Analyzing the Co-evolution Impacts of Interconnected Relationship Strategies on the Behaviors and Structures of Supply Networks

（サプライネットワークの挙動と構造に関する相互関係方策の共進効果の解析）

Mohamad Sofitra
D１１２６６３

Production System Engineering Laboratory
Department of System Cybernetic Graduate School of Engineering
Hiroshima University

A dissertation submitted to the Graduate School of Engineering, Hiroshima University for the degree of Doctor of Engineering

Hiroshima University
March 2015

Abstract

A supply network (SN) inherently has two challenges for decision makers to deal with. Firstly, as a network, it is complex. In SN environments, not only firms that interconnected through relationships, but also the relationships themselves are interconnected. Secondly, SN is not static. SN structures and behaviors are co-evolved.

Inter-firms relationships studies have been investigated for decades, especially in the 1990s emphasizing on dyad or triad relationship, however the theory of relationships among firms, especially in the context of broad network is still emerging. The dyad and triad level of SN analysis come from reductionism methodologies positing that an entire system mechanism under investigation can be fathomed by studying its parts. However, most systems, especially those that are composed of living things or man-made i.e., network of social/economic systems; behave in a more complex manner than the sum of their components. Such systems comprise many loosely coupled entities whose individual interactions are based on local information, but collectively this arrangement would lead to complex emerging behavior.

Although bottom-up and evolutionary-approach modeling methodologies of complex adaptive systems (CAS) which are more suitable for overcoming the dynamic and complex issues have existed for decades in the fields of biology and physics, researchers have only recently employed CAS perspective to intensively investigate SN. CAS theory perspective for SN has been popularized under the name of complex adaptive supply networks (CASN). CAS methodology explains how phenomena or features of a complex system emerge from co-evolution of local interactions among all components of the complex system. From a CASN framework, firms in SNs can be regarded as part of an interconnected living being that exhibits co-evolution, self-organizing and recursion.

There have been several studies emphasizing SNs relationship evolution using CASN perspective. Nevertheless, these studies have drawbacks. Firstly, previous studies still concentrated on co-evolution between cooperation and defection. In fact, there are other archetypes of relationship strategies that exist and might have a significant influence on relationship strategy co-evolution inside SNs, i.e., competition and co-opetition. Secondly, they have not considered the natural driving force of the relationship engagement i.e., resources similarity and resources heterogeneity. Finally, previous research

still focuses on the behavior of the relationships and not yet on the impact of the emergent behavior itself to the SN e.g., firm survivability or SN structures.

This thesis consist of two stages of study. At the first stage, a research framework and several experiments have been conducted to investigate the co-evolution of interconnected relationship strategies of CASN using cellular automata. The first stage of study is aimed to address the following research questions: how and under what conditions does co-opetition in CASN co-evolve simultaneously with competition, cooperation and defection? What kind of interconnected relationships behavior will emerge as the result of this co-evolution? The second stage of study investigated the impact of the emergence macro behavior of interconnected relationships co-evolution of CASN to its firms' survivability and network structure. It is questioned how and under what conditions the survivability of firms inside the SN are affected by the co-evolution of interconnected relationship strategies among them and whether this co-evolution will emerge an efficient SN structure. The complete literature review of this study background can be found in chapter 1 and 2 of this dissertation while the novel methodology that has been used to develop SN model can be found in chapter 3.

The results of the first stage of the study are written in chapter 4. The results of the first stage of this study have demonstrated that specific relationship types inside CASN are not only influenced by reward scheme stimulus but, more importantly, also co-evolved with the existence and behavior of other types of relationship. The study demonstrates how a set of simple micro-conditions (agent parameters, reward schemes stimulus and agent interaction policies) can develop into complex macro-behavioral patterns of the interconnected relationships among firms. The experimental results show the emergence of attractors of interconnected relationship behaviors which are sensitive to SN population changes. These attractors suggest that cooperation promotes co-opetition and reduces the tension of the competition while defection leads to the escalation of competition and generates barriers to co-opetition. In a practical situation, the strength of cooperation relationships inside the SN of the rivals should be considered before adopting these rivals as partners in a co-opetition relationship. A strong alliance, or cooperation relationships that are embedded in a rival's SN, will ensure maximum benefit from the planned co-opetition relationship.

The results of the second stage of the study are written in chapter 5 and 6 respectively. Two results are obtained for the second stage of study concerning the impacts of the co-evolution of interconnected relationship strategies. Firstly, the impact on survivability of firm. The results show that cooperation coupled with co-opetition policy in SN business environments that are favorable for cooperation can promote further lifespan of nodes at both individual level and SN level. This means, when a business environment favors alliance cooperation, the result suggest that managers should not only exploit a cooperation strategy with their allies but also consider coupling the cooperation strategy of allies with a co-opetition strategy to their potential competitors as a strategic opportunity to increase the survivability of their firm. Even though cooperation and co-opetition might introduce some disadvantages such as appropriation risks or technology diffusion risks, also short-term opportunistic behavior might offer more incentives in certain business environment conditions, nevertheless in the long-run cooperation coupled with a co-opetition strategy has positive impacts on the survivability of firms at the individual and network level. Secondly, the impact on SN structure. The preliminary experiment has demonstrated that the co-evolution of interconnected relationship strategies of cooperation, defection, competition and co-opetition could emerge the efficient SN structure. Portfolio rearrangement mechanism conducting by nodes has empowered the selection process in composing their relationship portfolio. This mechanism consequently plays important role in the emergent of SN efficiency. This mechanism has guaranteed the node to always attract to the fittest neighbor. Unfitted neighbor means it's not well supported by its embedded network or it is supported by inefficient embedded network which both are not preferable or bad situations. Therefore, this mechanism in the long run will eliminate unfitted nodes and their inefficient embedded network out of SN. In the practical situation, the process of partner selection is a natural process which secures the fitted individual existence in SN and consequently it is responsible for the emergent of the efficient SN structure.

Table of Contents

List of Tables

List of Figures

Chapter 1 Introduction

1.1. Background of Study

A supply network (SN) inherently has two challenges for decision makers to deal with. Firstly, as a consequence of its "network" nature, it is complex. In SN environments, not only firms that interconnected through relationships, but also the relationships themselves are interconnected and not independent or isolated from others (Ritter, 2000). The quantity of relationships among firms inside SN dictates the complexity level of the network. Secondly, SN is not static. At any time, firms could leave or enter the network, regularly firms make some decision to reconfigure their relationship portfolio to adapt to business environment changes or to respond to partners and rivals actions. As a result, SN structures and behaviors are evolved.

Inter-firms relationships had been investigated for decades, especially in the 1990s (Ritter & Gemünden, 2003) emphasizing on dyad or triad relationship. However, the theory of relationships among firms, especially in the context of broad network is still emerging. The dyad and triad level of SN analysis comes from reductionism methodologies positing that an entire system mechanism under investigation can be fathomed by studying its parts. However, most systems, especially those that are composed of live beings or man-made i.e., network of social/economic systems, behave in a more complex manner than the sum of their components (Choi, Dooley, & Rungtusanatham, 2001). Such systems comprise many loosely coupled entities whose individual interactions are based on local information, but collectively this arrangement would lead to complex emerging behavior.

Although bottom-up and evolutionary-approach modeling methodologies of complex adaptive systems (CAS) which are more suitable for overcoming the dynamic and complex issues have existed for decades in the fields of biology and physics, researchers have only recently employed CAS perspective to intensively investigate SN (Nair, Narasimhan, & Choi, 2009; Pathak, Day, Nair, Sawaya, & Kristal, 2007; Pathak & Dilts, 2009). CAS methodology explain how phenomena or features of a complex system emerge from co-evolution of local interactions among all components of the complex system.

A CAS theory perspective for SN was initially proposed by Choi et al., (2001) in their seminal work. They popularized this approach under the name of complex adaptive supply networks (CASN). From a CASN perspective, firms in SNs can be regarded as a part of an interconnected live being that exhibits co-evolution, self-organizing and recursion. To investigate SNs, a researcher can develop an SN model while emphasizing the three fundamental foci of CAS, namely the internal mechanisms, the environment and co-evolution (Choi et al., 2001).

Using CASN perspective, Nair et al., (2009) developed a CAS framework using cellular automata (CA) model to investigate the co-evolution of relationship strategy decisions among firms at the SN level. Their experiments successfully showed how relationship strategy co-evolution inside SNs causes the emergence of complex interconnected relationship behaviors of cooperation and defection. In accordance with Nair et al., (2009) frameworks, Li, Gu, & Song (2013) investigated the impacts of SN topologies on the co-evolution of a cooperation and defection strategy inside SN. They concluded that heterogeneous network structures are helpful for promoting cooperation. Nonetheless, both papers still focus on co-evolution between cooperation and defection. In fact, there are other archetypes of relationship strategies that exist and that might have a significant influence on co-evolution of relationship strategy inside SNs, i.e., competition and co-opetition (Choi, Wu, Ellram, & Koka, 2002).

A cooperation relationship between firms is motivated by a common goal (e.g., to solve problems, to improve products and streamline processes, etc.) (Choi et al., 2002) and/or a resource dependency (Ritter, 2000; Lee & Leu, 2010). This type of relationship builds upon teamwork by sharing information and resources. Conversely, a defection relationship between firms is provoked by short-term opportunistic behavior (e.g., being lured by better terms of a contract from other firms) (Nair et al., 2009).

A competition relationship between firms is based on the logic of economic risks (e.g., appropriation risk, technology diffusion risk, forward integration by suppliers and/or backward integration by buyers, etc.) that can introduce threats to the core competence of a firm (Choi et al., 2002). Conversely, co-opetition is a strategy employed by firms that simultaneously mixes competitive actions with co-operative activities (Gnyawali & Madhavan, 2001). The motivation for engaging in co-opetition between rival firms in SN varies; namely, companies may choose co-opetition to pursue the advantages by pooling resources and competences (accessing new channels and/or markets, developing new products, learning new processes or technologies) (Bengtsson, Eriksson, & Wincent, 2010) or because of obligations to buyers, government regulations or other third-party firms ((Gnyawali & Madhavan, 2001; Z. Wu & Choi, 2005).

All the archetypes of relationship strategies should be considered in the construction of co-evolution models of interconnected relationship strategies. Considering only cooperation and defection in a model will mean that the model represents only interaction among firms with dissimilar resources. At the same time, interactions among firms that have a high resource similarity, where competition or co-opetition relationships could naturally emerge, have been neglected. Changing its relationship strategy toward other firms is part of the natural adaptability behavior of a firm. For example, one type of relationship strategy (e.g., cooperation) can be affected by other relationship strategies and can transform into other types of strategies (e.g., defection) (Nair et al., 2009). Two types of strategies (i.e., cooperation and competition) can operate simultaneously in the form of co-opetition (Wu & Choi, 2005). Therefore, to reproduce more comprehensive behavior of interconnected relationship strategies inside SN, we need to extend the research framework of Nair et al., (2009) by means of accommodating not only cooperation and defection but also co-opetition and competition relationship strategies into the model.

1.2. Research Questions and Aims

In this study, I have two stages of research. At the first stage, I developed a research framework and conducted several experiments to investigate the co-evolution of interconnected relationship strategies of CASN using CA (Sofitra, Takahashi, & Morikawa, 2012a, 2012b, 2013a). I aimed to address the following research questions: how and under what conditions does co-opetition in CASN co-evolve simultaneously with competition, cooperation and defection? What kind of interconnected relationships behavior will emerge as a result of this co-evolution?

If I could successfully identify and understand the emergence of collective behavior of SN firms as the result of the interconnected relationship strategies among them, then it is also important to investigate the impacts deriving by this emergent behavior which is emphasized in the second stage of my study. The first impact is on firms' survivability. Investigation on the first impact is very important because any relationship strategy which engages firms with each other, mainly intends to achieve a firm's goals. One crucial goal of firms is to prolong its survival in the market.

The second impact of this emergent behavior is on the network structure of SN. Many researchers have investigated how local interaction of components of particular CAS can affect its network structure

(Biely, Dragosits, & Thurner, 2007; Gross & Blasius, 2008; Poncela, Gómez-Gardeñes, Traulsen, & Moreno, 2009; Zimmermann & Eguíluz, 2005). Among CASN features, understanding of the underlying structure of CASN is very important. CASN structures play crucial roles in affecting the functionality and behavior of the complex system represented by it such as power, learning, innovation, or flow of resources (Wang, 2002), (Estrada, 2011).

To sum up, at the second stage of my study, I investigated the impact of the emergence of macro behavior of interconnected relationships co-evolution of CASN to its firms' survivability (Sofitra, Takahashi, & Morikawa, 2013b) and to its network structure (Sofitra, Takahashi, & Morikawa, 2014). I question how and under what conditions the survivability of firms inside the SN is affected by the co-evolution of interconnected relationship strategies among them? And whether this co-evolution of interconnected relationship strategies emerges efficient SN structures?

Why is the co-evolved behavior of interconnected relationship strategies inside CASN a fascinating issue? As managers realize that their firms are not actually isolated entities but are integrated parts of a network, they will become interested in learning how the network should be controlled and the potential effects on the network and on their firm (Hakansson & Ford, 2002). Therefore, the objective of this study is to gain better understanding of the coevolution impact of interconnected relationships strategy to SN behavior and structure. The conceptual figure of the study can be seen in Figure 1.1.

1.3. The Structure of The Dissertation

After this introductory chapter, I structured this dissertation as follows:

- The second chapter

  Since my research utilized some theories coming from quite a wide field of study, I need to provide literature reviews on several background knowledge that may needed by readers to have a complete depiction of how I drive my hypothesis and conclusion.

- The third chapter

  In this chapter, I describe all of my novel methodologies that had been used in this study.

- The fourth chapter

  This chapter provides the result of my first stage study dedicating in the investigation on the behaviors that emerge as a result of the co-evolution of interconnected relationship strategies.

- The fifth chapter

This chapter provides the result of my second stage study mainly on the co-evolution impacts of the interconnected relationship strategies on firms' survivability.

- The sixth chapter

  This chapter provides the result of my second stage study on the impact of the co-evolution of interconnected relationship strategies on the structure of SN.

- The seventh chapter

  The seventh chapter compiles the conclusion from all the study results and gives the direction for further work.

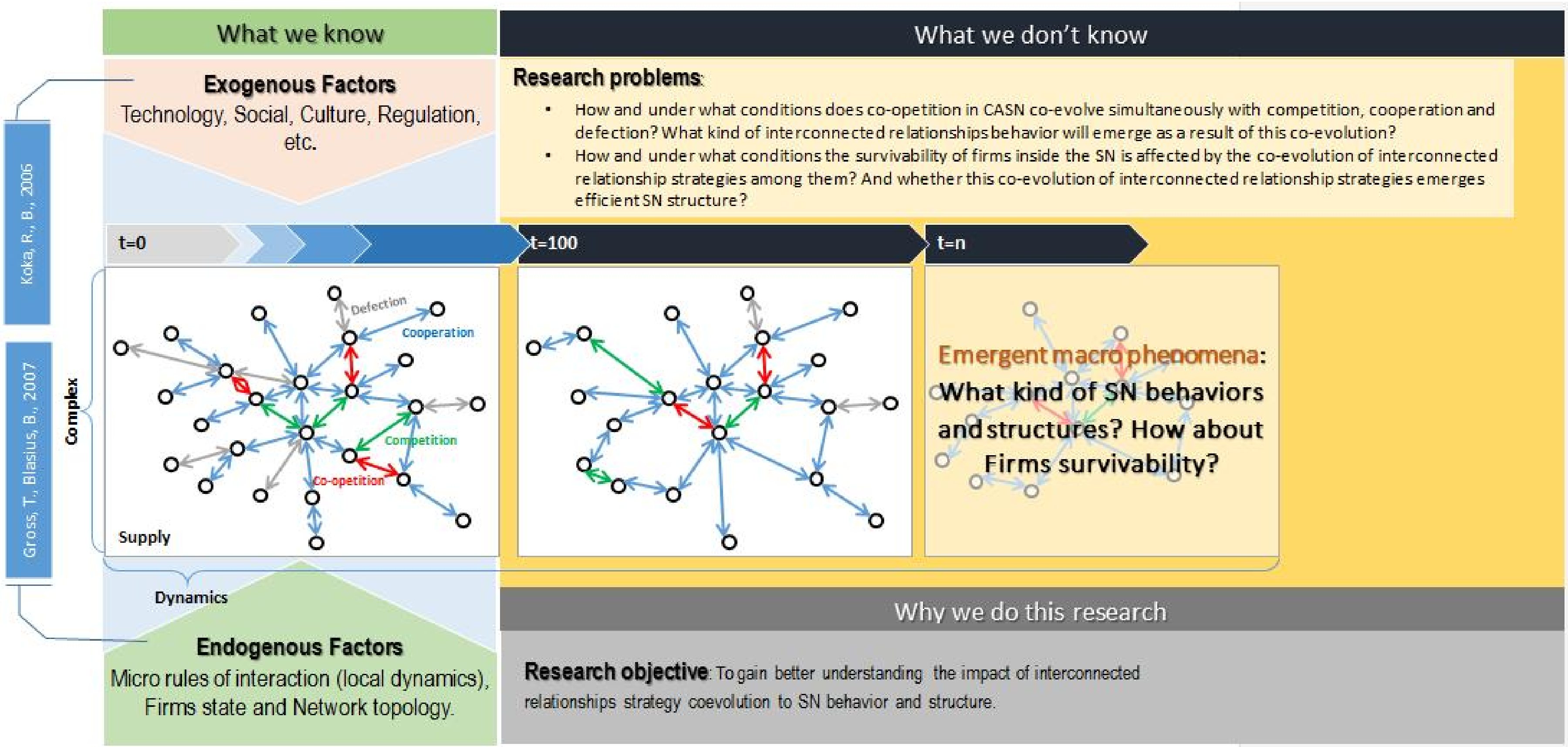


Figure 1.1 Conceptual Figure of the Study

Chapter 2 Relationship Strategies, Supply Networks and Complex Adaptive System

2.1. Supply Network and Relationship Strategies

All businesses that involved in value-adding activities acquire goods and services form a group of suppliers. This group of suppliers is called the ‘‘supply-base’’ and the buying company that purchases from its supply base is commonly referred to as the ‘‘focal company’’. Supply networks (SNs) include all companies that take part directly or indirectly in supplying industrial inputs to a focal company with or without that company’s knowledge (Choi et al., 2001). Another researcher defined supply networks as a collection of large numbers of firms from multiple interrelated industries. Such networks are subject to shifting strategies and objectives over time within a dynamic environment (Pathak, et al., 2007). Despite of the growing number of papers and interest among researcher in the management of SN, there still exists a big gap between our current understanding and how a SN actually behaves and evolves (Li, Ji, Sun, & Lee, 2009).

In a SN there are four archetypes of supplier-supplier relationship (Choi et al., 2002) i.e., competition, cooperation, co-opetition and defection. A cooperation relationship is motivated by common goals (e.g., to solve problems, to improve products or to streamline processes) (Choi et al., 2002) and/or could be motivated by resource dependency (Ritter, 2000). Cooperation relationships build upon team work, sharing information and resources. A defection relationship is provokes by short-term opportunistic behavior (e.g., to obtain better terms from other firms) (Nair et al., 2009). A competitive relationship or an "arms-length" interaction, is based on the logic of the economic risks that threaten the core competence of a firm (e.g., appropriation risk, technology diffusion risk, forward integration by suppliers, backward integration by buyers) (Choi et al., 2002).

Co-opetition is a strategy running by a firm that mixes competitive actions with cooperative activities simultaneously (Gnyawali & Madhavan, 2001). Some interrelated firms in various supply networks (SN) have reported in several papers exhibiting co-opetition relationship strategy (Gnyawali & Madhavan, 2001; Hamel, Doz, & Prahalad, 1989; Z. Wu & Choi, 2005). The motivation for doing co-opetition between rival firms in a SN can be varied namely to pursue the advantages by pooling resources and competences (e.g., access to new channels and/or markets, developing new products, learning new processes or technologies)(Bengtsson et al., 2010) or because of the obligation that coming from buyers, government regulation or other third party firms(Choi et al., 2002; Z. Wu & Choi, 2005). This fact reveals that co-opetition is the one among three kinds of relationships strategy in a SN (the two others are competition and cooperation) that in some certain situation has to be taken by firms whatever they like it or not.

Substantial empirical evidence has shown that co-opetition relationships between firms have existed for many decades (Choi et al., 2002; Gnyawali, He, & Madhavan, 2006). In contrast, research in co-opetition is relatively new and co-opetition relationship theories remain emergent (Bengtsson & Kock, 2000; Galvagno & Garraffo, 2010), especially research that addresses co-opetition interconnectivity with other types of relationship inside a network.

In networks of interrelated firms, such as in SN environment, instead a particular relationship exists and being independent from the others, they are interconnected (Ritter, 2000). No relationship in a network has been built or operates independently with the others (Hakansson & Ford, 2002). Moreover, small shift on a particular relationship state in a given network could affect the other relationships that directly connected and then in turn will affect the other indirectly connected relationships. This domino effect can bring either a minor or major implication for both individual firm and the entire SN.

In addition, the relationship strategy between firms in a SN is very dynamic instead of fixed from time to time. One type of relationship strategy (e.g., cooperation) can transform into another type of relationship strategy (e.g., competition), or two types of strategy (i.e., cooperation and competition) can run simultaneously in the form of co-opetition (Z. Wu & Choi, 2005).

Investigation of the emergent patterns of interconnected relationships of firms inside SN is very challenging. The complex interwoven and dynamic nature of the interrelationships that have evolved over time present specific challenges. Consequently, a static and reductionism approach to modeling could not be utilized.

2.2. Complex Adaptive Supply Network and Network Theory

Although bottom-up and evolutionary-approach modeling methodologies of complex adaptive systems (CAS) which are more suitable for overcoming the dynamic and complex issues has existed for decades, researchers have only recently employed CAS perspective to intensively investigate SN (Nair et al., 2009; Pathak, Day, et al., 2007; Pathak & Dilts, 2009). A CAS theory perspective for SN was initially proposed by Choi et al., (2001) in their seminal work. They popularized this approach under the name of complex adaptive supply networks (CASN).

In CASN perspective, a network of supply firms is regarded as a complex adaptive system that exhibits adaptation, self-organizing, co-evolved, and self-similarity. Since CAS theory has been well developed for years in the field of biology and physics, it will provide not only new different perspectives of a SN, but also offer abundant of tools, frameworks and approaches that can be adjusted or modified in such a way that may valuable for investigating and interpreting a CASN. Three foci of CAS which are relevant to CASN can be seen in Figure 2.1

From the perspective of inter-organizational networks; actors, activities, and resources constitute a network (Hakansson & Johanson, 1992). Actors perform activities and control resources, activities transform resources and are used by actors to achieve goals, and resources give actors power and enable activities. These elements are influencing upon each other. Networks can be seen as self-organizing systems, i.e. no leader or coordinator. In case such leaders have been identified, these structures have been called ‘‘strategic networks’’ (Jarillo, 1988). However, Wilkinson & Young (1994) argued that in the majority of cases points out that organizations in networks do both at the same time, managing and being managed.

One aspect which crucial to the behavior of any system is the pattern of connections between its components. The pattern of connections in a given system can be represented as a network (Newman, 2010). Network theory consists of elaborating how a given network structure interacts with a given process (such as information/product flow) to generate outcomes for the nodes or the network as a whole (Borgatti & Halgin, 2011). According to Brass (2002), network theory emphasizes the consequences of network variables, such as having many ties or being centrally located. Therefore, we need a network theory to explain the characteristic of network (e.g. whether it is efficient/inefficient or whether it is robust/vulnerable).

Why is network anatomy so important to be analyzed and characterized? Because its structure always affects its functionality (Strogatz, 2001). Since supply chain is composed of some interrelated companies thus, its structure or network characteristics (such as the number of companies involved, degree of relationship, topology, collaboration mechanisms, etc.) are vital in determining its behavior and performance (Nair & Vidal, 2011). "If we are to truly practice the management of supply networks, we need to understand the structure of supply networks and be able to build theories of supply networks" (Choi & Hong, 2002).

