Understanding Business Network Dynamics Using Agent-based Modelling and Simulation

Final seminar manuscript

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List of abbreviations

ABM	Agent-based Model(ling)
ARA	Actors -Resources- Activities
CAS	Complex Adaptive Systems
FSN	Food Supply Network
INA	Industrial network Approach
SFL	Scandfibre Logistics

1 Introduction

This thesis aims at gaining a better understanding of business network dynamics. More specifically, it is about the structural changes that emerge in business networks as results of endogenous and exogenous triggers. This thesis focuses on the emergent change process in business network, some of its influencing factors and their implications for the structure of the business networks. Industrial Networks Approach (INA) and Complexity Perspective are the theoretical points of departure in this thesis.

Business networks dynamics are prominent research topics among INA scholars (e.g., Andersson & Mölleryd 1999; Easton & Lundgren, 1992; Gadde & Mattsson, 1987; Halinen et al., 1999), still more research is needed for understanding of the influence of endogenous and exogenous change triggers and how the interactions of multiple interdependent business actors affect the consequent changes in the network structure (e.g., Knoben, Oerlemans and Rutten, 2006).

Within INA, it is argued that often the business actors tend to form long-term relationships and the networks seem to be rather stable structures. Still many changes (mostly incrementally but also radically) happen over time in the patterns of business interactions and connectivity in the network (Gadde & Mattsson, 1987; Håkansson & Snehota, 1995; Kamp, 2005). These changes cannot be understood in themselves (Håkansson & Henders, 1995) and should be studied in a context with patterns of stability in the networks, i.e. business network dynamics and their underlying mechanisms leading to those changes need to be explored. Moreover, since business networks are basically about the relationships and interactions among business actors, they are dynamic phenomena. Consideration of these dynamics over time and the factors influencing them are critical for understanding the business networks in general. From managerial point of view, better understanding of business networks can contribute to better strategizing and better responses in dealing with imposed changes and their implications.

Business network dynamics have been significant research topics among INA scholars (e.g. Easton & Lundgren, 1992; (Halinen, Salmi & Havila, 1999; Andersson & Mölleryd 1999). Viewing change in business networks as a process, one can identify certain triggers, drivers (underlying forces) and mechanisms and their implications (outcomes), have been the topics of research within INA.

Change processes within business networks may be initiated by various endogenous and exogenous triggers[1] at various levels of networks. Since INA scholars do not assume any real boundaries for business networks, they argue that most of the changes in business networks are initiated internally in business actors and their relationships. They may involve intra-organizational modification in the organization of actors, activities and resources of a firm, or changes emerging within one dyad or a set of dyads in their actor bond, activity links and resource ties (Hulthén & Mattson, 2010) and for the purpose of changing their roles or improving their positions in the network (Harrison, Holmen & Pedersen, 2012; Pardo & Mischel, 2015).

Still, holding a nested view of business networks, certain triggers can be considered external to a specific business network of interest. Exogenous triggers arise in the form of external environment factors simultaneously affecting several actors. Some examples are the general economic, political and social conditions (Halinen at al., 1999; Mattsson, 2003), such as government policies and regulations (Harrison & Easton 2002), rapid changes in the global business landscape (Guercini & Runfola 2012) and key industry events such as change in regulatory infrastructures and dramatic shifts in consumer preferences (Madhavan, Koka & Prescott, 1998). When these external triggers are identified, they are often transformed into endogenous network changes depending on business actors' perceptions of them and how they are responded to by business actors and business relationships (Halinen et al., 1999; Hertz, 1999). Therefore, endogenous and exogenous change triggers are interdependent. There is little research on these interdependencies and more importantly, on how change processes and network dynamics initiated by endogenous and exogenous triggers may differently unfold over time. Exogenously triggered changes often influence a wider range of business actors and may imply more widespread changes. Then more interdependencies and complexities may emerge that render the investigation of such changes more challenging.

Next, INA scholars identify that business actors and relationships, when faced with certain change triggers, depending on their interpretation

[1] Change triggers themselves can be changes or parts of a change process initiated before. Usually, calling an event or change, a trigger, is an analytical choice depending on the purpose of research and the chosen boundaries of the business network under study. Here, triggers are those points of the initiation of a change process that we have chosen to focus on.

of the change respond to these triggers differently (e.g. Abrahamsen, Naudé & Henneberg, 2011; Corsaro & Snehota, 2012; Kragh & Andersen, 2009). The connectivity of business relationships and the actors' responses are the main mechanisms that lead to the dynamics in business networks. Depending on actors' interactive responses to change triggers, the direction of the change processes and their outcomes may differ. These responses are driven by actors' intentionality as well as stabilizing forces of inertia that cause some level of resistance to change in business networks (Halinen et al., 1999). Business actors may reflect, absorb, adapt, transmit or transform the change and hence disperse or internalize it (Easton & Lundgren, 1992). These mechanisms may lead to a circular influence where changes in the dyadic relationships lead to changes at the network level and vice versa (Halinen et al., 1999).

Depending on actors' interactive responses to change triggers, the direction of the change processes and their outcomes may differ. Actors' responses to change triggers and various implications for resources and activities inside organizations and in connected relationships in different contexts have been widely studied conceptually and empirically by INA scholars. Two different points of departure can be recognized. Adopting a relational view, the business network is more of a context and it is mostly the dynamics of actors and their relationships which are focused on. However, adopting a structural view, the changes in the networks as structural entities, in terms of their actor compositions and (re)organizations are focused on (Thilenius, Pahlberg & Havila, 2016). Still, both perspectives can be related.

Some INA scholars have focused on actors' responses and their implications in terms of changes of network structures. Here, INA have some overlaps with strategic management literature since in the latter scholars often talk about structural changes of business networks, their dimensions, micro-foundations and dynamics (e.g. Madhavan et al, 1998; Koka, Madhavan & Prescott, 2006; Ahuja, Soda & Zaheer, 2012). Network structure is generally related to the actors' pattern of connection and how they are positioned vis-à-vis each other. Although change in network structure is basically about changes in the actor bonds but it simultaneously has implications for the resource ties and activity links as well.

This stream of research involves both structural changes being triggers for further changes in the network- e.g. in mergers and acquisitions (e.g. Havila & Salmi 2000) , and structural changes being the implication of certain actors' responses, strategizing and their interactions – e.g. in transformations of distribution networks (e.g. Hulthén & Mattsson, 2010; Abrahamsen & Håkansson, 2012; Pardo & Mitchel, 2015).

Some actor responses reinforce the relationship and network structures while others have loosening effects (Madhavan et al. 1998). Actors may react in a way that integrates their current relationships or reorganizes their relationships by substituting some or all of their partners (Guercini & Runfola, 2012) and forming new ones (Guercini & Milanesi, 2019). They may support a change force or may decide to stick to the current structure and organization of activities and resources (Abrahamsen & Håkansson, 2012). Harrison and Easton (2002) found that business actors often respond in a way to minimize the impacts of change (Harrison and Easton, 2002). Moreover, since the structure of network ties may change, the roles and positions of actors may change during the process (e.g. Anderson & Sweet, 2002; Anderson et al., 1998).

Despite the studies mentioned above, our understanding of the evolution of business network structures and the factors influencing them is still limited (Knoben et al., 2006). Most of the studies mentioned above have focused on a limited number of actors, in terms of changes and responses in a few dyadic or triadic relationships. There are some understanding of the nature of different types of actors' responses and how they may form new relationships, strengthen current ones or terminate them and hence lead to changes in the structure of their business networks. The aggregate outcomes of various actors' actions, reactions and interactions at different network levels over time can be different structural changes. However, this level of aggregation in studying these collective reorganizations is often missing within the INA as the scholars focus on a limited number of business relationships. Moreover, our understanding of the factors that may influence these structural change processes are very limited both theoretically and empirically. INA and Strategic Management scholar mentioned above have identified, actors' intentionality and strategizing, inertia and exogenous factors, various actor responses and the connectivity of business networks as influencing factors of the change process (Ahuja et al, 2012; Halinen et al., 1999). However, our knowledge of these factors and their mechanisms of influence are underdeveloped.

The above limitation can be expected, when one considers the challenges in studying business network dynamics in general, and specifically when the highly connected and interactive nature of multiple business actors are to be accounted for. Business networks as structural entities involving multiple interdependent business actors, involve high levels of complexity.

The actors involved are purposeful and capable of strategizing, still their decisions are under the influence of the network in which they are embedded. As they are acting and interacting within the context of their business networks, their interactions are simultaneously influencing and being influenced by various elements of their networks including other actors and their relationships. Consideration of all these interdependencies can make the investigation of network dynamics especially when higher number of actors are involved rather challenging if not impossible.

In fact, business networks can be seen as Complex Adaptive Systems (CAS) comprised of a set of connected autonomous components (business actors) which are constantly interacting with each other and adapting to their environment (the business network context) (e.g., Easton, Georgieva and Wilkinson, 1997; Wilkinson and Young, 2013; Wilkinson, 2006). Their interactions at the micro level, in a non-linear process, give rise to macro-level emergent phenomena or a recurrent pattern of regularities. The non-linear processes refer to the feedback effects and highly interactive nature of this system. The emergent character of business networks implies that the outcome of a dynamic process cannot be explained or understood by solely examining single-actor interactions. Neither can the resulting pattern be used to explain and understand the behavior of single business firms. These features of the business networks in transition resemble the features of complex systems and more specifically CASs, the type of systems currently being the research topic within the Complexity Perspective. More details of this resemblance are explained in Chapter 2.

A few scholars within INA have suggested applying the Complexity perspective asserting that business networks are complex adaptive systems (e.g., Easton et al.,1997; Wilkinson and Young, 2013; Wilkinson, 2006). CAS view of business networks is also sometimes implicit in INA studies or sometimes loosely applied by INA scholars. Moreover, almost all of the INA scholars who adhere to the CAS view of business networks have ignored the ontological implication of combining an INA view of the network with a system view of CAS (Prenkert, 2017). Rarely, the complexity perspective on business networks is clearly discussed in terms of its implications of the type of insights that are achieved and the implications for methodologies adopted.

Adopting a Complexity perspective, structural changes of a business network can be considered as a macro-level pattern that may emerge in the system. Then these changes could be explained by identifying the interactive components of the system (business actors and their interactions), the underlying mechanisms of these nonlinear interactions and how they lead to emergence of the network structural changes from bottom-up.

Considering that the complex nature of business networks has contributed to limitations of our understanding of their dynamics mentioned above, methodological challenges need to be addressed. The most significant implication of viewing business networks as CASs for the purpose of this thesis is methodological. Viewing a phenomenon as a CAS, to understand the phenomenon, one can approach it through the common methodological perspective adopted to study many of CASs in various fields of science. The specific methodology used here for studying CASs is Agent-based Modeling (ABM) and simulation. ABM and simulation (as a tool within computational social sciences) involves modeling some social reality as computer programs (Gilbert, 2008, López-Paredes, Edmonds & Klugl, 2012). ABM and simulation, for the purpose of this thesis, functions as "simplified reproduction of portions of the reality" (Fioretti, 2013, P. 228) through which we can examine and understand the underlying mechanisms of structural changes that emerge in the networks by experimentation and testing of our proposed mechanisms.

More on methodological considerations are presented in Section 3 of this chapter. Moreover, in chapter three, this methodology is explained in detail and further methodological discussions relevant to the thesis, the choice of methodology and its implications are provided.

1.1 The purpose and research questions of this thesis

Given the above setting, the aim of this thesis is to enhance this current understanding of business network dynamics in general and particularly our understanding of their structures and how they evolve over time when changes are triggered endogenously and exogenously.

The overall purpose of the thesis is to better understand the structural changes that emerge in the business networks in response to endogenous and exogenous triggers, by viewing business networks as Complex Adaptive Systems and exploring the phenomenon of structural change in such a complex context.

The overall research questions of the thesis are formulated as below:

1. How can the structure of a business network evolve over time as a result of endogenous and exogenous change triggers?
2. What moderating factors may influence this change process and its outcomes?

These overall research questions are foundations for this thesis and are broken into more detailed questions in the two cases of this thesis and approached in the specific contexts of the cases. The purpose is to understanding structural changes of the networks by exploring them in two settings, one empirically and the other theoretically. In the former the change process emerging from an endogenous trigger are explored while in the latter, emerging change processes of an exogenous trigger are explored. The aggregate of the two then help gain a better understanding of some of the mechanisms involved in network structural changes. More specifically, I explore the phenomena of structural change processes by describing and formalizing the phenomena in the form of computational models. I.e. the purpose is to examine the implications of my assumptions about the phenomena and their underlying mechanisms by trying to generate it in computational models. Then the purpose is to better understand the emergent processes of structural changes in the network in response to endogenous and exogenous triggers by proposing and examining different assumptions about some of the involved mechanism and analyzing the changes that arise.

With the first and rather overarching research question of the thesis, the purpose is to understand and explore the processes of network structural changes, by proposing and formalizing a set of mechanism that can influence the process, test those mechanisms and explore the structural changes that emerge as a result.

As part of the understanding of the change process mentioned above by exploring some underlying mechanisms, in the second research question the influence of certain factors that may affect the change process are explored. Moreover, when analyzing the outcomes of these explorations, I offer possible explanations of them since the formalized model itself is a proposed possible explanation of the generated outcomes.

1.2 Methodological implications

The major contribution of the thesis is methodological, addressing the research questions through computational experiments with ABM and simulation as a novel methodology. The thesis illustrates the potential of such an approach in addressing business network dynamics specifically under more complex and highly interactive context of larger number of actors (beyond what is common within INA with the dominant case study methodology). The thesis shows how ABM and simulations can contribute to a better understanding of business network dynamics.

The majority of INA studies on business network dynamics and specifically structural changes have adopted qualitative case studies. Qualitative case studies can to a large extent capture the complexities of business interactions in network context. This research design within INA is so dominant that Easton (1995) warns against the fact that sometimes within INA research the methodological approach is taken for granted without reflecting on its assumptions and epistemological issues. Still he argues that this approach is often the most appropriate approach to analyse business networks in terms of epistemological considerations.

Understanding the processes of change and their implications in business networks requires a multi-level analysis of highly interactive multi-actor business networks. Most importantly, the emergent and non-linear nature of the interaction processes involved, require a type of explanation different from the simple causal links between actor's behaviour and its outcomes. The outcome of such processes are not reducible to the individual interactions. The descriptions of qualitative case studies may be able to provide insights into the process; however, their capacity is diminished when the number of business actors involved increases and more specifically when cross-level analysis are needed. Apart from the challenges that may arise in collecting the data, more difficulties are involved in analysing and interpreting such data and tracing the dynamics and effects of different elements of the phenomenon to offer a comprehensive and valid description and understanding of the mechanisms underlying the phenomenon.

The most important implication of viewing business networks as CASs, for this thesis, is the methodological implications that can help overcome some of the challenges in understanding structural change processes in business networks in response to endogenous and exogenous change triggers, by applying Agent-based Modelling and Simulation. ABM and Simulation is the most common methodological tool applied for understanding CASs in various fields of science (Miller & Page, 2007). In social sciences, they involve modelling some social reality as computer programs (Gilbert 2008).

ABMs' application in studying business networks is not unprecedented. A few INA scholars have promoted viewing business networks as CASs and exploring them through ABMs (e.g., Wilkinson & Young, 2005; Folgesvold and Prenkert, 2009; Iandoli et al., 2009; Gottardi, 2011; Purchase, Olaru & Denize, 2014). Moreover, they are suggested as complements to case studies within INA (e.g., Prenkert, 2012).

ABM and simulation is the common approach to study CASs since it is a bottom-up approach where the interactions of the entities (business actors' responses in terms of adoption of sustainability) at the micro-level generate the macro-level outcomes (changes in the network structure). The approach may involve various elements of both case studies and common variance-based approaches while having characteristics and applications beyond those two.

In this thesis, through systematic experimentations with ABM, I develop a theoretical understanding of business networks' structural changes. Clearly, this choice of methodology has implications for the theoretical development that is achievable in this thesis.

ABMs allow systematic experimentations to make the arguments and explanations of a certain phenomenon stronger by comparing and contrasting it to alternative competing explanations and elaborating them by identifying more and more conditions under which the phenomenon holds or not (unlike case studies that represent researchers' access to only a limited number of the instances of the phenomenon).

1.3. The research process and outline

In chapter 2, the theoretical backgrounds and the relevant literature of the thesis are discussed. This includes INA scholar's research on business network dynamics as well as introduction of the Complexity perspective in viewing business networks. A brief overview of research on sustainability issues within INA is also presented, the reason for this is explained further below. Moreover, the theoretical framework of the study is presented.

Chapter 3 discusses the methodological considerations of this study by referring to the main features of qualitative case studies as the common methodology within INA, its limitations and how ABM and simulation can contribute to address some of these limitations. Then the research process of the thesis is explicated, explaining how the general research questions of the thesis are addressed by extending them in two empirical and theoretical directions and the modelling phases that follow.

To address the primary interest of this thesis which is to gain a better understanding of the structural changes that emerge in business networks as a result of endogenous and exogenous change triggers, I expand in two directions by breaking the research questions in terms of the type of change trigger.

First, in chapter 4, I focus on endogenous change triggers. This process of structural change is illustrated empirically through a case of a railway operator in Sweden called Scandfibre Logistics (SFL). In this first case, SFL as the focal firm internally initiates a change trigger. For efficiency reasons and improvement of its position, SFL plans to introduce a solution to its network of current and potential customers. This focal actor's strategizing, functions as an endogenous change trigger in its network and is shown to have implications for the network structure. Although initiated deliberately, but the new strategic initiative of the focal firm may give rise to various customer responses and their interactions that over time and in a non-linear way may generate certain emergent and unpredictable changes in the network structure.

The following specific research questions drawn from the overall questions mentioned above are formulated to be addressed in this first case:

1. What are the possible implications of SFL's new solution for the structure of its business networks?
2. What moderating factors may influence this process of change and its outcomes?

Based on the case data collected during the FutureRail Project on SFL and its business network, the first ABM of the thesis (SFL-ABM), which involves formalizing the theoretical propositions of the thesis in the form of a causal model and then modeling the business network of the case firm, SFL. All the assumptions of the modeling phase are elicited from the data collected during the FutureRail project and the theoretical lenses adopted in the thesis. In chapter 4, the details of the SFL's case and the methodological steps followed to address the above research questions by computational experimentation are elaborated. The results are presented and then analyzed.

Following the first model results, and to complement them in order to address the aim of the thesis and the overall questions, I then in chapter 5, focus on exogenous change triggers and the structural changes that then emerge in the business network. Following the empirical extension of the research purpose in the first case, now in the second case I ask how the structural change may emerge if the change trigger is exogenous and address this theoretically. By theoretically addressing this question, I can focus on a wider view of network, incorporate more actors and interdependencies and hence address higher levels of complexity than are addressed in the first case. Studying a real-world situation comprising of this level of complexity, with high number of interacting business actors involves collection and analysis of high amount of longitudinal data which is impossible to do in a short time. This approach to ABMs that are aimed at theoretical exploration are quite common. Although the model does not represent a specific real-world business network in detail, it represents an abstract business network –typifying a real-world situation- with enough details to help researchers capture the specific theoretical aspect of interest in the phenomenon.

I decided to illustrate a food supply network comprising of various supply chains as a rather complex business network, in terms of nested networks. Moreover, the sustainability pressures coming from shifts in consumers' attitude and increased demand for environmentally sustainable products is chosen as the specific exogenous trigger, simultaneously affecting a wide range of business actors in the supply network pushing them towards making their operations more sustainable (i.e. adopt sustainability) with no individual business actor in control of the process (as opposed to the first case where the perspective of a focal actor and its strategizing are considered).

