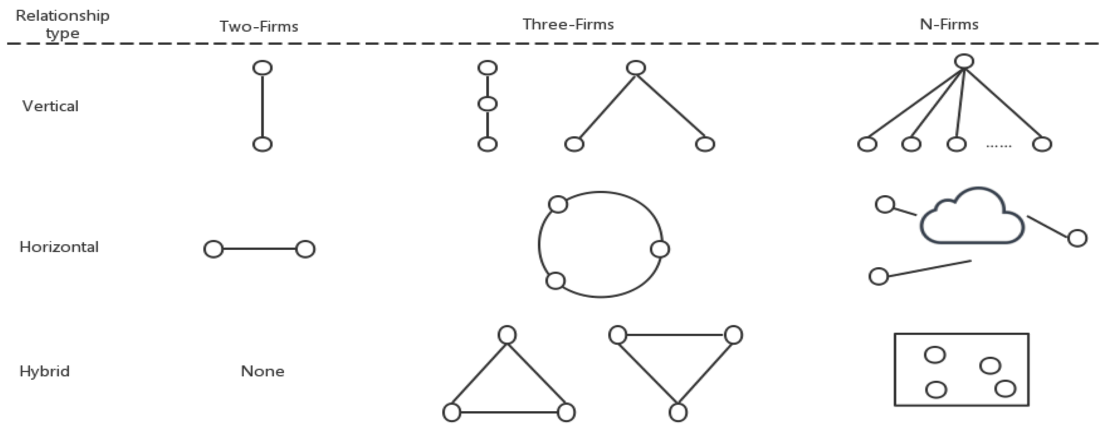

Figure 5. Topology of IT value cocreation structure (reproduced from Zhang [2014, p. 6])

Vertical – Vertical relationship exists between suppliers and consumers. Two-firms scenario depicts basic network structure: one supplier and one consumer. By increasing structure depth, new structure contains a supply chain with three sequential firms, defined as buyers, intermediaries, and suppliers (Sankaranarayanan & Sundararajan, 2010). Extending width means a supplier may cooperate with two consumers or a consumer has two suppliers[3]. In N-firms scenario, the majority of cases are that a focal firm has numerous vertical relationships with alliances.

Horizontal – On the contrary, horizontal relationship is relationship between competitors. The form of two-firms scenario is same with vertical relationship. However, the firm relationship contains a higher degree of competition. In three-firms and N-firms scenarios, all cocreation structures can be understood as industry alliance structure. Each firm is both an alliance and a competitor of any other firm in these structures.

Hybrid – This kind of structure generally evolves from vertical and horizontal structures to better leverage profits from focal firms. At least three firms are required to form a hybrid cocreation structure. There are two types of three-firm hybrid structure: one supplier with two competing consumers or one consumer with two competing suppliers. As competition between suppliers and consumers are different, both structures are illustrated in Figure 5. A black box is given to illustrate complex N-firms scenario.

4 DISCUSSION AND FUTURE WORKS

This simulation design adopts a top-down approach. Although this offers an overarching framework, the design itself lacks concrete details. Several future studies will be explored: (i) Conduct empirical case studies on cocreation networks, (ii) Identify the differences between different types of cocreation networks, and (iii) Analyze the effects of the presence of IT on value cocreation (e.g., how IT value cocreation process is different from other kinds of value cocreation process).

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[3] The latter case is similar to former and thus do not mention in Figure 5. It is the same in N-firm scenario.

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