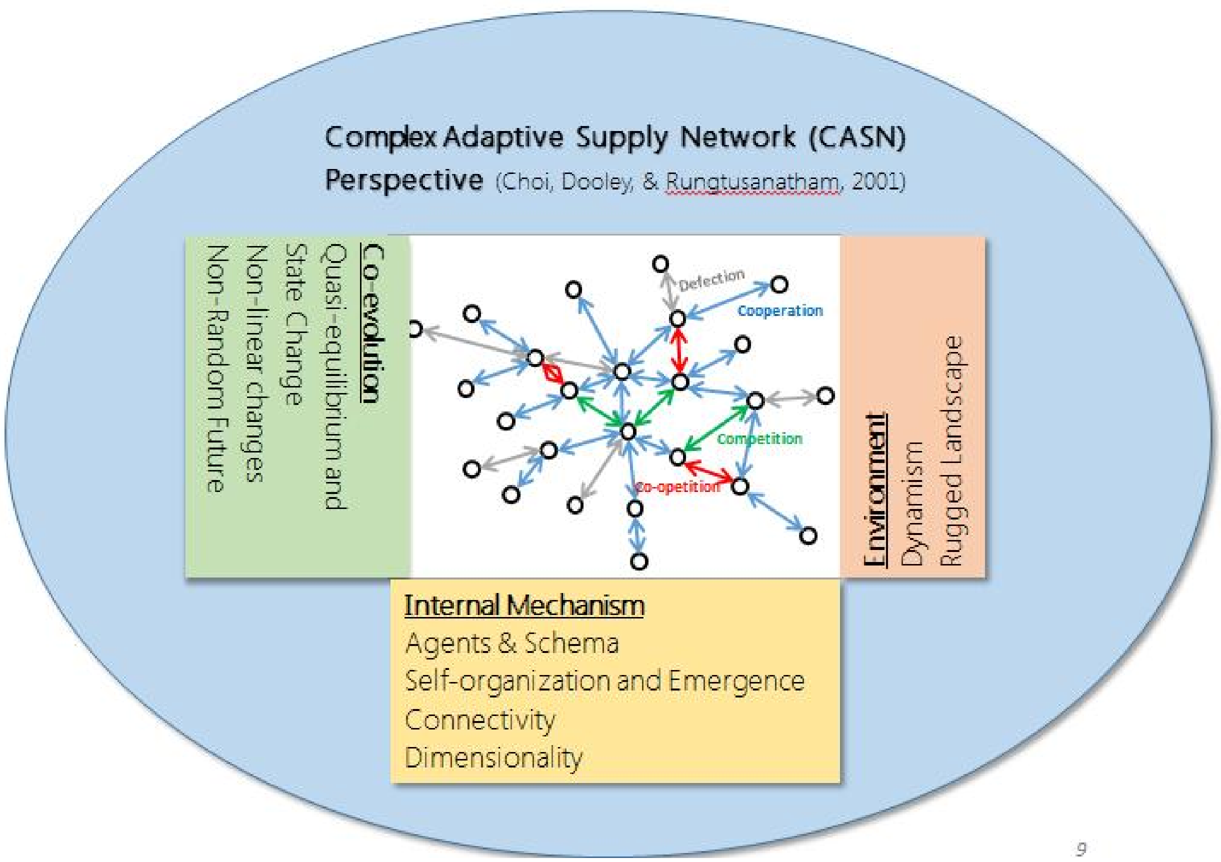


Figure 2.1 The Relevance of Three Foci of Complex Adaptive System to CASN

Chapter 3 Methodology of Research

Among the available methodologies that can be used in researching CASN problems, I utilized simulation methodology that allows us to observe the time dependent behavior and emerge phenomena of the system under consideration. Simulation also provides us with several merits e.g., insight into complex theoretical relationships among constructs, provide an analytically precise means of specifying the assumptions and theoretical logic that lie at the heart of verbal theories and also can clearly reveal the outcomes of the interactions among multiple underlying organizational and strategic processes, especially as they unfold over time (Davis, Eisenhardt, & Bingham, 2007).

3.1. Lattice and Heterogeneous Networks Structures

At the first stage of my study, I use cellular automata (CA) model that used fixed lattice structure. CA model is very suitable for this stage of study since it simplifies the structure of SN. Emphasizing the analysis of the behavior of interconnected relationships needs to reduce the complexity to the degree where the interconnectedness of the relationship could be tractable. Therefore, I simplifies the assumption of real network structure into the lattice structure.

At the second stage of my study, I emphasize on the enquiry of how the particular structure of SN emerges from the co-evolution process. This means, I need a network model that has structural features that most similar to the real world network. Consequently, I cannot use CA lattice models which use fixed structure. For the second stage of my study, I choose to use non-lattice (heterogeneous) network structure model. Table 3.1 summarizes the differences of characteristics between lattice and heterogeneous network structures.

3.2. Novel Approaches

On the first and second stage of my study, I use a common novel approach in constructing my simulation model, i.e. multi-type node and links; and dual prisoner's dilemma game payoff matrix. These approaches are detailed in the following subtitle.

3.2.1. Multi-type of Node and Link

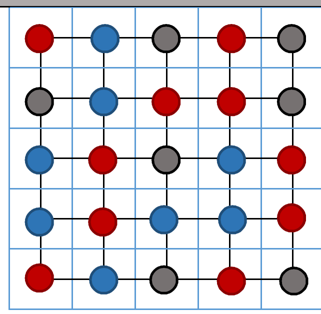
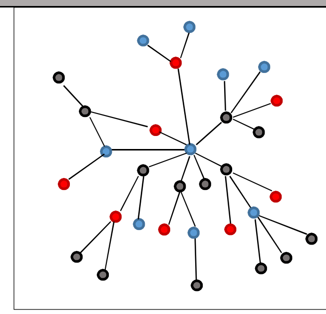
While many of previous researchers used a single type of node and link in their research framework ((Biely et al., 2007; Gang Li et al., 2013; Nair et al., 2009)) to represent firms and their relationships inside SN, I introduce a multi-type of node and link in my research framework. I used three types of node represent three different types of firm in SN that each has different resources and specific supply needs.

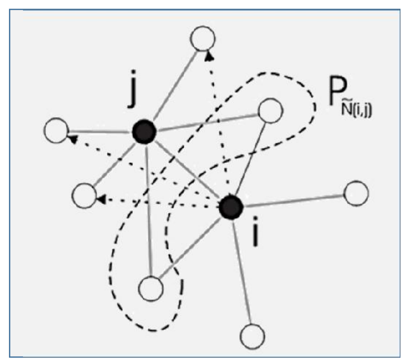
Types of node in my model (that possess and control particular resource types) represent two constructs. First, it represents the heterogeneity of resource among firms in actual SN. The objective of this first construct is to exhibit the resource heterogeneity among firms which are the driving force of the resource interdependency behaviour. This behaviour in turn will emerge cooperation or defection relationships. Second, it represents resource similarity among firms in actual SN. The objective of the second construct is to exhibit how resource similarity among firms could produce competition or co-opetition relationship.

Although in real SN, heterogeneity of resource type among firms is very high, nonetheless, in developing a simple model, I need to reduce high complexities of the real world. Consequently, I have to simplify the heterogeneity into only three types of firm. In developing this simplified assumption, I follow the argumentation of researchers positing that triad relationship (relationship among three companies, e.g., buyer-supplier-supplier) are the fundamental building blocks of a network (Choi & Wu, 2009). Therefore, every greater system (the networks) can be deconstructed into triads for analytical purposes and network effect can be demonstrated using only triad (Ritter, 2000).

Node resources and the interdependency of their supply needs are illustrated in Figure 3.1 and described in the following example: the white node possesses two types of resources, namely, black-type and grey-type resources. The white node needs a white-type resource that can only be received from the black node (the white node sends black-type resource to the black node and get white-type resource as an exchange) and/or from the grey node.

Table 3.1. Lattice vs. Heterogeneous Network Structures

<table>
<tr><th colspan="2">Differences</th><th>Lattice structure</th><th>Heterogeneous structure</th></tr>
<tr><td colspan="2">Illustration</td><td></td><td></td></tr>
<tr><td colspan="2">Connectivity structures (topology)</td><td>Connectivity is fixed and uniform (homogeneous) according to neighborhood rule. Less complex and more tractable.</td><td>Not Fixed. Heterogeneous. Can be very complex.</td></tr>
<tr><td rowspan="2">Spatial</td><td>Position</td><td>Fixed. Important in determining the way of interaction, represented by certain rules of interaction e.g., von Neumann, Moore, etc.</td><td>Not fixed. Not important.</td></tr>
<tr><td>Distance</td><td>Fixed. Not important</td><td>Not Fixed. Can be important according to the model objectives</td></tr>
<tr><td colspan="2">Neighborhood structures</td><td>

The maximum number of potential neighbors is fixed (eight or less) which follows a particular neighboring rule.</td><td>

Picture Source: (Biely et al., 2007)
The number of potential neighbors is dynamic according to model objectives. Changing neighbors means balancing the benefits and costs of exploitation versus exploration. In managing a firm's relationship portfolio this means trading off the gains from working more closely with existing partners against the potential gains from developing new relations (Hakansson & Ford, 2002).</td></tr>
</table>

All archetypes of relationships of SN, namely, cooperation, defection, competition and co-opetition, which intertwine the relationships of firms are abstractly modelled into four separated types of link. These four types of link are grouped into two categories of interaction, in accordance with the nature of the node types. The first category includes hetero-type interaction (HET) that occurs between neighboring nodes which have a different type. These HET links consist of cooperation link and defection link. The second category includes homo-type interaction (HOT) that arises between neighboring nodes of the same type. Competition link and co-opetition link constitute the HOT category. This logic represents a cooperation or defection relationship, which naturally occur between firms, that have asymmetrical resources (hetero-type), also the logic represents competition or co-opetition relationships between firms that exhibit market communality (homo-type) (Luo, 2007).

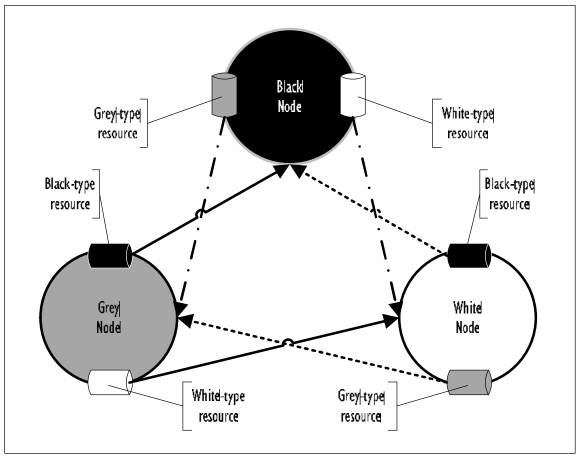


Figure 3.1 Resource Interdependency Mechanism among Cooperators and Co-opetitors

3.2.2. Dual Payoff Matrix of the Prisoner's Dilemma Game

The prisoner's dilemma game (PDG) payoff matrix is used in my model to structure and stimulate the nodes in selecting their relationship strategies toward others over time. Since my model has involved all of the archetypes of relationship strategy, therefore I have to accommodate all of these four archetypes of relationship strategy into the prisoner's dilemma game (PDG) payoff matrix. Two types of PDG payoff matrix structures were provided for the two interaction categories of HOT and HET, as shown in Table 3.2(a) and Table 3.2(b).

The PDG payoff matrix structure of HOT interaction has two types of strategy options and its consequence rewards to be considered by a HOT pairing node, i.e. competition or co-opetition strategy. The PDG payoff matrix of HET offers two types of strategy options, i.e. cooperation or defection strategy. For HOT interaction there are four type of reward namely reward for mutual competition R1, reward for mutual co-opetition R2, temptation for competition T1 and temptation for co-opetition. For HET interaction there are also four type of reward namely reward for mutual cooperation R3, punishment for mutual defection P, temptation for defection and sucker's payoff S.

When a game is on playing, actual reward will be collected by any player after both party revolve their strategy selection. For example, at the second row and last column of Table 3.2(a) we can see that if player A use a competition strategy while player B use a co-opetition strategy than player A and B will acquire T1 and T2 respectively.

Table 3.2 The payoff matrix of PD game

(**a**)

HOT Interaction		**Player B**	
		Competition	**Co-opetition**
Player A	**Competition**	**R1, R1**	**T1, T2**
	Co-opetition	**T2, T1**	**R2, R2**

(**b**)

HET Interaction		**Player B**	
		Cooperation	**Defection**
Player A	**Cooperation**	**R3, R3**	**S, T3**
	Defection	**T3, S**	**P, P**

R1 : Reward for mutual competition
R2 : Reward for mutual co-opetition
R3 : Reward for mutual cooperation
T1 : Temptation for competition
T2 : Temptation for co-opetition
T3 : Temptation for defection
S : Sucker's payoff
P : Punishment for mutual defection

Chapter 4 The Emergent Behaviors of the Interconnected Relationship Strategies inside Supply Networks

4.1. Introduction

At the network level of analysis, network complexity is the main challenge for decision makers, in predicting the consequences of their firm's relationship strategy decisions. The number of relationships that exist among the firms, and their interconnectedness, constitute SN complexity (Choi et al., 2001). Adding more to the complexity, relationships among firms are co-evolved. A small shift in the specific state of a relationship in a network could affect other relationships that are directly connected and then, in turn, will affect other relationships that are indirectly connected. Because networks constitute both a way to influence and a way to be influenced (Hakansson & Ford, 2002), the affected firms could react in turn could react back and cause negative effects.

Studying the relationships between firms was the basis of a large amount of research in the 1990s (Ritter & Gemünden, 2003), however, the theory of relationships between firms, especially when a specific relationship is situated in the context of a network, is still emerging. Ritter (2000) developed a framework that analyzed the outcome of the interconnected relationships of business networks. He posited that performance in a given relationship can be improved by managing other connected relationships. Nevertheless, his approach was limited to a static conceptual model of a triad relationship, and thus it is unclear what relational dynamics would look like if the time function was considered, and more than three players exist. Wu & Choi (2005) reveal empirical evidence of eight different types of supplier-supplier-buyer (triad) relationships. They describe how each of these eight triad relationships formed and interconnected to one another historically. Unfortunately, they do not describe how the evolution of these triad relationships is viewed in a wider context, with respect to the networks.

The dyad and triad level of SN analysis comes from reductionism methodologies in which an entire mechanism of the system under investigation can be fathomed by studying its parts. However, most systems, especially those that are composed of live beings or man-made social/economic systems, behave in a more complex manner than the sum of their components. Such systems comprise many loosely coupled entities whose individual interactions are based on local information, but collectively this arrangement would lead to complex emerging behavior.

Investigation of the emergent behavioral patterns of the interconnected relationships of firms inside SNs is challenging in two ways. First, an SN is very complex and dynamic in nature. Relationships inside an SN are not only interconnected but also co-evolved. Consequently, static and reductionism approaches could not be effectively utilized in modeling SN phenomena. Second, analysis at the network level requires a very large collection of data across many firms which may be neither available nor accessible due to confidentiality, reluctance, or other issues.

To address the first challenge, some researchers used bottom-up/evolutionary-approach methodologies of CAS which are more suitable for overcoming dynamic and complex issues. They posited that CAS perspectives and methodologies could be employed to intensively investigate SNs (Nair et al., 2009; Pathak, Day, et al., 2007; Pathak & Dilts, 2009). A CAS theory perspective on SNs was initiated by Choi et al., in 2001 and popularized as that of 'complex adaptive supply networks' (CASN). From a CASN perspective, firms in SNs can be regarded as part of an interconnected living being that exhibits co-evolution, self-organizing and recursion. To investigate SNs, a researcher can develop an SN model while emphasizing the three fundamental foci of CAS, namely the internal mechanisms, the environment and co-evolution (Choi et al., 2001).

Following this work, Nair et al. (2009) developed a CAS framework to investigate the co-evolution of relationship strategy decisions among firms at the SN level. Their experiments successfully showed how co-evolution of relationship strategy inside SNs causes the emergence of complex interconnected relationship behaviors of cooperation and defection. In accordance with Nair et al. (2009) frameworks, Gang Li et al., (2013) investigated the impacts of SN topologies on the co-evolution of a cooperation and defection strategy inside an SN. They concluded that heterogeneous network structures are helpful for promoting cooperation. Nonetheless, both of the papers still focus on co-evolution between cooperation and defection. In fact, there are other archetypes of relationship strategies that exist and that might have a significant influence on relationship strategy co-evolution inside SNs, i.e., competition and co-opetition.

Interaction between firms in an SN can be manifested in several types of relationship strategies that are closely related to one another. Choi et al. (2002) identified three archetypes of supplier-supplier relationships, i.e., competition, cooperation, and co-opetition. A cooperation relationship is motivated by common goals (e.g., to solve problems, to improve products or to streamline processes) (Choi et al., 2002) and/or could be motivated by resource dependency (Ritter, 2000). Cooperation relationships build upon team work, sharing information and resources. A defection relationship is provoked by short-term opportunistic behavior (e.g., to obtain better terms from other firms) (Nair et al., 2009).

A competitive relationship or an "arms-length" interaction, is based on the logic of the economic risks that threaten the core competence of a firm (e.g., appropriation risk, technology diffusion risk, forward integration by suppliers, backward integration by buyers) (Choi et al., 2002). Co-opetition is a relationship strategy that mixes competitive actions with cooperative activities (Gnyawali & Madhavan, 2001). The drivers of co-opetition vary, specifically, the structural conditions; the need to pool resources and competencies for innovation, production, or distribution (Bengtsson et al., 2010); changes in market, institutions or regulations, or complementary resources or knowledge (Padula & Dagnino, 2007). Broader network relationships with embedded dyadic relationships are the driving force for why and how co-opetition occurs (Bengtsson et al., 2010).

All the archetypes of relationship strategies should be considered in the construction of interconnected relationship strategy co-evolution models. Considering only cooperation and defection in a model will mean that the model represents only the interaction among firms with dissimilar resources. At the same time, interactions among firms that have a high resource similarity, where competition or co-opetition relationships could naturally emerge, have been neglected. Changing its relationship strategy toward other firms is part of the natural adaptability behavior of a firm. For example, one type of relationship strategy (e.g., cooperation) can be affected by other relationship strategies and can transform into other types of strategies (e.g., defection) (Nair et al., 2009). Two types of strategies (i.e., cooperation and competition) can operate simultaneously in the form of co-opetition (Wu & Choi, 2005). My research extends the research framework of Nair et al. (2009) by means of accommodating not only cooperation and defection but also co-opetition and competition relationship strategies into my model.

The aim of this study is to investigate interconnected relationship co-evolution behaviors inside SNs and address the following SN relationship co-evolution questions:

- Under certain contexts of firm interaction policies and business situations, how does a specific relationship strategy connect and co-evolve with other types of relationship strategy? What types of macro-behavioral patterns will emerge as a result of the co-evolution process of these interconnected relationships?
- SN population will potentially add to the level of complexity in a network. Dynamically, some firms will join or leave the business, increasing or decreasing the level of complexity of the SN. If there are some attractors of interconnected relationships that emerge in a specific SN context, could the SN population alter or shift these attractors?

The answers to the above research questions will hopefully be beneficial for increasing our understanding of CASN behavior.

In this paper, I model the interactions of firms inside SNs using a CA simulation framework and CAS perspectives (for further discussion on CA model advantage in analyzing CASN, readers can refer to Davis et al. (2007). Experiments that use PDG reward schemes representing various business situation factors have been built to answer the research questions. The experiment results show that co-evolution of interconnected relationship strategies has generated interesting macro-attractors.

This chapter is organized as follows: Section 4.2 discusses the simulation model development; Section 4.3 provides the experimental designs and results of the simulation; finally, a discussion, conclusions and managerial implications are given in Section 4.4.

4.2. Model Development

4.2.1. The Agents

I modeled actual SNs consisting of interconnected heterogenic firms, possessing and controlling a large variety of resources, into a CA model. Different types of nodes (agents) possessing and controlling a unique combination of resources constitute this CA model (see Figure 4.1).

The types of node serve two modeling objectives: to represent resource heterogeneity and resource similarity concepts among firms in actual SNs. Resource heterogeneity among nodes is designed to produce resource interdependency behavior that, in turn, will elicit cooperation or defection relationships. At the same time, resource similarity among nodes is designed to be a driver for competition or co-opetition relationship.

To produce a simple model, I simplify firms' heterogeneity of SN into three types of nodes. I argue that by using only three types of nodes I can still maintain the rich variety of possible combinations of node relationships. My argument is based on the triad relationship (e.g., buyer-supplier-supplier) concept, which is a fundamental building block in networks (Choi & Wu, 2009). Every network can be decomposed into triads for analytical purposes, and the network's effect can be demonstrated using only triads (Ritter, 2000). Because my model should adopt CAS perspectives, I have consequently developed a model that is composed of many triad relationships (micro-rules) to investigate macro-phenomena that could emerge from such a system.

Resource interdependency mechanisms among nodes are illustrated in Figure 4.2 and can be described in the following exchange situation example, in which the white node is considered to be a focal firm. By default, the white node possesses two types of separable resources, namely, β and γ types. To survive, the white node needs α type resource, which can be fulfilled by exchange of the β type resource with the black node and/or exchange of the γ type resource with the gray node.

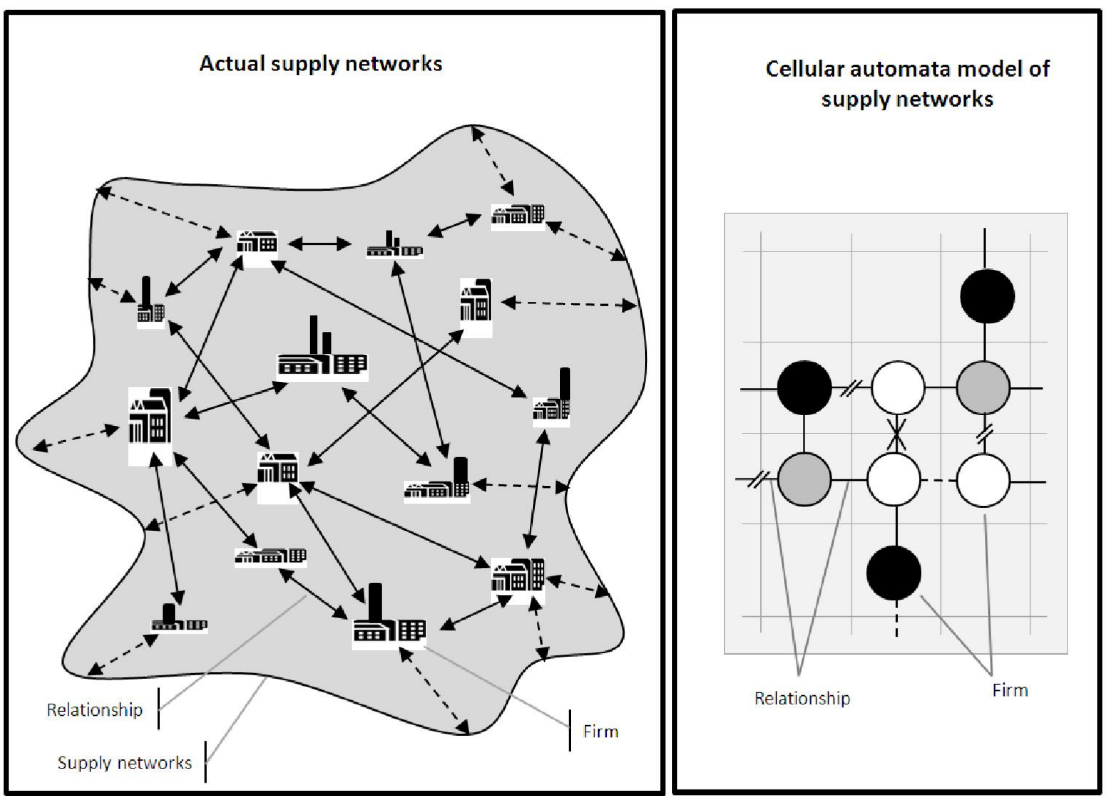


Figure 4.1 Actual SN (left) and CA Model of CASN (right)

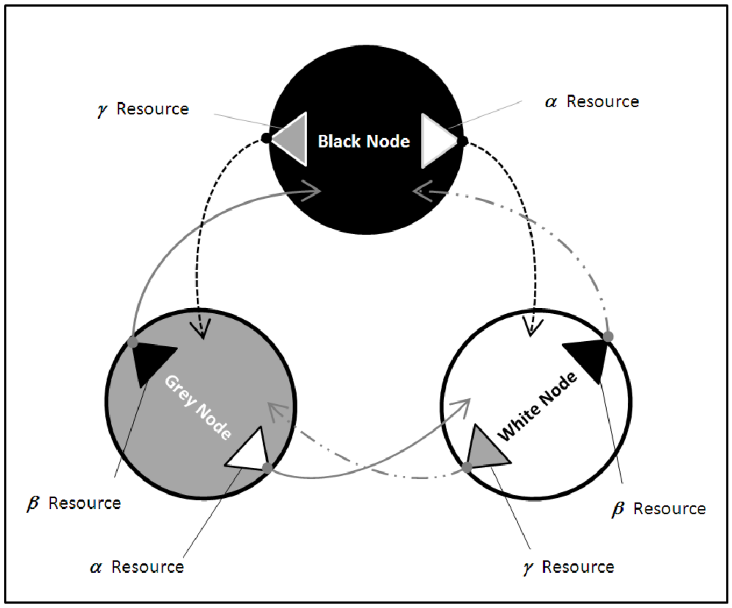


Figure 4.2 The Resource Interdependency among Nodes.