Sustainability was chosen first because following the review of INA literature on sustainability (an overview is offered in chapter 2), it was realized that sustainability is an issue that needs to be addressed at the aggregate level of multiple directly/indirectly connected organizations rather than a single organization and hence is embedded in the complex interactions in business networks (e.g. Öberg, Huge-Brodin & Björklund, 2012; Frostenson & Prenkert, 2015). Second, INA scholars have approached the process of adoption of sustainability in business networks as a process of change (e.g., Andersson & Sweet, 2002; Harilainen, 2009; Harrison & Easton, 2002; Johnsen, Miemczyk & Howard, 2017; Meqdadi, Johnsen & Johnsen, 2017 & 2019; Veal & Mouzas, 2011). Hence, it could offer a dynamic context to address the purpose of the thesis. The following research questions are adopted for this theoretical exploration, from the main research questions of the thesis in a way that addressing them would be complementary to the insights gained from previous empirical case of SFL:

1. What are the possible implications of end-customers' increased demand for sustainable products for the structure of a supply network?
2. What moderating factors may influence the process and its outcomes?

The rest of the steps followed are similar to the first case. This time the model specifications including the types of business actors to include and their behavior are based on common knowledge of the field and the theoretical assumptions of INA. More importantly, the purpose of the simulation and research questions help define the boundaries and specifications of the supply network to be modeled. The methodological steps explained in chapter 3 are followed for the second ABM of the thesis (FSN-ABM). The whole process in details, the experiments conducted and the results are presented in chapter 5.

2 Theoretical Background

Industrial Network Approach (INA) and Complexity perspective are the theoretical points of departure in this thesis. This choice of theories has important implications for the methodological approach adopted in the thesis as it embraces the requirements of both the INA and Complexity perspective. As the audience of this thesis are mainly scholars within the INA, this chapter starts by briefly going through the main building blocks and assumptions inherent to INA. Thereafter, the current state of research within INA on business network dynamics is described. Since sustainability is the empirical context adopted in the second part of the thesis (in the second case), I then briefly go through the INA studies on sustainability adoption in business networks. The discussion will follow by introduction of the Complexity perspective and how considering business networks as complex systems can enhance our understanding of the dynamics and evolutionary processes of business networks. The chapter ends with depiction of the theoretical framework adopted in this research.

2.1 Industrial Network Approach (INA)

Industrial Marketing and Purchasing (IMP) scholars developed Industrial Network Approach (INA) as a research tradition in 1970s as a result of extensive empirical research in different industry sectors and markets. Based on observations along many different industries, it was realized that the mainstream Neo-classical economic theories of firms doing business does not fit the business exchange in reality. Early INA scholars observed an inclination toward stable and long-term relationships among business actors. This behaviour of firms could not be explained by the Neo-classical view of markets as atomistic, which implied that firms were self-interested agents and would constantly change partners to find the most beneficial one.

Grounding their theoretical considerations in marketing theories, business economic theories and organizational and social sciences, resource dependency theory and social exchange (Håkansson et al., 2009), INA scholars developed the business network idea. They state that “no business is an island” and firms (actors) are embedded in a highly interconnected and dynamic web of business relationships. Within these networks, actors try to access different resources and mobilize their own resources by forming ties to other firms (Håkansson and Snehota, 1989). The main unit of analysis in this research tradition is the business relationship and the most significant characteristic of business in networks is the interaction between the parties involved rather than what happens within those firms (Håkansson, 1982).

Håkansson and Johanson (1992) provided a framework to analyse the interaction process and its outcomes by suggesting three layers of business relationships; Activity, Resource and Actor, each layer focusing on a certain dimension of the interaction – the ARA-dimensions. The activity layer constitutes the activity links of the counterparts involved, the extent to which they are interdependent and tied together. The resource layer includes all resources of the actors involved, how they are collectively utilized and how one actor tries to mobilize its own resources by tying them to the resources of counterparts. The actor layer contains the interrelatedness of the parties involved. It is more about the subjects of the interactions, which are usually considered as firms and organizations (however, generally speaking, the concept of actor within INA research can be used to denote an individual, a group of individuals within a firm and an organization itself) and how they perceive each other, their interactions and the extent to which they are bonded to each other (Håkansson & Snehota, 1995).

2.1.1 Change and dynamics in business networks

Although business relationships and networks within the INA perspective are considered relatively stable, changes in the patterns of business interactions and connectivity have been observed over time (Gadde & Mattsson, 1987; Kamp, 2005; Håkansson & Snehota, 1995). Even relatively stable periods are characterized by continuous incremental changes in the content and strength of relationships and are thus not static 'states' (Halinen et al., 1999). Considering that business relationships are the building blocks of business networks, implies that they cannot be assumed stable and static structures since relationships are inherently dynamic. Therefore, networks are in constant change even if a snapshot of them would reveal a similar structure at different points in time. I.e. both change and stability are present in the network. Even in long-term relationships, change is a fundamental aspect of the interaction processes over time (Håkansson & Snehota, 1995; Freytag & Ritter, 2005) with changes happening in all three layers of the firms and the relationships between them (activities, resources and actors) (Abrahamsen & Håkansson, 2012).

It is important to analyze the dynamics in business relationships and business networks, rather than just focusing on the change. Since changes in business networks are dependent on each other, "…each change can be seen in itself but cannot be understood in itself" (Håkansson & Henders, 1995, p. 142.) and it must be put into the context of past, present and future (so consideration of time is important for investigating the dynamics). Business network dynamics are basically the result of the interdependencies (at various levels of activities, resources and actors) in business networks and the intentionality of the actors which are constantly trying to find opportunities to improve their position in the business networks. These mechanisms of the business relationships and business networks trigger forces of change and stability (inertia) which define the dynamics in relationships and networks. Hence, dynamics are the underlying processes of change including various forces of stability and change. It is about the patterns of change and stability. It is a feature of the context in which the change arises. Therefore, it triggers changes, while at the same time changes also affect it.

Business network dynamics is a significant research topic among INA scholars (e.g., Andersson & Mölleryd 1999; Easton & Lundgren, 1992; Gadde & Mattsson, 1987; Halinen et al., 1999). Halinen et al. (1999) is probably the most influential conceptual study of change from INA perspective, which defined the most basic assumptions about business network dynamics. According to Halinen et al. (1999) business relationships are most fundamental change mechanism in networks which can be the generator, recipient or transmitter of change in business networks and dyads. Changes are initiated in interactions within business relationships. Then this change (in the deep structures of the dyad- i.e. actors, resources and activities) may stay only in its initial relationship which then is called a *confined change*. However, and more interestingly, the changes initiated in one dyad may affect other actors and relationships surrounding it and then the dyad is functioning as recipient or transmitters of the *connected change*.

The most important features of change in business networks, argued by Halinen et al. (1999) is, first, the circularity rather than unidirectionality of change mechanisms. Due to the connectivity of business relationships, changes within dyads may lead to changes in the network level and vice versa. Second, business network dynamics can be viewed from punctuated equilibrium model, where periods of constant incremental changes in the business networks and dyads are interrupted by radical changes (often triggered by critical events). The above assumptions and concepts are the most important aspects focused on in studies of business network dynamics following Halinen et al. (1999).

2.1.1.1 The Process of Change

Viewing change in business networks as a process, one can identify certain triggers, drivers (underlying forces) and mechanisms and their implications (outcomes) that have been the topics of research within INA. There are some main forces of change behind business network dynamics. The interdependencies of actors, activities and resources arising from the interactions of business actors make the networks dynamic, as there are constant processes of interaction and negotiation where changes in one aspect of ARA at one level may influence other aspects and relationships at different levels (e.g. dyad and network). Moreover, actors' intentionality and mental processes of enactment to achieve its goals and enhancing its network position through strategizing processes are also other forces of change. Many scholars within INA and Strategic management literature have focused on these forces of change in networks. Although those studies may not be explicitly categorized as studies of business network dynamics, still they are focusing on actors' strategizing processes and their consequences for various dimensions of the network (ARA) and at different levels of analysis (strategy implications for the focal firm, its relationships and the wider business network) (Öberg et al., 2016).

As another force underlying business network dynamics, Halinen et al. (1999) argue that inertia is a force of stability within business networks and contributes to network dynamics. The tendency of actors to develop long-term relationships to better handle uncertainties of the business network context, lead to high levels of resource interdependencies and rigidity. This rigidity lead to certain level of heaviness and costs in changing status quo in business interactions which the business actors try to avoid and cause some level of resistance to change.

In addition, INA scholars have identified various triggers of change in business networks that can be categorized into two general classes; endogenous triggers and exogenous triggers. Change triggers themselves can be changes or parts of a change process initiated before. Usually, calling an event or change, a trigger, is an analytical choice depending on the purpose of research and the chosen boundaries of the business network under study. In this thesis, triggers are those points of the initiation of a change process that I have chosen to focus on.

Endogenous triggers arise from the inside of the network and can be either an intra-organizational modification in the organization of actors, activities and resources of a firm, or changes emerging within one dyad or a set of dyads in their actor bond, activity links and resource ties initiated by actors in the network (Hulthén & Mattson, 2010) and for the purpose of changing their roles or improving their positions in the network (Harrison et al., 2012; Pardo & Mischel, 2015). Since INA scholars see business networks as boundary-less, they argue that most changes in business networks are initiated internally in business actors and their relationships. Then due to the interdependencies existing in business networks, endogenous change triggers that may arise in a business actor, dyad or network, may lead to further changes in different parts of the network.

Although the boundaries in business networks are theoretically blurry, but holding a nested view of business networks, certain triggers can be considered external to a specific business network of interest or from the perspective of a specific business actor. In addition, exogenous triggers arise in the form of external environment factors simultaneously affecting several actors, such as general economic, political and social conditions (Halinen at al., 1999; Mattsson, 2003), government policies and regulations (Harrison & Easton 2002), rapid changes in the global business landscape (Guercini & Runfola, 2012; Mattsson, 2003), and dramatic shifts in consumer preferences (Madhavan et al., 1998). Sometimes changes "…made are not only partly driven by issues endogenous to the relationship, but also partly due to the response to changes in the wider business network" (Thilenius et al., 2016, P 318).

When these external triggers are identified, they are often transformed into endogenous network changes depending on business actors' perceptions of them and how they are responded to by business actors and business relationships (Halinen et al., 1999; Hertz, 1999). Moreover, seemingly similar changes may be triggered either endogenously or exogenously, e.g. actors may change partners due to some relationship-internal factors or certain external critical events (Kamp, 2005). Therefore, endogenous and exogenous change triggers are interdependent. Exogenous changes are transformed into or combined with endogenous changes (Eiriz & Carreiras, 2018; Hertz, 1999) and then the business relationships working as transmitters, will further spread the change (Halinen et al, 1999). There is little research on these interdependencies and more importantly, on how change processes and network dynamics initiated by endogenous and exogenous triggers may differently unfold over time. Exogenously triggered changes often influence a wider range of business actors and may imply more widespread changes. Then more interdependencies and complexities may emerge that render the investigation of such changes more challenging.

Upon perception of triggers of change in business networks, actors involved depending on their interpretation of the change respond differently to the change through interactions and reorganize themselves accordingly. (e.g. Abrahamsen et al., 2011; Corsaro & Snehota, 2012; Kragh & Andersen, 2009). The connectivity of business relationships and the actors' responses are the main mechanisms that lead to the dynamics in business networks.

Different INA scholars have tried to identify different categories of actor responses to change triggers. Easton & Lundgren (1992) conceptualizing changes in business networks as flow through nodes identified different actor responses to change. According to them business actors may reflect, absorb, adapt, transmit or transform the change. They can further modify the amplitude of the change and decide on whether to disperse it or internalize it. An interesting proceeding question, might be: if each actor in the network is responding in terms of any of the categories above, then how one can understand the aggregate outcome of these reactions for the network. These mechanisms may lead to a circular influence where changes in the dyadic relationships lead to changes at the network level and vice versa (Halinen et al., 1999). Harrison & Easton (2002), through 10 case studies investigated the process of firm-level responses to the regulation of chlorofluorocarbons banning. They found that impact/change minimization was the deep mechanism underlying the patterns of response outcomes with varying firm-internal (such as strategic approach and culture and experience) and firm-external factors (such as other actors and technological availability) affecting those outcomes. Veal & Mouzas (2011) through a case study examined the effect of new environmental regulation in the aviation industry. They investigated the responses of a focal organization to these new regulations as a result of its sense-making and network picture and its relationships with other actors. They found out that the organizations did not simply complied with the new regulations. Although the interactions of the actors involved was influenced by the new rules, but those responses at the same time, caused further changes in the regulations.

The way to deal with change and dynamics in business networks differs depending on the vantage point from which the dynamic is considered.

Business networks can be considered as merely a context for business interactions and their embeddedness. In such a view, the components of the network such as the actors, their relationships and their dynamics are central thus representing what can be labelled a relational view. On the other hand, business networks can be considered as structural entities. In this view, the change is usually an independent variable and its implications for the network structural features, its actor compositions and (re)organization are central thus representing what can be labelled a structural view (Eiriz & Carreiras, 2018; Dahlin and Havila, 2007; Dahlin & Thilenius, 2006; Knoben et al., 2006).

It is the business interactions that drive this change process and its outcomes in business networks (Håkansson & Snehota, 1995). Depending on actors' interactive responses to change triggers, the direction of the change processes and their outcomes may differ. In this network context, change initiations and responses at the organizational level and business relationship level, in most cases will not be limited to that specific firm or relationship (confined change) but will have consequences for other connected direct or indirect relationships, resulting in spread of the change (connected change) (Halinen et al., 1999). The outcome is not always a change-change situation in which change at one level will cause change at another level, but also change at one level may lead to stabilizing effects on another level (change-stability situation) (Freytag & Ritter, 2005). However, there is no optimal configuration towards which the networks and its constituents can move, because the heterogeneity of its elements and its high interconnectedness.

2.1.1.2 Structural changes in business networks

The aggregate outcomes of changes at different network levels over time can be different structural changes in the overall network (as an entity) when multiple business relationships are terminated and new ones are established resulting in what Mattsson (2003) calls reorganization of activities, resources and actors. Some INA scholars have focused on actors' responses and their implications in terms of changes of network structures. Network structure is generally related to the actors' pattern of connection and how they are positioned vis-à-vis each other. Hence, it is basically about the actor bonds in business networks. However, these patterns of connection have implications for the actors' level of access to resources and how they organize their activities both internally and in relationships. Hence, although change in network structure is basically about changes in the actor bonds but it simultaneously has implications for the resource ties and activity links as well. More importantly, different network structures imply different positions for the actors and hence certain constellation and access to resources.

In research on business network structural dynamics, structural changes can be viewed as triggers for further changes in the network. Havila & Salmi (2000), adopting the analytical framework of Halinen et al. (1999), study structural changes in the context of mergers and acquisitions. They show that how mergers and acquisitions (in terms of dyadic structural changes) may trigger radical changes in the network by formation of new business relationships and termination of old ones.

Structural changes may also be the implications of certain actors' responses, strategizing and interactions – e.g. in transformations of distribution networks (e.g. Abrahamsen & Håkansson, 2012; Hulthén & Mattsson, 2010) in terms of intermediation, disintermediation and re-intermediations in these networks (Pardo & Mitchel, 2015). Some responses reinforce the relationship and network structures while others have loosening effects on the structure (Madhavan et al. 1998). These authors define network structure as "variation over time in the underlying pattern of relationships that bind a given set of actors" (P441). Actors may react in a way that integrates their relationships or reorganizes their relationships by substituting some or all their partners. Abrahamsen & Håkansson (2012) in the empirical setting of Japanese seafood distribution network investigate how the actors may act in networks which are transforming. They suggest that business actors in these network transformations may support the change force or decide to stick to the current structure and organization of activities and resources.

Andersson & Mölleryd (1999) in a longitudinal case study of the distribution network of mobile telephony, focused on a set of behavioral responses to new technologies in business network, which may maintain or change the structure of network. Guercini & Runfola (2012) studied two cases in the Italian textile industry where business model innovation worked endogenously and caused changes in the structure of the business networks of the two focal firms. The authors identified two paths of change; integration (which strengthens the current relationships of the focal firm, i.e. consolidate its network) and substitution (in which the focal firm moves toward substituting certain partners with new ones, i.e. changing the structure of its network).

In this topic, INA has some overlaps with strategic management literature since in the latter scholars often talk about structural changes of business networks, their dimensions, micro-foundations and dynamics (e.g. Ahuja et al, 2012; Koka et al, 2006; Madhavan et al, 1998). Koka et al. (2006) and Ahuja et al. (2012), explicitly focused on various structural changes that happen in networks. Koka et al. (2006) developed a framework to investigate the effect of certain exogenous environmental factors (uncertainty and munificence) on the patterns of network structural changes (expansion, strengthening, churning and shrinking) in terms of creation or deletion of business ties. Ahuja et al. (2012) argued for the importance of more detailed view on network architectures to understand network dynamics.

Despite the studies mentioned above, our understanding of the evolution of business network structures and the factors influencing them is still limited (Knoben et al., 2006). Most of the studies mentioned above have focused on a limited number of actors, in terms of changes and responses in a few dyadic or triadic relationships. There are some understanding of the nature of different types of actors' responses and how they may form new relationships, strengthen current ones or terminate them and hence lead to changes in the structure of their business networks. The aggregate outcomes of various actors' actions, reactions and interactions at different network levels over time can be different structural changes. However, this level of aggregation in studying theses collective reorganizations is often missing within the INA as the scholars focus on a limited number of business relationships. Moreover, our understanding of the factors that may influence these structural change processes are very limited both theoretically and empirically. INA and Strategic Management scholar mentioned above have identified, actors' intentionality and strategizing, inertia and exogenous factors, various actor responses and the connectivity of business networks as influencing factors of the change process (Ahuja et al, 2012; Halinen et al., 1999). However, our knowledge of these factors and their mechanisms of influence are underdeveloped.

This thesis investigates the dynamics underlying structural changes that happen in business networks in both cases of the study. In line with the scholars mentioned above, the structural changes are examined in terms of the new relationships being created and current relationships being terminated. As mentioned previously, in the first case- of a railway operator-, the change is initiated deliberately and endogenously by the focal actor in its network of customers- comprising of a set of shippers/terminal operators. The purpose of the focal actor is introducing a new solution in its network to improve its position within the network. In such a context, “Understanding network dynamics is also important because of the potential role of conscious agency by network participants in creating network structures that benefit them. In other words, some deliberate network modifying actions by network actors in the present may have consequences for network structure later.” (Ahuja et al., 2012, p. 435)

In the second case, a food supply network comprising of multiple food supply chains with various actors at various tiers of the network is focused on. In this case, the change –adoption of sustainability by business actors- is initiated remotely as a response to an exogenous pressure from end customers who ask for more environmentally sustainable food products. Again, as in the first case, network structural implications of this change process –this time with no focal actor- are examined.

The issue of sustainability is mostly an empirical context for the purpose of this thesis to illustrate a food supply network comprising of various supply chains as a rather complex business network, in terms of nested networks. Moreover, the sustainability pressures coming from shifts in consumers’ attitude and increased demand for environmentally sustainable products is chosen as the specific exogenous trigger, simultaneously affecting a wide range of business actors in the supply network pushing them towards making their operations more sustainable (i.e. adopt sustainability) with no individual business actor in control of the process (as opposed to the first case where the perspective of a focal actor and its strategizing are considered). Sustainability in business networks offers a dynamic and complex context to address the purpose of the thesis. To elaborate more on the relevance of this choice of context for this thesis, next section presents an overview of the INA literature on sustainability and explains how INA scholars have approached the process of adoption of sustainability in business networks as a process of change.

2.1.2 Research on sustainability from INA perspective

Sustainable development is a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland Report, 1987, Towards Sustainable Development Section, para. 27). The agenda on sustainable development goals have three main components, environmental protection, economic growth and social equity. As the goal is the mitigation of the negative effects of consumptions, the role of businesses and more specifically supply chains in achieving sustainable development goals is constantly emphasized. As "Supply chains are the links between consumption and its impact" (WWF living planet report, 2018, p. 34), they are the setting in which business sustainability of the actors involved in production, distribution and consumption of products are manifested.

In line with discussions in previous sections on business network dynamics and triggers of change, the business actor's decision to adopt sustainability, may be triggered endogenously or exogenously. A business actor may endogenously adopt a sustainable business practice to gain competitive advantage or to satisfy the sustainability requirements of another partner in order to sustain/improve its position in the network and stay profitable. Exogenous triggers arise in the form of external environment factors simultaneously affecting several actors (Halinen at al., 1999), such as government policies and regulations on sustainability requirements of businesses (e.g., Harrison & Easton 2002), and transformation of end customers' demand towards more sustainable products.