4.2.2. General Rules for Agent Interactions and Connectivity

In my model, the nodes, their interconnected relationships and the environment co-evolve the following designed simulation mechanisms. To represent spatial functions for nodes in my model, I adopted von Neumann neighborhood rules in a two-dimensional toroidal grid structure. I define node interaction in this grid in two categories. The first category includes the hetero-type (HET) interaction that occurs between neighboring nodes that are displayed by different colors. These neighboring HET nodes can choose to cooperate with each other or to defect from their previous cooperation relationship. The second category includes the homo-type (HOT) interaction that arises between neighboring nodes of the same color. HOT neighboring nodes can choose to compete with each other or to engage in a co-opetition relationship. This logic represents a cooperation or defection relationship, which naturally occurs between firms that have asymmetrical resources and also the logic represents competition or co-opetition relationships between firms that exhibit market and/or resource communality (Luo, 2007).

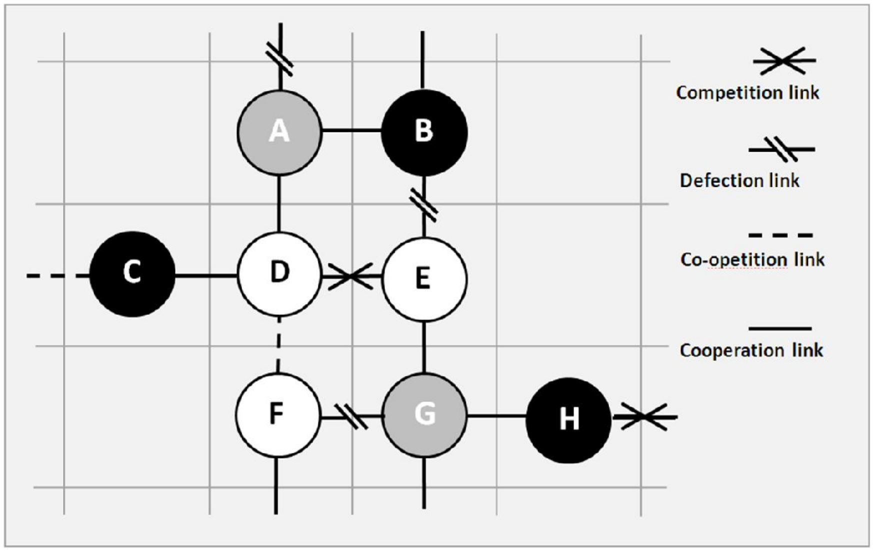


Figure 4.3 An Illustration of All the Relationship Types.

To illustrate agent interactions and connectivity in action, Figure 4.3 reveals situations in which a specific relationship has occurred at a certain point in the simulation cycle (tick). First, we can see a cooperation relationship emerging when a pair of HET nodes is situated as neighboring cells (e.g., between node *A* and *B*). When these nodes eventually agree to establish a cooperation relationship, the simulation system will generate a cooperation link. Second, we can see a defection relationship (e.g., between node *F* and *G*) occurring when one or both HET neighboring nodes decide to terminate their previous cooperation relationship.

Third, neighboring HOT nodes that have the same resource types (e.g., nodes *D* and *E*) will compete with each other. A competition relationship is a default relationship emerging automatically when HOT nodes are neighbors.

Fourth, when neighboring HOT nodes that previously competed with each other simultaneously decide to cooperate (e.g., node *D* and *F* in Figure 4.3), an emergent relationship called a co-opetition relationship begins. In a co-opetition relationship, resource exchanges do not occur between the two parties involved, but it involves their neighbors. Before a co-opetition relationship can be established between *D* and *F*, both parties will access information about their pairing partner concerning the resources owned by their partner's neighbor (e.g., *F* will access information about *D* concerning resources owned by *C* and *A*, whereas *D* will access information about *F* concerning resources owned by *G*). The co-opetition relationship is established when *D* agrees to convey the resources of *C* and/or *A* to *F*.

Consequently, this agreement requires that a cooperation relationship between *D* and *C* and/or *A* be established concomitantly. Note that *D* agrees to convey only the resources that it does not require for itself in the current cycle. Therefore, a pair of firms that are involved in a co-opetitive relationship must have distinctive resources that are used for a competitive business core and concurrently have other unique resources that simultaneously enhance and develop both firms (Bengtsson & Kock, 2000).

A resource exchange mechanism implies that a firm can act as a buyer (supplier) in one transaction and a supplier (buyer) in another transaction. This mechanism is an important feature of high-level abstraction of our problem in CA, which emulates complex interrelationships between firms in an SN, as argued by Nair et al. (2009) and Choi & Krause, (2006).

As mentioned in the introduction, my CA model also employs PDG reward schemes. The following subsection will discuss how I integrate PDG reward schemes into my CA model.

4.2.3. Reward Schemes of the Prisoner's Dilemma Game

PDG reward schemes are used to stimulate node decision making in selecting relationship strategies over time. Two categories of RPDG payoff matrix were simultaneously employed in this model, as shown in Table 4.1 (a) and (b). The first category, named hetero-type (HET) RPDG payoff matrix (P_{ij}^0), is designed to serve the interaction game between node *i* and its neighboring nodes of different colors (N_i^0). HET RPDG offers two relationship strategies, i.e., cooperation (a^c) or defection (a^{def}). The second category includes the homo-type (HOT) RPDG payoff matrix (P_{ij}^1), which serves the interaction game between node *i* and its neighboring nodes of the same color (N_i^1). HOT neighboring nodes may choose to compete with each other (a^{com}) or to engage in a co-opetition strategy (a^{cop}).

In this CA model, nodes and their interconnected relationships inside a grid Γ are dynamically co-evolved. They will occasionally be produced, eliminated and reproduced over time. After nodes play RPDG with their neighbors and make several decisions regarding their relationship strategies, actual relationship links of chosen strategy a^x between node *i* and *j* (l_{ij}^x) are then established by the simulation system in accordance with the designed simulation mechanism or rules.

When a game is on playing, actual reward will be collected by any player after both party revolve their chosen strategy. For example, at the second row and last column of Table 4.1 (a) we can see that if player A use a competition strategy (a^{com}) while player B use a co-opetition strategy (a^{cop}) than player A and B will acquire rewards T1 and T2 respectively.

Every node in the CA grid must simultaneously make a number of decisions about relationship strategy that depend on the number of existing neighbors. As shown in Figure 4.3, each of the nodes can concurrently have a maximum of four relationships with its neighboring nodes at each tick.

4.2.4. Agent Attributes and CA Environmental Parameters

In this CA simulation model, several node attributes have been considered, namely, capacity ($\lambda_{ij}(t)$), fitness ($w_i(t)$), cost ($c_i(t)$), and profit ($p_i(t)$). Two types of environmental parameters, i.e., environmental expectation ($0 < W_c \leq 1$) and the birth rate (θ), have also been considered.

The fitness function as employed by Li et al., (2009) is adopted. Fitness expressed by a real number [0-1] represents the ability of a firm to exist and adapt to survive. The higher the value of $w_i(t)$, the higher the ability of a firm to adapt to its environment. At every tick, each node's fitness will be evaluated. If $w_i(t) < W_c$, then node *i* will be eliminated from the grid at the subsequent tick. The fitness constructed in my CA model accommodates the balance mechanism of internal-fit and environmental-fit of a firm's fitness concepts (McCarthy, 2004). The Internal-fit is represented by the capacity attributes of a node, whereas environmental-fit is represented by the efficiency of the node supply, i.e., its cost attribute.

Table 4.1 The Reward Schemes of PDG**.**

(**a**)

<table>
<tr><th colspan="2" rowspan="2">Homo-Type Interaction</th><th colspan="2">Player B</th></tr>
<tr><th>Competition</th><th>Co-opetition</th></tr>
<tr><td rowspan="2">Player A</td><td>Competition</td><td>R1, R1</td><td>T1, T2</td></tr>
<tr><td>Co-opetition</td><td>T2, T1</td><td>R2, R2</td></tr>
</table>

(**b**)

<table>
<tr><th colspan="2" rowspan="2">Hetero-Type Interaction</th><th colspan="2">Player B</th></tr>
<tr><th>Cooperation</th><th>Defection</th></tr>
<tr><td rowspan="2">Player A</td><td>Cooperation</td><td>R3, R3</td><td>S, T3</td></tr>
<tr><td>Defection</td><td>T3, S</td><td>P, P</td></tr>
</table>

R1 : Reward for mutual competition
R2 : Reward for mutual co-opetition
R3 : Reward for mutual cooperation
T1 : Temptation for competition
T2 : Temptation for co-opetition
T3 : Temptation for defection
S : Sucker's payoff
P : Punishment for mutual defection

The capacity $\lambda_{ij}(t)$ represents the amount of a separable resource *j* possessed by node *i* at the beginning of time t. Each node at the initial simulation stage possesses the same number of resources. Some of the attributes and environmental parameters have been set to dynamically affect another attribute as shown in Equations (4.1) to (4.5). In Equation (4.1), $\Delta\delta_i(t)$ denotes the decay rate for a firm's fitness, which is related to W_c. This equation states that, at every tick, a firm's fitness will always decrease unless the firm can generate a positive increase in profit at time *t,* i.e. $\Delta p_i(t)$.

$$w_i(t+1) = w_i(t) + \Delta p_i(t) - \Delta\delta_i(t) \qquad (4.1)$$

$$\lambda_{ij}(t+1) = \lambda_{ij}(t) + \Delta w_i(t) \qquad (4.2)$$

$$c_i(t+1) = c_i(t) - \Delta w_i(t) \qquad (4.3)$$

$$p_i(t) = f[e_i(t), c_i(t), r_i(t)] \qquad (4.4)$$

$$\theta(t) = \max(\theta, n(t)) \qquad (4.5)$$

A positive change in a node's fitness at time *t* has a positive influence on its capacity at time *t*+1 (Equation (4.2)) and has a negative influence on its cost at time *t*+1 (Equation ((4.3)). Clearly, an increase in the fitness value of a node will increase its supply and demand capacity and decrease its supply cost, whereas a decrease in the fitness value of a node will decrease its supply and demand capacity and increase its supply cost or decrease its efficiency.

Profit is a function of the resources exchange $e_i(t)$ and is a consequence of the cost $c_i(t)$ and reward $r_i(t)$ (Equation (4.4)). In Equation (4.5), $n(t)$ represents the numbers of empty cells at time *t* while θ corresponds to the rate of newcomers in the business at a specific stage.

4.3. The Simulation Experiments

A series of experiments has been conducted. The first experiment was designed to answer the first research question (i.e. how does a specific relationship strategy connect and co-evolve with other types of relationship strategy? What types of macro-behavioral patterns will emerge as a result of the co-evolution process of these interconnected relationships?), and an extended experiment was designed to answer the second research question (If there are some attractors of interconnected relationships that emerge in a specific SN context, could the SN population alter or shift these attractors?). Both of the experiments used identical CA simulation models and experimental designs. However, the extended experiment used varying grid sizes and node population sizes as additional experimental factors.

4.3.1. Experimental Design

The PDG reward schemes, i.e., the HET and the HOT, are designed as experimental factors *A* and *B* respectively. I introduce three business situation scenarios for each experimental factor to be its levels, as follows:

Factor-A. HET reward scheme:

A.1. Favorable for cooperation ($R3 \geq T3$).

A.2. Favorable for defection ($T3 > R3$).

A.3. Dilemma between cooperation and defection ($T3 > R3 > P > S$).

Factor-B. HOT reward scheme:

B.1. Favorable for competition ($R1 \geq T2$).

B.2. Favorable for co-opetition ($T2 > R1$).

B.3. Dilemma between co-opetition and competition ($T2 > R1 > T1 > R2$).

The experimental runs are generated from permutations of the levels' factors. To confirm the results, and for replication purposes, two sets of reward scheme parameters (Table 4.2) are generated for each level. These two factors will therefore produce 6^2 permutations in total, which outline all of the experimental runs.

Table 4.2 Levels and Sub-levels of Factors A and B

Level	Sub-Level	Reward Scheme Parameter Setting
Favorable to cooperation **(A1)**	***a***	[(R3= T3=3); (P=S=0)]
	b	[(R3=5); (T3= 3); (P=1); (S=0)]
Favorable to defection **(A2)**	***c***	[(T3=P=3);(R3= 1); (S=0)]
	d	[(T3=5); (P=3); (R3=S=1)]
Cooperation - defection dilemma **(A3)**	***e***	[(T3=5); (R3=3); (P=S=0)]
	f	[(T3=4); (R3=3); (P=2); (S=1)]
Favorable to competition **(B1)**	***i***	[(R1= T2 =3);(R2=T1=0)]
	ii	[(R1=5); (T2= 3);(R2=1);(T1=0)]
Favorable to co-opetition **(B2)**	***iii***	[(T2=R2=3);(R1= 1);(T1=0)]
	iv	[(T2=5); (R2=3); (R1= T1=1)]
Co-opetition-competition Dilemma **(B3)**	***v***	[(T2=5); (R1=3); (R2=T1=0)]
	vi	[(T2=4); (R1=3); (R2= 2);(T1=1)]

4.3.2. Agent interaction policies, parameter settings and response variables

In this experiment, nodes that are exposed to certain business situations will react to the stimulus according to the designed interaction policies (see Table 4.3) For example, in a business situation that favors competition, a node will tighten the selection process of competitors that become its co-opetition partner. Therefore, each node will decide to run a selective co-opetition policy toward their HOT neighbor. In a business situation in which dilemmas over interaction strategies occur, the best policy is to maintain all the established relationships or to use a strategy that is employed by the partner/opponent, i.e., a tit-for-tat (TFT) strategy. To hinder a network that has all defection and all competition relationships, a TFT policy with 0.05 odds of forgiveness has been employed.

At each tick, nodes that engage in cooperation or co-opetition relationships in the grid exchange their resources with each other and simultaneously act as suppliers and demanders, which indicate that a firm can act as a buyer (supplier) in one transaction and a supplier (buyer) in another transaction.

Each node in the CA grid has to simultaneously make several relationship strategy decisions that depend on the agent's relationship policy O_r and the number of its existing neighbors. As shown in Figure 4.3, each node can concurrently conduct a maximum of four similar or different types of relationships with its neighboring node at one particular tick.

The amount of resource exchange $e_i(t)$ was defined as

$$e_i(t) = \sum_j e_{ij}^c(t) + \sum_j \sum_k e_{ijk}^{cop}(t); \tag{4.6}$$

Where the sum of resource exchange from cooperation

$$\sum_j e_{ij}^c(t) = \min\left\{\lambda_{is}(t), \sum_{j\epsilon N_i^0(t;O_r)} \lambda_{js}(t)\right\} \tag{4.7}$$

And the sum of resource exchange from co-opetition

$$\sum_j \sum_k e_{ijk}^{cop}(t) = \min\left\{\lambda_{is}(t) - \sum_j e_{ij}^c(t)\,, \sum_{j\epsilon N_i^1(t;O_r)} \sum_{k\epsilon N_j^0(t;O_r)} \lambda_{jks}(t)\right\} \tag{4.8}$$

Figure 4.4 shows the basic rule of agent's interaction that has been described above.

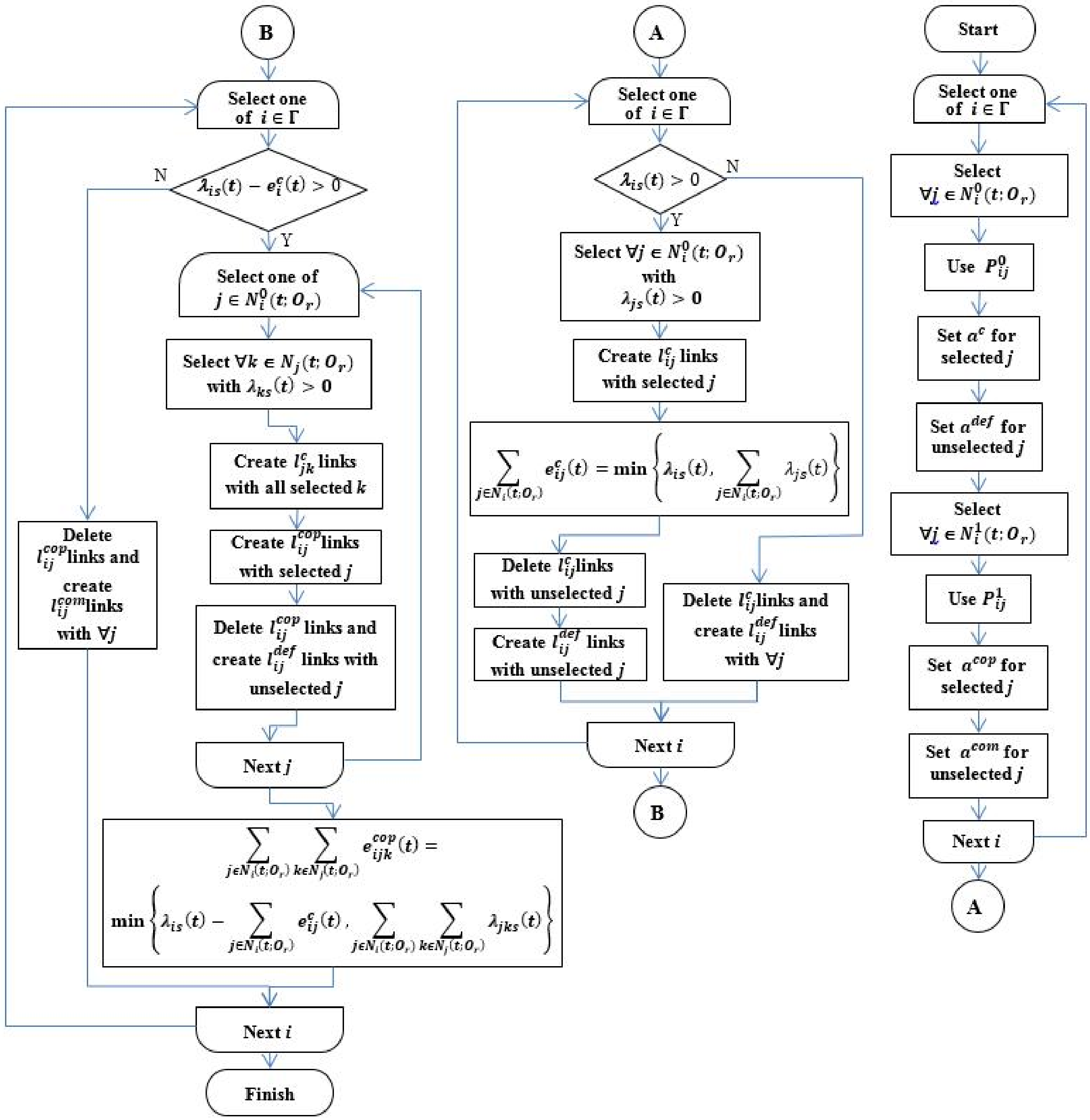


Figure 4.4. Basic rules of Agent's Interaction Flowchart

The experiment was initiated with the following settings: an equal proportion of node's type, i.e., (1:1:1) for (gray:black:white); initial node I=1300; environmental expectation W_c=0.25; and birth rate θ=20. From pre-experimental simulation runs, I found that these parameter settings guaranteed an equal proportion for every agent type and produced agent populations from 90% to 100% on the grid during the simulation time.

In accordance with the point of interest, I measure the intensity of a specific type of relationship strategy by counting the number of relevant links that have emerged during the experimental cycle. I therefore collect four response variables from the experimental runs, i.e., the number of cooperation links for every tick (x_{coo}); the number of defection links for every tick (x_{def}); the number of co-opetition links for every tick (x_{cop}); and the number of competition links for every tick (x_{com}).

Table 4.3 Agent Interaction Policies

No	Business Environment Situation	Agent's Interaction Policy (O_r)	
1.	Favorable for cooperation	*Full cooperation:* Node will decide to engage cooperation relationship strategy with all hetero-type neighbors and exchange resources proportional to the neighbors' fitness (or according to the availability of a neighbor's resources)	Hetero-type relationship
2.	Favorable for defection	*Selective cooperation:* Node will decide to engage cooperation relationship strategy only to the hetero-type neighbor which has the highest fitness, and engage defection strategy to the others.	
3.	Dilemma between cooperation or defection	*TFT 0.05 odds forgiveness*: Node will make decisions about their relationship with their hetero-type neighbors based on the tit-for-tat (TFT) strategy with 0.05 odds of forgiveness.	
4.	Favorable for co-opetition	*Full co-opetition:* Node will decide to engage co-opetition relationship strategy with all of their homo-type neighbors and exchange resources proportional to their neighbors' fitness (or according to the availability of their neighbor's neighbor resources).	Homo-type relationship
5.	Favorable for competition	*Selective co-opetition:* Node will decide to engage co-opetition relationship strategy only to the homo-type neighbor which has the highest fitness, and engage competition to the rest of the hetero-type neighbor.	
6.	Dilemma between competition or co-opetition	*TFT 0.05 odds forgiveness*: Nodes will select competition or co-opetition strategy based on the TFT strategy using 0.05 odds of forgiveness.	

4.3.3. First experiment implementation

According to the first research question, I hypothesize that, under certain business situations, a specific relationship strategy will dominate, and its existence will co-evolve with other types of relationships.

The first experiment uses a 51×51 grid (i.e., 2601 empty cells available) which is similar to that of Nair et al. (2009). The simulation is initiated by generating nodes which are randomly distributed over the empty grid cells. The attributes and environmental parameter settings are then established.

The iteration at each simulation tick is composed of the following three steps:

- First step:

  Every node will examine the PDG reward scheme and select the most suitable interaction policy. In the case where it selects a TFT strategy policy, it will also evaluate the neighbors' relationship decision at the last tick. Afterward, it starts to simultaneously decide the types of strategies it will engage in with each neighbor at the current tick.

- Second step:

  An appropriate type of relationship link for every pair of nodes is generated based on their total decisions (e.g., a cooperation link will be generated if both HET nodes decide to cooperate, otherwise a defection link will be created). In the case of cooperation or co-opetition relationships, the nodes will start to supply each other after the link is established. At the end of the step, each node will calculate its profit and update its current fitness, capacity and cost.

- Third step:

  The simulation eliminates all of the nodes whose fitness $w_i(t) < W_c$. In accordance with birth rate $\theta(t)$, I defined 1000 simulation ticks as a stopping rule because it is known from pre-experimental simulation runs that relatively stable situations for all response variables have been achieved when the simulation reaches 1000 ticks. The snapshot of the running simulation can be seen in Figure 4.5

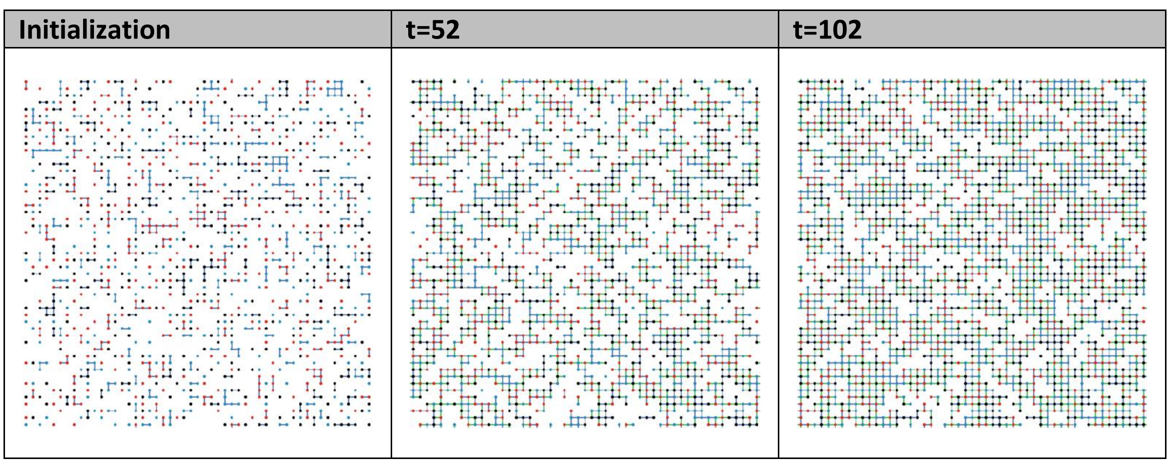


Figure 4.5 Snapshots of the Running Simulation

4.3.4. The results of the first experiment.

Since the simulation results from 27 replication runs have conformed to the nine main experimental runs, I only need the results from the nine main experimental runs to represent the behavior of all of the response variables throughout the simulation ticks, as shown in Figure 4.6. This figure shows that all response variables in the nine business situations exhibit similar phase shifts, from transient to stable after 100 ticks.

To obtain a better comparison of the behavior of similar types of response variables for the nine unique business situations, the average value of all of the response variables/ticks, i.e., average number of cooperation link $\bar{X}_{coo}$, average number of defection link $\bar{X}_{def}$, average number of co-opetition link $\bar{X}_{cop}$, and average number of competition link $\bar{X}_{com}$ for all 36 experimental runs calculated. The run have been grouped them into their own type and plot them on surface charts, as shown in Figure 4.7. The charts in Figure 4.7 use two axes; the first axis is for the experimental factor *A* called HET axis, which is composed of sub-level *a* to *f*. The second axis is for the experimental factor *B* called HOT axis, which is composed of sub-level *i* to *vi.*

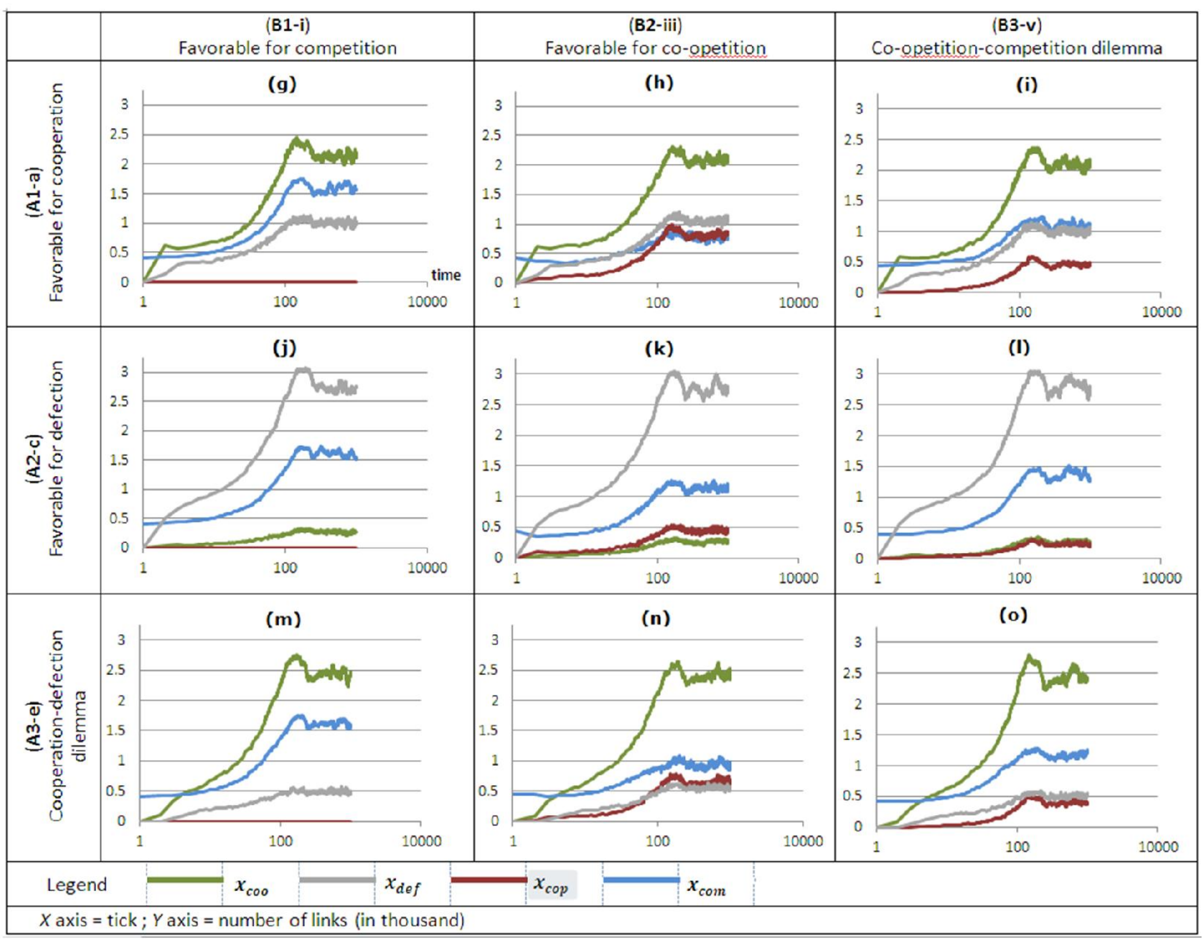


Figure 4.6 Semi-log Plots of the Behavior of All Response Variables in Nine Unique Business Environment

Figure 4.7(p), shows that the average number of co-opetition link $\bar{X}_{cop}$ is at its highest point when the business situation is favorable for co-opetition and cooperation (cross-section block of *iii*−*iv* and *a*−*b*). This behavior emerges because of the interaction rules that obligate every co-opetition relationship's existence to be simultaneously supported by the existence of related cooperation relationships. Interestingly, average number of co-opetition link $\bar{X}_{cop}$ in a business situation that is favorable for defection (*c*−*d* block) throughout the HOT axis, is lower compared with the *a*−*b* and *e*−*f* blocks. This emerging phenomenon can be explained by the notion that the business situation that is favorable for defection results in fewer nodes conducting cooperation relationships (see Figure 4.6 (j), Figure 4.6 (k), and Figure 4.6 (l)). Because co-opetition relationships require the establishment of cooperation relationships, a reduction in x_{coo} will also reduce the probability that co-opetition relationships will dominate. This finding provides support to my experimental hypothesis (i.e. under certain business situations, a specific relationship strategy will dominate).

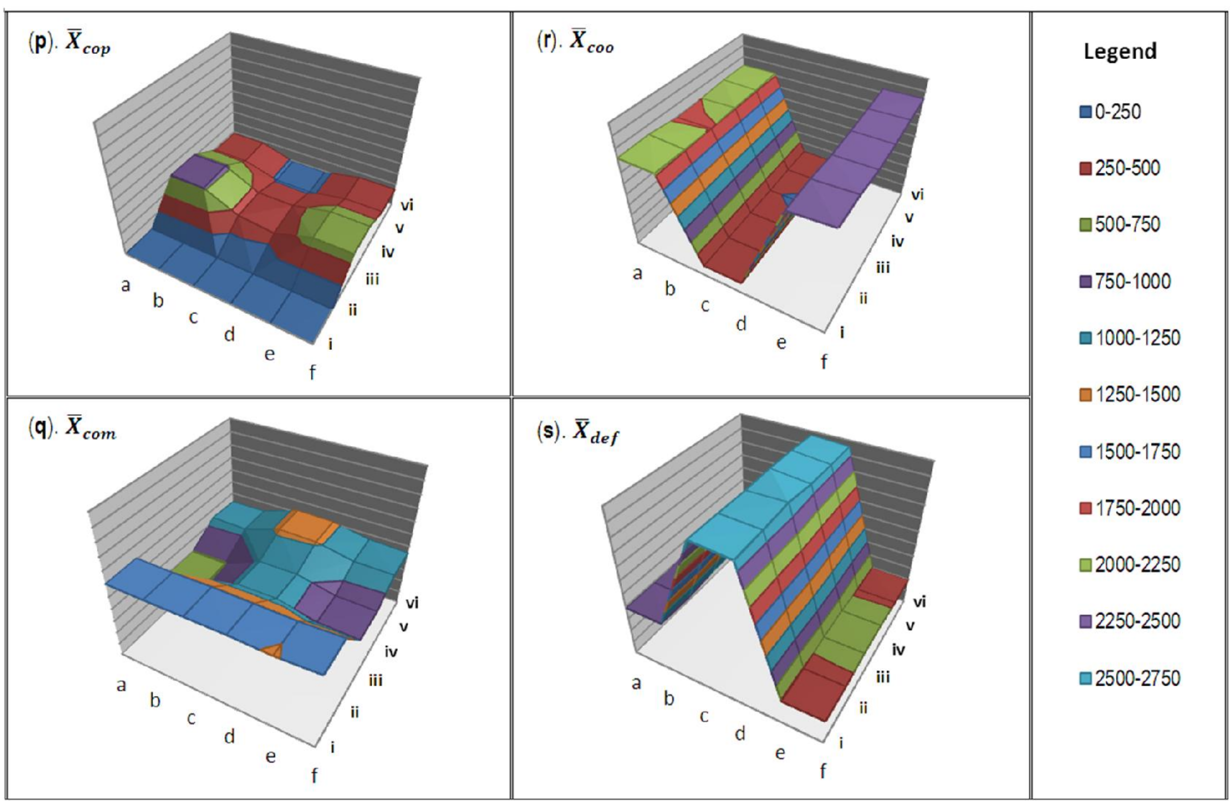


Figure 4.7 Surface Chart of Average Number of Cooperation Link $\bar{X}_{coo}$(r), Average Number of Defection Link $\bar{X}_{def}$(s), Average Number of Co-opetition Link $\bar{X}_{cop}$(p) and Average Number of Competition Link $\bar{X}_{com}$(q) in Nine Environmental Situation Scenarios.

As illustrated by Figure 4.7 (q), average number of competition link $\bar{X}_{com}$ is at its lowest point when the business situation is favorable for co-opetition and cooperation (cross-section block of *iii*−*iv* and *a*−*b*), whereas, in the business environment that is favorable for defection (*c*−*d* block), the average number of competition link $\bar{X}_{com}$ number are relatively high. This result is also an intriguing finding that supports the experimental hypothesis. My rationale for this behavior is that high numbers of number of co-opetition link x_{cop} require high numbers of number of cooperation x_{coo} to be established concurrently. Conversely, in the business situation that is favorable for defection, competition will become salient (see Figure 4.6 (j), 4.4(k), and 4.4(l)).

The surface charts of average number of co-opetition link $\bar{X}_{cop}$ (Figure 4.7 (p)) and average number of competition link $\bar{X}_{com}$ (Figure 4.7 (q)) are clearly complementary. This observation is also valid for the surface charts of average number of cooperation link $\bar{X}_{coo}$ (Figure 4.7 (r)) and average number of defection link $\bar{X}_{def}$ (Figure 4.7 (s)). Furthermore, the effect of the business situation favoring defection relationships can not only be seen on the surface-chart of average number of cooperation link $\bar{X}_{coo}$ but also appears on the surface-charts of average number of co-opetition link $\bar{X}_{cop}$ and average number of competition link $\bar{X}_{com}$. These apparent phenomena reveal the interconnected aspects of the relationship co-evolvements inside the CASN. It can therefore be confirmed that all of the results from this experiment support my hypothesis (i.e. under certain business situations, a specific relationship strategy will dominate, and its existence will co-evolve with other types of relationships).

Additional runs for the first experiment several times show that the shape of each of the surface charts in Figure 4.7 always appears similar. This phenomenon suggests that these shapes are archetypal of behavioral patterns or attractors. To further explore these attractors and investigate how they could shift, an extended experiment is developed in the following subsection.

4.3.5. Extended experiment design

There is a concern that the attractors demonstrated in the first experiment have enforceable limits. Motivated by the second research question (i.e. If there are some attractors of interconnected relationships that emerge in a specific SN context, could the SN population alter or shift these attractors?), the extended experiments were conducted by altering the population size of the SN. The SN population size is expressed by the percentage of occupied grid cells. Its value is dynamically changed within certain intervals throughout the simulation ticks and is determined by initial node *I*, environmental expectation W_c, birth rate θ and the grid size.

The extended experiment inherits all factors and sub-levels from the first experiments (Factor *A* and *B*) and utilizes additional factors, as follows:

Factor-C Grid size.

Levels of grid size: 11×11; 31×31; 51×51; 71×71; and 91×91.

Factor-D Interval of SN population percentages.

Levels of intervals: 30%−40%; 60%−70%; and 90%−100%.

For each level factor *D,* two sets of environmental parameters are arranged for confirming the results as shown in Table 4.4. The total number of extended experimental runs is therefore 6×6×5×6=1080 experimental runs.

Table 4.4 The Environmental Parameter Settings for the Extended Experiment.

Levels			**(C1)** 11 x 11			**(C2)** 31 x 31			**(C3)** 51 x 51			**(C4)** 71 x 71			**(C5)** 91 x 91		
			I	***Wc***	θ	***I***	W_c	θ	***I***	W_c	θ	***I***	W_c	θ	***I***	W_c	θ
(D1) 90%-100%	**Sub-Levels**	**1**	109	0.25	1	865	0.25	8	2341	0.15	12	4537	0.15	30	7452	0.20	60
		2	121	0.02	1	961	0.25	10	2600	0.10	21	5041	0.25	50	8281	0.15	60
(D2) 60%-70%		**3**	73	0.35	1	577	0.35	8	1561	0.35	21	3025	0.30	40	4968	0.35	60
		4	84	0.30	1	672	0.40	10	1820	0.30	21	3529	0.40	50	5796	0.20	40
(D3) 30%-40%		**5**	36	0.55	1	288	0.35	4	780	0.30	12	1512	0.30	20	2484	0.45	50
		6	49	0.50	1	385	0.45	6	1041	0.45	14	2017	0.45	30	3312	0.50	60

4.3.6. The results of the extended experiment.

Surface Chart of average number of cooperation link $\bar{X}_{coo}$, average number of defection link $\bar{X}_{def}$, average number of co-opetition link $\bar{X}_{cop}$ and average number of competition link $\bar{X}_{com}$ (from a single replication of the *D* factor only i.e., 540 experimental runs) are plotted on to Figure 4.8, Figure 4.10, Figure 4.12 and Figure 4.14 respectively. These figures show that all the average value of response variables increases as the grid size increases. Although the incremental rates are varied, they are coensistent for different population percentages.

The attractors of $\bar{X}_{cop}$ and $\bar{X}_{com}$ that emerged in the first experiment, exist only in the first row of Figure 4.9 and Figure 4.11 respectively, while the second and third row of these figures show that these attractors have shifted. However, the attractors of $\bar{X}_{coo}$ and $\bar{X}_{def}$ are consistent throughout all of the rows and columns of Figure 4.13 and Figure 4.15 respectively. These results indicate that altering the percentages of the node population only shifts the attractors of co-opetition and competition while the cooperation and defection attractors are still fixed.

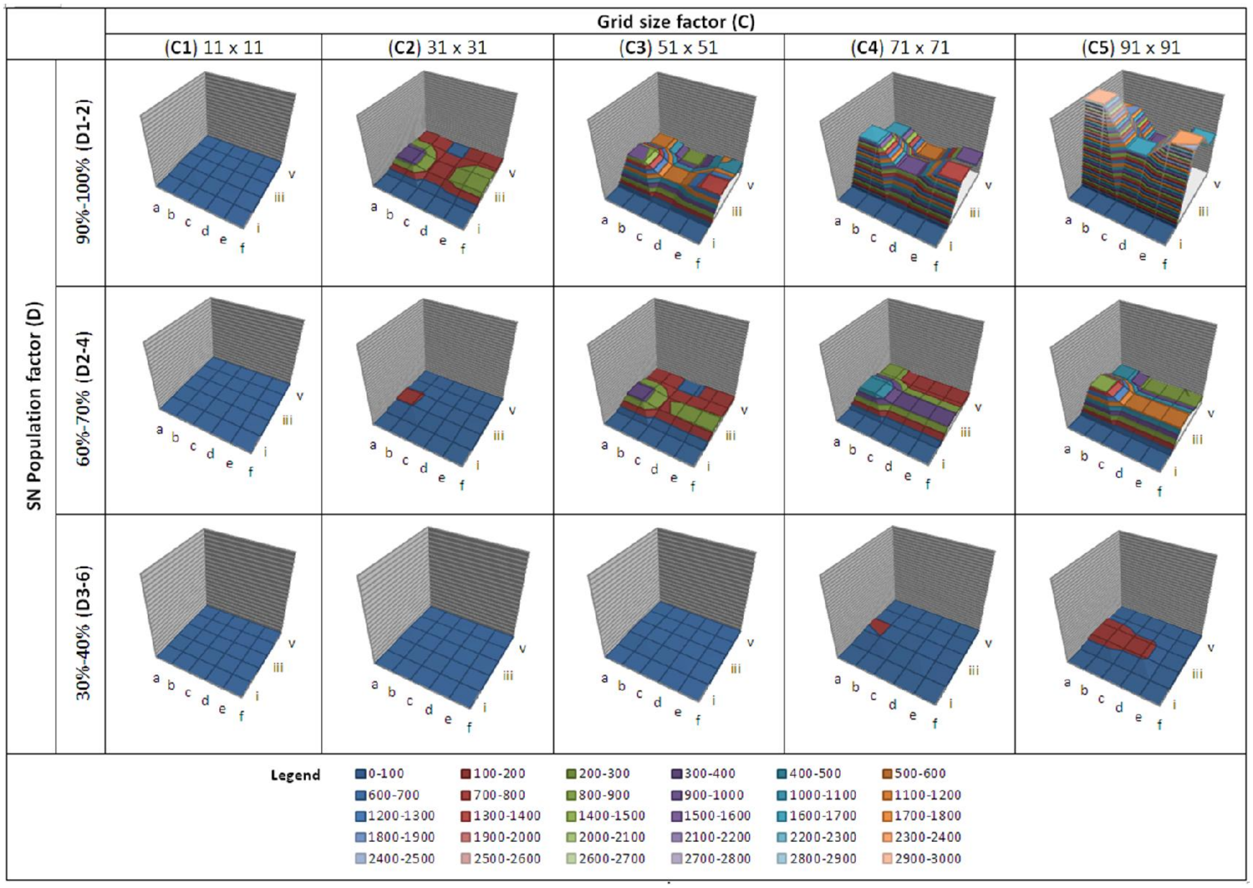


Figure 4.8 Surface Charts of the Average Number of Co-opetition Link $\overline{X}_{cop}$ of the Extended Experiment.

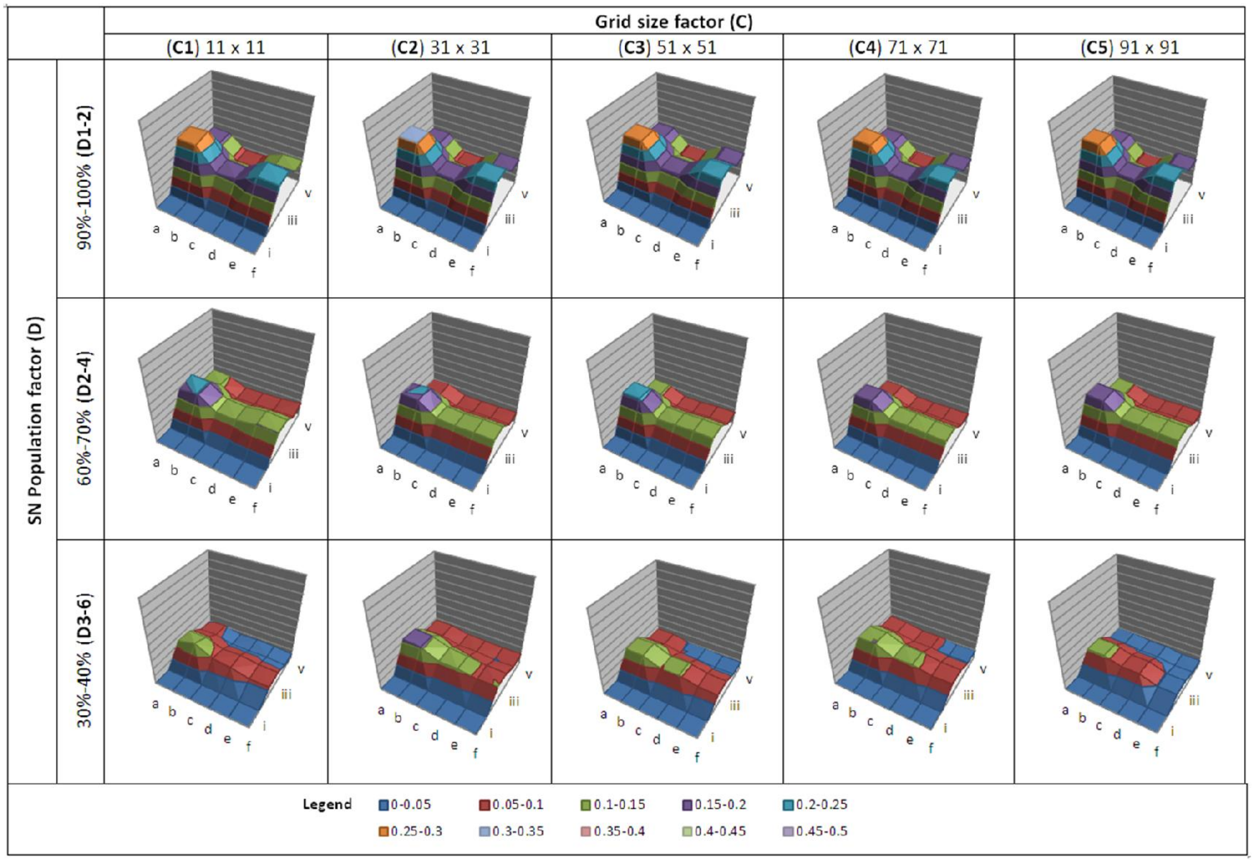


Figure 4.9 Normalized Surface Chart of Average Number of Cooperation Link $\overline{X}_{cop}$ of the Extended Experiment.

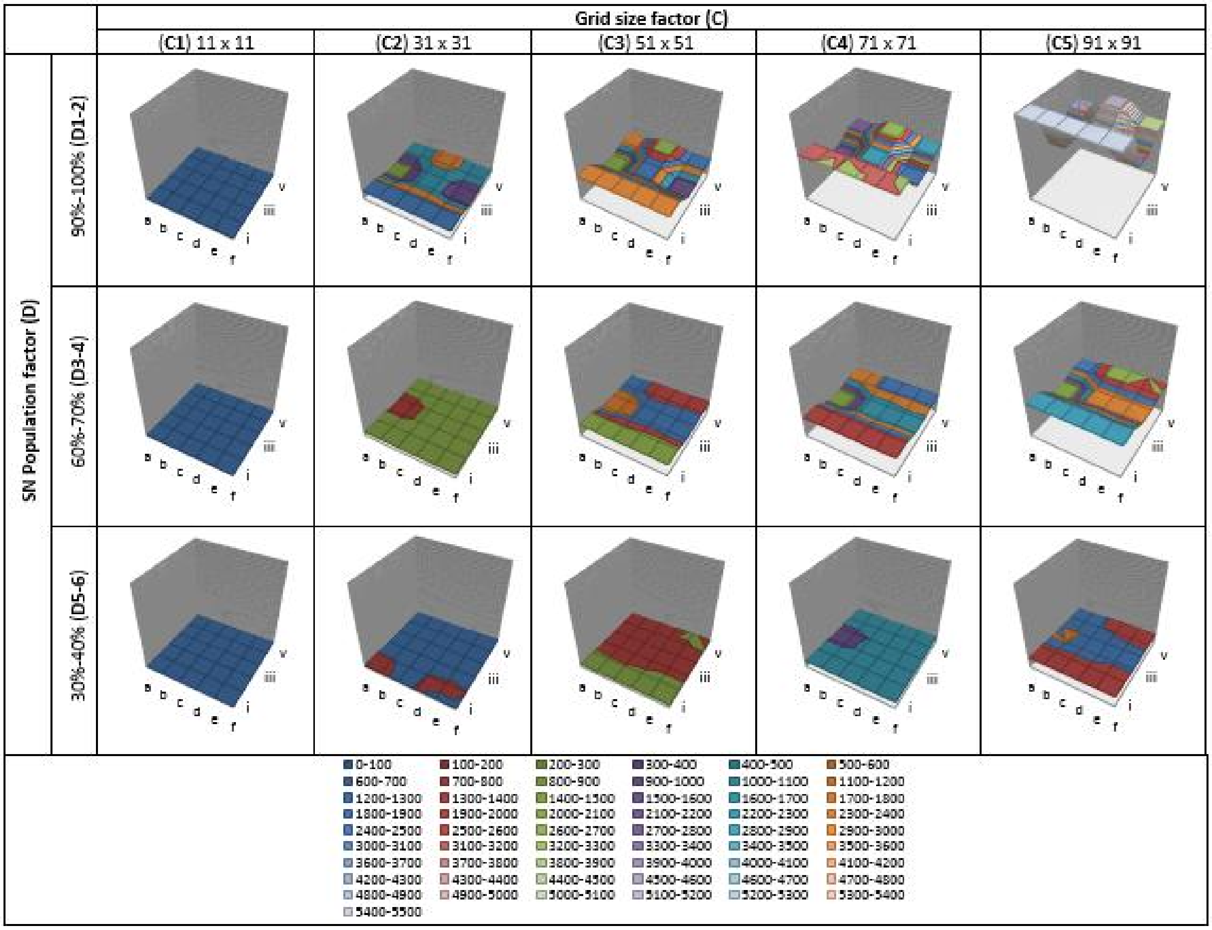


Figure 4.10 Surface Charts of the Average Number of Competition Link $\bar{X}_{com}$ of the Extended Experiment.