Sustainability requirements and pressures imposed on businesses have added to the complexity of supply networks as they introduce dependencies among apparently independent organizations with probably conflicting objectives in the network. Common actors with higher power positions in business networks are now dependent on less powerful actors for achieving their sustainability goals. The sustainability of products and practices of a business actor, at any tier of the supply chain, very much depends on the sustainability of products and practices of their partners specifically their suppliers at other tiers.

In a similar fashion, from the perspective of the end customers, the sustainability of the product is the collective result of the various production and distribution activities along the supply chain of the product. This has implication specifically for retailers and brand owner who are the closest actors to the end customer. Although these actors may not have a direct influence in the production processes of their assortments, they are constantly being held responsible for the unsustainable practices of their upstream suppliers and partners. Still the supplier or the customer of a focal firm are not just passive actors. They are active, and constantly react and respond to the sustainability initiatives imposed on them. These interdependent interactions can influence the whole process of adoption.

This implies an emphasis on the interactions and interdependencies between the actors and their relationships where the initiation of the adoption of sustainability is not a mere deliberate process with predictable outcomes. Rather, this initiation provokes responses from a wide set of directly/indirectly connected actors and initializes a change process in the business network in which no single actor is in control, and the outcomes and implications for the whole network and the involved individual actors are not discernable from the beginning. As Andersson and Sweet (2002, P. 477) stated "There is a need to understand more about the interplay between the structure of the moving network context, the actions of change agents mobilizing other actors for change, and the characteristics of the actual change processes.". To better understand how this change process unfolds overtime and its implications, one needs to take into account the actors' strategizing and mobilization, the interactive and dynamic context of business networks and the specific nature of the sustainability issues-as being interactive and requiring a collective approach.

Sustainability performance of businesses is better captured at the aggregate level of multiple directly/indirectly connected organizations rather than a single organization. Since interactions within supply chains are of connected nature, a firm-level sustainable performance assessment may improve the sustainable performance of the focal firm while deteriorating the sustainable performance of its partners, making the aggregate sustainable performance unclear (Öberg et al., 2012). A simple example may be the firm-centric goal of a wholesaler to improve the Green House Gas (GHG) emissions of its transport operations through relocating its warehouses so shorter distances will be travelled. This change in turn may increase the distances travelled by the retailer partner of this wholesaler to ship the products from the wholesaler's warehouses to its own warehouses and hence affecting the retailer's GHG-emissions negatively. More importantly, the overall sustainability of the chain or the final product in this case, which depends on the sustainability of the operations of both the wholesaler and the retailer, will probably not be positively influenced if a firm-centric perspective is adopted. Hence, sustainability is not a mere firm-level goal to achieve in isolation and the sustainability implications of actors' operations need to be assessed on a higher level –at the network level with multiple firms rather than a single-firm (Ryan, Kajzer Mitchell & Daskou, 2012). Especially, due to the nature of the sustainability goals in general, the sustainability of the collective actions of the businesses and not only single firms are of importance. Considering the interactions and interdependencies inherent to business networks, firms become highly dependent on the performance of each other regarding the sustainability goals. For instance, retailers, although not necessarily involved in the production of certain products, are being held responsible for the sustainable performance of their suppliers, the same may hold for the dependence of their suppliers on their own suppliers. Frostenson & Prenkert (2015) assert that managing sustainability in traditional sense is difficult since the focal actor does not have access to all the resources required for sustainability. All these make the adoption of sustainability a very interactive issue, which needs to be handled among a wide range of business and non-business actors through interactions, negotiations and collective action. Hence, sustainability cannot be achieved in isolation and its adoption in the business network is a dynamic process with complex interdependencies.

2.1.3 Sustainability adoption as a process of change in business networks

Apart from the INA scholars mentioned above, which argue for viewing the adoption of sustainability from a network perspective (e.g., Frostenson & Prenkert, 2015; Ryan et al., 2012; Öberg et al., 2012), there are also other studies within INA- adhering to the network view of sustainability adoption-, who have further focused on the process of the adoption of sustainability in business networks. These studies within INA view this process as a process of change (e.g., Andersson & Sweet, 2002; Harilainen, 2009; Harrison & Easton, 2002; Johnsen et al., 2017; Meqdadi et al., 2017 & 2018; Veal & Mouzas, 2011). Generally, the change towards sustainability in business networks is problematic and a slow process in which firms slowly adapt by finding solutions that minimize the change in their current systems (Andersson & Sweet, 2002; Harrison & Easton, 2002).

Some scholars have empirically investigated the actors' responses to environmental initiatives and regulations (Andersson & Sweet, 2002; Harrison & Easton, 2002; Veal & Mouzas, 2011). Andersson & Sweet (2002), focused on the implementation of a recycling system is an inter-organizational network of a food retail chain as a process of change. The change process was described in different stages. Changes in the network structure and in individual exchange relationships in terms of their pattern, intensity and content were identified. Moreover, some actors also changed their positions and roles throughout different stages of the process. Harrison & Easton (2002) investigated the process of response to regulations related to banning of CFCs. Considering those regulations as externally imposed changes, they identify "change minimization" as the deep process involved in the patterns of the firms' responses. Similarly focusing on an exogenous change trigger, Veal & Mouzas (2011) investigated how actors within aviation industry made sense of the new regulations and their consequent network pictures, responses and interaction further affected the development of new rules.

Harilainen et al. (2009) provided a conceptual framework presenting various stages of spread of corporate social responsibility practices in the supply networks. Emphasizing the connectedness of the relationships in business networks and the consequent interaction effects involved in the network context, their conceptual framework describes the change in four stages; trigger of new practices, adoption of the practice in the focal buyer-supplier relationship, adoption of the practice in the directly connected buyer-supplier relationships and adoption of the practice in the indirectly connected buyer-supplier relationships.

A few other scholars investigated certain factors that can affect the adoption process. Meqdadi et al. (2017) looked into two moderating factors of the process of the adoption of environmental sustainability practices in supply networks, namely, trust and power. They found out that both power and trust significantly affect the actors' engagement in sustainability initiatives and its wider adoption in supply networks. Following a similar focus, Meqdadi et al. (2018) investigated the different effects of different forms of power -coercive and non-coercive power- on the successful adoption of environmental sustainability practices in supply networks. Their results show that while coercive power may have a hindering effect on the adoption process, non-coercive power can facilitate the adoption of sustainable business practices since business relationship would work as conduits and spread the adoption further in the network.

To sum up the above discussions, different scholars have used INA to approach the issue of the adoption of sustainable business practices in business networks. Some have argued for the importance of the network and interactive view in studying the adoption of sustainable business practices along the supply networks and business networks in general (Frostenson & Prenkert, 2015; Ryan et al., 2012; Öberg et al., 2012). Most INA scholars in this area hold on to the idea of adoption of sustainability as a process of change in business networks and have conducted empirical and conceptual studies to better understand how this interactive process unfolds by focusing on the changes it brings to the business networks' structure and the relationships among actors (Andersson & Sweet, 2002; Harilainen, 2009; Harrison & Easton, 2002; Veal & Mouzas, 2011). Moreover, the influence of two specific moderating factors –power and trust- on the adoption process are focused on by Meqdadi et al. (2017) and Meqdadi et al. (2018). Although the INA approach is recognized as having great potential in this area, one can see that its applications are very limited (Johnsen et el., 2017) and fragmented, specifically in terms the extent of influence of sustainability adoption for the actors' interaction in the network and the factors influencing these emergent processes and their direction. Sustainability as an empirical context for the second case of this thesis, is then a relevant setting for studying business network dynamics in terms of the structural changes that emerge in business networks when actors start to adopt sustainability in response to the pressures coming from end customers.

Going back to the business network dynamics and the discussion of their structural changes, as was elaborated above, structural changes initiated by endogenous or exogenous triggers in business networks may emerge when actors begin to respond to these triggers and lead to further changes in business relationships and networks (connected changes). However, due to the connectedness, interdependencies and the interaction that exist in business networks- as well as the lack of central focal firm in control of the process- often it is not predictable in advance that how all these reactions and interactions and their consequent change processes unfold overtime. In other words, these processes are emergent, non-linear and with no centralized control. These features of the business networks in evolution resemble the features of complex systems and more specifically Complex Adaptive Systems, i.e. business networks can be seen as Complex Adaptive Systems comprised of a set of connected autonomous components (business actors) who are constantly interacting with each other and adapting to their environment (the business network context)) (e.g., Easton et al.,1997; Wilkinson, 2006; Wilkinson and Young, 2013).

Thus, due to this resemblance, I decide to complement the INA perspective with Complexity perspective in this thesis to better understand the business network dynamics and more specifically the structural changes that arise from endogenous and exogenous change triggers. More importantly, the Complexity perspective on business networks is the foundation of the methodological contribution of this thesis to INA since combining these two perspectives have implications for the explanation, causality and the methodological approaches applied here. By viewing business networks as Complex Adaptive Systems, I can approach them with the specific methodology most commonly used to study such systems in various fields of natural and social sciences. In the following section, Complex Adaptive Systems are introduced, and it is explicated why business networks can be viewed as one of them.

2.2 Complex Systems Perspective

Complexity science is a multidisciplinary set of theories and perspectives for modelling and analyzing complex systems. Complex Adaptive Systems (CAS) are one kind of complex systems. They comprise a set of connected autonomous components who are constantly interacting with each other and adapting to their environment. Their interactions at the micro level, in a non-linear process, gives rise to macro-level emergent phenomena or a recurrent pattern of regularities. These regularities and system-level changes in turn affect the behavior of the components. Such systems have been identified in various fields such as biology, physics, chemistry, sociology and economics.

Complexity view of systems is related to Synthetic Holism as opposed to the reductionist view of science. Traditionally the systems and problems within sciences were approached mainly from a reductionist perspective by breaking down the system into its components, analyzing those components, and then forming a description of the whole system. This view tends to ignore the interactions that might exist within the components of a system, which may give rise to non-linear outcomes in a way that the whole would not be the sum of its parts. On the opposite side, there is the Holism view in which the system as a whole may exhibit properties that are not visible by only observing its components. In such a situation, it is said that the system property has emerged as a result of the synergies raised from the interactions among its components. Complexity view of the systems has ontological and epistemological implications, which need to be considered when scholars formulate research questions, choose methodologies and render explanations for different phenomena, as the causalities are very different from the common unidirectional causal determinism.

Economy, markets, organizations, supply chains, supply networks and specifically business networks are said to be complex adaptive systems which has led to conceptualizations such as Complex Adaptive Social Systems (Miller and Page, 2007), Complex Adaptive Supply Network (Pathak et al., 2007) and Complex Adaptive Logistics Systems (Wycisk, McKelvey & Hülsmann, 2008). A unique distinction of these CASs with the ones in biology, chemistry or physics is that their components are humans or human-based (organizations) which are highly cognitive and can make decisions consciously and based on a foresight towards the possible outcome of their actions (Arthur, 1999; Marchi, Erdmann & Rodriguez, 2014; Wilkinson 2006; Wilkinson & Young, 2005). This makes such systems even more complex.

A few scholars within INA have suggested applying the Complex Systems perspective asserting that business networks are complex adaptive systems (e.g., Easton et al.,1997; Wilkinson, 2006; Wilkinson and Young, 2013;). Studies on changes in industrial networks exist, but they usually fail to go below the surface in order to model the mechanisms, deep structures and fundamental processes to explain changes (Easton et al., 1997). This is mainly because firms through their strategizing are affecting the context that is actually giving rise to its actions. However, these feedback mechanisms are usually ignored in studies because of their complexities (Wilkinson, 2006). Wilkinson and Young (2013) argue that, not only market systems have long been recognized as complex and adaptive, but also business networks in general are becoming more interconnected and hence more complex. Therefore, the current approaches need to be complemented with approaches that can consider non-linearity, dynamism and mechanism of the business networks evolutions. Complex Systems perspective can be a suitable complement; still INA scholars rarely acknowledge its application explicitly.

In the following paragraphs, the main characteristics of CASs in general are explained and their manifestation in business networks are illustrated in order to show why business networks can be viewed as complex adaptive systems.

Autonomy, Schemata, Connectivity, Adaptability: a CAS is composed of a number of autonomous components –agents- with their own schemata (rules of behavior). These components are connected to each other and their interactions form them into a network-like structure. These components can learn so they may adapt their behavior to their environment and to the aggregate system outcome. Similarly, business networks comprise of various heterogeneous firms, which are autonomous, and having their own goals to pursue. It is the interactive nature of the relationships between these firms, which brings about the business networks. The firms in business networks have learning capabilities, so that they can adapt to the changing context of their interaction in order to be able to survive.

Non-linearity, Self-organization, Emergence: The interactions among the system components in a CAS are non-linear, meaning that the outcome of local interactions of the components is not proportionate to the local interactions of the components or as Anderson (1972, P. 393) put it, "More is different". The sum may be more or less than the parts and hence the reductionist view of these systems is not applicable since for understanding the dynamic patterns of the system, one cannot merely break it into parts and study the behavior of those parts. Two main critical features of a CAS are self-organization and emergence. The non-linear interactions of the components, in self-organized process with no centralized control, lead to the emergence of patterns at the system level. As there are many autonomous components involved which are interacting in a non-linear and distributed fashion, the outcome of their interactions is largely impossible to predict. Small variations can lead to the emergence of very different outcomes over time (butterfly effect).

Highly relevant to the above features of the CASs, is the issue of control in business networks. A basic characteristic of INA view on business networks is the lack of "channel captain" or a focal firm who is in complete control of the whole network. There maybe a few powerful actors in business networks, still not in control of the processes of the network. More importantly according to the third network paradox, centralized control in business networks can be detrimental (Håkansson and Ford, 2002). Hence, the interactions of the firms self-organize a network of relationships, with no one actor in control of the process. Consequently, the outcome of the actors' interactions is emergent and not predictable. Since actors and their relationships in business networks are constantly influenced by other directly or indirectly connected relationships, the actions of a focal actor is dependent on the actions, reactions and interaction of other actors which make the outcome of the focal actor's action non-linear, emergent and unpredictable. Hence, in contrast to the many studies in economics and management fields, one cannot simply assume a causal link between actor's behavior and its outcomes because the actor is influenced both by its own internal control and by external influences (Huemer, Håkansson & Prenkert, 2009; Prenkert, 2017).

All these further give rise to the issue of management in business networks. If there is no central control in the network and if the result of actor's deliberate strategizing is dependent on the responses of the other actors, then it is more relevant to talk about managing "in" business networks rather than managing business networks (Ritter, Wilkinson & Johnston, 2004). In this context, a more adaptive planning or "soft assembled solutions" are needed (Wilkinson, 2006).

Path dependency: CASs are dynamic and evolve over time. Their pattern of development and evolution is affected by the shadow of past and future in human-based systems. In other words, the components' interactions in the past and the resulting states of the system affect the range of actions and states that the system can achieve in the present and future time (Arthur, 1999; Held, 2013; Wilkinson, Wiley & Lin, 2010).

Path dependence is a well-known concept in INA which mainly build on the two main studies of Arthur (1989) and David (1985) defining path dependence as a lock-in effect by historical events (Aastrup, 2003). However, I find their perspective on path dependence a bit different from the path dependency as a feature in CASs. INA scholars seem to see path dependence as a mechanism and mainly adopted by individual business actors rather than a general pattern observed in the business network evolution. Still, Aastrup (2003) argues that some of the INA contributions such as the coexistence of stability and change in networks implicitly deal with this idea of path dependency. However, the dominant view is path dependence as a mechanism, a mechanism that traditionally –and mainly in relation to technological trajectories- is said to work as "inertia" or lock-in, and self-reinforces the path that the actor is currently involved in and hence has a restricting effect on the actions of the actor and the direction that it follows. Many INA researchers depart form this common perspective and argue that path dependence is not always restricting the actor.

Accordingly, the concepts such as "path breaking" (Håkansson & Lundgren, 1997; Håkansson & Waluszewski, 2002), "reactive sequences" as opposed to "self-reinforcing sequences (Araujo & Harrison, 2000) are suggested to argue that "…that actors are products, but not prisoners of their own histories."(Ibid, p. 6). Still, complementing these ideas with the complexity view on the path dependency of the system-wide dynamic patterns seems possible and fruitful to be further explored by INA scholars specifically when the dynamics and evolution of the business networks is in focus. In the complex system view of path dependency, it is mainly a feature of the agents' interaction outcomes over time because agents are constantly interacting with and responding to each other and to the aggregate system outcome and their environments and hence all these preceding connected interactions has a role in an observed regularity in the system.

In spite of the above accounts of the analogies that exist between business networks and CASs, still combining the two perspectives needs to be done with consideration and acknowledgement of the possibility of combining their ontologies and theoretical assumptions. Viewing business networks as CAS may help us to enhance our understanding of the dynamics of business networks from the INA view. However, initially a reflexive approach to theoretical development is required (Okhuysen & Bonardi, 2011) to examine the possibility of importing certain theoretical perspectives, assumptions and vocabulary from Complex systems perspectives into the INA.

Almost all of the INA scholars who adhere to the CAS view of business networks have ignored the ontological implication of combining an INA view of the network with a system view of CAS. Prenkert (2017) points to two of the implications and discusses how business networks can be conceptualized and fit in to a system perspective. Two main issues need attention in this discussion.

First, from INA perspective, business networks are inherently boundary less which means that it is not possible to distinguish between the network and its environment. Complex system perspective views organizations as open systems (Scott, 1998). Although system and the environment are two main building blocks of systems, still distinguishing between the system and its environment "…is revealed to be shifting, ambiguous, and arbitrary" (Ibid, P. 29) and environment is not just something "out there". Moreover, CAS is a hierarchical structure. Again, according to the open system perspective, this hierarchical structural does not imply a power/authority hierarchical structure. Rather, systems are composed of multiple subsystems and they themselves are parts of a larger system. Interactions of the components gives rise to a higher level of aggregation, which in turn, the interactions at that level of aggregation can lead to emergence of patterns at the next level of aggregation and so on.

From INA perspective, one cannot distinguish between the network and its environment. Business networks are open and not hierarchically structured. Still, in practice, certain boundaries are set between the network and its environment. Concepts such as network pictures and network horizons (Ford et al., 2003), refer to this issue of setting a boundary. The blurriness of the boundaries of business networks may, to a large extent, refer to the problems in identifying the boundaries of the business actors themselves. The business actor's boundaries are movable and constantly re-enacted.

The issue arises because of the inherent focus of INA on business relationships and their interactive nature. This brings up the two related issues of the interactive nature of the business actor and its intentionality. As touched upon in previous sections, in such an interactive landscape, the definition of actor itself is dependent on the interactions, i.e. the actor is an actor because there are counterparts who acknowledge it and its resources and activities, as relevant. Then, according to La Rocca (2013) actor's identity becomes relationship and context-specific and so does its boundaries.

Munksgaard, Olsen and Prenkert (2017) suggest approaching the actor's boundaries from its intentionality (rather than the ownership boundaries) while recognizing the influences imposed on it by the other network actors. With this view "…the more relevant 'actors' to be moved to the center of the analysis are not those representing the firm, but rather those representing the particular interacted representation of intentions that has come to shape the given activity patterns and resource constellation" (Ibid., P 218). This implies that the intentional actor can be any actor-entity in the network. For instance, the idea of meta-actor may be formed as a sub-network consisting of multiple firms with a shared objective. Then this meta-actor has intentions of its own and is capable of moving its boundaries. The idea is similar to the system and sub-systems in the complex systems view mentioned above.

Therefore, similar to the above issue of actor's boundaries in INA, to resolve the ambiguity of the network boundaries in general, the idea of systems and subsystems of Complex systems view can help us to set boundaries for business networks. Prenkert (2017) suggests the idea of encapsulated or nested networks (networks within networks). This implies forming sub networks (of firms or collection of firms) and then all that is not included in those sub networks is part of the supra network. Considering those sub networks as black boxes and the supra network as the environment, then they can exchange inputs and outputs. Still, these structures of networks within networks are not hierarchical, only formed for practical purposes and the black boxes may be opened at any time to make the boundaries blurry again.

The second issue regarding the implications of combining INA and Complex Systems perspective, concerns the type of causal explanations that can exist in business networks as complex adaptive systems. This issue is specifically important to this thesis, as its methodological contribution is a response to the need for these types of causal explanations in the field. As previously explained, in INA perspective –whether combined with CAS or not- it is recognized that the outcomes of an actor's actions are not predictable. In other words, one cannot have a reductionist view and clearly relate a certain outcome or network regularity to a specific action or interaction of the actors. Hence, usually the unidirectional causality in the form of cause and effect does not have an explanatory power in this area. Instead, the explanations in business networks are in the form of identification of the generative mechanisms, i.e. the processes that generate the regularities of the system in a particular setting. Hedström (2005) define mechanism as consisting "…of entities (with their properties) and the activities that these entities engage in, either by themselves or in concert with other entities. These activities bring about change…" (Ibid, P. 25). Mechanism explanation of social phenomena is said to provide middle range theories (Hedström and Swedberg 1998). Middle range theories are a level of explanation between detailed descriptive hypotheses and the higher level unifying general theories (Merton, 1968). Hence, in business networks identifying the mechanism that bring about or prevent a change within business networks includes identifying the actors, their actions and interactions at a micro level, which bring about an aggregate macro outcome. Prenkert (2017) calls these mechanisms "causal networks". In business networks, they are the interactions of networks of actors, resources and activities that cause certain patterns to emerge repeatedly over time.

In line with other scholar within INA, I view business network –and supply networks as a form of business networks- as complex adaptive systems- in which heterogeneous business actors are interacting with each other. They are responding and adapting to the environment, and their local interactions in a non-linear way give rise to the emergent macro-level outcomes and regularities, which in turn may exert a top-down influence on the actors' behavior. According the above discussion, viewing business networks as CAS, implies certain underlying assumptions about the nature of the business networks and their dynamics and consequently has implication for the way I choose to approach business networks in order to explain their dynamics (methodological consequences).

When studying business networks, their relevant phenomena and specifically their dynamics and patterns of development over time, researchers try to identify and explain the causal mechanisms involved in them. The type of explanation that such arrangements ask for –identification of generative causal mechanisms- will consequently have implications for the methodological approaches to investigating and explaining these phenomena. The case study's ability in providing detailed descriptions of the complex interdependencies in business networks, justifies its dominance in the INA field. Specifically researches that are somehow concerned with change, dynamics and the emergent patterns in various aspect and levels of business networks, require generative perspectives on methodology. Agent-based computational modeling and Simulation is a technique well suited for such purposes. Agent-Based Models allow us to model business networks comprising of heterogeneous actors, interactions and adoption of sustainable business practices among them and generate the macro-level regularities (business network structural changes). With that, I explain those changes because I grow them (Epstein, 2006).

The implications of viewing business networks as CASs are further discussed in the methodology chapter.

In the following section, the mentioned theoretical grounds of this these which are explained above, are summarized to form the theoretical framework adopted in this thesis.

2.3 Theoretical Framework

This thesis investigates the structural changes that emerge in business networks as results of endogenous and exogenous triggers. Business networks are viewed from the INA perspective and as an empirical manifestation of Complex Adaptive Systems. The change processes initiated endogenously or exogenously emerge under the influence of actors' interactions, responses and connectedness and unfold over time, leading to changes in the structure of the network.

The following theoretical framework is adopted in this thesis in order to understand business network dynamics in terms of changes in its structure. (Figure 1).

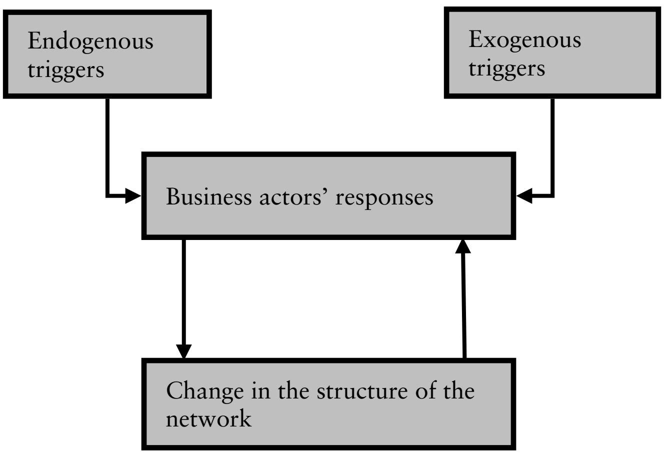

Figure 1. The theoretical framework of the thesis

Changes may be triggered endogenously (e.g. through a focal actor's strategizing in its network of relationships) or exogenously (e.g. shifts in customers' demand), influencing a wide range of business actors and relationships simultaneously. These triggers, depending on actors' interpretations of them, invoke various responses that may initiate change processes. These triggers are considered separately in two different cases in this thesis.

In the first case (illustrated empirically by a case of a railway operator in Sweden), the process of change in the network is initiated endogenously through focal actor's strategizing. Although initiated deliberately, but the new strategic initiative of the focal firm may give rise to various customer responses. These individual actors' responses simultaneously set the context for others' interactions and responses. These interactions may over time and in a non-linear way generate certain emergent and unpredictable changes in the network structure.

In the second case, adopting sustainability as the empirical context of the study, the exogenous trigger is the end customers' demand shift towards more sustainable products. Business actors' responses to this trigger is basically about deciding on whether and how to adopt sustainability. These responses then lead to further changes in the network and actors' relationships because of the connectivity and interdependencies among the actors in the network. More specifically, the issue of sustainability adoption in business networks is influenced by the interactive context in which individuals actor's adoption of sustainable business practices as well as the level of the sustainability of the whole network. This may be manifested in the sustainability of the products and services offered to end customers in business networks, hence adoption of sustainability becomes an interactive issue. Sustainability needs to be addressed at the aggregate level of multiple directly/indirectly connected organizations rather than a single organization and hence is embedded in the complex interactions in business networks (e.g., Frostenson & Prenkert, 2015; Öberg et al., 2012). Moreover, as an overview of the INA literature on sustainability issues above showed, the adoption of sustainability in business networks is a process of change (e.g., Andersson & Sweet, 2002; Harilainen, 2009; Harrison & Easton, 2002; Johnsen et al., 2017; Meqdadi et al., 2017 & 2018; Veal & Mouzas, 2011). Business actors' interactive responses to the customers' demand shift, then eventually may give rise to reorganization of the network, since individual actors cannot by themselves achieve sustainability in the context of the network and hence, it is the aggregate outcome of various actors' responses that determines the changes that eventually emerge in the structure of the network.

Network structure is generally related to the actors' pattern of connection and how they are positioned vis-à-vis each other. Hence, it is basically about the actor bonds in business networks at the macro level. However, these patterns of connection have implications for the actors' level of access to resources and how they organize their activities both internally and in relationships. Therefore, although changes in network structure is basically about changes in the actor bonds but it simultaneously has implications for the resource ties and activity links as well. All these implications are the results of various actors' responses to change triggers and further emergent interactions in the network. Depending on actors' interactive responses, the direction of the change processes and their outcomes may differ. This thesis focuses on these processes of network structural changes, how they unfold over time and certain moderating factors that may affect the emergent changes in the structure of the networks. The structural changes in this thesis are manifested in the business relationships that are terminated or newly developed between business actors and generally partner changes that various actors may adopt in order to respond to triggers of change.

The process is emergent, non-linear and with no centralized control:
Adhering to the INA perspective on network change processes, a change process is inherently of a connected nature where a change initiated in any part of the network and at any level (actor, dyad or network) may spread in the network through different levels. The reason is the connectivity and interdependencies of the business relationships, where a change is perceived, interpreted and responded to, differently by different actors. The simultaneous influence of these complex, connected influences (directly/indirectly) coming from various actors and relationships and the feedback effects that emerge, make the strategizing process of the focal firm incremental and emergent with unpredictable outcomes. This explanation of the change process in the business networks resembles many features of CASs. Building on this resemblance between the features of business networks and CASs and similar to the few scholars within INA (Easton et al., 1997; Prenkert, 2017; Wilkinson, 2006; Wilkinson et al., 2001), I view business networks as CAS in which heterogeneous business actors are interacting with each other, responding and adapting to the environment. Their local interactions in a non-linear way give rise to the emergent mac-

ro-level outcomes and regularities, which in turn may exert a top-down influence on the actors' behavior. In terms of complex systems perspective, in CASs, patterns and regularities arise in a bottom up manner where the nonlinear interaction effects of a number of micro level and highly interactive components lead to emergence of macro level regularities. By viewing BNs as empirical manifestations of CAS, I can study the dynamics of business networks as a type of regularity that emerge in business networks as the result of the interactions of the business actors, simultaneous influences of these interactions and consequently the feedbacks that lead to non-linearity and unpredictability of the outcomes of change. I.e. the network dynamics emerges in a bottom up manner. It is important to note that discriminating between the micro-macro and bottom-up is merely for analytical purposes and the micro is actually embedded in the macro, in a way that they both are simultaneously influencing each other. The interactions of the business actors are forming the overall situation of the network while also the network itself is setting the context for the behavior of actors.

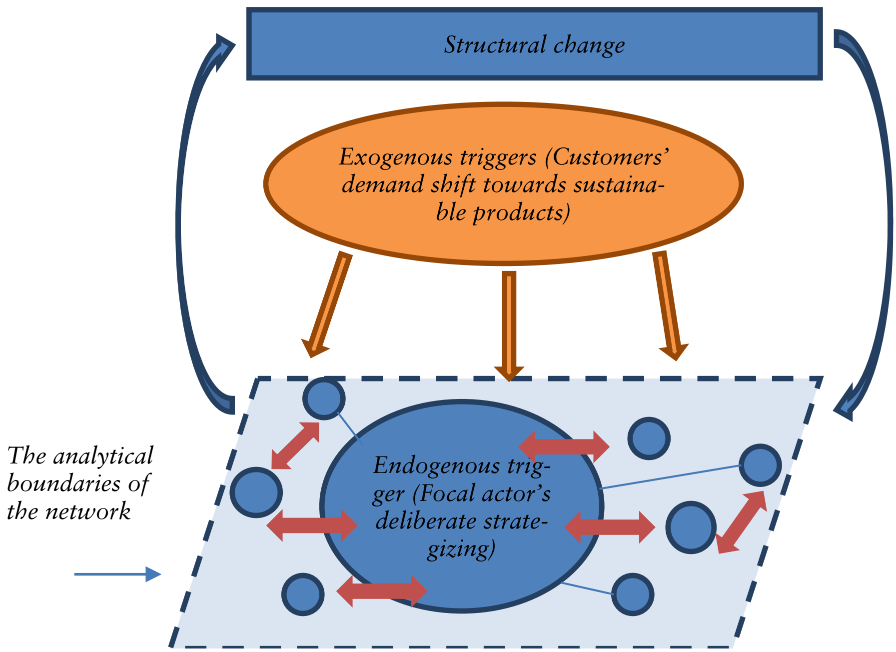

Figure 2. Illustration of the emergence of structural changes in business networks

Adopting this combined perspective, then it is proposed any aspect of the micro-level components of the CAS, which in the case here resemble the business actors, their behavior (responses) and interactions, may be among the moderating factors affecting the macro level regularities (structural changes of the network).

An important issue to note here, specifically when adopting the Complexity perspective is studying such change processes is the two-way interaction between the actors' responses to change triggers and their implications for the network structure (See Figure 1 and Figure 2) . The process is not unilateral and the actors' responses are affecting the network structure over time, while also this dynamic structure itself is the context of further interaction and responses. Hence, the business network structure is also simultaneously affecting the business actors' interactions and responses over time.

To sum up, in the theoretical framework of this thesis (Figure 1), I focus on the business network dynamics and more specifically the structural changes that emerge in response to certain endogenous or exogenous triggers. In the first empirical case of this thesis, the deliberate strategizing of the focal firm to improve its network position and competitive advantage, functions as an endogenous trigger, giving rise to various actors' responses and leading to changes in the business network of the focal actor. The point of departure is a single actor and the changes process is triggered endogenously. In the second case, the change –adoption of environmentally sustainable business practices- is initiated remotely as a response to an exogenous pressure from end customers who ask for more environmentally sustainable food products.

Thereafter, actors' interactions, responses to those triggers, and the actors' interdependencies at the micro level lead to further changes over time by forming new business relationships and terminating old ones leading to macro level implications in terms of reorganization of the business relationships in the network, i.e. changes of the structure.

This is investigated by applying Agent-based Modeling and Simulation, with a combined INA and Complex Systems perspective. An agent-based model is built for each case. Experiments are developed based on these models to address the research questions of the thesis in general, and the research questions specific to each case, in particular. The methodological details of the study come next in chapters 3, 4 and 5.

3 Research Design & Methodological Considerations

In the previous chapter, it was explained that, in order to tackle the research questions of this thesis and achieve the purpose of the study – gaining a better understanding of business network dynamics- this thesis departs from the INA and Complex Systems perspectives. The most significant function of combining INA and Complex Systems perspective for the specific research questions in this thesis is the important methodological implications of viewing business networks as Complex Adaptive Systems (CASs), which allows us to approach the research questions with a specific tool; Agent-based Modelling and Simulation. In this chapter, it is argued that this specific computational approach can help researchers to address some of the challenges involved in studying business networks' evolutions. In the following sections, a discussion of the thesis' choice of methodology and then the adopted research design of the thesis are explicated.

3.1 Methodological considerations

Within INA field of study, qualitative case study research strategy is the dominant research design (e.g. Anderson et al., 1998; Chou & Zolkiewsky, 2012; Ford & Redwood, 2005; Holmen, Pedersen & Jansen, 2007). In fact, the whole tradition was initially developed based on extensive empirical case studies in various industries and markets (Ford 1990).

Business networks and their dynamics are the topic of discussion here. The thesis is based on the presumption that business networks do exist in reality. They are viewed as an empirical reality independent of our various perceptions of them. We as researchers are able to gain partial understanding of business networks and the mechanisms underlying them as it has been done by INA scholar for more than 40 years now. Most of the phenomena that are studied in the context of business networks are interactively complex epistemologically-emergent phenomena

The complex and interacting (and sometimes unknown) mechanism underlying business networks give rise to certain observable phenomena that researchers focus on. I.e. parts of the reality of business networks can be observed and studied by the researcher. Business network dynamics, i.e. the patterns of change and stability in business networks, are one of those emergent phenomena that can be studied and explained from different perspectives and at different levels, hence gaining partial understanding of the mechanisms leading to the network dynamics.

But how can we come to grasp this knowledge? The (already known or unknown) causal mechanisms underlying those phenomena need to be identified, which involves identifying the involved objects such as understand the business actors and their relationships and then their causal powers in observed events (Easton,1995). In other words, for studying any business network phenomenon, the only way to capture its complexities is to focus on business actors involved, their perspectives, their actions and reaction and interaction with others and how all these build up a specific phenomenon.

Accordingly, this view shapes the methodological choice of the researcher on how to produce that knowledge. For the type of phenomena in INA, often a useful methodology must be able to handle large amounts of data, on different organizations, blurriness of the boundaries of the business actors and networks and even the phenomenon itself, their complex interdependencies and simultaneous feedback effects. Qualitative case study approach is one suitable methodology that can handle these requirements and hence is the dominant approach adopted in by INA scholars.

There are different reasons for this common choice of methodology. First, the phenomena within INA match the type phenomena associated with case studies. When studying various phenomena within INA, it is usually impossible to imagine a distinct boundary between the network and its environment, i.e. it is difficult to decide on what actors, resources, activities and relationships to consider as internal and what should be considered as external to a business network. These features of business networks illustrate the two most important elements of phenomena which according to Yin (2014), make case study research a suitable approach to study those phenomena; a contemporary phenomenon being studied within its context which has no clear boundaries.

Second, scholars within INA are interested in understanding and offering thick descriptions of business relationships and unique contexts of different relationships and interactions under study. They are concerned mainly with the "why" and "how" of business relationships and networks developments and evolution, which requires a process view that can consider developments or consequences of interactions over time. The unit of analysis in INA studies itself has a dynamic nature. Qualitative case studies allow the study of contextual factors and processual elements (Halinen and Törnroos, 2005).

Third, the explanations that INA scholars offer do not only involve causal explanations but also offer a more holistic understanding of the phenomenon by for example keeping track of various events leading to the phenomenon or the mechanisms involved. That explains why case studies are the most dominant and established methodology followed by INA scholars (Halinen and Törnroos, 2005), because case studies can provide detailed descriptions of the events and interdependencies involved in business networks and help researchers to identify the relevant mechanisms to the phenomenon under study. Moreover, it can handle various sources and types of data and data collection methods. The qualitative case study design within INA is so dominant that Easton (1995) warns against the fact that sometimes within INA research the methodological approach is taken for granted without reflecting on its assumptions and epistemological issues. Still Easton (1995) argues that this approach is probably the most appropriate approach to analyze business networks in terms of epistemological considerations.

When it comes to quantitative studies within INA, they are very few compared to case studies. These studies are survey-based (e.g., Hadjikhani & Thilenius, 2009; Håkansson & Ingemansson, 2013) or experimental (e.g. Corsaro et al., 2011), where the quantitative data are analyzed with statistical methods. These quantitative approaches that explore the correlation between certain variables of interest can hardly explain various interactive and complex phenomena within business networks- such as how business relationships develop, how do firms interact in the network context and how these evolve over time. This often involves reducing the phenomenon to simple measurable variables, which cannot capture the processes, and complexities of the phenomenon – the aspects that most concern INA scholars. Since the scholars within INA dig into the often context-dependent complex phenomena and are looking for gaining deeper insights and offering thick descriptions, their unique phenomena of interest are not easily reducible to a set of measurable dependent and independent variables. Moreover, INA scholars are interested in understanding the uniqueness of business contexts rather than reducing them to a set of variables and attaining results that are statistically generalizable to a population of firms and networks.

Focusing on the specific area of inquiry in this thesis -business network dynamics in general and their structural evolution over time- INA researchers have adopted qualitative case studies (with single and multiple case studies), using various sources of data and data collection techniques, such as semi-structured interviews, secondary data and participant observations. Data analysis is often in the form of thick descriptions, narratives, event-based process strategies (Halinen, Törnroos & Elo, 2013; Lundberg, Andresen & Törnroos, 2016), and the specific tool of network picture(e.g. Abrahamsen et al., 2012).

Another methodology applicable to study the complexities of business networks is Agent-based Modelling (ABM[2]) and Simulation. This modelling method specifically if used in combination with other methodologies can help overcome some of the shortcomings of qualitative case studies and survey-based approaches, while opportunities for gaining wider range of insights on the topic are enhanced.

The research questions of this thesis are also concerned with the transformation of business networks (involving a number of heterogeneous actors) and their dynamics over time. In studying the evolution of networks, case studies can be challenging leading to a gap in INA scholars' understanding of the development and evolution of business networks over time. (Prenkert, 2012). The focus of this thesis, the structural changes that emerge in business networks as results of change specific triggers, requires a multi-level analysis of highly interactive multi-actor business networks. Qualitative case study research design – the common methodological approach of the field- can be resource-intensive (practicality), and restricting in terms of the range of understanding offered.

Moreover, the common survey-based approaches in the form of reducing the change processes into measurable variables and merely testing the relationship among them are rather descriptive and cannot capture the dynamic processes of the network transformation and actors' interactions. Hence, insights to the underlying mechanisms, i.e. the explanation of the relationship between variables is missing in those approaches as they merely offer descriptive accounts of the phenomena.

ABM and simulation, for the purpose of this thesis, functions as "simplified reproduction of portions of the reality" (Fioretti, 2013, P. 228). Complex systems perspective is the underlying perspective of this method, proposing that some business network aggregate phenomena –such as network structural changes- can be viewed and explained as properties of

[2] In this thesis, ABM may stand for both Agent-based Modelling or Agent-based Model

the network, emerging from the interaction of heterogeneous business actors at the micro level. Simultaneously, those network properties, themselves set the context of those micro level interactions of business actor and impose a top-down influence on them.