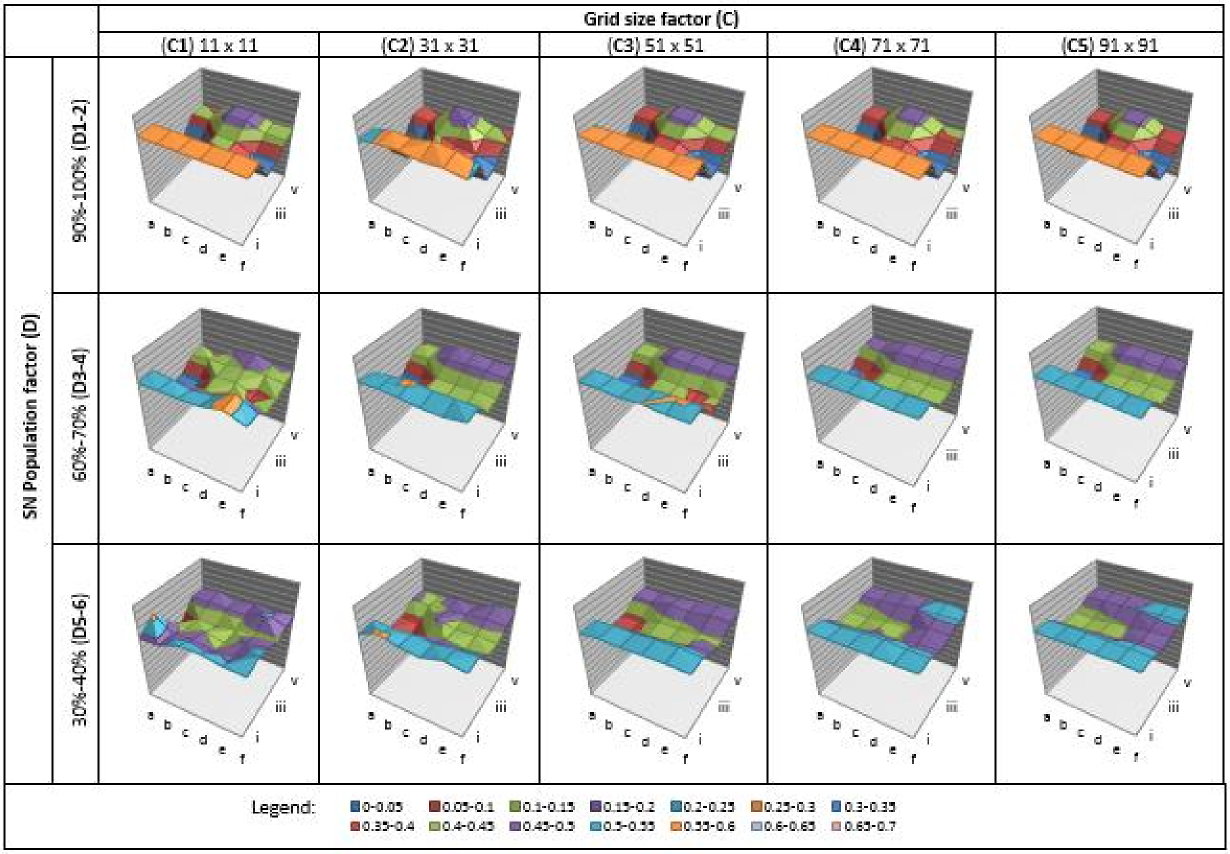


Figure 4.11 Normalized Surface Charts of the Average Number of Competition Link $\overline{X}_{com}$ of the Extended Experiment**.**

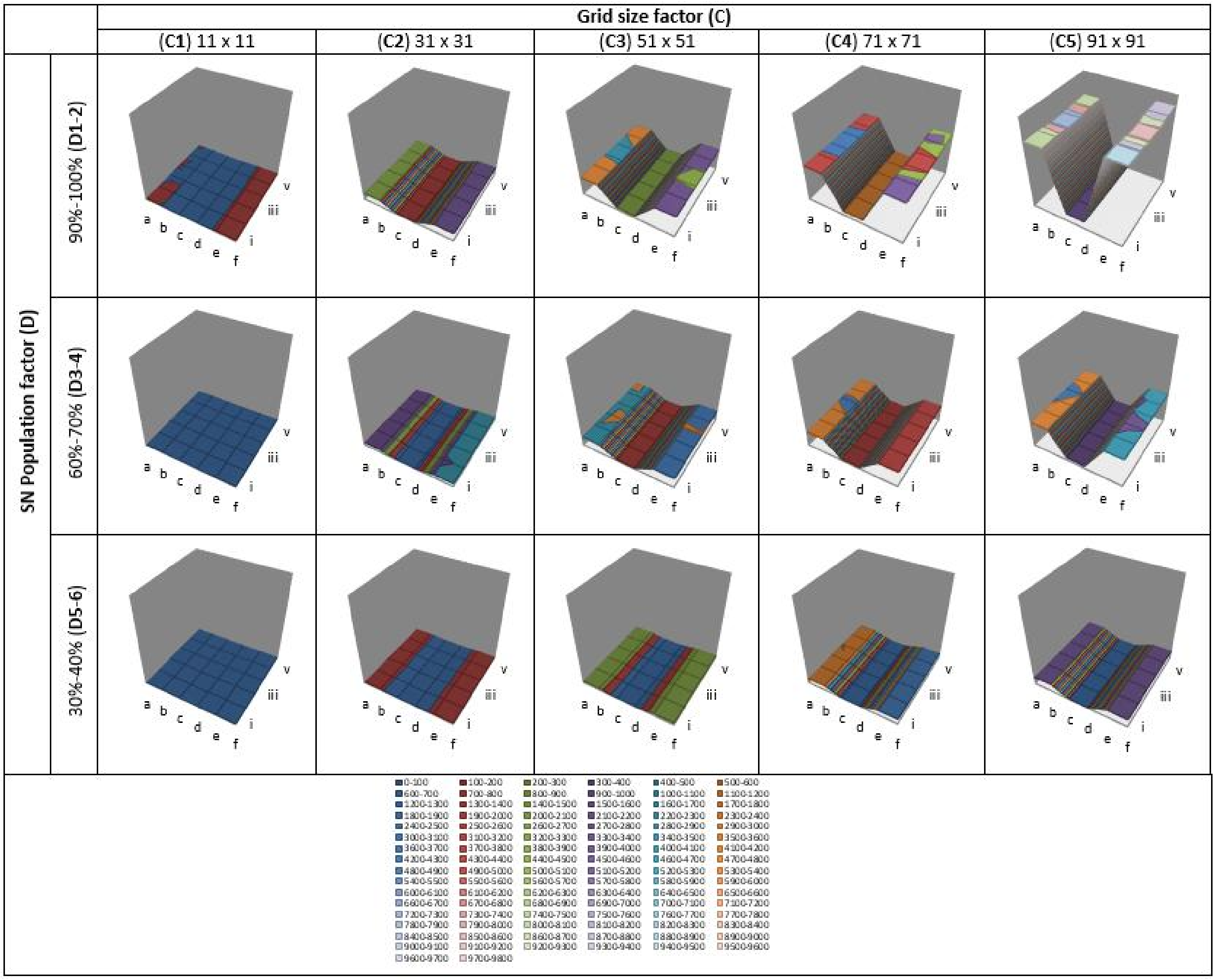


Figure 4.12 Surface Charts of Average Number of Cooperation Link $\overline{X}_{coo}$ of the Extended Experiment.

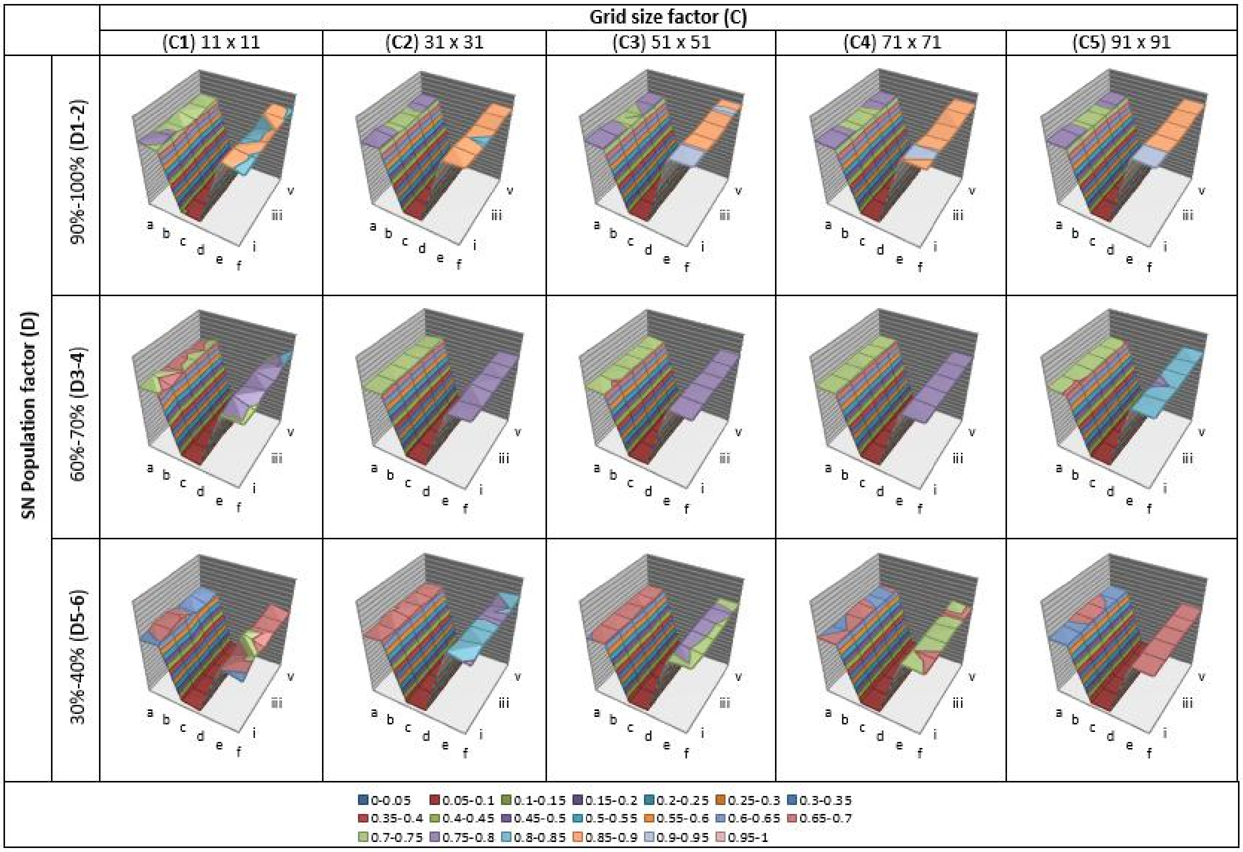


Figure 4.13 Normalized Surface Charts of Average Number of Cooperation Link $\overline{X}_{coo}$ of the Extended Experiment.

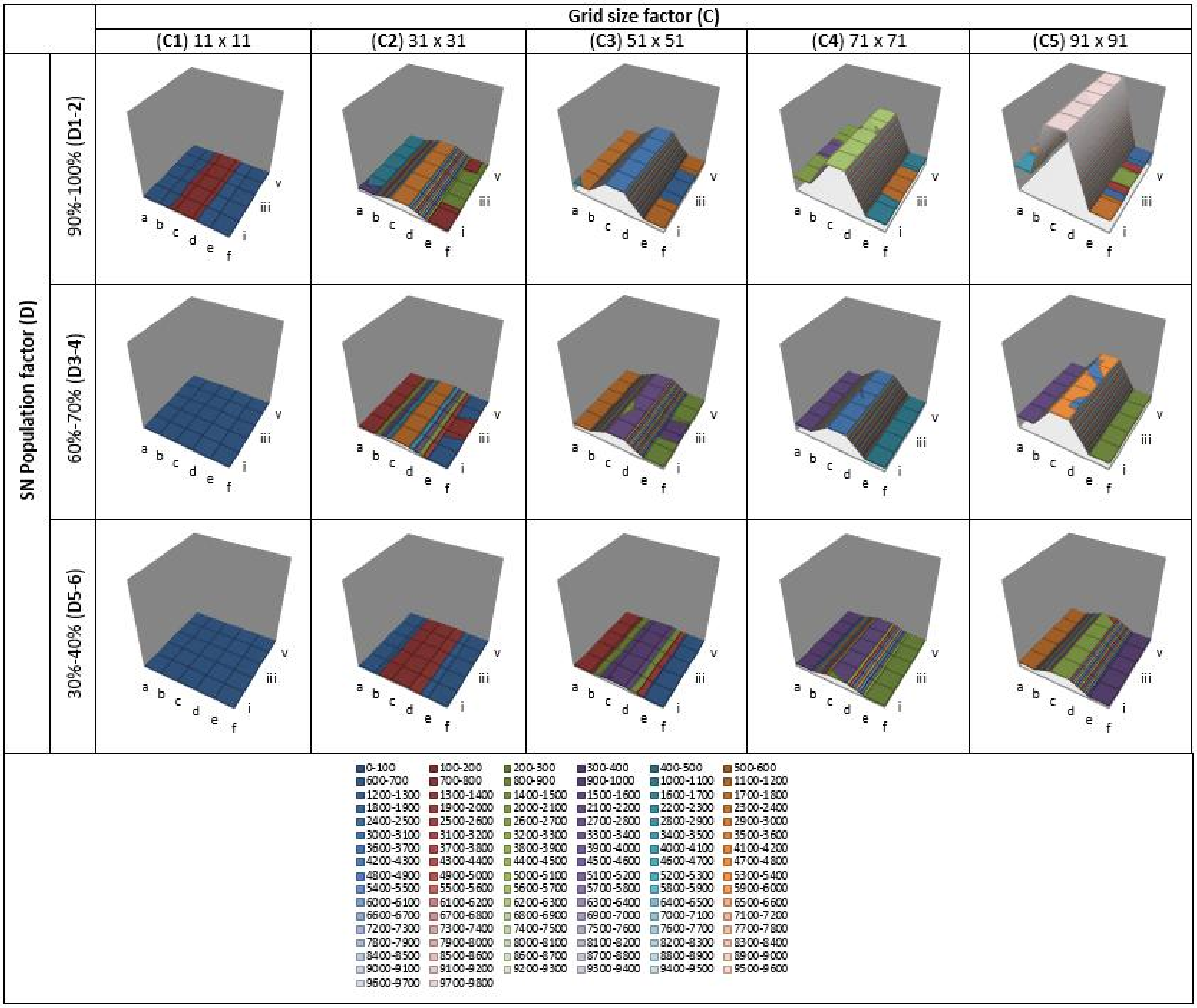


Figure 4.14 Surface Charts of Average Number of Defection Link $\overline{X}_{def}$ of the Extended Experiment.

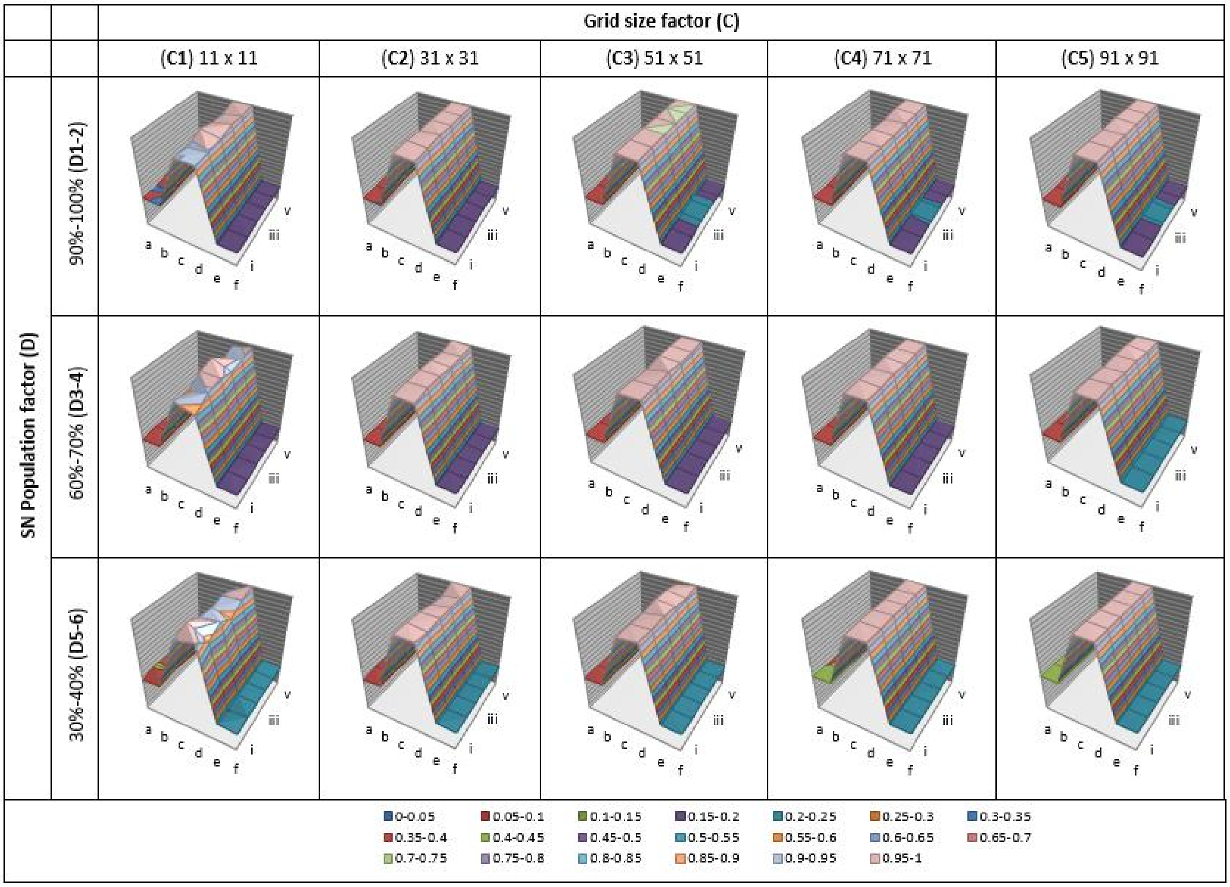


Figure 4.15 Normalized Surface Chart of Average Number of Defection Link $\overline{X}_{def}$ of the Extended Experiment.

4.4. Discussion and Conclusions

4.4.1. Interconnected Relationship Co-evolution in CASN.

The first experimental results have demonstrated that specific relationship types inside CASN are not only influenced by reward scheme stimulus but, more importantly, also co-evolve with the existence and behavior of other types of relationship. Based on the results of the first experiment, I can develop a diagram that shows the influence of all the relationship types on each other, as seen in Figure 4.16.

In Figure 4.16, eight correlations of influence among interconnected relationships in CASN are defined and can be classified into three groups. The first group exhibits correlations of influence between HOT relationships (i.e., denoted by dashed line arrows). The second group exhibits correlations of influence between HET relationships (i.e., dash-dot line arrows). The third group exhibits correlations of influence among HOT and HET relationships (i.e., denoted by solid line arrows). These first and second groups are obvious since they can be intuitively drawn from the general rules of agent's interactions. However, the third group is intriguing and can only be concluded from this experiment results and their logical consequences. The third group of influence correlations shows the follows:

- The increasing number of cooperation links between the HET nodes will cause a decrease in the number of competition links between the HOT nodes. This correlation is derived from the result of the first experiment, which showed average number of competition link $\bar{X}_{com}$ to be at its lowest point when the business situations are favorable for co-opetition and cooperation (see sub-section 4.3.4; and Figure 4.7 (q)).
- The increasing number of cooperation links between the HET nodes will cause an increase in the number of co-opetition links between the HOT nodes. This correlation can be verified from the result of the first experiment, which shows average number of co-opetition link $\bar{X}_{cop}$ to be at its highest point when the business situations are favorable for co-opetition and cooperation (see sub-section 4.3.4; ; and Figure 4.7 (p)).
- Consequently, the increasing number of defection links between the HET nodes will cause a decrease in the number of co-opetition links between the HOT nodes, and it will increase the number of competition links between the HOT nodes.

These correlations of influence suggest that cooperation relationships will promote the co-opetition and reduce the tension of the competition. The act of defection will extend the tension of competition and decrease the probability of co-opetition.

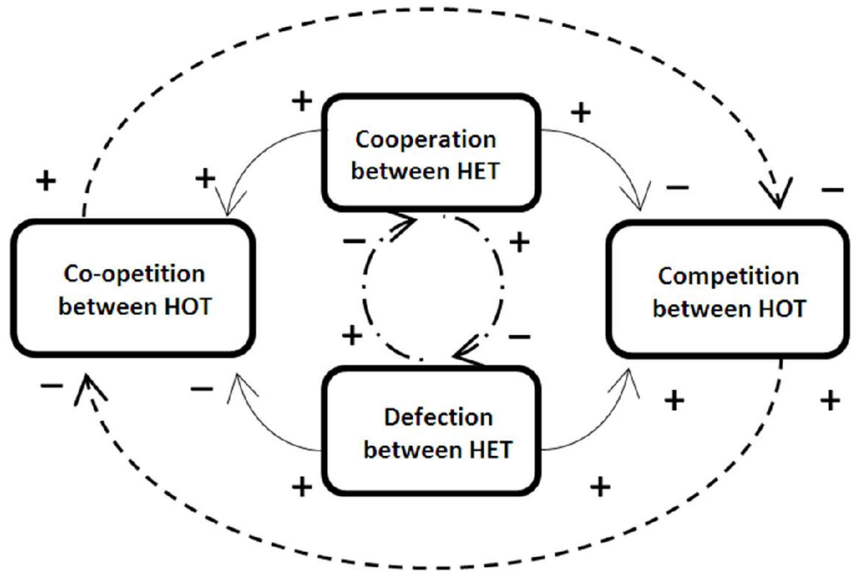


Figure 4.16 Influence Diagram among the Interconnected Relationship.

The results of this chapter also indicate that the attractors of co-opetition and competition inside interconnected relationships in SNs are sensitive to the SN population percentage, which means that these attractors will shift when there is a certain alteration in the SN population percentage. It is also suggested that co-opetition and competition relationships behave in a more complex way compared with those of cooperation and defection, in that the original attractors of cooperation and defection relationships remain unchanged throughout the SN population percentage.

4.4.2. Conclusions

A CA model is developed to capture complex patterns of interconnected relationship co-evolution processes among co-opetition, competition, cooperation and defection. The study in this chapter demonstrates how a set of simple micro-conditions (agent parameters, reward schemes and agent interaction policies) can develop into complex macro-behavioral patterns of the interconnected relationships among firms. The experimental results show the emergence of attractors of interconnected relationship behaviors. The emergent attractors suggest that cooperation promotes co-opetition and reduces the tension of the competition while defection leads to the escalation of competition and generates barriers to co-opetition. These attractors are sensitive to SN population changes.

4.4.2.1. Managerial implications

In an SN, the relationships between firms are interconnected. Consequently, it is important for decision makers to consider the complex effect of their decisions. The ability to ingeniously listen, reflect and react to other firms should be developed as central activities (Hakansson & Ford, 2002).

The following managerial implications are derived from the simulation results in this chapter:

- Decision makers should consider not only the consequence of their firm's condition and business environment situation but also the complexity of the firm's interconnected relationships.
- Cooperation promotes co-opetition and reduces the tension of competition, while defection leads to the escalation of competition and generates barriers to co-opetition. In a practical situation, the strength of cooperation relationships inside the SN of the rivals should be considered before adopting these rivals as partners in a co-opetition relationship. A strong alliance, or cooperation relationships that are embedded in a rival's SN, will ensure maximum benefit from the planned co-opetition relationship.
- A firm's decisions about a relationship strategy in an SN can be affected by a shift in the SN population. Consequently, I should reevaluate decisions about a specific relationship strategy when there are shifts in the SN population.

4.4.2.2. Remaining issue and future research directions

In this chapter the emergence of collective behavior of SN firms as the result of the co-evolution of interconnected relationship strategies among them is successfully identified. It is also important to investigate the impacts deriving by this emergent behavior which is emphasized in the second stage of my study. The next chapter is dedicated to present the result of investigation on the first impact of the coevolution of interconnected relationship strategies i.e. on firms' survivability.

Chapter 5 The Co-evolution of Interconnected Relationship Strategies: The Impacts on Firms Survivability

5.1. Introduction

Each firm situated in any network needs to build relationships with other firms. A relationship strategy, which engages firms with each other, mainly intends to achieve a firm's goals. One goal of firms is to prolong its survival in the market. Issues in the buyer-supplier relationship strategy and its impact on the individual or dyad level of firms have been studied for over two decades(Choi & Wu, 2009). However, at networks level, it recognized that instead a particular relationship strategy (e.g., cooperation, defection, competition and coopetition) exists and being independent from each others, they are complexly interconnected (Ritter, 2000). None of the relationships in a network are built or operate independently of the others (Hakansson & Ford, 2002). A small shift in a particular relationship state in a given network could affect the other relationships that are directly connected and then in turn affect the other indirectly connected relationships. This domino effect can result in either a minor or major complication at both the individual and SN level. Moreover, firms and their relationship strategies are very dynamic, similar to living entities that co-evolved over time (Choi et al., 2001; Pathak, Dilts, & Biswas, 2007). Therefore, to further our understanding of the complex nature of a SN, we must extend our analysis from individual firms or the dyadic level to the network level. At the network level of analysis, this chapter attempt to determine how individual strategies (i.e., cooperation, defection, competition and co-opetition) interconnect and co-evolve inside the SN and investigate the related emergence network effects.