Here, this research is a rather theoretical investigation of this macro-level phenomenon of business network (still being grounded in business networks as empirical reality, and partly based on a specific empirical case, SFL-Case business network in the first case of the thesis). This thesis largely departs from theories of business networks, interactions and complex system perspectives to understand certain aspects of the business network's reality, namely their dynamics and processes of structural change. The models here are built on the empirical phenomenon of interest (business networks), involve certain already-known mechanism of business actors' interactions (based on theoretical assumptions of INA). Then the aim is to explore the implications of these assumptions and further extending them by changing parts of them and see what happens to the network structure. Hence, in this thesis, to investigate the dynamics of business networks and more specifically their structural changes, an abstraction of the reality is created. This involves isolating the phenomenon by the researcher to delineate its boundaries.

For the first ABM of the thesis, this delineation is based on the empirical case data of SFL's business network as well as theoretical assumptions of INA and in the second ABM, FSN-ABM, it is done mainly based on theoretical assumptions and common knowledge of supply networks. Then certain explanatory factors about the business actors and their interactions in those business networks are put into model as assumptions. Some of them are controlled and kept unchanged in order to be able to investigate and do experiments on others. Therefore, the first ABM of the thesis mainly based on empirical data and the second one theoretically aims at giving us complementary insights on the main research questions of the thesis. ABM and simulation fit the purpose of this thesis for the following reasons:

First, data collection challenges, investigating the dynamics of business networks and their evolution over time would require longitudinal studies to capture a development over time. Specifically, when the number of business actors involved increases, data intensity increases. A large set of longitudinal data about a large number of actors, their relationships and the interdependencies are needed in order to be able to capture a comprehensive view of the research topic and identify the underlying mechanisms of the dynamic processes over time. This can make case studies resource intensive if not impossible.

Second, even if this amount of data could be collected, then their analysis is even more challenging because of the high complexities, interdependencies existing between events and interactions which make identification of patterns or tracing of certain events and changes over time, almost impossible to do. Challenges are involved in interpreting such data and tracing the dynamics and effects of different elements of the phenomenon to offer a comprehensive and valid description and understanding of the mechanisms underlying the dynamic phenomenon. Because of the interactive and non-linear nature of the components of business networks, analysis of such systems specifically when going beyond dyadic or triadic interactions and investigating certain phenomena on the network level can significantly add to the complexities and decrease the traceability of interactions and their effects over time. Therefore, cross-level analysis of this multi actor context such as the effect of change in one relationship on a portfolio of relationships (cross level effects moving from relationship level to network level) can be difficult. Specifically, the need for consideration of the "time" aspect in studying business network dynamics makes both data collection and data analysis of qualitative case studies rather challenging. Hence, exploring and understanding these systems can be too difficult to be accomplished by common analytical and theoretical research approaches. With case studies specifically, their capacities diminish, as both data collection and analysis can become very time consuming, resource intensive and often too difficult.

Third, viewing business networks as CASs allows us to approach the research questions with a specific tool of Agent-based Modelling and Simulation, to overcome some of the shortcomings and difficulties associated with the qualitative case studies common in the field. Moreover, although, the process of business network transformations are explored in terms of measurable variables, the ABM and simulation technique adopted in this thesis goes beyond identifying the descriptions and correlation among variables, by modeling the mechanisms underlying the change processes of those variables and can have explanation capabilities.

ABM and simulation (as a tool within computational social sciences) involves modeling some social reality as computer programs (Gilbert 2008, López-Paredes et al., 2012), The approach may involve various elements of both case studies and common variance-based approaches while having characteristics and applications beyond those two. ABM is known to be an appropriate modeling technique for gaining insights into CASs and have been applied successfully to model many CASs in various disciplines (Miller & Page, 2007).

The underlying mechanisms of ABMs fit the theoretical assumptions of CASs. Their specific features have made them an appropriate tool for modelling CASs and overcoming many of the challenges involved in modeling such systems (e.g. Holland, 2006; North & Macal, 2007; Wilensky & Rand, 2007). ABMs are capable of generating insights about the mechanism involved in CASs by modeling the entities of the system and their relationships and following the processes and mechanisms through which they give rise to certain outcomes. ABMs in social sciences are computational models with a bottom-up approach, in which the micro-specifications of the individuals give rise to the macro-specification or macro-level regularities- the interaction patterns and macro-level outcomes of interest. I.e. populations of autonomous heterogeneous agents are situated in an environment and are social and capable of interaction and influencing each other and their environment while learning and adapting their behaviors to the environment. They interact based on a set of rules; these interactions generate the macro level outcomes from the bottom up and generate patterns that can be analyzed at various levels of aggregation (Epstein, 2006). They are built on the idea that "the whole of many systems or organizations is greater than the simple sum of their constituent parts." (North & Macal, 2007, p. 299). They are capable of incorporating details of the system, heterogeneity of the agents and adaptation that leads to highly dynamic models and nonlinearity (North, 2014). This ability of capturing heterogeneity is valuable in understanding business network dynamics. Agents' interactions and feedback effects can also be modeled. The ABMs can model the heterogeneous and autonomous components of CASs as individual agents with their own specific schemata or sets of behavioral rules.

The firms (business actors), can be modeled as agents with heterogeneous features and more importantly the ability to interact and adapt accordingly within an environment (the network structure involving other business actors). Their interactions in a non-linear way give rise to certain outcomes in the business network. When concerned with the dynamics of multiple business actors' interactions in business networks, by viewing business networks as the empirical manifestation of CASs, one can benefit from ABMS as the methodology associated with CASs.

In each of the two cases of this thesis and depending on their specific research questions, a set of micro-specification are defined for these agents (in the first case, based on the empirical case data and in the second case, theoretically). These specifications involve the behavioral rules according to which the agents respond to certain change triggers they perceive. In various simulation experiments (scenarios), agents (business actors) interact over time and the outcome of their interactions are generated over time and analyzed in terms of changes in the structure of the network.

The fourth reason of the match between ABMs and the purpose of this thesis is that ABMs allow systematic experimentations. With qualitative case studies – the common methodological approach within INA- researchers have access to only a few (and often only one) instances of the phenomenon to study. Then accordingly, the opportunities for theory development with those few instances of the phenomenon are limited. ABMs allow systematic experimentations to make the arguments and explanations of a certain phenomenon stronger by comparing and contrasting it to alternative competing explanations and elaborating them by identifying more and more conditions under which the phenomenon holds or not. ABM experiments in this context resemble experiments in natural sciences (although some differences exist). One can model the target (the system or phenomenon of interest) and its functioning (formalizing what goes on inside the system), which may involve explanations of the outcome. Then by incorporating other conditions into the model, another set of explanations can be tested to better understand the phenomenon, outcomes and processes at work. Compared to the common forms of experimentation, with ABM the processes involved are the main focus rather than the inputs and their corresponding outputs. Moreover, it allows the consideration of non-focal factors, a greater variety of variables and dependencies and hence a richer environmental context can be modeled. Therefore, theory development opportunities are enhanced since one has access to other different instances of the phenomenon of interest (Jaccard & Jacoby, 2010).

This thesis makes use of this opportunity of the systematic experimentations offered by ABM and simulation in order to enhance the insights into the dynamic processes of structural changes emerging in business networks. This is specifically manifested in exploring the effect of different moderators on this process and how it unfolds over time. These influences are not merely descriptive in the sense of testing whether certain factors can affect the change process and its outcomes or not. Rather, various alternative explanations of the observed influences can be offered by modifying the processes in the model. I.e. possible explanations are built into the computational ABMs and experiments are performed to see whether they generate a certain outcome or not. If the specific outcome of interest is generated then the model itself acts as a proof of that effect. Accordingly, various experiments can be designed to capture the dynamics of the business networks' structural change processes to gain deeper insights into the mechanisms underlying those processes.

Boero & Squazzoni (2005) identify three general types of ABMs in terms of the level of specificity of an empirical phenomenon in them:

1. Case-based models: these models are often rich representation of an empirical target, with idiosyncratic and individual features.
2. Typifications: these are abstract models aimed at understanding some mechanisms underlying a class of empirical phenomena. The purpose of the modeler is to investigate some of the theoretical properties of that class of phenomena (as opposed to a specifically defined phenomenon).
3. Theoretical abstractions: these focus on abstract theories about general social phenomena which are applicable to different contexts. They are aiming at simplification, generalization, gaining new intuitions and areas for theoretical debate. Examples of this type are game-theory-based ABMs such as general models of competition and cooperation (e.g. Axelrod 1997).

This categorization is more of a continuum rather than discrete types (Figure 3). Moreover, although it is not made very explicit by the authors (Boero & Squazzoni, 2005), this categorization is not exactly about the purpose of the modeling, more specifically although case-based models and Typicfications are empirically grounded still they may be used for theoretical explorations too .Both ABM of this thesis are representing an empirical phenomenon. More specifically, they are models of business networks as real empirical phenomena. Considering the purpose of the thesis, to investigate the business network dynamics as a specific theoretical property of business networks (empirical phenomenon of interest), the ABMs in this thesis are positioned somewhere between the typifications and case-based models. The first one –SFL ABM- is more towards the case-based end of the continuum while the second model is more towards typifications.

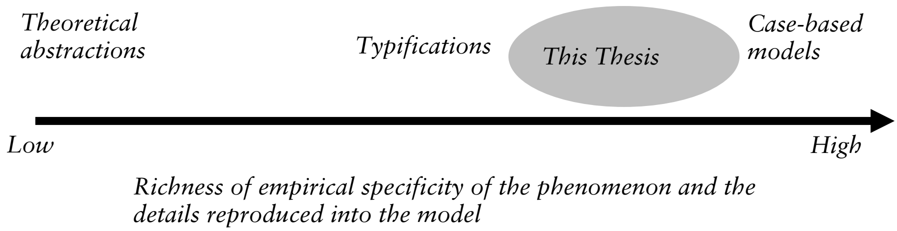

Figure 3. Connection of the ABMs of this thesis to empirical phenomena Adapted from Boero & Squazzoni (2005)

SFL-ABM is grounded in a specific case of a business network hence many of its underlying assumptions are taken from the case data collected during a research project. Still, considering the limitation of the empirical data and the purpose of the thesis, this model is not an exact representation of the case firm's (SFL's) business network. Exploring the dynamics of that network –specifically structural changes- implies focusing on specific theoretical properties of the SFL's business network. The research questions, interpretations of the SFL's respondents of their problem as well as the researcher's interpretation of the situations (based on her theoretical lenses) helped delineate the case, make some abstractions and simplifications in order to be able to gain some understanding of the SFL's business network.

FSN-ABM, built to extend the theoretical understandings achieved from the SFL-ABM by -this time- focusing on change processes triggered exogenously, is not case-based in terms of Boero & Squazzoni (2005)'s categorization. Rather it represents a wider class of empirical phenomenon – generally business networks and specifically supply networks. It does not focus on a specific supply network (e.g. the supply network of banana in Sweden) and its individual features. Hence, the richness of empirical details and their reproduction into the model is lower than the SFL's case and the model is theoretical and more of a typification (Figure 3). Therefore, it represents a class of supply networks (as empirical realities), involves some of their common features and theoretically explores some mechanisms underlying their dynamics- structural changes. Here then the model assumptions are based on common knowledge of the supply networks, the business sustainability context and the theoretical lens of the researcher in this thesis.

The application of simulation approaches and more specifically ABM to study business networks is not unprecedented. As mentioned in the chapter on theoretical framework, a few INA scholars have promoted viewing business networks as CASs (e.g., Easton et al., 1997; Wilkinson and Young, 2013). These scholars further introduce ABMs as an appropriate methodological implication of such a combined theoretical perspective in business networks. ABMs within INA are usually combined with case study research design and form a mixed methodology. It is argued that there is a gap in INA scholars' understanding of the development and evolution of business networks over time mainly because of the methodological challenges involved (Prenkert, 2012). Although the ABMs of this thesis stand alone, combining ABM and simulation with case studies – strengthening the ABM with case data (and vice versa)- is suggested as a robust methodology to reduce this gap. ABMs have been used to study the development of business relationships and their underlying mechanisms over time (Folgesvold and Prenkert, 2009; Gottardi, 2011; Iandoli et al., 2009; Prenkert and Folgesvold, 2014; Purchase et al., 2014; Wilkinson and Young, 2013).

To conclude, ABM and simulation techniques for understanding the dynamics of business networks' evolution seem to be able to offer opportunities and cover some of the shortcomings of case studies as the common methodological approach within INA. This thesis is concerned with the structural changes of the business networks as results of endogenous and exogenous triggers, with multiple actors and non-linear interactions- corresponding to a CAS view of these networks. Therefore, ABM and simulation are adopted as the main methodology to achieve the purpose of this thesis.

In the next section, ABM and simulation technique and its main building blocks are discussed to offer a general introduction to this technique. The discussion will be referred to, later on when its application to answer the research questions are explained.

3.2 Agent-based Modelling and Simulation technique

> “"You are a modeler." Anyone who ventures a projection, or imagines how a social dynamic—an epidemic, war, or migration—would unfold is running some model.”
>
> (Epstein, 2008, P. 1)

We are all modelers of some sort; when reflecting and theorizing about business network dynamics and their development, somehow an often-implicit model with both hidden and clear assumptions (e.g. the theoretical framework of INA involving interaction model, ARA model, etc.) are being built and run in our minds. Making these models explicit is beneficial as one needs to make the assumptions clear and clearly express the relationships between various features of the target (the phenomenon that is being modelled). By manipulating this model’s assumptions, then one can gain understandings on how the target works (Gilbert, 2008). Often, understanding the model is easier than observing the target. Based on the purpose of modeling a target, one can build, justify and assess the model accordingly (Edmonds et al., 2019).

A simulation is basically a replication or imitation of a model for a specific purpose, hence simulations are based on models (Grüne-Yanoff and Weirich, 2010). For a scientist, it may involve experimentations for various purposes such as stressing theories, finding explanations, prediction, description, etc. (for an overview of different definitions, purposes and topologies of simulation methods please see Grüne-Yanoff and Weirich (2010)). Computer simulations allow running the models repeatedly, systematically manipulating the underlying assumptions and parameters and observe their effects on the outcome measures (which may be both qualitative and quantitative).

There is no common definition of ABMs in the community of ABM and Simulation. Macal (2016) acknowledging this issue, and since *agents* are the most important distinguishing characteristic of the ABMs, offer four definitions based on agent’s properties. The most complete definition offered is what he called an adaptive ABM “…one in which the interacting, autonomous agents change their behaviors during the simulation, as agents learn, encounter novel situations, or as populations adjust their composition to include larger proportions of agents who have successfully adapted.” (Ibid., P. 150).

ABMs are models of multi-agent systems. They are representations of multi-agent systems as the reference systems. Multi-agent systems are systems comprised of several interacting agents (Klügl & Bazzan, 2012). Business network and more specifically supply networks and supply chains are natural multi-agent systems.

Compared to other common simulation methods such as variable-based or system-based methods, their distinguishing feature is the ability to model heterogeneous individuals rather than the variables that represent certain characteristics of those individuals.

Before going into the research design of this thesis and how ABMs are applied in this context, first their main building blocks are introduced to set the scene for their application to the thesis' research questions. ABMs have two main elements: agents and environment that are needed to be defined when building an ABM. These elements and their features come next. Their more detailed application to ABMs of this thesis are later referred to in the research design section and the next two chapters.

3.2.1 Agents

Agents within an ABM are those components of the model, which represent social actors (Gilbert, 2008) such as individuals, groups of individuals, firms, departments, groups of firms, networks. One can recognize the analogy with the definition of the business actor within INA involving agency at various levels of aggregation, which is capable of purposeful behavior (Håkansson and Snehota, 1995; Munksgaard et al., 2017). Conventionally agents within an ABM have the following characteristics:

- Heterogeneity: Agents can have different attributes and behavioral rules for their interactions. This feature is specifically important for addressing the business network dynamics.
- Autonomy: each agent is basically autonomous is a sense that during the simulation there is no central control dictating the actions it should follow (unless it is part of the design of the model and the modeler's decision). The agent act based on the way it is programmed to act under different situations.
- Interactivity: the agent has social abilities and it can interact with other agents- a feature that makes this modelling approach specifically interesting for social sciences. This interaction may be direct- through sending and receiving messages of some sort- or indirect through observing other agents' behavior or the effect of the behavior.

- Adaptability: the agent has a (complete or incomplete) perception of itself and its environment and is capable of reacting to certain stimuli perceived. The agent's decision rules may not be constant and the agent can adapt its behavior under certain circumstances according to certain adaptation rules.

In this research, agents represent individual business firms with their own specific agenda and features, acting purposefully towards achieving a goal. Each agent has a specific set of behavioural rules to act based on. These business firm agents are capable of communicating with other agents in the environment through sending/receiving information about different aspects of the interactions and environment. They can form and break business relationships. Moreover, they can perceive certain features and conditions, interpret them, and act based on them. I.e. these business firm agents based on their perception of the conditions going on in their environment are able to adapt their behaviours based on a set of "what-if" rules of action.

3.2.2 Environment

Agents in ABMs act within an environment. The environment involves the agents and other objects or features. For instance, it can represent a geographical area, a supply network structure, resources and any other kind of space with the population of agents interacting within it. Individual agent's actions can affect its environment either by affecting other agents or some general feature of the environment, e.g. the level of a resource within an environment. At the same time, the agents are themselves under the influence of the environment, in terms of the effect of other actors on their behavior as well as an external macro level feature of the environment such as a certain governmental policy or regulation imposed on the whole industry or groups of firms.

Accordingly, in this research, the environment of business firm agents involve other agents and certain characteristics regarding the general features of the interaction context of the agents. For instance, in the second case, the environment is a market populated with a set of farmer agent, wholesaler agents, retailer agents and consumer agents which may be working with each other or not. These agents' operations and interactions within the market are simultaneously influencing and being influenced by the market including other agents' decisions as well as the features of the market.

In the following sections, the steps followed for answering the research questions of this thesis are presented and discussed. The research process is depicted in a rather general way in order to cover the general processes followed in each of the two cases. These steps are followed in both cases of the thesis. However, since the settings, detailed research questions and the models are specific to each case, the details of the steps followed in each case are presented in the next two chapters.

3.3 The Research Process

3.3.1 The Exploratory Phase

Given the primary interest of the thesis – business network dynamics (a complex multi-level phenomenon, see Figure 5) - the purpose of thesis is developed through immersing into the INA literature. If one views the changes in business networks generally in terms of 1) a change trigger, 2)a process of change which is then initiated because interdependent business actors respond to the trigger and then 3) certain outcomes (structural or relational) of this process, various studies could be identified focusing on each of these different aspects. Still, a review of the literature shows that more understanding of this whole process and the dynamics involved is needed. Specifically, most research on business network dynamics, focus on actors' responses to internally initiated changes by focal actors in their dyadic relationships with tight boundaries in terms of the number of actors and relationships accounted for. With this confined focus then both structural changes (to a limited extent) and relational changes (to a larger extent) e.g. in terms of changes in activity links, resource ties and actor bonds are investigated by INA scholars. These areas of attention are understandable considering the dominant methodology of the field, case studies which can become resource intensive and difficult to do if more complexities are to be studied. Hence, most INA studies fall short when it comes to accounting for the aggregate outcome of business actors' responses especially when larger number of actors are involved and more macro-level outcomes of change are the topic of interest. Moreover, limited insights on structural transformation of business networks as radical changes exist within the field.

Further, I asked how could structural change processes of business networks evolve differently over time depending on the type of triggers that initiate the change and stimulate responses. Exogenous changes triggers although impose an influence on business networks and their components only through transforming into endogenous changes; still their significant difference is that they often affect a larger number of actors almost simultaneously. They then probably have wider influences and it can be fruitful to investigate these processes and certain conditions that may affect the emergent network structure. With these points of inquiry then adopting the Complexity perspective was proved fruitful as these framings of the features of business network resemble CASs.

Given this setting and as elaborated in the Introduction chapter the following research questions are formulated:

1. How can the structure of a business network evolve over time as a result of endogenous and exogenous change triggers?
2. What moderating factors may influence the process and its outcomes?

With the network settings above, to address the research questions, a methodology is needed that allows us to capture non-linear interdependencies of heterogeneous business actors, and the emergent aggregate outcome of these interdependencies over a long time horizon. As discussed earlier in this chapter, ABM and simulation as one of the potential methodologies is chosen. This choice of methodology is an implication of the theoretical lens of Complexity perspective adopted.

Departing from these theoretical considerations, to better approach and handle the purpose and research questions of the thesis two related paths are pursued. The paths followed are illustrated in figures 4. In one path, the focus in on network structural transformations that emerge as a result of endogenous triggers initiated internally and deliberately by an actor in its relationships. In another, exogenous triggers are focused on where a set of network actors simultaneously face an exogenous change trigger and respond. In both parts, the structural changes that emerge in the network are of interest.

Focusing on the first direction, the investigation was coincided with an ongoing university research project called FutureRail in collaboration with a business partner (the Swedish railway operator)-Scandfibre Logistics (SFL). This company was considering the introduction of a solution to its business network and were concerned about its possible negative implications. That solution could cause changes in the structure of the SFL's business network. The empirical setting of this project is adopted to expand the research questions and my understanding in the first direction mentioned above to empirically investigate the structural changes of the network under an endogenous change trigger (SFL's new solution) (See Figure 4).

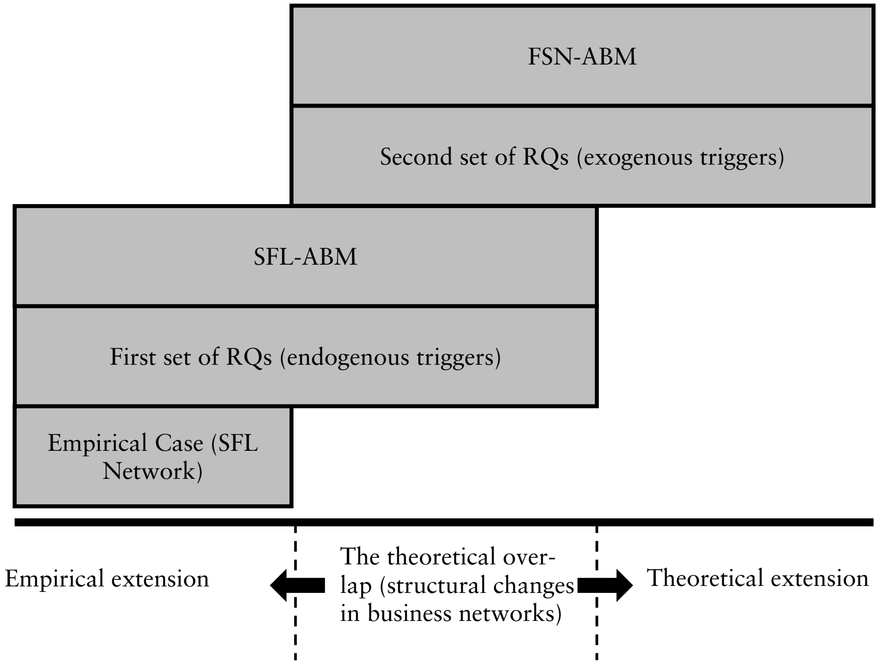

Figure 4. Illustration of the exploratory phase of the thesis

Having the empirical setting of the SFL-case (details of the case are presented in chapter 4) and considering the purpose of gaining a better understanding of structural changes of network emerging from an endogenous change trigger, the first set of research questions are elicited as below:

1. What are the possible implications of SFL's new solution for the structure of its business networks?
2. What moderating factors may influence the process of change and its outcomes?

Considering the theoretical lenses of INA and Complexity perspective, the theoretical framework mentioned in chapter 2 and the empirical data of the SFL case, I then enter the modelling phase (See Figures 5), where the

SFL network is modelled computationally (SFL-ABM). This phase is elaborated in the next subsection.

On the second path of the research, I extend the insights gained from the first empirical part by focusing this time theoretically on structural changes emerging from exogenous triggers. Moreover, more complexities are involved in this part considering that multiple heterogeneous actors of the network, facing an exogenous trigger, respond, react, and simultaneously affect their own context of interaction. Those could be almost impossible to study empirically at least in a short time, since it implies collecting large amounts of data, from different actors, identifying their dependencies and interactions and reactions and then tracing all these influences over the long run for understanding the structural changes that emerge. By theoretically addressing this question, I can focus on a wider view of network, incorporate more actors and interdependencies and hence address higher levels of complexity than addressed in the first case to gain an understanding of the dynamics involved in terms of structural changes of the network.

To have a more tangible and insightful investigation of such a complex network, the business sustainability of a food supply network comprising of various supply chains as a rather complex business network (nested networks) is the adopted context further specifying my research. The sustainability pressures coming from shifts in consumers' attitude and increased demand for environmentally sustainable products is chosen as the specific exogenous trigger, simultaneously affecting a wide range of business actors in the supply network , stimulating various types of reactions(i.e. decisions on adopting sustainability) with no individual business actor in control of the process (as opposed to the first case where the perspective of a focal actor and its strategizing are considered).

Sustainability is chosen first because following the review of INA literature on sustainability (an overview is offered in chapter 2), it was realized that sustainability is an issue that needs to be addressed at the aggregate level of multiple directly/indirectly connected organizations rather than a single organization and hence is embedded in the complex interactions in business networks (e.g. Frostenson & Prenkert, 2015; Öberg et al., 2012). Second, INA scholars have approached the process of adoption of sustainability in business networks as a process of change (e.g., Andersson & Sweet, 2002; Harilainen, 2009; Harrison & Easton, 2002; Johnsen et al., 2017; Meqdadi et al., 2017 & 2018; Veal & Mouzas, 2011;). Hence, it can offer a dynamic context for the theoretical exploration in this thesis.

Given the above setting, the following research questions were adopted for this theoretically oriented extension of the research, from the main research questions of the thesis in a way that addressing them can lead to insights complementary to the ones gained from previous empirical case (See Figure 4):

1. What are the possible implications of end-customers' increased demand for sustainable products for the structure of a supply network?
2. What moderating factors may influence the process and its outcomes?

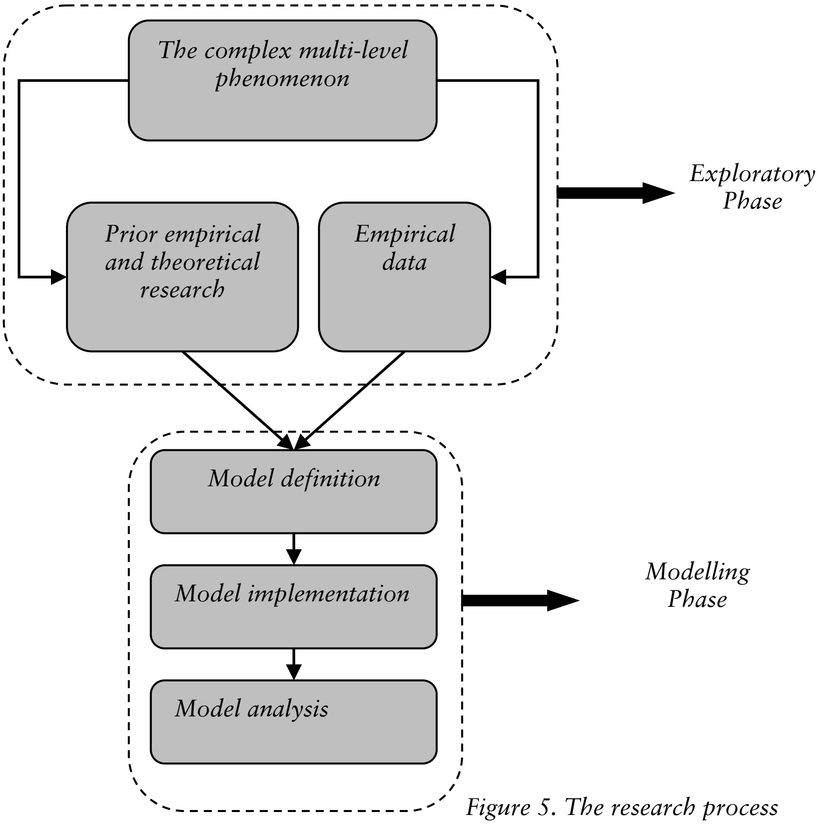

Figure 5. The research process

I then enter the computational modelling phase of the proposed supply network (FSN-ABM) (See Figures 4 and Figures 5) which is based on the theoretical understanding of and assumptions about business networks from INA and Complexity perspective.

Having formulated the detailed research questions of the two cases, then ABMs of each case need to be designed and implemented. Here, the steps involved are labeled as the "modelling phase" which are presented in the next subsection. In this chapter a general account of the steps followed in both cases are presented. Since the modelling details of each case vary due to different specifications of their target, more details of the modeling process of each case are presented in their respective chapters (chapter 4 and 5).

3.3.2 The Modelling Phase

3.3.2.1 Model Definition

Designing the Causal Model

For each case, based on the research question specific to that case, as well as the specific features of each case, a causal model is designed, which involves formulating the research questions in terms of variables and links, hypothesizing certain relationships. The causal models are depicted through boxes and arrows. The causal models designed for the cases of this research are generally in the form drawn in Figure 6.

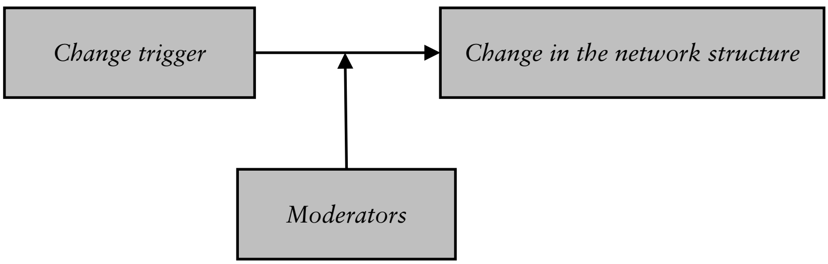

Figure 6. The structure of the causal models designed for this thesis

The causal model represents the general research question of the thesis which is about structural changes emerging from certain exogenous/endogenous triggers in business networks. The change trigger (independent variable) has implication for the actors involved and consequently the network structure (the dependent variable). This part of the model corresponds to the first question in each set of the research questions presented above. Then, I explore how certain moderating factors may influence the outcome of this process (the implications). It is important to note that although drawn in terms of arrows and boxes as well as variables and links, the arrows and links do not imply simple causal relations in the form of cause and effects and correlations. In fact, they stand for mechanisms and generative processes that shape the emergent network structures (the phenomena of interest in this thesis).

The important step in designing the causal model is the definition of each variable/concept in the model and how it can be identified and presented in each case. For instance, the change trigger in the first case is the SFL's deliberate strategizing in terms of introduction of a new solution into the network and hence is endogenous. In the second case of the supply network, the end customers' demand shifts towards more sustainable products, simultaneously affecting all the supply chains involved and hence is exogenous. The definitions are aligned with the theoretical definitions of the concepts discussed in the theoretical framework presented in chapter II. For example, whenever links are created or terminated between business actors in a network, it is interpreted that, the structure of the network, i.e. how the actors are connected to each other, changes.

Causal models similar to the one in Figure 6 are designed for each case. However, the details and the context of exploring the model and the hypotheses that they present vary between models, i.e. what each box represents may have a different manifestation in each case. Moreover, different moderators are focused on in each case.

Although the ABM definition is presented as a separate step in the next section, still, while designing the causal model and defining the variables and their representations, their possible representations and (qualitative or quantitative) measurements in their corresponding ABM was being considered simultaneously.

Agent-based Model Definition

The very initial step in building ABMs (and any other model) is clarifying the purpose of the modeling. This is a critical step of the research process, as it has implications for the way one builds, justifies and assesses the model as well as the way the model is communicated to the reader. Edmonds et al. (2019) reviewed seven main purposes of using ABMs of complex social phenomena: prediction, explanation, description, theoretical exploration, illustration, analogy, and social learning. They have suggested that researchers working with ABMs, use this categorization to clarify the purpose of their modeling. This is important as part of the productive standardization of this research strategy and because of the critical role of this clarification for the development, checking and presentation of the model.

In line with the above discussion, here the purpose of building an ABM is theoretical exploration defined as "[...] establishing then characterizing (or assessing) hypotheses about the general behavior of a set of mechanisms (using a simulation)." (Ibid, P. 10) while also offering some possible explanations. Certain theoretical properties of the structural changes processes that emerge in response to certain change triggers in business networks are investigated. The purpose is to gain insights on the mechanisms at work and systematically exploring how the system outcomes (the network structure) may vary under different assumptions. Hypotheses are defined about the working of the simulation under a range of given conditions and test them using simulation experimentations. For instance, the network structural changes are studied under different values of a number of moderating factors to gain an understanding of the mechanisms at work that may influence the emergent structures.

In terms of Edmonds et al. (2019) categorization, this purpose is not exactly explaining a real empirical phenomenon, mainly because there is no strong real relationship with the empirical data and evidences. The second case is an abstract one based on no real empirical setting. The first case, the designed SFL-ABM, the empirical data inform the general decision rules of the agents and the structure of the model and the research questions and the model specifications are inspired by those empirical settings. The real structural implications of the SFL's solution are not available so there is no observed real phenomenon for which I wanted to find an explanation by modeling it.

In modelling and simulation process of this study, both the empirically grounded case of SFL and the theoretical case of the supply network are theoretically explored by observing the simulation outcomes in terms of certain emergent properties of the networks –their structures. For the sake of theoretical exploration, these simulations generate certain regularities which are then systematically explored as the consequences of the assumptions for those regularities, to gain insights in to the mechanisms at work.

The simulations here still can offer explanations. The assumptions underlying the functioning of the model, including the features of the agents, their interactions and decision rules and their environment, are actually candidate explanations for the simulation outcome that are observed. Although, the findings of the simulation model are in the form of the relationship between variables, they will further be interpreted in relation to the model specifications as the generative mechanism involved. The model specifications and simulation processes that lead to a specific macro-level regularity, in fact, themselves are explanations of that regularity. I.e. the models are the *possible* explanations while the simulation experiments are tests of those explanations. Hence, the model specifications that generate those regularities, or grow those regularities (Epstein, 2006), *are* candidate explanations of the observed outcomes[3].

After clarifying the purpose of ABM in this thesis, below I explain what *agents* and the *environment* (please see Section 3.2 in this chapter) stand for in the ABMs of this thesis.

Agents. For each case, I identify the agents which are the entities with heterogeneous attributes and decision rules. The definition of agents, their specific attributes and their behavioral rules of interaction are defined based on the specifications of the data available from the description of the cases as well as the theoretical ideas of INA in general. These also include a set of rules on how the agents can affect the environment and vice versa (Gilbert, 2008). For empirical ABMs, which aim at modelling a certain, *observed* empirical social phenomena, both qualitative (e.g. case study data) and quantitative (e.g. survey result) data can be fed into the model (Edmonds, 2015; Ghorbani, Dijkema & Schrauwen, 2015; Prenkert, 2012; Purchase et al., 2014). In this research, the general data that are incorporated in the model from the empirical case of SFL network are mainly qualitative (there are some numerical parameters such as production cost which are designed either through expert opinion or sensitivity analysis) and inform the agents' attributes, behavioral rules and some features of the environment.

In both cases, agents represent individual business firms (and in second case, they also represent individual consumers). Depending on specifications of each case, different features and decision rules are designed for

[3] ABMs are generative and not exactly inductive or deductive in their common definitions (Epstein, 2006). Although they can be empirical but technically, they are not inductive since they are not about observing a regularity and then driving aggregate inferences about it. They may be viewed as deductive but they are a specific kind of deduction based on construction or generation of the proof.

agents. Agents may represent various business firm types such as retailers, wholesalers, terminal operators. Moreover, as ABM allows for modelling *heterogeneous* agents, each agent type (e.g. retailers) may be comprised of different sub-categories (e.g. customers who are highly risk averse and customers who are not risk averse at all). Each agent type has a set of variables and parameters, which their variations lead to the creation of different sub-categories of that agent type.

The above stages may involve high levels of abstraction. Obviously, the more detailed information about the business actors, their features and decision rules one incorporates into modelling, the more realistic the model becomes and the more complicated will be the modelling and later on analysis of the results. The non-linearity and interactions in such systems can easily lead to highly complex and intractable emergent outcomes that one cannot understand and interpret why certain outcomes showed up. Hence, there is a trade-off between the practicality of the models and their descriptive adequacy (Boero & Squazoni, 2005; Edmonds & Moss, 2005) which pretty much depends on the context and the purpose of modeling as discussed earlier in this chapter. Since the purpose here is theoretical exploration, the agents are modelled in a rather abstract sense, just enough to capture the theoretical phenomenon of interest and gaining fruitful insights - guided by the causal model.

The environment. After designing the agents, the features of the agents' environment are defined. These features may include the number of the agents, the way the agents are connected to each other, the features of a specific government regulation, the resources, spatial characteristics of the agents' interaction space, etc. Again, as the purpose is the theoretical exploration, in each case, the features of the environment are designed based on both the case specifications and the theoretical backgrounds (while trying to balance the simplicity and descriptiveness of the model).

The environment features in this research involved the number of the agents of each type and each sub-group (e.g. the number of eco-friendly and non-eco-friendly consumer agents), the specific market features (e.g. the price ranges of different products representing different market segments), the way the agents may connect to each other (e.g. certain retailers can connect to some wholesalers and not others), etc. Hence, these features may be some general characteristic of the context in which the agents interact or they may represent how a set of agents can interact with another set of agents.

The process of identifying the characteristics of agents and the environment are not arbitrary. They are based on the case specifications (in SFL-Case) as well as existing theoretical understandings (in both cases) that are relevant and enough to delineate the business network under study and address the purpose of the research. Operationalization of certain theoretical features of the agents and the environment are defined to formalize them and use them for their implementation into the modeling platform of this thesis: SeSAm. For instance, a market setting in which the buyer-seller interactions (e.g. the relationship between a retailer and its wholesaler) are in the form of business relationships with long-term features rather than single transactions is modelled by considering a "relationship strength" variable. Each time two agents work with each other their relationship strength increases and the relationships with higher strength last longer.

The environment features and the agents' features are fed into the model as parameters and variables of various types; they may be defined as numerical values, Boolean, lists of numbers, lists of strings, etc. These features may stay constant over the simulation or they may vary as agents keep interacting over time. Individual agents' interactions and operations may lead to changes in variables representing the environment and vice versa, the environments' features are affecting and shaping certain behaviors of the agents. All these show the interactive and feedback effects of the micro-level and macro-level specifications that over time build up the specific outcome patterns that are analyzed.

The model. Apart from the definitions and design of agents and their environment, the model itself needs to be designed; a representation of how all those agents are connected to each other, how they interact with each other and with the environment and all the mechanisms involved in the emergence of macro-level outcomes from these micro-level specifications.

In each model, I start by drawing a basic flowchart of the steps that each agent type is supposed to follow in each simulation run, i.e. the flowchart of the algorithms. A similar flow chart is also designed for the functioning of the market in each case, e.g. the sequence in which agents may operate, when the market opens and ends, etc. Further, it is decided how the different flow charts of the agent types should be connected to each other so that the modelled society of agents can function. For instance, in the second case, the decision of a retailer agent is dependent on a specific step in the process that a wholesaler agent is following.

All these processes designed in the flowcharts are based on the causal model specific to each case. More specifically, they involve a general idea of how the causal model can be implemented into the computational ABM. This means that each variable of the causal model is operationalized somehow into the ABM either by a specific variable of agents and their environment or by a set of those variables. Moreover, for understanding the outputs of the model I need to think about how I can interpret certain features of the phenomena of interests from the set of variables and system outcomes at the end of the simulation. These interpretations and definitions need to be grounded in the literature.

These flowcharts which were basically drawn on the paper and revised during meetings with supervisors of the thesis, were the point of departure for the implementation phase of the flowcharts in implementing the model in the software platform SeSAm.

An important issue to highlight here is the iterative process of the model specification that is followed. Although, for each case there is a basic causal model to work with and ground the modelling on, the model specifications varied during the later stages of modeling when doing experimentations with the simulation models. An important reason for this iterative process is the specific purpose of modelling; theoretical exploration. I actually am forming and enhancing my understanding of the processes at work by doing more and more experimentations. Certain experimentation lead to further theorizing and consequently further experimentation to test those. I.e. based on the analysis of the outcomes of the experiments, for understanding and explaining certain observed outcomes, I come up with further ideas about what other possible features of their agents might be influential for the mechanisms at work. These interpretations sometimes have led to addition or deletion of certain variables, parameters, agents' decisions and interaction rules, etc. in an iterative and explorative process.