Studies of relationship strategies in the context of complex supplier networks have only recently emerged. Nair et al. (2009) investigated how decisions on cooperation and defection among firms in a SN have evolved over time. They employed a cellular automata simulation framework and a complex adaptive system perspective. Based on observations of the emerged behavior of cooperation and defection, they established propositions on the relationship development for managing supply networks. Li et al. (2013) conducted a study similar to that of Nair et al. (2009) using a non-lattice network structure and concluded that a heterogeneous network structure promotes cooperation. Departing from the premise that a triad is the simplest form of a network, Childerhouse (2013) investigated how the interactions and relationships in triadic relationships change over time; he developed a conceptual model of eight triadic relational states and the hypothetical evolutionary state between them. The previous chapter has demonstrated that specific relationship types inside CASN are not only influenced by reward scheme stimulus but, more importantly, also co-evolve with the existence and behavior of other types of relationship. We also have known that emerged attractors of CASN behavior in the chapter three suggest that cooperation promotes co-opetition and reduces the tension of the competition while defection leads to the escalation of competition and generates barriers to co-opetition. All of these studies mainly focused on the emergence of behavioral patterns of the co-evolution of interconnected relationship strategies.

This chapter steps forward to investigate the impact of the co-evolution of interconnected relationship strategies on the survivability of firms inside the SN. It is aimed to determine how and under what conditions the survivability of firms inside the SN is affected by the co-evolution of interconnected relationship strategies among them. The result of this chapter can hopefully contribute to further the understanding of the complex nature of a SN. To achieve the aim of this chapter, new simulation experiment is developed using the CA model of chapter four.

This chapter is organized as follows: Section 5.2 discusses how the simulation model and experimental design were developed. Section 5.3 provides the analysis and discussion of the experimental results. Finally, this paper ends with conclusions and insights for practitioners, which are given in Section 4.

5.3. Simulation Experiment

5.3.1 Experimental Design

This study aimed to determine how and under what conditions the survivability of firms inside a SN is affected by the co-evolution of interconnected relationship strategies among them. To this end, two simulation experiments are developed and compared for the CA model. Both experiments used a similar CA simulation model and experimental factors from chapter four, which represented SN business environment conditions that allow interconnected relationship strategies to co-evolve. However, each experiment used a different set of agent relationship policies. A comparative analysis between the results of these experiments revealed how the co-evolution of interconnected relationship strategies impacts the survivability of nodes. The survivability of a node is measured by its lifespan, i.e., in simulation cycles (ticks).

5.3.1.3 Policy Setting of Agent Relationship

Nodes that are exposed to certain business conditions produced by the RPDG payoff structure react or adapt in accordance with a given set of agent relationship policies. Agent relationship policies are the adjusted micro-rules of interaction of node that have been described in section 2.2. In these experiments, how these micro-rules produce a macro-network effect that impacts the lifespan of nodes inside SN is observed.

In the first experiment, a set of extreme agent relationship policies that employ total competition and total defection strategies were designed. Intuitively, the result of the first experiment shows that the total competition and total defection strategies result in a low survivability of nodes. Nevertheless, the first experiment was run as a control for the second experiment and to serve as the internal validity of my CA simulation model. My second experiment introduced a set of modified agent relationship policies that employed a selective cooperation policy and selective co-opetition policy. This set of agent relationship policies represents the logical decisions of firms that more natural compared to the agent's relationship policies in the first experiment. It was hypothesized that a business environment condition that favors cooperation and co-opetition would result in an atmosphere that is most conducive for all nodes in the SN to remain in business longer. Table 5.1 exhibits the complete set of agent relationship policies for both experiments and is explained in the subsequent paragraph.

Table 5.1. Agent's Relationship Policies for the Experiment #1 and Experiment #2

No	Business Environment Situation	Agent's Relationship Policy (O_r)		
		Experiment #1	Experiment #2	
O_1	Favorable for cooperation	**Full cooperation**: A node will decide to engage in a cooperation relationship strategy with all HET neighbors and exchange resources proportional to the neighbors' fitness (or according to the availability of a neighbor's resources)		For Hetero-type relationship
O_2	Favorable for defection	**Total defection:** A node will decide to totally defect from all of their HET neighbors.	**Selective cooperation:** A node will decide to engage in a cooperation relationship strategy with only to the HET neighbor that has the highest fitness and engage in a defection strategy with the others.	
O_3	Dilemma between cooperation or defection	**TFT 0.05 odds forgiveness:** A node will make decisions about their relationship with their HET neighbors based on the tit-for-tat (TFT) strategy with a 0.05 odds of forgiveness.		
O_4	Favorable for co-opetition	**Full co-opetition:** A node will decide to engage in a co-opetition relationship strategy with all of its HOT neighbors and exchange resources proportional to its neighbors' fitness (or in accordance with the availability of its neighbor's neighbor resources).		For Homo-type relationship
O_5	Favorable for competition	**Total competition:** A node will compete with all HOT neighbors.	**Selective co-opetition:** A node will decide to engage in a co-opetition relationship strategy with only the HOT neighbor that has the highest fitness and engage in competition with the remaining HOT neighbors.	
O_6	Dilemma between competition or co-opetition	**TFT 0.05 odds forgiveness:** A node will select a competition or co-opetition strategy based on the TFT strategy using a 0.05 odds of forgiveness.		

Nodes that are exposed to business conditions that favor competition will react in accordance with the designed relationship policies of each experiment as follows: in the first experiment, a node will choose a total competition strategy policy. This strategy would allow the node to only engage in competition with all of its HOT neighbors. In the second experiment, a node will tighten the selection process of competitors that becomes its co-opetition partners. Therefore, the node will engage in a selective co-opetition policy, which suggests that the node will engage in a co-opetition relationship strategy with only the HOT neighbor that has the highest fitness.

In a business environment that favors defection, nodes will choose a total defection strategy policy in the first experimental setting. A total defection strategy will stop all cooperation relationships of a node with its HET neighbors. In the second experiment setting, nodes will engage in selective cooperation, which suggests that nodes will engage in a co-operation relationship strategy only with the HET neighbor that has the highest fitness.

In an environment that features some dilemmas in relationships, the best strategy is to maintain all established relationships or use a strategy that is being employed by the partner/opponent, i.e., a tit-for-tat (TFT) strategy. In HET relationships, an iterated TFT strategy will result in a situation in which nodes become trapped in defection relationships, while an iterated TFT strategy will situate all nodes in HOT relationships in competition relationships. In the first experiment, the SN containing only defection relationships is an undesirable situation for a dilemma business condition. Similar to the first experiment, a SN with only competition relationships in the dilemma scenarios in the second experiment is not permitted. To overcome this problem, a TFT strategy with a 0.05 odds of forgiveness was employed.

5.3.1.2 Parameter Settings, Response Variable and Implementation

This CA model uses a 51×51 toroidal grid similar to that proposed by Nair, et.al. (2009), which signifies 2,601 available empty cells. The experiment employed the following agent attributes and environmental parameter settings: 2,341 initial nodes; equal proportion for each type of node; an environmental changing factor (W_c) of 0.15; 1% of W_c for the decay rate ($\Delta\delta$); and 12 nodes/tick for the birth rate. These parameter settings guaranteed an equal proportion for all node types and maintained existing node populations from 90% to 100% on the grid during the simulation time. In accordance with the point of interest, data of the lifespan of all nodes that had either died during simulation or survived until the end of the simulation are collected.

The simulation was initiated by generating nodes at a given and identical number for all types at randomly distributed grid cells. The attributes and environmental parameter settings were then established. Three general simulation steps were employed for each simulation tick. In the first step, each node examines the RPDG payoff structure and selects the most suitable interaction policy. When it selects a tit-for-tat interaction policy, it also evaluates the neighbors' relationship decision at the last tick. Subsequently, it begins to simultaneously interact with all neighbors by deciding the types of relationships it will engage in with each neighbor in accordance with its current interaction policy. In the second step, the relationship link for each pair of nodes is generated based on their total decisions (e.g., if both HET nodes decide to cooperate, then a cooperation link will be generated, whereas if one of the pair's members decides to defect, then a defection link will be created). For cooperation or co-opetition relationships, nodes will begin to supply resources to each other after the link is established. In this model, any optimal allocations of resources between nodes was not considered. To avoid deadlock in the requesting and supplying process between nodes, the simulation system will automatically and randomly grant priority to a particular node at a time to implement its relationship strategy. At the end of the second step, each node will calculate its profit for the recent tick's round and update its current fitness, capacity and cost. In the third step, the simulation environment will eliminate all nodes whose fitness values fell below a given environmental expectation (W_c) setting. In accordance with a given birth rate setting, the environment generates new nodes of random types and randomly spreads them throughout the empty grid. In this experiment, 1000 ticks was used as a stopping rule.

5.3.2 Experimental Result

The data of the lifespan of nodes collected from the simulation runs of experiment #1 and experiment #2 were organized into a distribution of the node's lifespan (DNL). Based on both experiments, which each had 6^2 experimental runs, the results of nine experimental runs that represent nine business environment situations are exhibited, as shown in Figure 5.1 and Figure 5.2. These figures show that all data distributions follow a Beta (α; β) probability distribution in all nine business situations of both experiments.

In all columns of the first row of Figure 5.1, where the business situation favors cooperation, the DNL of all nodes reaches 500 ticks. These phenomena emerged as all nodes engaged in a full cooperation strategy with all of their HET neighbors. As expected, when all nodes engage in a total defection strategy in a business situation that favors defection (i.e., all columns of the second row of Figure 5.1), their DNL drastically shortens, i.e., no more than 250 ticks. A total defection strategy indicates that no resources could be exchanged and no profit could be made at each tick of the simulation. Consequently, a total defection strategy leads to a continuous decrease in the fitness of nodes until nodes were unfitted and eliminated from the business.

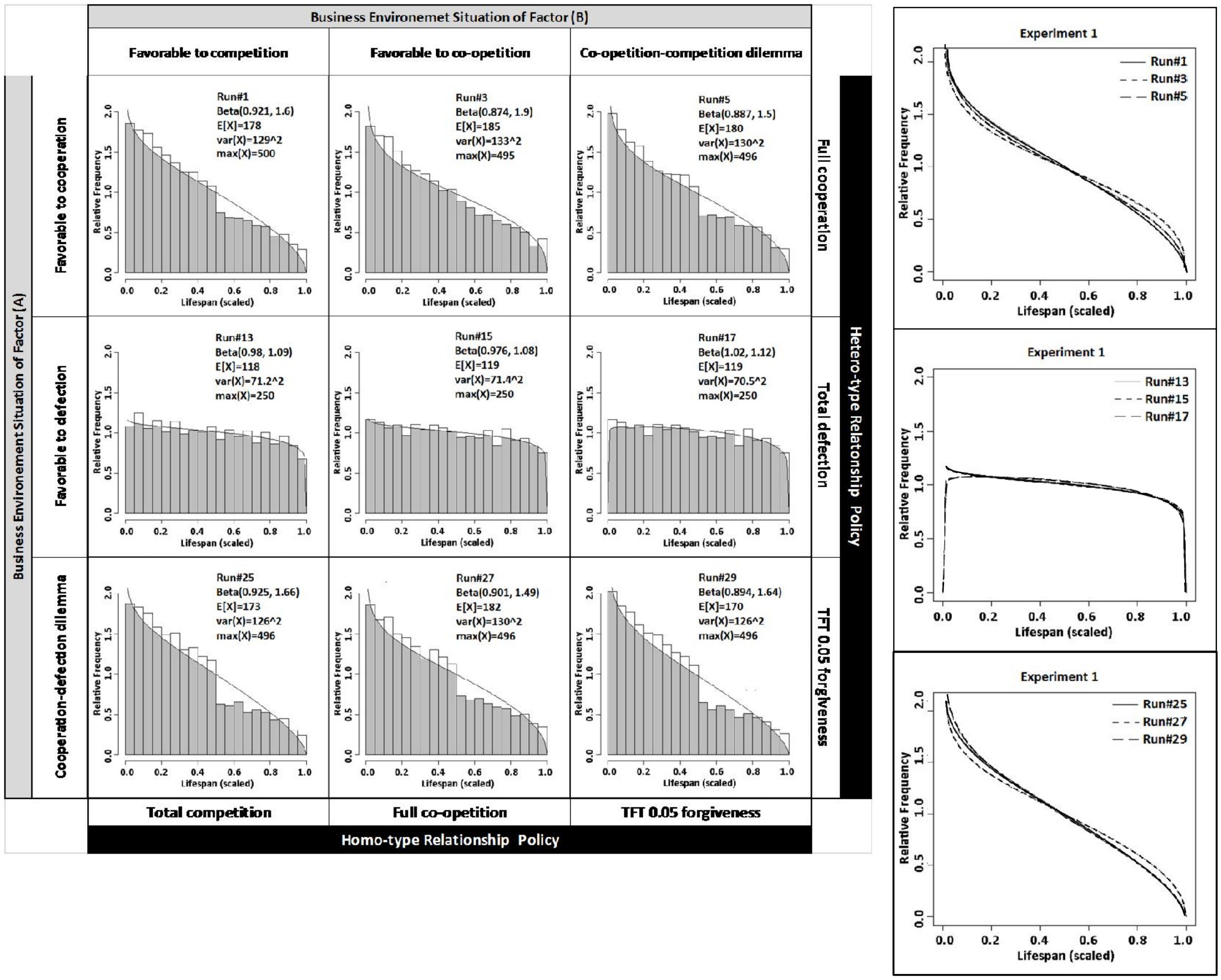


Figure 5.1. The Results of Experiment #1: Distribution of Node's Lifespan (DNL) of for Nine Business Environment Situation

All DNL of second experimental runs that are shown at the second row of Figure 5.2 show a significant improvement compare with the result of the first experiment in the second row of Figure 5.1 These phenomena are expected because the second experiment uses selective cooperation, which means that all nodes can exchange resources, make a profit and improve their fitness, even though a maximum of only one connection per tick is allowed.

Surprisingly, the second row in Figure 5.2 (i.e., runs #13, #15 and #17 of the second experiment), which use a selective cooperation strategy, produce a DNL that performs close to the DNL of run #3 of both experiments. Recall that run#3 of both experiments used a full cooperation strategy. These phenomena can be explained as follows: because the resource interdependency mechanism among HET nodes was designed to only need at least one other type of node to allow a particular node to have an exchange of resources (see Figure 4.2), the critical value of the connectivity among nodes in my simulation is only one connection. When any network reaches its critical value of connectivity, the inter-relationship effect will dramatically emerge (i.e., when the node's interaction policy is changed from total defection to selective cooperation). Beyond the point of critical connectivity, any additional connections will contribute little to inter-relationship effect (Choi et al., 2001) i.e., the lifespan of nodes in this case.

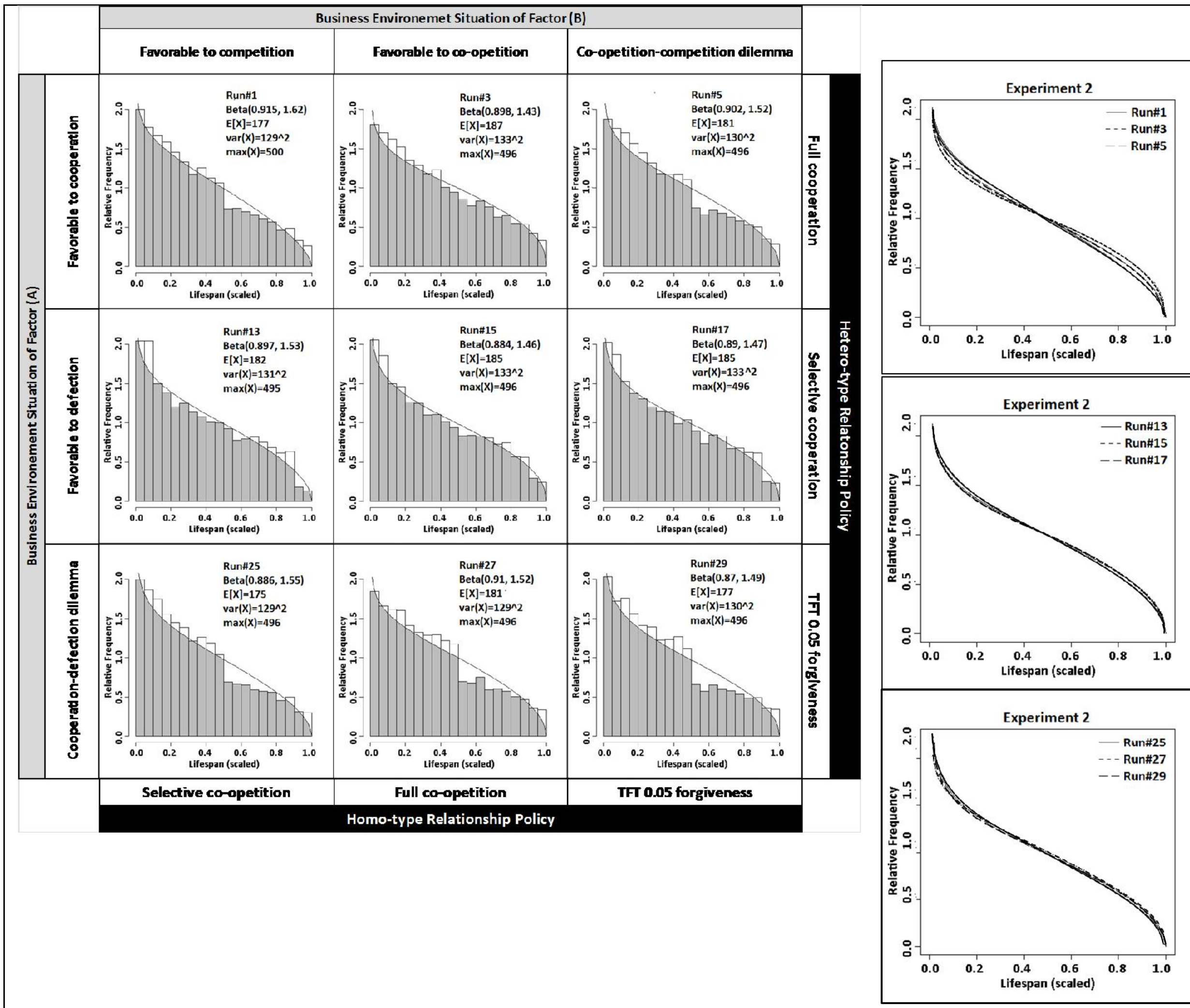


Figure 5.2. The Results of Experiment #2

Figure 5.1 and Figure 5.2 show that the best phenomenon emerged during experimental Run #3 of both experiments (i.e., when full cooperation combined with a full co-opetition interaction policy). The DNL curves of both Run #3 experiments were more convex at the beginning and more concave at the end compared with all other experimental runs. The DNL curves of Run #3 suggest a phenomenon in which the number of nodes that have a longer lifespan exceeds the number of nodes that die at early ages compared with all other experimental runs. The result of both experimental Run #3 emerges by means of the co-opetition relationship strategy, which makes breakthroughs at the HOT interactions of nodes. The co-opetition relationship breakthroughs opened new channels of resource supply and market demand among nodes. Run #1 of both experiments exhibits a DNL that is worse compared with Run#3 from both experiments. Therefore, these phenomena suggest that a cooperation strategy combined with a co-opetition strategy can further increase the survivability of nodes inside the grid compared to a situation in which all nodes only engage in a cooperation strategy.

Figure 5.1 and Figure 5.2 show that the TFT strategy with 5% odds of forgiveness successfully meets all dilemma situations. Even though the DNL that results from this strategy (e.g., Run #5 of both experiments) is not as good as Run#3 of both experiments that determines the upper bound of DNL, this strategy does not emerge as the worst. Moreover, a TFT strategy with 5% odds of forgiveness performed moderately in these simulation experiments. Thus, a TFT strategy that maintains the established long-term relationships of reciprocal cooperation and/or co-opetition was proven as a robust strategy to meet any dilemma or uncertain situation in supply networks.

5.4. Conclusion

In this chapter, firms inside SN was modeled into nodes in grid of cells in CA simulation framework. This CA model use resource interdependency among HET nodes and market/resources commonality among HOT nodes as their general drivers of interaction. Using this model, the impact of interconnected relationship strategies co-evolution to the lifespan of nodes inside SN was investigated. Two experiments have been conducted and showed that cooperation coupled with co-opetition policy in SN business environments that are favorable for cooperation can promote further lifespan of nodes at both individual level and SN level.

5.4.1. Insights for Practitioners

According to the analysis of experimental results in this chapter, insight into understanding the interconnected relationship strategy for practitioners in a SN is offered as follows:

- When a business environment favors alliance cooperation, it is suggested that managers should not only exploit a cooperation strategy with their allies but also consider coupling the cooperation strategy of allies with a co-opetition strategy to their potential competitors as a strategic opportunity to increase the survivability of their firm. Even though cooperation and co-opetition might introduce some disadvantages, such as appropriation risk and technology diffusion risk (Choi et al., 2002), and short-term opportunistic behavior might offer more incentives in certain business environment conditions, cooperation strategy coupled with a co-opetition strategy significantly and positively impacts the survivability of firms at the individual and network level in the long-run. Furthermore, the results of cooperation strategy coupled with co-opetition strategy outperform those of the cooperation strategy alone at both the individual firm and SN level. This situation arises because a co-opetition strategy by means of cooperating with competitors offers opportunities that differ from those of allies, i.e., access to new resource supply, new market channel, technology, etc. (Bengtsson & Kock, 2000). Based on the Intel and Apple agreement from 2005, other researchers posited that co-opetition is a logical strategic opportunity when the accumulation of alliance competencies that emerge from a successful cooperation strategy with the allies push firms to search further prospects of cooperation with other firms (i.e., competitor) in a related market or SN (Marco & Di Guardo, 2007).

- When a business situation presents a dilemma between cooperation and defection or between co-opetition and competition, maintaining the established stable reciprocal cooperation or co-opetition relationships is a better strategy option that results in better, stable performance to firms. A good performance stability of firms will increase firms’ fitness and thus promote their lifespans. Parallel to this insight, Wu & Olson, (2008) stated that long-term commitments are a strategy to reduce risk. Moreover, Gang Li, Yang, Sun, Ji, & Feng (2010) posited that long-term relationships in CASN lead to a better fit with the environment, which improves the stability and performance of the partner firms.

5.4.2. Limitation and Future Research Direction

While in this chapter I investigate the first impact of the co-evolution of interconnected relationship strategies inside SN i.e. on the firms’ survivability, in the next chapter the second impact will be studied. In chapter five, it is stepped further to investigate on how a particular structure of SN has emerged from the co-evolution of interconnected relationship strategies.

Chapter 6 The Emergence of Efficient Supply Network Structure under the Co-evolution of Interconnected Relationship Strategies

6.1. Introduction

As it had classified in a CAS research area of adaptive networks (Gross & Blasius, 2008), the majority of CASN research can be also classified into two distinct research stream. The first stream concerns on how firms' state or behavior in a particular network structure evolves. The second concern on how structure of a network co-evolves. The first research stream extends our understanding of how the state of firms e.g., its decision on relationship has evolved in a particular structure of the network (Gang Li et al., 2013; Nair et al., 2009; Sofitra et al., 2012a). The second research stream extends our knowledge of how and why a particular network structure emerges from evolution (Gang Li et al., 2010; Pathak & Dilts, 2009). The first stream of research is aligned with what I have accomplished in the first stage of my study as presents in the chapter four. Now I will step forward to get involved in the second stream of CASN study i.e. investigate on how a particular network structure has emerged from co-evolution.

Among CASN features, understanding of the underlying structure of CASN is very important since network structures play crucial roles in affecting the functionality and behavior of the complex system represented by it (Estrada, 2011; Wang, 2002).

CASN structure defines many of its functions such as innovation, learning or flow of material and information. Recent study has provided strong argumentations and evidences that an efficient CASN structure and an efficient real-world network share similar properties i.e., a short characteristic path length, a high clustering coefficient and the presence of a power law connectivity distribution (Hearnshaw & Wilson, 2013).

CAS methodology perspectives use bottom-up or evolutionary methodology which explain about how phenomena or features of a complex system emerge from co-evolution of local interactions among all components of the complex system. Consequently, the network structure of CASN is also can be explained as an emergence phenomenon. Many CAS researchers have investigated on how local interactions of components of the particular complex adaptive system can affect its network structure (Biely et al., 2007; Gross & Blasius, 2008; Poncela et al., 2009; Zimmermann & Eguíluz, 2005).

Nevertheless, though the network structural properties had been recognized constituting an efficient SN, it has been criticized that local rules or interaction mechanisms of agents of CAS proposed by previous research still could not emerge the network structure that ensemble an efficient SN (Hearnshaw & Wilson, 2013).