3.3.2.2 Model Implementation

Implementation

The next step followed is the implementation process of the model, i.e. translating those flowcharts drawn on paper into computerized models in a software platform to create the artificial business societies of agents. There are currently various platforms for coding and implementing ABMs and simulations. For this thesis, the models are built and the simulations are run in SeSAm (Shell for Simulated Agent Systems) (Klügl & Bazzan, 2012). SeSAm is a generic environment for developing and simulating agent-based models.

Agents, *resources* and the *World* are the main entities of this platform. Agent types (e.g. consumers, retailers, wholesalers, customers) were defined under the Agent entity in SeSAm. For each agent type a set of variables are defined. There is a visual space to draw the reasoning of each agent type. For each agent type and based on its corresponding flowchart, the reasoning of the agents are modelled. The model involves a set of activity boxes connected with conditional arrows guiding the steps through which the agent must follow. Inside each activity box, a set of implementation are modelled representing what a single agents does in that activity box. Screenshots of these modelling spaces are provided in the next two chapters.

Resources, are specific entities of this platform for the modeler to be able to distinguish between the active and passive objects (in other platforms, often this distinction is not made and all objects are represented as agents). In SeSAm, an agent is an active object that has a set of variables representing its state, and a behavior (the set of activities it follows which were referred to above as flowcharts of activity boxes and arrows). A resource is a passive object that only has a state and no behavior on its own. Its state may be dynamic, but all changes on the resources are imposed by agents.

The environment of the agents, which in both cases of this research are representing the exchange context in which the agents interact, are modelled under the *World* entity in SeSAm. Again, the variables and parameters that are global to the model (rather than being agent-types' specific features) and represent the environment specifications are defined under *World* entity. Moreover, the general functioning of the environment (the context of business actors' exchanges in this research) which is initially depicted in flowcharts, are then implemented into the model in terms of activity boxes and arrows.

Further specifications of the model and more practical issue of the model implementation are not explained in this document. However, the SeSAm model files will be available and are self-explanatory in terms of the practical model implementation in the platform.

Verification

In next stage, the long process of checking or verifying the model implementation begins. Verification is about assuring that the software implementations of the model are operationally right and the model works in the right way as intended. This involves making sure that the program is modelled correctly, the algorithms are properly planned and the model does not have bugs and errors (North & Macal, 2007). This can be achieved in a number of ways.

Documentation is an important process that needs to be done at the same time that one is programing (Edmonds et al., 2019; Gilbert, 2008; North & Macal, 2007; Rand & Rust, 2011). In ABMs of this study, a detailed documentation of all the variables and their meanings, every single step of the algorithms and all the comments that need to be there to make it easier to understand the model and processes involved, is done. Other than enhancing the replicability of the models for other researchers, the benefits of this documentation were constantly becoming apparent as the implementation process progressed, because eventually the models got very complex that it was difficult to remember the details of the models such as how a specific type of agent was supposed to respond to a specific stimuli. The programing codes are also publicly available for reviews. While contributing to the transparency of the models (ABMs are inherently complex and making them more transparent for further reviewing and replication can be challenging), it can also enhance the interested readers' experience of the model. Here, my experience of the model and modeling process is of course very different from the readers' experience of them. With these documentations, is to narrow down this gap as much as possible. Miller neatly explains this issue:

> "The reader encounters a model as a finished product. The modeler's preceding research process is inaccessible to the reader. The reader picks up the model like an unfamiliar tool. Rather than working with the model, the reader examines the research report and tries to understand how the model functions. The reader works linearly through the model specification and reported findings, and attempts to evaluate the model's assumptions and understand deductively its implications. In contrast, the modeler's participation was creative, developmental, experimental, and iterative." (Miller, 2015, P. 187)

Debugging the programing codes and checking the codes thoroughly is another approach adopted for verifying my ABM codes. This is mainly done by debugging walkthroughs (North & Macal, 2007). This involves running the model almost line-by-line and following the agents' actions and interactions as they happen to make sure that the model is working as intended. Moreover, certain milestones are defined in different parts of the model implementation capturing the progress of agents' activities and making sure that the agents do what I want them to do. If those milestones are not caught, error signs are designed to pause the simulation process and allow for further investigation and debugging.

Another approach followed is testing the model with extreme values of parameters (this potentially can contribute to the validation as well) to make sure that the model is not acting too aberrantly and no errors are returned. Many times, the extreme values of some agent/environment parameters, have revealed some implementation issues.

Another issue that contribute to the verification of ABMs in this thesis, is the specific feature of SeSAm, which is the visual programming (Klügl, 2009; Klügl, Herrler & Fehler, 2006). In other words, a very similar representation of agents and environment functioning to what was initially depicted in hand-written flowcharts of the researcher, are created in the SeSAm, enhancing, simplifying and sometimes omitting many of the debugging processes that an ABM programmer often goes through in other ABM platforms such as Netlogo. In other platforms the flowchart-like programing is not possible and model is implemented in the form of programming codes. This almost one-to-one correspondence of the flowcharts on paper (what I want the agents to do) and the visual program of those flowcharts that is implemented in the SeSAm (what the computer agents actually do) is another source of verification of ABMs of this thesis.

3.3.2.3 Model Analysis

Validation & Sensitivity Analysis

After verification, the model needs to be validated. Generally, validation is about assuring that the model outcomes are good representations of their real-world target. In other words, it is about assuring that the model addresses the right problem (Klügl, 2008). It involves validating both the inputs (micro-level specifications) and outputs (macro-level outcomes) of the model, meaning that both agents and their decision-making as well as the simulation results need to be validated; Moss & Edmonds (2005) called them micro-level validation and macro-level validation respectively. However, it very much depends on whether the model is empirical or an abstract model. Generally, the key aspect of model validation is about checking it against the real-world phenomenon that it is supposed to be representing.

However, not all models are based on empirical data sets of a certain phenomenon and no real cases exist against which the modeling outcomes can be compared to assess their quality. The ABMs of this thesis fall into this category (Boero & Squazzoni, 2005). As was explained about the purpose of modeling in this thesis, the purpose has implications for the assessment of the model. The models in this thesis are not pure empirical models (case-models), meaning that they are not modeling an observed empirical phenomenon. Hence, there is no corresponding and *specific* real-world regularities and evidences against which I can assess the validity of the model outcomes.

Validation of such models is about assuring that their underlying assumptions and the model outcomes are plausible. This plausibility can be assessed through comparison with the already known mechanisms involved in certain relevant phenomena. I initially enhanced the validation of the models by clarifying the links between the theories (INA and Complex Systems view) and the model assumptions about agents' attributes and interaction rules, when (in the previous chapter and the early parts of this chapter) I explained the correspondence of business networks with CASs and further how ABMs are used to study CASs. Hence, showing how the theoretical lenses match with this specific modelling approach adopted.

The model assumptions and outcomes can be further validated on face (North & Macal, 2007). Face validation makes sure that the model processes and outcomes are plausible to the "knowledge of system experts or stake-holders" (Klügl, 2008). The model assumptions of this thesis are checked with the supervisors as well as the researchers involved in the data collection phase of the project associated with SFL-Case to make sure that the assumptions have a certain level of plausibility on face.

Another approach for validation and perhaps the most important one is doing sensitivity analysis of the model parameters. This involves systematically changing the parameters over a range of values and check the robustness of the outcomes. For a complete sensitivity analysis, one needs to check the whole range of each single parameter as well as their interaction effect. Clearly, the computational demand of such an action is too high and in some cases impossible. Hence, as suggested by North & Macal (2007), In this research, this possible range is limited to certain variables and parameters of interest with limited number of test values, trying to mostly test for extreme values of the parameters. A number of important parameters, corresponding to both agents and the environment in each model are chosen for doing the sensitivity analysis. A number of values for each parameter including extreme values are tested to assess the model outcome's robustness. In addition to contributing to the validation of the model, these sensitivity analyses also help with verifying the model as explained in the verification section above. Sensitivity analysis is also done for some parameters that somehow represented specific factors of the causal model. Hence, it also contributes to the main experimentation processes of the models as well. Details of the sensitivity analysis done for each ABM of this research are presented in the next chapters.

Scenario Design, Experimentation and Analysis

After assuring that the model is working as intended (verification) and it is also modelling the right phenomena (validation), based on the initial causal model, I start designing scenarios for investigating the mechanisms at work and testing various hypotheses through experimentation with the agent-based simulations.

The causal models of each case are the points of departure for analyzing the computational model and its results. The model is actually a formalization of the complex phenomenon of interest in this thesis, built based on theoretically driven assumptions from INA and Complexity perspective. I.e. the business networks are reproduced by formalizing some of their known mechanisms. This formalization then becomes a test bed for further exploration of processes leading to structural changes of the network and some of the influencing factors, i.e. the factors in the causal models represent certain theoretical properties of the networks of the thesis, which I aim to understand better.

For analyzing the model in each case, it is acknowledged that any causal mechanism defined in the causal model has a set of corresponding mechanisms in the computational model which themselves are represented by a set of variables and parameters (as indicated before, this shows the explorative and often iterative process of model definition and analysis, as already in the definition of the model one needs to have considered the analysis of its results).

In each set of experiments, I vary the corresponding parameters and variables of the causal factor under study while keeping the rest of the features unchanged. The results of the experiments then need to be analyzed in terms of the causal model factors and the adopted theoretical perspectives of the thesis.

Different settings are created by changing the value of the parameter of interest or a decision rule of an agent type that is representing a variable of interest in the causal model, and keeping all other model settings constant. E.g. if I am about to test the influence of increasing the number of eco-friendly consumers on the business actors' (agents') adoption (or not) of sustainability practices, then a set of scenarios can be designed to test this influence. Various values for the share of eco-friendly consumer e.g. 30%, 50% and 90% market share represent three different settings with low, medium and high level of eco-friendly market demand. Then the level of business agents' adoption as the simulation outcome of interest can be measured and analyzed in each of these three settings.

Initially, I decide what measures and outcome variables need to be focused on in order to confirm or reject the specific hypothesis of the causal model. The specific phenomenon of interest in both cases of the thesis are the structural changes of the networks. In both case the reorganization of the networks are manifested in terms of the current business relationships which are terminated and the new relationships which are formed. These measures then have their specific representation in each case. For example, in the first case (SFL), the number of customers who change their mode of interaction with the focal firm (shifts from auction system to contracts and vice versa) represents the changes in the network structure. In the second case, the number of supply chains which are restructured over a number of interaction periods are recorded.

Since, the designed ABMs are not deterministic and involve random factors, each simulation run might turn out a different set of outcome values. In both models one simulation run corresponds to 52 periods of agents' interactions. Each period represents one round of agents' interaction. For instance, in the first model of the SFL, it is assumed that customers rent wagons weekly. Hence, one period involves all the transactions, interactions, decision and operations going on among agents in the market for one week of business. Then one simulation run corresponds to 52 weeks of business. In the second model of a food supply network, one period represents one shopping period of consumers buying food from retailers (consumers buying food once a week from a retail store). Similar to the first model, one period involves all the transactions, interactions, decision and operations going on among consumer agents and business agents (retailers, wholesalers and farmers) in the market for one week of business. Then, one simulation run corresponds to 52 weeks of consumers shopping and business agents' strategic decision-making. Simulation outcomes are collected and analyzed at the end of those 52 weeks. To account for the randomness in the results each experimentation with a setting involves repeating each simulation run of the model for *N* times (more details on chapter 4 and 5).

Each scenario is explored according to the above conditions and then the significance of the results is statistically tested to assess the corresponding hypothesis. To come to preliminary results, statistical tests are applied to the outcome variables to check the significance of them. For all statistical analysis conducted in this thesis, the Kruskal-Wallis non-parametric statistical test with 0.95 confidence level is adopted in SPSS.

The measures of outcome variables mentioned above, merely show the amount of restructuring that happens in the composition of the actors of the networks. Next, for any results generated, no matter if they show significance or insignificance of a certain factor's influence on the changes of the network structure, I need to analyze the results further and come to explanations for them. This is done by checking the model and agents' interactions in different settings to understand why certain results show up, e.g. why the agents' interactions in one setting lead to severe changes in the network structure but not in another setting. While testing and exploring the initial hypotheses and looking for explanations, more hypotheses and scenarios are designed and tested. Hence, as explained earlier, because of the explorative nature of the modelling purpose in this research, an iterative process is followed which leads to constant adaptations to the causal model, model specifications, scenario designs and experimentation to further elaboration of the theoretical understanding of the processes.

Sometimes reasons for certain behaviors of the system are straightforward considering the assumption that I have fed into the model. However, most often, the types of factors that are of interest in studying a complex target may lead to emergence of certain patterns of outcomes that are not easily and directly comprehensible from the model assumptions. In this thesis, to come up with explanations of the observed patterns of outcomes in each sets of experiments, a set of processes are followed, the main purpose of which is to understand the causal mechanisms that has led to that specific outcome. First, I try to think of a set of relevant parameter values and variables that can capture the process through which that specific outcome has emerged. For example, in the second case (FSN), I basically sum up the number of supply chains being restructured over the 52 weeks of interaction as the main variable that captures the amount of structural changes in the network. However, since I need to know why a certain amount of restructuring has happened in a network under a specific experimental setting, I start by simply observing the supply chains which are restructured in *each period*. This way a more processual view can be achieved that may give more insights in to the emergence of those structural changes.

Here various techniques for summarizing and visualizing the variables of interest may be used. This is an important step in analyzing data since in each simulation run a huge amount of data are generated which contain information both about the process (e.g. measures of a certain parameter in each period) and about the final outcomes of interest.

Since each experimental setting is run for a number of times (to account for randomness involved in simulations), most of the data on results are presented in box and whickers plots. To facilitate readers' understanding, in the following paragraphs I briefly introduce boxplots as a tool for data representation and explain how they can be interpreted.

Boxplots are useful for comparing different sample distributions with each other. They basically represent the central tendency and variability within a sample. A box in a boxplot summarizes five characteristics of the distribution of data within the sample; the median, the first quartile, the third quartile, minimum value and maximum value (Lewandowski & Bolt, 2010). In this thesis, I do not refer explicitly to each of these five numbers during analysis, rather, the relative differences in the general range of different sample data are of interest.

Since in each of the cases in this thesis, each simulation is run for more than one times (100 times for the first case and 80 times for the second case), boxplots are useful tools to visualize and compare the output data under different experimental setting to see whether the distribution of data in settings with different values of the parameter/variable that is of interest, are different or not.

Boxplots used for comparing different experimental settings are most often accompanied by statistical tests to confirm/reject significant differences between settings (in this thesis, the non-parametric Kruskal-Wallis test). If two boxes in a boxplot do not overlap at all, then the distributions of the represented data are different between the two settings. Otherwise, statistical tests can be good complements to boxplots for exploring the differences between settings.

Going back to the focus of thesis, by observing the periodic changes of the structure then one can see that e.g. two settings which have the same total amount of restructuring, may have reached those changes in very different processes, where in one of them most of the changes are in the earlier periods while in the other one the changes are mostly starting in later periods. Eventually these types of analysis of the outcomes and processes gives insights on the process through which the changes emerge in the networks. Most importantly, many of these insights are not easily comprehensible directly from the beginning merely by reviewing my assumptions of the agents' features.

Due the high complexities of the CAS phenomena and specifically the non-linearity of the interactions of the components, exploring throughout various mechanisms involved in the change processes of the network by studying their representations in the results (such as the example above), does not always give a clear explanation for an observed pattern of outcomes. In such situations, I then start to follow the agents step by step in the computational model to understand why certain behaviors emerge.

When potential explanation of an observed pattern of outcomes are identified, more experiments are then conducted to see whether they hold or not. Sometimes, to make sure that the potential explanation holds, more complementary hypotheses need to be designed and further tested. For example, in the second case of the thesis, it was realized that, networks with different number of retailers in them were not showing expected results in terms of the amount of changes in their structure. Going through processes mentioned above, I came up with a potential explanation that, the number of existing wholesalers of the network was the moderating factor, causing the network to behave different from what was initially expected. To make sure, then I performed further extended experimental settings, this time also varying the number of wholesalers, to see whether it was the right potential explanation. Then to present my explanations of the observed outcomes, I frame them in terms of the theoretical perspectives adopted in the thesis.

Finally, the results and identified potential explanations are put into the context of the causal models of this thesis and I explain how the research questions are then answered.

To sum up and as is depicted in Figure 5, although the process is presented in separate steps, but it is an iterative one –which one may call playing with the model- where simulations are run, results are analyzed and the model implementations are adapted if needed. This *playing* contributes both to the quality of the model implementation into the SeSAm and to my immersion into the modeling for getting insights into the mechanisms at work which together generate various outcomes in the models. In this sense, the process mitigates the "epistemic opacity" of the simulation model specifically the more complex ones – a disadvantage of ABM and simulation that is sometimes referred to by scholars. It is said that although the mechanisms of the agents and their interactions are clearly specified in the model, it may be difficult to understand how they work in combination and hence the relationship between the initial inputs and the outcomes may not always be clear (Grune-Yanoff & Weirich, 2010; Miller, 2015). Choosing traceable phenomena, making appropriate simplifying assumptions as well as this playing process can reduce this issue and contribute to gaining an understanding of the mechanisms at work and perhaps coming up with (candidate) explanations.

3.4 Some Reflections on This Research

What kind of knowledge is generated here with ABMs and how?

As it is perhaps clear by now, ABMs are suitable for studying social phenomena that involve the generation and formation of some macro-level regularities. As Epstein put, they can be applied to generativist questions in the general form of: "How could the decentralized local interactions of heterogeneous autonomous agents generate the given regularity?" (Epstein ,2006, P. 5), i.e. they are best to apply in interactively complex epistemologically-emergent phenomena (Miller, 2015). In ABMs social entities and their actions-micro specifications- are modeled and put into action. These actions and interactions over time give rise to further interactions and eventually certain phenomena (macro regularities) are generated (computed) which are often not reducible to those micro specifications. In this way, ABMs are actually explaining the emergence of those phenomena. They have the potential of explaining social regularities by identifying the mechanisms underlying their formation. The mechanisms are the model specifications that are built into the model and further are developed as agents keep interacting. All these agents and interactions actually grow a macro level regularity and hence are explaining it; "if you didn't grow it, you didn't explain it" (Epstein, 2008, P. 8).

However, the quality of this explanation is not necessarily high as it is very much dependent on the quality of data fed into them as well as the abstraction level of model specifications. First, the models are the abstraction of their corresponding real-world target and even the most descriptive one does not necessarily include all of the real processes involved. Second, modelers follow different purposes when building ABMs and consequently they might simplify their models or choose to focus on certain aspects of their system of interest. Hence, the generative mechanisms identified as the explanations of a certain social phenomenon are not the only explanation possible and are considered as candidate explanations. Still, depending on the purpose of the modeling they are able to offer some insights into the working of the mechanisms involved. In fact, “the entire simulation process constitutes a methodology for theory development, starting with assumptions and model construction and ending with predictions of the theory (findings).” (Harrison et al., 2007, P. 1233). The whole process of modeling certain micro specifications and interaction processes and letting them to operate and grow certain outcomes is some sort of theorizing with the help of a formal model, or theoretical exploration in terms of Edmonds et al. (2019). This systematic approach forces the researcher to clearly identify and formalize the definition of his/her concepts or variables of interest and the processes and relationships involved.

In this thesis, the general phenomenon of interest is business networks’ structural changes emerging from certain change triggers. In each case, a set of agents representing the business actors are modeled in their specific business setting- the agents’ environment. A set of decision rules are built into the model and the agents are let to interact based on those rules to generate certain outcomes that are defined and interpreted as changes in the structure of the networks. Then if those changes are interpreted from the results, it means that the model specifications -representing the generative mechanism underlying those changes- are a candidate explanation of those changes.