Therefore, this chapter tries to answer several problems of how the co-evolution of interconnected strategies (i.e. cooperation, defection, competition and co-opetition) of local interaction in SN can influence its network structure? Could this co-evolution emerges efficient SN structure?

To answer above research question, I developed a CASN simulation model is developed where its agents may dynamically alter their relationship strategies as well as their co-player by playing iterated prisoner dilemma game (PDG). Then it is observed how this co-evolution of local interactions motivating by profit maximization could affect the structure of CASN.

The research in this chapter contributes in two ways i.e., for overall network and for decision makers of individual firms. For overall network, the research of this chapter provides a model of how local decision of firms on their relationship strategy based on local information –in order to struggle in the business network- could play its roles in shaping the network structure.

For decision makers of individual firms, the research of this chapter contribute to the improvement of network visioning capability of manager (Möller & Halinen, 1999) on deciding their relationship portfolio arrangement, i.e. what relationships that should be invested in? For instance: Should we or should we not conduct a co-opetition strategy at the first place (Related to our network competences)? How and when to engage particular strategy in order to influence the SN evolution? For instance: Should we change our competition strategy to co-opetition strategy with a particular competitor in order to maintain or improve our current network position (related to network's phase of change)?

6.2. Model Development

6.2.1. Network Elements of the Model

Nodes and links are used as elements of my CASN model (see Figure 6.1). Similar to model in previous chapter, three types of node representing in three different colors are used. Different type of nodes used in this model is intended to mimic resource interdependency mechanism among firms in real world representing the driving force of SN business processes. Each type of node is assumed to possess a unique type of resources. Resource similarity among nodes will promote competition or co-opetition relationships, while asymmetrical resources will promote cooperation or defection (Luo, 2007). Contrast to the model in previous chapter, only two types of dynamic link are used in this model represent established relationship strategies between a peer of node i.e., cooperation and co-opetition.

For incentive scheme of node interaction, two categories of PDG payoff matrix are employed. First, P_{ij}^{0} which is designed specifically for hetero-type (HET) interaction i.e., between a pair of nodes that have different colors. Second, P_{ij}^{1} which is designed for homo-type (HOT) interaction i.e., between nodes that have similar color (see Table 6.1).

N nodes (agents) compose an adaptive network Γ where node *i* and its linked nodes define neighborhoods set N_i. The neighbor's neighbors of node *i* are a set of its potential neighbors $\widetilde{N}_i$.

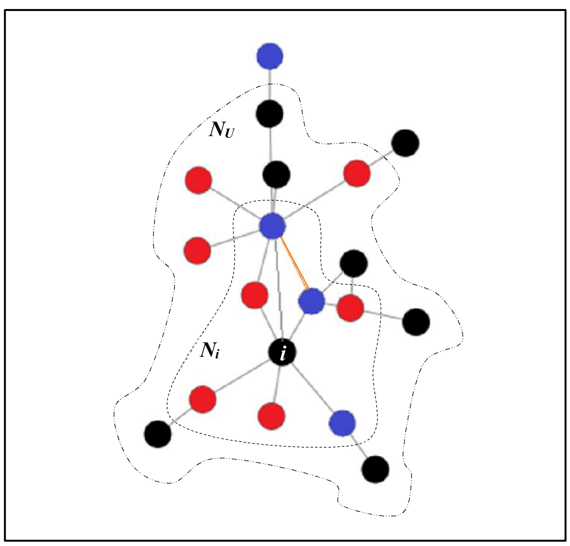


Figure 6.1. Three types of nodes and two types of link constitute CASN model Γ.

Table 6.1. PDG reward schemes.

(a)

Hetero-Type Interaction		Player B	
		Cooperation	**Defection**
Player A	**Cooperation**	**R3, R3**	**S, T3**
	Defection	**T3, S**	**P, P**

(b)

Homo-Type Interaction		Player B	
		Co-opetition	**Competition**
Player A	**Co-opetition**	**R1, R1**	**T1, T2**
	Competition	**T2, T1**	**R2, R2**

R1 : Reward for mutual co-opetition
R2 : Reward for mutual competition
R3 : Reward for mutual cooperation
T1 : Temptation for co-opetition
T2 : Temptation for competition
T3 : Temptation for defection
S : Sucker's payoff
P : Punishment for mutual defection

6.2.2. Interaction and Co-evolution Mechanisms of the Model

Three main mechanisms, namely attachment, rearrangement and elimination are applied in this model. The attachment mechanism regulates how new nodes attached to an existing network. A formulation from (Poncela et al., 2009) is modified as follows: A new birth node will select node *j* that has a different color in a random cluster $N_{U_{rand}} \subseteq \Gamma$ to develop a cooperation link with probability:

$$p_j = \frac{e^{+\varepsilon\pi_j}}{\sum_{j=1}^{N_{U_{rand}}} e^{+\varepsilon\pi_j}} \quad (6.1)$$

For $N_{U_{rand}} = j_{rand} \cup N_{j_{rand}} \cup \widetilde{N}_{j_{rand}}$

Where:

ε : Preferential parameter, where:

- $\varepsilon = 0$, attachment is random.
- $\varepsilon =$ small, attachment is approximately linear with payoff.
- $\varepsilon =$high, the newcomers will make connections to only very few nodes with high payoffs.
- $\varepsilon \rightarrow \infty$, all newcomers will always attach to the most successful nodes.

π_j : Payoff of node *j* at time *t*.

This attachment mechanism that uses N_{sub} instead of *N*, fulfills the assumption of local information.

Rearrangement mechanism dictates how a node could maximize payoff by altering its neighbor arrangement. Each node in Γ plays an iterated PDG only with its neighbors and its potential neighbors. For HET and HOT interaction, node *i* has options of action as follows:

$$a_i(t) = \begin{cases} \text{HET}\begin{cases} a^c = (1,0), \text{cooperation} \\ a^d = (0,1), \text{defection} \end{cases} \\ \text{HOT}\begin{cases} a^{cop} = (1,0), \text{co-optition} \\ a^{com} = (0,1), \text{competition} \end{cases} \end{cases} \tag{6.2}$$

In rearrangement mechanism, a pair of HET node establishes a link when they decide to cooperate with each other, and resolve the link upon a defection decision that may happen later on. In a similar way, a pair of HOT nodes establishes a link when they decide to engage co-opetition relationship and resolve the link in the future if they decide to compete with each other.

While node *i* plays iterated PDG, its try to maximize its future payoff:

$$\max\ \pi_i\,(t+1) = \sum_{j \in N_u(\mathrm{t+1;\beta;C}_i)} a_i(t+1) P_{ij}^0 \bar{a}_j(t+1)^T \pi_j^*(t) + \sum_{j \in N_u(\mathrm{t+1;\gamma;}C^*)} a_i(t+1) P_{ij}^1 \bar{a}_j(t+1)^T \pi_j^*(t) \tag{6.3}$$

For $N_u = (N_i \cup \widetilde{N}_i) \subseteq \Gamma$
β : Maximum number of defections from neighbor set $N_i(t)$.
*C**: Minimum accumulated network competence requirement.
γ: Maximum number of co-opetition relationship.
C_i: Capacity/competence of node *i* to build a link.

Equation (6.3) is an extended version of the formulation of Biely et al. (2007) to accommodate an additional choice of interaction strategy. The first term in this equation represents HET interaction decision on cooperation or defection while the second term represents HOT interaction decision on competition or co-opetition. Both terms contain the expectation of node *j*'s future decision $\bar{a}_j(t+1)$ and its current accumulative payoff $\pi_j^*(t)$ as main consideration. This arrangement mechanism represents the logic of portfolio relationship management.

Elimination mechanism is responsible on evaluating and eliminating unfitted node out of the network. While payoff $\pi_j^*(t)$ that represents fitness of a node can increase by rearrangement mechanism, it's also can be eroded gradually by a decay rate $\Delta\delta_j(t)$ which cause by factors of change in business environment. When payoff $\pi_j^*(t)$ of a node has dropped below environment expectation W_c, this node will be eliminated from the network. The simulation model elements and mechanics and their relation to the conceptual model of network dynamics can be seen in Figure 6.2

6.3. Simulation Experiment

6.3.1. Design of Simulation Experiment

To attack the problems, operational questions that accordance with the research questions is developed as follows: Firstly, could co-evolution of cooperation and defection strategy emerge efficient CASN structure? Secondly, what are co-opetition and competition strategy roles on co-evolution influencing the efficiency of CASN structure?

The CASN model of this chapter was implemented in two related experiments. Both experiments run similar simulation step as shown in Table 6.2. The first experiment involved the model which considers only HET interaction at the rearrangement mechanism of simulation step-i. This treatment is intended to deal with the first operational question. The second experiment involved the model in which both HET and HOT interaction are applied at the rearrangement mechanism of simulation step-i. This second experiment is designed to answer the second operational question.

Table 6.2. General Simulation Steps.

Steps	Descriptions
Initialization	Generate free scale network of N_0 nodes with a proportional number for each type and random cooperation relationship links.
i	**For** all nodes: **update** their relationship portfolio through rearrangement mechanism.
ii	**For** all nodes: **calculate** its current tick payoff and **calculate** accumulates payoff.
iii	**Run:** elimination mechanism.
iv	**Run:** birth and attachment mechanism.
Evaluation	**If:** stopping condition is **not** satisfied **Then: back to** Step-*i*.

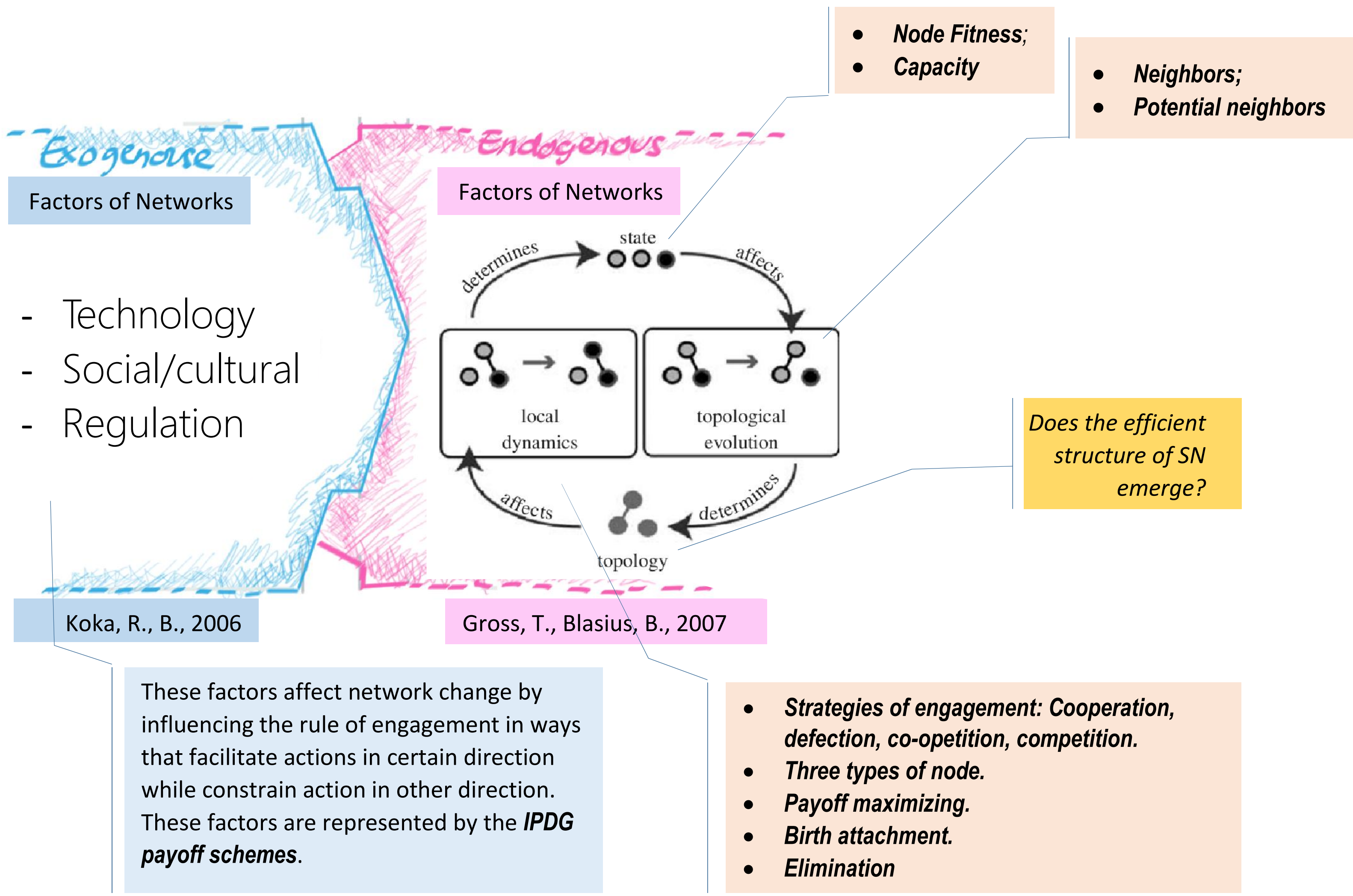


Figure 6.2 Model Elements and Mechanisms and Their Relation to Conceptual Model of the Network Dynamics

Parameters setting for both experiments are shown by Table 6.3. Finally, three gauges are used for network efficiency measurement accordance to efficient SN structure characteristics, namely degree distribution, average path length and clustering coefficient (Hearnshaw & Wilson, 2013). The snapshot of the running simulation can be seen in Table 6.3.

Table 6.3 Parameters Setting

Parameter	Experiment 1#	Experiment 2#
Iteration	100	100
Repetition	2	2
Relationship strategies	Cooperation – Defection (**HET**)	Cooperation – Defection (**HET**) Competition – Co-opetition (**HOT)**
ε	5; 10	5; 10
β	50%;100%	50%;100%
γ	100%	100%
% of C_i	50%;100%	50%;100%
W_c	0;10%	0;10%

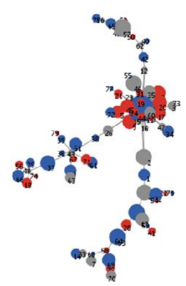
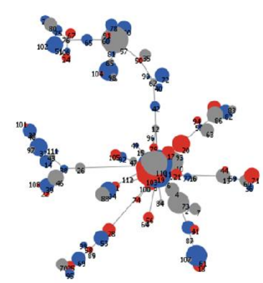
Initialization	**t=26**	**t=41**
		

Figure 6.3 Snapshot of the Running Simulation

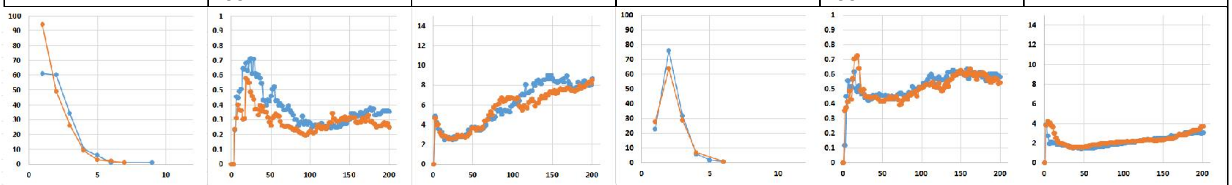
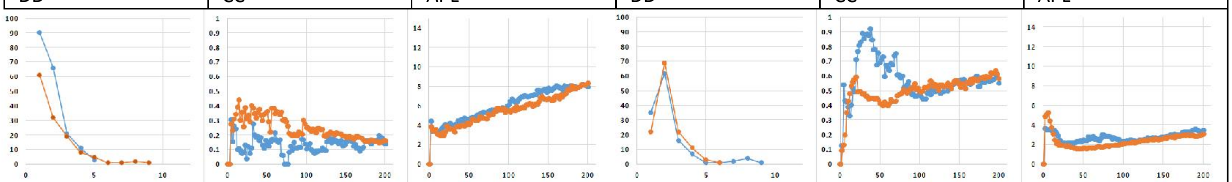
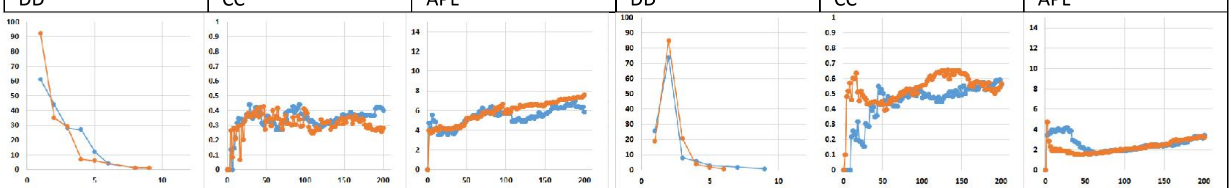
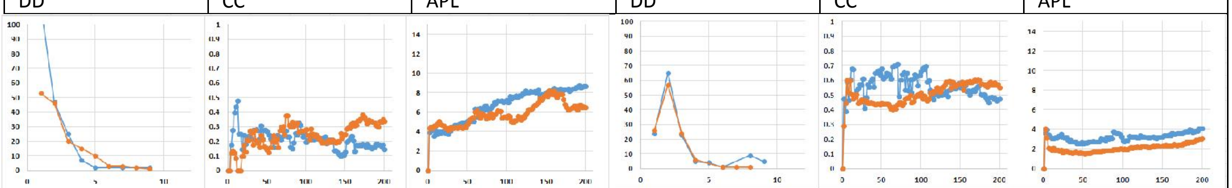
6.3.2.Experiment Result

The results of the first and second experiments are exhibited in Figure 6.4 until Figure 6.7. Each of these figures is organized as follows: it mainly consists of eight blocks of experimental results in which each of the block consist of two replication of the running experiment (e.g. RUN: 2# and 16# in the left top side of Figure 6.4). Each of the block exhibits three graphic which show the observed performance measurement i.e. degree of distribution (DD), clustering coefficient (CC) and average path length (APL).

These eight blocks of experimental results are divided into two columns based on variations of the percentage of C_i used in the experiment (i.e. C_i =50% on the left column and $C_i = 100\%$ on the right column). There are four rows in each figure based on two variations of the preferential parameter ε (i.e. 5 and 10) and two variation of the environmental expectation W_c (i.e. 0.0% and 10%).

These figures show that the first and second experiment have produced almost similar result which mean current configuration of parameters still could not emerge any different effect of employing only HET interaction and the effect of employing both HET and HOT interaction in the SN. However, from these figures we can see how variations on the percentage of C_i which reflects the intensity of cooperation relationship strategy have significant impact on the efficiency of SN structure. These facts can be seen on the degree distribution (DD) charts' shape that almost resemble the power law distribution shape. Therefore, all the characteristics of efficient SN structure as suggested by Hearnshaw & Wilson (2013) can be seen at both experiment runs when the intensity of cooperation relationship C_i = 50%. Why when the capacity of cooperation was used at 50% then the efficient SN structure emerges? Why it was not happened when the capacity of cooperation was used at 100%? This could be mean that selective cooperation strategy is playing important role for efficient SN structure establishment.

Variation in rate of defection β from 50% to 100% in the first and second experiment are not produced any diffrences. Therefore, these experiment results show us that this parameter which reflects the rate of reconfiguration (change) of the current relationship portfolio has an insighifacant impact on the efficiency of SN structure. Environmental expectation W_c values variantion from 0.0% which reflects very soft environment to 10% which reflects normal business conditons have insignificant impacts on the efficiency of SN structure. Finally, variation on preferential parameter ε values from 5 which represent fare rational decision maker to 10 which represent high rational decision maker have also make insignificant impact on the efficiency of SN structure. The summary of all parameters and their impact on the efficiency of SN structure can be seen in Table 6.4.

ε : 5					
β : 50%					
Wc : 0.0%					
% of C_i					
50%			100%		
RUN: 2#;16#			RUN: 17#;26#		
DD	CC	APL	DD	CC	APL
					
Wc : 10%					
RUN: 3#;5#			RUN: 19#;30#		
DD	CC	APL	DD	CC	APL
					
ε :10					
Wc : 0.0%					
RUN: 4#;11#			RUN: 22#;24#		
DD	CC	APL	DD	CC	APL
					
Wc : 10%					
RUN: 8#;13#			RUN: 23;28		
DD	CC	APL	DD	CC	APL
					

*) DD: Degree distribution; CC: Cluster coefficient; APL: Average path length

Figure 6.4 First Experiment Results with β = 50%.

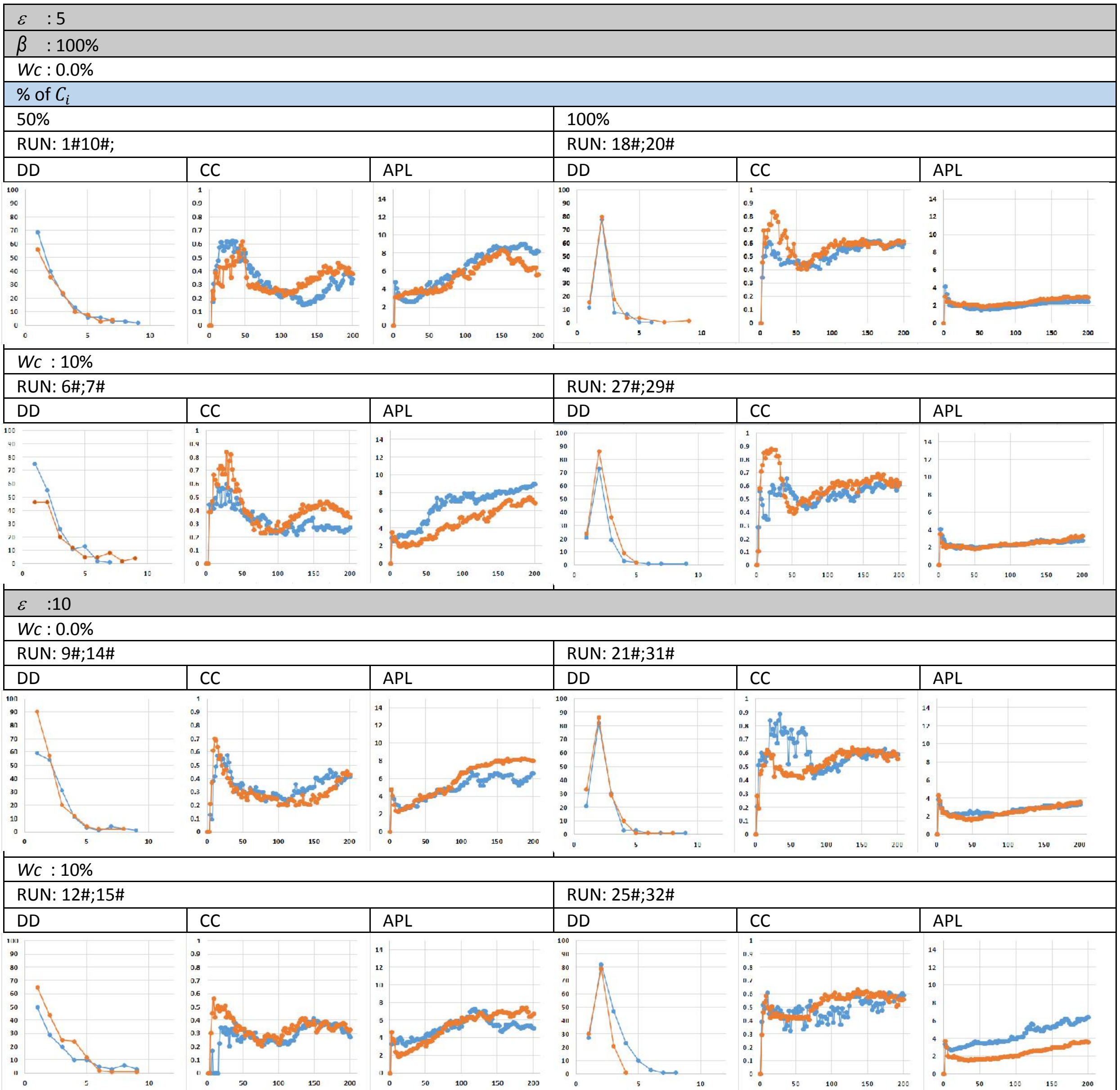
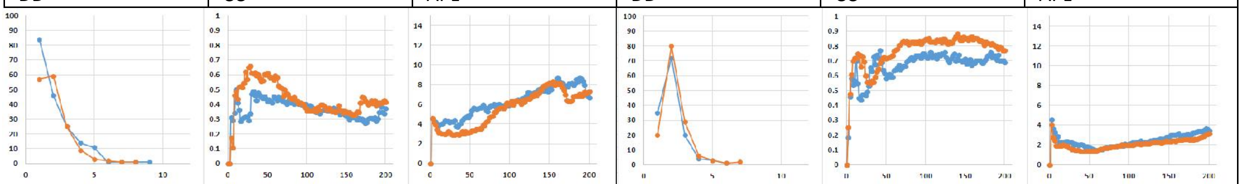
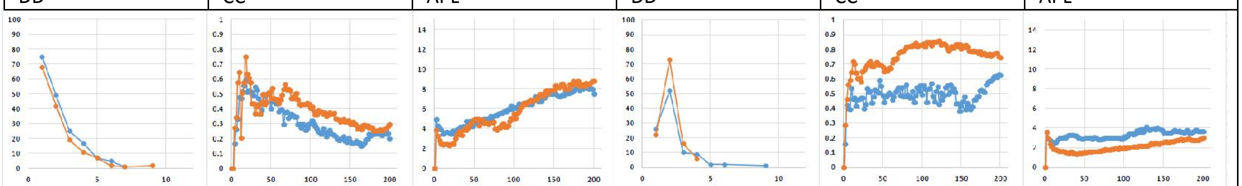


Figure 6.5 First Experiment Results with β = 100%.

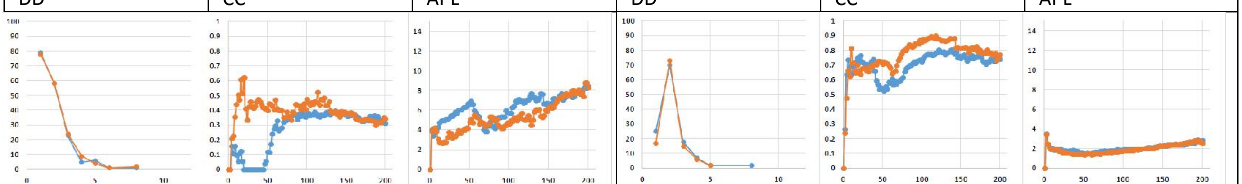
ε : 5					
β : 50%					
Wc : 0.0%					
% of C_i					
50%			100%		
RUN: 1#;16#			RUN: 2#;26#		
DD	CC	APL	DD	CC	APL



Wc : 10%					
RUN: 19#;22#			RUN: 12#;32#		
DD	CC	APL	DD	CC	APL



ε: 10					
Wc: 0.0%					
RUN: 3#;15#			RUN: 24#;25#		
DD	CC	APL	DD	CC	APL



Wc: 10%					
RUN: 9#; 13#			RUN: 11#;31#		
DD	CC	APL	DD	CC	APL

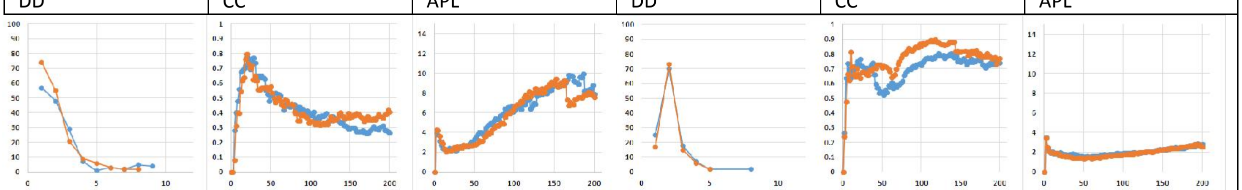


Figure 6.6 The Second Experiment Results with β = 50%.

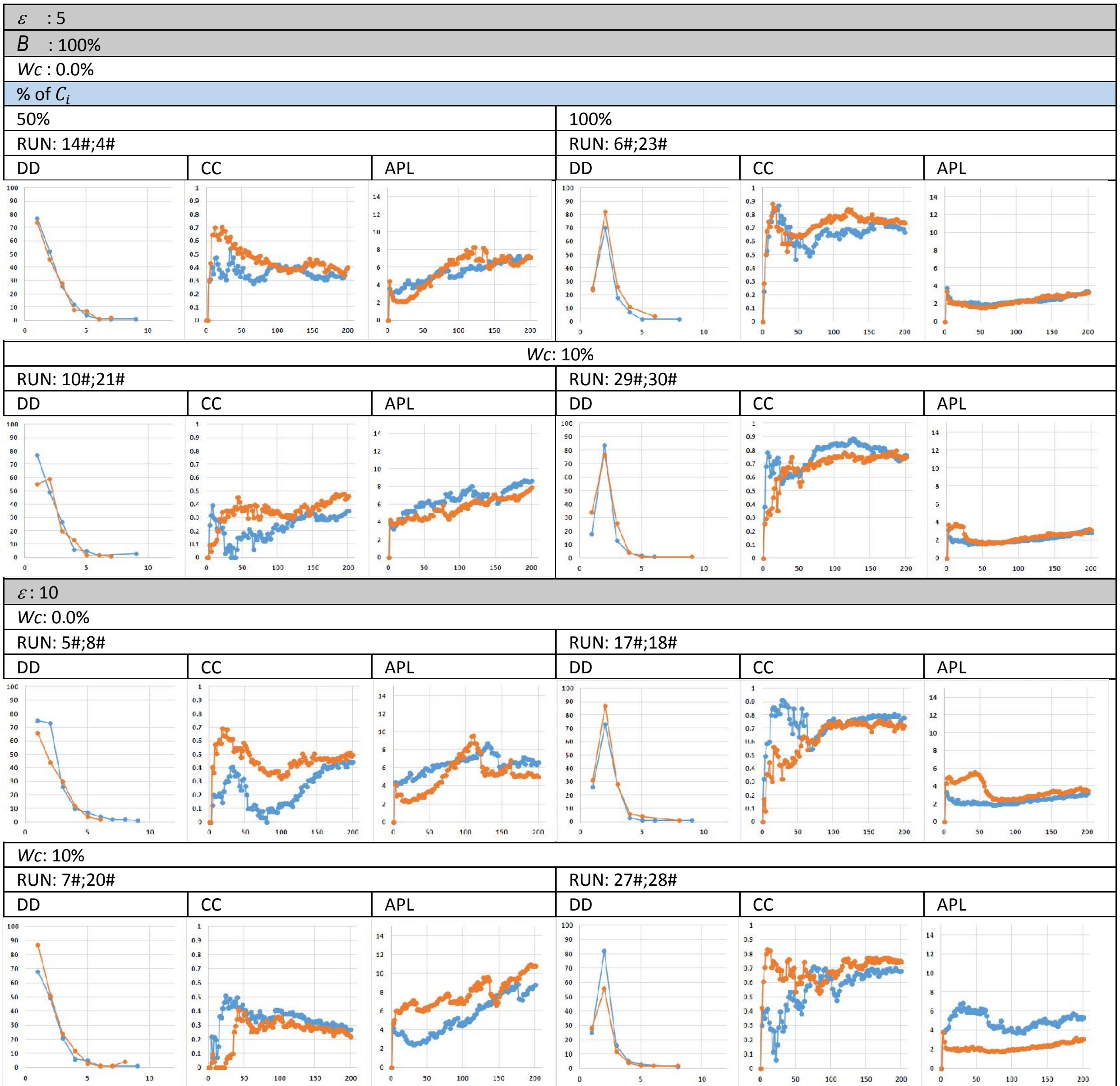


Figure 6.7 The Second Experiment Results with β = 100%.

Table 6.4 Parameters setting and their Impact on the efficiency of SN

Parameter	Experiment 1#	Experiment 2#	Impact
Relationship strategies	Cooperation – Defection (**HET**)	Cooperation – Defection (**HET**) Competition – Co-opetition (**HOT)**	Insignificant
ε	5; 10	5; 10	Insignificant
β	50%;100%	50%;100%	Insignificant
γ	100%	100%	Insignificant
% of C_i	50%;100%	50%;100%	Significant
W_c	0;10%	0;10%	Insignificant

6.4. Conclusion and Future works

The research in this chapter investigates how co-evolution of interconnected relationships in SN affect its structure and whether it could emerge into the efficient SN structure. All archaic of relationship strategies which naturally interconnected in SN has been considered, namely cooperation, defection, competition and co-opetition. To deal with the research question, a CASN simulation model has been developed for this study and has been implemented into two experiments.

The results from the preliminary experiment has demonstrated that the co-evolution of interconnected relationship strategies of cooperation, defection, competition and co-opetition could emerge the efficient SN structure. The promising impact mainly came from the variation of the intensity of cooperation relationship strategy. The variation of this parameter had significantly produced different network structure at a different level and one of its level had produced efficient structure. However, this preliminary experiment results are still very limited. It is necessary to explore the behavioral space from further exhaustive experiment.

It can be claimed that the payoff maximizing mechanism conducting by nodes has empowered the selection process in composing their relationship portfolio. This mechanism consequently playing important role in the emergence of SN efficiency. The payoff maximizing mechanism has guaranty the node to always attract to the fittest neighbor. Unfitted neighbor means it has not well supported by its embedded network or it has supported by the inefficient embedded network which both are not preferable or bad situations. Therefore, this mechanism in the long run will eliminate unfitted nodes and their inefficient embedded network out of SN. In the practical situation, the process of partner selection that has happened in SN is a natural process that not only secure the fitted individual existence in the SN but also responsible for the emergence of the efficient SN structure.

Finally, the preliminary experiment in this chapter is very limited. it still have very limited clues to answer the research questions about how co-opetition has roles and impacts on the SN structure evolution. Therefore, further experiments are needed in future work to explore the behavioral space of the model.

Chapter 7 Conclusions and Future Works

7.1. Conclusions

In this thesis, the research consists of two stages of research. At the first stage, as present in chapter four, a research framework is developed and several experiments are conducted to investigate the co-evolution of interconnected relationship strategies of CASN using CA. the following research questions are aimed to address: How and under what conditions does co-opetition in CASN co-evolve simultaneously with competition, cooperation and defection? What kind of interconnected relationship behavior will emerge as a result of this co-evolution? At the second stage of my study present in chapter five and six, the impact of the emergence macro behavior of interconnected relationship co-evolution of CASN to its firms' survivability (Sofitra et al., 2013b) and to its network structure (Sofitra et al., 2014) are investigated. It is questioned about how and under what conditions the survivability of firms inside the SN is affected by the co-evolution of interconnected relationship strategies among them? And whether this co-evolution of interconnected relationship strategies emerges efficient SN structure?

The result of the first stage of this thesis has demonstrated that specific relationship types inside CASN are not only influenced by reward scheme stimulus but, more importantly, also co-evolve with the existence and behavior of other types of relationship. The study demonstrates how a set of simple micro-conditions (agent parameters, reward schemes stimulus and agent interaction policies) can develop into complex macro-behavioral patterns of the interconnected relationships among firms. The experimental results show the emergence of attractors of interconnected relationship behaviors. These attractors suggest that cooperation promotes co-opetition and reduces the tension of the competition while defection leads to the escalation of competition and generates barriers to co-opetition. In a practical situation, the strength of cooperation relationships inside the SN of the rivals should be considered before adopting these rivals as partners in a co-opetition relationship. A strong alliance, or cooperation relationships that are embedded in a rival's SN, will ensure maximum benefit from the planned co-opetition relationship. These attractors are sensitive to SN population changes.

It can be claimed two results for the second stage of study regarding the impacts of the co-evolution of interconnected relationship strategies. Firstly, the impact on survivability of firm. The result showed that cooperation coupled with co-opetition policy in SN business environments that are favorable for cooperation can promote further lifespan of nodes at both individual level and SN level. This means, when a business environment favors alliance cooperation, it can be suggested that managers should not only exploit a cooperation strategy with their allies but also consider coupling the cooperation strategy of allies with a co-opetition strategy to their potential competitors as a strategic opportunity to increase the survivability of their firm. Even though cooperation and co-opetition might introduce some disadvantages, such as appropriation risk and technology diffusion risk and short-term opportunistic behavior might offer more incentives in certain business environment conditions, cooperation coupled with a co-opetition strategy significantly and positively impacts the survivability of firms at the individual and network level in the long-run. Secondly, the impact on SN structure. The preliminary experiment of chapter six has demonstrated that the co-evolution of interconnected relationship strategies of cooperation, defection, competition and co-opetition could emerge the efficient SN structure. Payoff maximizing mechanism conducting by nodes has empowered the selection process in composing their relationship portfolio. This mechanism consequently playing important role in the emergent of SN efficiency. The payoff maximizing mechanism has guaranty the node to always attract to the fittest neighbor. Unfitted neighbor means that it has not well supported by its embedded network or it has supported by the inefficient embedded network which both are not preferable or bad situations. Therefore, this mechanism in the long run will eliminate unfitted nodes and their inefficient embedded network out of SN. In the practical situation, the process of partner selection that has happened in SN is a natural process that not only secure the fitted individual existence in the SN but also responsible for the emergence of the efficient SN structure

7.2. Future Works

There are some important limitations regarding the model in this thesis. First, this research used high-level abstraction and simplicity of real-world SN to construct the model and gain insight. Although real-world SN exhibit significantly more complex behavior, my model experiment is based only on a set of simple micro-conditions. Slight alteration of the micro-conditions setting (e.g. modifying the node's interaction policy) may result in completely different emergent patterns of macro-behavior. Second, there is a concern that the properties and behavior demonstrated by the model in the experiment have enforceable limits. Thus, extended experiments need to be conducted by altering certain parameter values of the model (i.e., grid size and other parameters that retain the existence of certain population numbers in SN over time). Third, all behavior of co-evolved interrelationship exhibited in this study are derived only from simulation experiments that are based on a theoretical rule of interconnectedness. Therefore, the result would inevitably benefit from further support through empirical or archival research.

These limitations also offer the opportunity for future research. Firstly, future research could extend the exploration of the first stage research model in this thesis on how various micro-condition settings will produce interesting emergent macro-behavior or to realize specific micro-conditions that cause well-known macro-behavior of interconnected relationships of SN. Secondly, future research could be conducted to further explore the behavioral space of the second stage research model. This attempt would achieve a much better description of the how various designed parameters of model have their roles in shaping the SN structure through the co-evolution process.

References

Bengtsson, M., Eriksson, J., & Wincent, J. (2010). Coopetition: new ideas for a new paradigm. In C. S. D. P. and L. F. Yami S (Ed.), *Coopetition strategy: Winning Strategies for the 21st century* (pp. 19–39). Cheltenham, UK: Edvard Elgar.

Bengtsson, M., & Kock, S. (2000). ” Coopetition ” in Business Networks — to Cooperate and Compete Simultaneously. *Industrial Marketing Management*, *29*(5), 411–426.

Biely, C., Dragosits, K., & Thurner, S. (2007). Prisoner ’ s dilemma on co-evolving networks under perfect rationality. *Physica D: Nonlinear Phenomena*, *228*(1), 40–48.

Borgatti, S. P., & Halgin, D. S. (2011). On Network Theory. *Organization Science*, *22*(5), 1–14. doi:10.1287/orsc.1110.0641

Brass, D. J. (2002). *Social Networks in Organizations : Antecedents and Consequences*. Lexington. Retrieved from gatton.uky.edu/faculty/brass/consequencesofsocialnetworks.doc

Childerhouse, P. (2013). Logistical Service Provider Triadic Relational Dynamics. *International Journal of Industrial Engineering: Theory, Applications and Practice*, *20*(1-2).

Choi, T. Y., Dooley, K. J., & Rungtusanatham, M. (2001). Supply Networks and Complex Adaptive Systems: Control Versus Emergence. *Journal of Operations Management*, *19*(3), 351–366.

Choi, T. Y., & Hong, Y. (2002). Unveiling the structure of supply networks: case studies in Honda , Acura, and DaimlerChrysler. *Journal of Operations Management*, *20*, 469–493.

Choi, T. Y., & Krause, D. R. (2006). The supply base and its complexity: Implications for transaction costs, risks, responsiveness, and innovation. *Journal of Operations Management*, *24*, 637–652.

Choi, T. Y., & Wu, Z. (2009). Triads In Supplier Networks: Theorizing Buyer–Supplier– Supplier Relationships. *Journal of Supply Chain Management*, *45*(1), 8–25.

Choi, T. Y., Wu, Z., Ellram, L., & Koka, B. R. (2002). Supplier – supplier relationships and their implications for buyer – supplier relationships. *IEEE Transaction on Engineering Management*, *49*(2), 119–130.

Davis, J. P., Eisenhardt, K. M., & Bingham, C. B. (2007). Developing Theory Through Simulation Methods. *Academy of Management Review*, *32*(2), 480–499.

Estrada, E. (2011). *The Structure of Complex Networks Theory and Applications* (p. 480). Oxford University Press.

Galvagno, M., & Garraffo, F. (2010). The promise of coopetition as a new theoretical perspective in strategic management. In S. Yami, S. Castaldo, G. B. Dagnino, & F. L. Roy (Eds.), *Coopetition Winning Strategies for the 21st Century* (pp. 40–57). Edward Elgar.

Gnyawali, D. R., He, J., & Madhavan, R. (2006). Impact of Co-Opetition on Firm Competitive Behavior: An Empirical Examination. *Journal of Management*, *32*(4), 507–530. doi:10.1177/0149206305284550

Gnyawali, D. R., & Madhavan, R. (2001). Cooperative network and competitive dynamics: a structural embeddedness perspective. *Academy of Management Review*, *26*(3), 431–445.

Gross, T., & Blasius, B. (2008). Adaptive coevolutionary networks: a review. *Journal of the Royal Society, Interface / the Royal Society*, *5*(20), 259–71. doi:10.1098/rsif.2007.1229

Hakansson, H., & Ford, D. (2002). How should companies interact in business networks? *Journal of Business Research*, *55*(2), 133–139.

Hakansson, H., & Johanson, J. (1992). A model of industrial networks. In *Industrial networks: a new view of reality* (pp. 28–34).

Hamel, G., Doz, Y. L., & Prahalad, C. K. (1989). Collaborate wiht your competitors and win. *Harvard Business Review*, *67*(1), 133–139.

Hearnshaw, E. J. S., & Wilson, M. M. J. (2013). A complex network approach to supply chain network theory. *International Journal of Operations & Production Management*, *33*(4), 442–469.

Jarillo, J. C. (1988). On Strategic Networks. *Strategic Management Journal*, *9*(1988), 31–41.

Li, G., Gu, Y. G., & Song, Z. H. (2013). Evolution of cooperation on heterogeneous supply networks. *International Journal of Production Research*, *51*(13), 1–9.

Li, G., Ji, P., Sun, L. Y., & Lee, W. B. (2009). Modeling and simulation of supply network evolution based on complex adaptive system and fitness landscape. *Computers & Industrial Engineering*, *56*(3), 839–853.

Li, G., Yang, H., Sun, L., Ji, P., & Feng, L. (2010). The evolutionary complexity of complex adaptive supply networks: A simulation and case study. *International Journal of Production Economics*, *124*(2), 310–330.

Luo, Y. (2007). A coopetition perspective of global competition. *Journal of World Business*, *42*(2), 129–144. doi:10.1016/j.jwb.2006.08.007

Marco, G., & Di Guardo, C. M. (2007). *The Dynamic Capabilities View of Coopetition: The Case of Intel, Apple and Microsoft* (pp. 1–19). Retrieved from http://ssrn.com/abstract=1013561

McCarthy, I. P. (2004). Manufacturing strategy: understanding the fitness landscape. *International Journal of Operations & Production Management*, *24*(2), 124–150.

Möller, K. K., & Halinen, A. (1999). Business Relationships and Networks : Managerial Challenge of Network Era. *Industrial Marketing Management*, *28*, 413–427.

Nair, A., Narasimhan, R., & Choi, T. Y. (2009). Supply networks as a complex adaptive system: toward simulation-based theory building on evolutionary decision making. *Decision Sciences*, *40*(4), 783–815.

Nair, A., & Vidal, J. M. (2011). Supply network topology and robustness against disruptions – an investigation using multi-agent model. *International Journal of Production Research*, *49*(5), 1391–1404. doi:10.1080/00207543.2010.518744

Newman, M. E. . (2010). *Networks: An Introduction*. Oxford University Press.

Padula, G., & Dagnino, G. (2007). Untangling the Rise of Coopetition: The Intrusion of Competition in a Cooperative Game Structure. *International Studies of Management and Organization*, *37*(2), 32–52.

Pathak, S. D., Day, J. M., Nair, A., Sawaya, W. J., & Kristal, M. M. (2007). Complexity and Adaptivity in Supply Networks: Building Supply Network Theory Using a Complex Adaptive Systems Perspective. *Decision Sciences*, *38*(4), 547–580.

Pathak, S. D., & Dilts, D. M. (2009). Investigating Population and Topological Evolution in A Complex Adaptive Supply Network. *Journal of Supply Chain Management*, *45*(3), 54–57.

Pathak, S. D., Dilts, D. M., & Biswas, G. (2007). On the Evolutionary Dynamics of Supply Network Topologies. *IEEE Transaction on Engineering Management*, *54*(4), 662–672.

Poncela, J., Gómez-Gardeñes, J., Traulsen, A., & Moreno, Y. (2009). Evolutionary Game Dynamics in a Growing Structured Population. *New Journal of Physics*, *11*(8), 083031.

Ritter, T. (2000). A Framework for Analyzing Interconnectedness of Relationships. *Industrial Marketing Management*, *29*(4), 317–326.

Ritter, T., & Gemünden, H. G. (2003). Interorganizational relationships and networks: an overview. *Journal of Business Research*, *56*(9), 691–697.

Sofitra, M., Takahashi, K., & Morikawa, K. (2012a). Analyzing Co-opetition Dynamics of A Complex Adaptive Supply Network Using Cellular Automata: A Research Framework. In K. Takahashi & H. Wang (Eds.), *Proceedings of the 11th International Conference on Industrial Management (ICIM 2012)* (pp. 205–211). Beijing: Beihang University Press.

Sofitra, M., Takahashi, K., & Morikawa, K. (2012b). Interrelationship Strategies Evolvement Model of Complex Adaptive Supply Networks. In *Proceeding for Conference of Japan Industrial Management Association Chugoku Chikoku Branch Vo. 19* (pp. 1–9).

Sofitra, M., Takahashi, K., & Morikawa, K. (2013a). Co-opetition Within Interconnected Relationships Dynamics of Complex Adaptive Supply Networks: A Researh Framework. *Asia-Pacific Journal of Industrial Management*, *4*(1), 57–71.

Sofitra, M., Takahashi, K., & Morikawa, K. (2013b). The Impact of Relationship Strategies on Survivability of Firms inside Supply Networks. In *Proceedings of 17th International Conference on Industrial Engineering Theory, Application and Pranctice (IJIE 2013)* (pp. 353–363).

Sofitra, M., Takahashi, K., & Morikawa, K. (2014). The Impact of Interconnected Relationship Strategies on Supply Network Structure. In *Proceedings of the 12th International Conference on Industrial Management (ICIM 2014)*.

Strogatz, S. H. (2001). Exploring complex networks. *Nature*, *410*(6825), 268–76. doi:10.1038/35065725

Wang, X. F. (2002). Complex Networks: Topology, Dynamics and Synchronization. *International Journal of Bifurcation and Chaos*, *12*(05), 885–916. doi:10.1142/S0218127402004802

Wilkinson, I. F., & Young, L. C. (1994). Business Dancing- The Nature and Role of Interfirm Relations in Business Strategy. *Australia Marketing Journal*, *2*(1), 67–79.

Wu, D., & Olson, D. L. (2008). Supply Chain Risk , Simulation , and Vendor Selection. *International Journal of Production Economics*, *114*(2), 646–655.

Wu, Z., & Choi, T. Y. (2005). Supplier–supplier relationships in the buyer–supplier triad: Building theories from eight case studies. *Journal of Operations Management*, *24*(1), 27–52.

Zimmermann, M. G., & Eguíluz, V. (2005). Cooperation, Social Networks, and The Emergence of Leadership in a Prisoner's Dilemma with Adaptive Local Interactions. *Physical Review E*, *72*(5), 056118. doi:10.1103/PhysRevE.72.056118

Publications

A. List of Journal Papers
A.1. Sofitra, M., Takahashi, K., & Morikawa, K. (2013). Co-opetition Within Interconnected Relationships Dynamics of Complex Adaptive Supply Networks: A Research Framework. *Asia-Pacific Journal of Industrial Management*, *4*(1), 57–71.
A.2. Sofitra, M., Takahashi, K., & Morikawa, K. The Impact of Relationship Strategies on Survivability of Firms inside Supply Networks*. International Journal of Industrial Engineering: Theory, Applications and Practice*. (Accepted)
A.3. Sofitra, M., Takahashi, K., & Morikawa, K. The co-evolution of Interconnected Relationship Strategies in Supply Networks. *International Journal of Production Research*. doi:10.1080/00207543.2014.991840.(in print)

B. List of Conference Papers
B.1. Sofitra, M., Takahashi, K., & Morikawa, K. (2012). Analyzing Co-opetition Dynamics of A Complex Adaptive Supply Network Using Cellular Automata: A Research Framework. In K. Takahashi & H. Wang (Eds.), *Proceedings of the 11th International Conference on Industrial Management (ICIM 2012)*
B.2. Sofitra, M., Takahashi, K., & Morikawa, K. (2014). The Impact of Interconnected Relationship Strategies on Supply Network Structure. K. Takahashi & H. Wang (Eds.), *Proceedings of the 12th International Conference on Industrial Management (ICIM 2014)*.