4 Case 1. The SFL's Business Network[4]

This chapters goes through the details of the first part of this thesis' explorative path focusing on network structural transformations that emerge as a result of endogenous triggers initiated internally and deliberately by an actor in its relationships. This first path of the research was coincided with an ongoing university research project called "Future Rail" between 2014 and 2018. The project was focusing on "collective organizing in logistics networks" of a business partner (the Swedish railway operator)- ScandFibre Logistics AB (hereafter 'SFL'). The case under study in this chapter is developed based on that research project. The first Agent-based Model (ABM) of this thesis, SFL-ABM, is built based on the specifications and the case data collected during that project by a research group. Parts of the data collected in that project is used to build this first case of the thesis and consequently the corresponding ABM in order to address the purpose and research questions of the thesis. This chapter covers these specifications, the model implementation and the experiments conducted by the SFL-ABM.

4.1 The Case of ScandFibre Logistics

SFL – the focal firm of this case- is a major railway operator and 4th party Logistics Service Provider in Sweden with the main mission of transporting paper and pulp products from paper mills in Sweden to terminals in Europe through their railway system. They are owned by three major paper producers, Billerud Korsnäs, Mondi and Smurfit Kappa. The SFL's transportation system is mainly based on the location of their main users' customers, i.e. those paper and pulp producers. SFL does not own any infrastructure, rather it delicately offers a packaged transport service by collectively organizing the flow and combining the resources of infrastructure owners, wagon rentals, terminal operators, etc.

4.1.1 Data Collection

During the FutureRail project, the data collections were done between Feb 2015 and May 2017. Various data collection methods were used; 13 face-to-face un/semi-structured interviews, with various interviewees at the SFL (and then by snowballing), paper producer companies, terminals, logistic

[4] This case and its model were presented in the 18th European Academy of Management Conference in Reykjavik, Iceland.

operators (Table 1)- each lasting 140 minutes on average. The respondents held various positions within the companies. Interviews as well as many field observations of production and distribution sites were conducted in Sweden, Germany, France, Italy and Netherlands. Moreover, various secondary data were collected including the presentations and reports of the companies, their annual reports and press releases. (Prenkert, Hasche & Linton, 2019)

The project had different points of foci. The data collected on the northbound flows of SFL were relevant to this thesis. During the project, three respondent-verified reports were prepared which are the main source of the information presented here.

Table 1. Interviews –Reprinted from Prenkert et al. (2019)

Date	Respondent(s)	Duration
02/18/2015	SFL, Production manager, Marketing manager, and Logistics developer	2,5 h
04/09/2015	SFL and Örebro Regional City Council, Logistics developers	2 h
04/13/2015	SFL, Production manager, Marketing manager, and Logistics developer	5 h
05/22/2015	SFL, Production manager, Marketing manager, and Logistics developer	2 h
06/10/2015	BillerudKorsnäs, Production manager and Logistics manager	2 h
06/22/2015	Innocenti, General Manager, Logistics Manager	2 h
06/23/2015	DSV Saima, Site Manager	2 h
09/24/2015	SFL, Production manager and Marketing manager	2 h
10/28/2015	SFL, Production manager, Marketing manager, and Logistics Analyst	2 h
11/06/2015	SFL, Production manager, Marketing manager, and Logistics Analyst	2 h
11/30/2015	Innocenti, Logistics manager and Site manager	1,5 h
12/01/2015	DSV Saima, General Manager	1 h
12/01/2015	SFL, Key Account Manager	4 h

4.1.2 SFL's Northbound Flow

As mentioned above, SFL collectively organizes of infrastructure owners, wagon rentals, terminal operators and route operators, to offer its railway service called Rail11/17 which involves high levels of cooperation and organization among all these independent actors. As this railway system operates based on a closed loop wagon pool, after delivering the freight cargos from paper mills to the terminals in Europe, the same wagons are available to carry goods of different European suppliers to Swedish retailers- without wagons being removed or added to the system. Hence, the southbound flow and in other words the production rate of the paper and pulp producers, define the northbound flow of wagons.

On the southbound flow, the wagons go through multiple terminals along the way, in which the train-sets might be re-arranged or stored for a while before continuing. Among the terminals who offer such transshipment services to SFL, some are proactively involved in finding customers for the northbound flow of the SFL and filling their wagons.

The customers of the SFL northbound flow are mainly domestic or international freight forwarders with end customers (e.g. grocery chains, wine importers, beer importers, tile importers, etc.) in the Nordic countries. An example is the largest grocery store chain in Sweden – ICA – which have many suppliers located in Italy and its shipments from Italy are transported with the SFL's northbound flow. ICA deals with EssingeRail and Innocenti, terminal operators in Sweden and Italy respectively, for transport of its products and these terminal operators are the customers and users of SFL's railway service.

Therefore, various actors are operating in the business network of SFL in order for the wagons and shipments to be transported southbound and northbound. The network involves various actor bonds interacting in the network. Figure 7 shows a schematic representation of this network of actors, each having a position in this network with their own specific roles.

The northbound flow of SFL needed to be managed to make the whole loop more efficient and sustainable. I.e. the more SFL could match northbound cargos and fill its wagons the more efficient and cheaper would be the southbound transportation and generally their whole system. The matching process was being done manually at the time of FutureRail project. In total, SFL have about twenty partners/customers (often freight forwards in Sweden on Europe) that buy empty wagons in the return flow from continental Europe back to Sweden. For reasons of limiting workload and sticking to core operations, SFL only provide the railroad link from terminal to terminal, and they sell only complete wagons.

Two current general categories of the customer for the northbound flow of the SFL's wagons are discernible. One set of customers are occasionally the "sister companies" of the Swedish paper and pulp producers - under the same ownership in Germany or elsewhere in Continental Europe - who are the owners of SFL. These companies may need SFL's services in the northbound flow. SFL takes the role of a freight forwarder in particular cases when one of their owners is the purchaser of transport service. In these cases, the return flow is considered as internal to the SFL system. In such situations, these internal customers are treated like the Swedish owners of SFL- paper and pulp producers. These interactions are not considered as buyer-seller relationships of SFL in the common sense. SFL allocates capacity for them in their northbound trains before they offer their wagons capacity to others, namely the second category of the customers of the northbound flow.

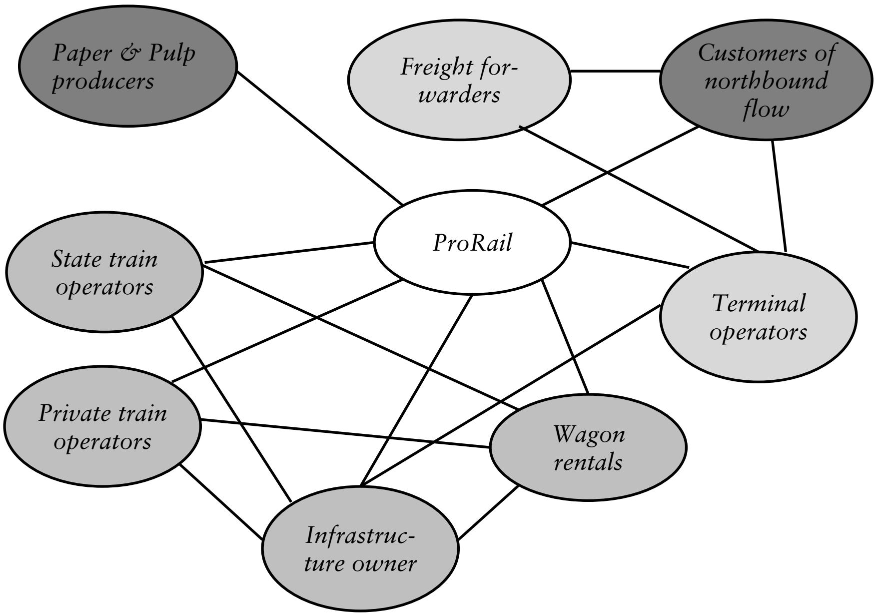

Figure 7. ProRail's network

This second category of customers are mainly freight forwards and terminal operators, which are proactively involved in finding customers for the northbound flow of the SFL and filling their wagons. The role of SFL vis-à-vis these actors is different from the role they have vis-à-vis the internal customers – sister companies of the SFL owners. These customer relationships with SFL are buyer-supplier relationships with the terminal operators or freight forwarders being the buyer of the empty wagon capacity of the transport service provider, SFL. These set of customers are called "contract customers" later on in the thesis, when referring to them within the agent-based model.

Filling the empty northbound wagons is often challenging and complicated, sometimes because of the high costs of railway transshipment in some terminals in Europe. This generally makes the railway transport not a cost-efficient alternative for short distances. The filling rate of SFL's northbound flow from Italy is relatively high but relatively low from Germany and the Netherlands. The filling rates from terminals in southern France and Spain are mixed. SFL contend that railroad transportation from that region has cost-wise potential to compete with trucks and boats, but the terminal operators that SFL works with, have so far not been successful in attracting goods to the railroad system.

The third category of customers, are then other terminal operators and freight forwarders who currently are not so active in attracting loads to the northbound flow of SFL. This set of customers would be different from those who are already working with SFL based on pre-defined contract terms (contract customers). In this study, they are called, "spot customers" as their demands for northbound railway service of SFL are only occasional.

4.1.3 Efficiency Concerns and Enhancing SFL's Network Position

Over the duration of the Future Rail project, about 50% of this return flow capacity was being utilized. SFL was trying to make a more efficient use of the empty space of their wagons. For this purpose, based on their perception and sense making of their surrounding network and discussions with researchers of FutureRail project, they were planning to introduce different solutions to the system. Moreover, it was realized that in mobilization of the northbound flows, SFL was not holding a privileged power position and most of the deals were called by the big retailers such as ICA and the proactive terminal operators and freight forwarders who were actually combining smaller loads of different customers into SFL wagons. These solutions that aim for filling the empty capacity of the SFL's northbound flow, would actually encourage a shift of loads from road transport system to railway system as a more sustainable alternative.

Transport section contributes to a quarter of Europe's Greenhouse Gas (GHG-) emissions and hence the reason for establishment of policies and regulations in the European Commission towards shift to low emission mobility. One of the objectives has been to enhance the quality, reliability, market share and the volume of the rail transport by shifting from road to rail/road freight and consequently reducing the GHG-emissions as one of the major component of transportation's environmental impacts (European Commission, 2016). SFL's solutions and initiatives for filling up their northbound wagons, can contribute to these purposes while also making their operations more efficient.

The specific solution that SFL were planning was an online matching system, in the form of an auction. SFL would offer its excess northbound capacity to potential customers (terminal operators or freight forwarders) on this online auction platform. With this online auction system, SFL were aiming to attract more of the spot customers (introduced above).

Many issues needed to be considered before putting the system to work. Many arrangements needed to be considered with actors involved in Rail11/17 since the new matching system would have implications specifically on the loads to be handled by various actors such as terminal operators across the railway system. Clearly many operational issues needed to be considered too, including the economic efficiency of the system, clear estimates of delivery times, operation factors of the auctions such when to open and close them, etc. The auction system needed to be tested carefully with various scenarios during mock-ups before being put into use. According to the case reports, some of these concerns were discussed and few tests and preparations of the auction platform were being conducted by the time the project ended.

4.1.4 Structural Changes & Cannibalizing Effect

During the meetings of FutureRail project researchers with SFL, another major concern was brought up which is the empirical context of the current research. Assuming that all the operational concerns mentioned above are addressed and the cooperation with related network actors are in place, the introduction of the online auction system, means attracting new customer relationships to the SFL network which can affect the already established relationships with *contract customers*. The question is, what would happen if spot customers could rent very cheap wagons through the auction system and over time, contract customers are stimulated to end their contracts and start working with SFL, through auctions and based on arm-length relationships. This is an unfavorable outcome of the auction system that SFL wanted to avoid since its current contract customers are of value to them and SFL needs to avoid such a cannibalizing effect of the new relationships. Therefore, cannibalization effect here means, the new customer relationships leading to the termination of the current contract customer relationships.

Spot customer relationships are of an arm-length nature rather than long-term ones, based on contracts. Their demand for transport may be occasional, with varying volumes and prices while the availability of the wagons for them (the supply) may also vary each time. Hence, the relationship is rather transaction-based with probably discrete exchanges, based merely on cost-profit analysis of the customer in choosing whether to rent wagons from SFL or not. A motivation of these customers to use the capacity of SFL wagons can be the increasing pressures of regulations as well as end customer's environmental awareness for lowering the GHG-emissions of the transportation sector. Shifting their loads from road to railway (at least for long distances) and designing multimodal transport systems can highly contribute to the reduction of the transport emissions of various actors within supply networks and in this case the activities of the terminal operators and freight forwarders.

In terms of INA, on the SFL's side, the introduction of this online auction solution, can be viewed as an strategic initiative and as a form of deliberate strategizing (Harrison, Holmen & Pedersen, 2010) and more specifically a positioning strategizing where the actions of the firm aim at broadening/changing its position within the network (Harrison & Prenkert, 2009). From a broader perspective, a change process might be initiated with various impacts on various aspects and levels of SFL's network, which may influence how the process unfolds over time. More importantly, although deliberately initiated, but SFL's embeddedness within the context of a network, makes this strategizing an interactive, evolutionary and responsive process involving both deliberate and emergent elements (Baraldi et al., 2007). The customers' responses and reactions to this initiative will have an impact on the implications of the introduction of this (experimental) online auction system and all these responses and interactions contribute to the emergent and rather unpredictable aspect of this strategizing (change) process. Changes in the structure of the SFL's network is clearly comprehensible specifically with new customer relationships being added to the network. However, certain emerging other structural changes, specifically the termination of contract customer relationships are network structural changes that need to be avoided. Accordingly, it was decided to focus on this specific structural changes of the SFL-case in this thesis, as it seemed to be a suitable context for addressing the research questions of this thesis.

4.2 The Research Design

As was elaborated in the previous chapter on methodology, this thesis aims at investigating certain theoretical properties of the business networks dynamics. In the SFL-case, it involves the introduction of online auction system by the focal firm and the customers' consequent actions and reactions towards using such a system. This involves focusing on the implications of this strategic initiative of SFL-as an endogenous change trigger- and customers' adoption of such a service –as responses to that trigger-, for the network structure. The purpose is to gain insights of some of the mechanisms at work and systematically exploring how the system outcomes in terms of network structural changes defined as creation or termination of customer relationships may vary under different assumptions.

The specific research questions of this case are:

1. What are the possible implications of SFL's new solution for the structure of its business networks?
2. What moderating factors may influence this process of change and its outcomes?

The general steps followed to achieve the purpose of this study and answering the research questions are presented in the previous chapter on methodological considerations That general framework is the basis for the way the following sections are structured to illustrate the research process for the specific case of SFL. The specific research questions were formulated during the explorative phase of the thesis (please see section 3.3.1 in the methodology chapter) through an iterative process of immersing into the literature and considerations of the empirical background of the case presented in the previous section. Meanwhile, in the modeling phase, the corresponding causal model of the case is designed and presented in the next section. The causal model, which is an abstract representation of the purpose of this thesis' inquiry and research questions of this case, is a key element and the basis for building the corresponding ABM of the SFL-case.

4.2.1 Model Definition

4.2.1.1 The Causal Model

In this section, based on the case descriptions which were framed within the INA, I build on the Complexity perspective of the SFL's network to reach the causal model that I further use as the basis of the SFL-ABM. The purpose is to illustrate the iterative processes of going back and forth between the empirical settings and the theoretical underpinnings of the case, to reach to the causal model of the study.

The structural changes explicated in the previous sections in the network are comprehensible as the emergent outcomes of the change process initiated by an endogenous trigger (the online auction system) in the SFL's business network as a Complex Adaptive System (CAS). This network comprises of the SFL itself and its current contracted customers and potential (spot)customer. For the specific case of this study, this delimited network of actors and more specifically, the focal firm and the customers (the agents), as well as the interactions between the customers and between the customers and the SFL are the Complex system of interest embedded within the network context (the environment). Although the process is deliberately initiated by SFL -through the introduction of the online auction system- reactions and responses of these interconnected relationships, over time and in a self-organized manner, give rise to an emergent macro-level outcome of the system. This outcome of interest is the structural changes that emerge, i.e. the transformed network connectedness. This transformation is the emergent macro-level outcome that is generated from bottom-up from the interactions, responses and interdependencies that exist between the autonomous and heterogeneous entities (SFL and the customers) of this CAS.

These interactions and feedbacks give rise to the network dynamics in a non-linear way. I.e. by simply adding up the individual customer's responses and reactions, one cannot explain the emergent outcome. As March (1996) puts it; "An organization reacts to the actions of others that are reacting to it. Much of what happens is attributable to those interactions and thus is not easily explicable as the consequence of autonomous action" (P. 283) .The customers in this system are simultaneously interacting with one another and with the whole network (as their environment). Their actions and reactions –in terms decisions on adoption of the auction system- are dependent on the environment (the overall pattern behavior of all the agents that emerge as the interactions progress over time) while also shaping the environment for others' actions and reaction, simultaneously. Certain spot customers' use of the auction system may influence how other spot customers and also contract customers decide to work with SFL.

The causal model adopted for SFL-case is depicted in Figure 8 which is an adaptation of the general causal model of the thesis explained in previous chapter (Section 3.3.2.1, chapter 3). This model, its relationships and particularly the moderating factors are what I explore with my simulation experimentations.

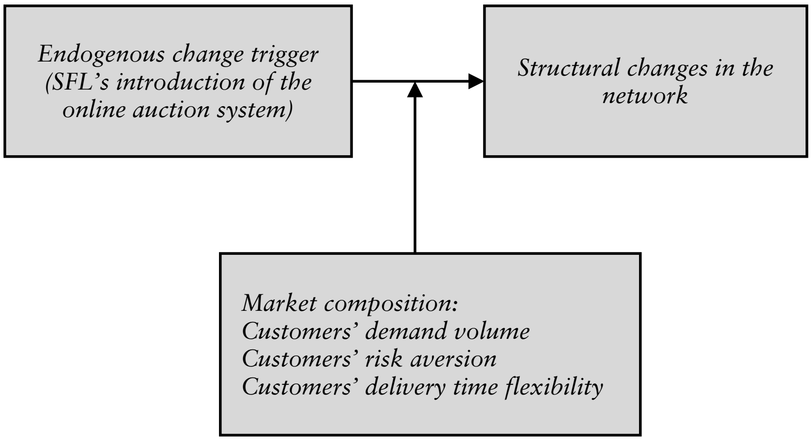

Figure 8. SFL-case causal model of structural changes

The change trigger- the independent variable of the causal model- in this case is SFL's deliberate strategizing in the form of introduction of the online auction system to its network of customers. Considering the boundaries delineated for this case, this change trigger is consequently considered endogenous to the network under study. This auction system initiates a change process in the SFL's network when the customers (both current and potential ones) start reacting to this system and its implications in the network, in terms of deciding how/whether to work with SFL. These reactions and further emergent interactions in the periods following the introduction of the online auction systems, may eventually lead to changes in the structure of the SFL's network. Hence structural changes in the SFL's network, defined as major transformations in the patterns of actors' connectedness which are observed in the new customer relationships being created and old ones being terminated, is the dependent variable of the causal model. To measure and interpret these changes in the network connectedness, I measure the number of customer links being created and terminated in each of my experiments. Moreover, to address the possible cannibalization effect of these structural changes, I measure the share of contracted and spot customers of the SFL, as lower shares of contracts represent situations where SFL has lost its contract customer relationships.

Three rather extreme conceivable outcomes are as follows (Shahin Moghadam, Prenkert & Klügl, 2018). These categories are important to SFL. Although they all generally involve certain relationships being formed or terminated but the types of relationships involved in each case have significant implications for how SFL will have to reorganize its activities in the network. Hence, I distinguish between different structural changes that may emerge:

1. The customers' interactions might generate a situation where the current contract customers are provoked to leave their contracts and join the auction market to buy cheaper wagons. Hence, over-time, this strategic initiative of SFL (the online auction system) may lead to loss of its contracts and it may end up providing transport services to mostly spot market customers and only a few or no contract customers. This major transformation in the SFL's network structure lead to relationships that are mainly arm's-length rather than long-term and hence their content is modified. In other words, there may be arm's-length relationships being created and contract relationships terminated. This is the specific structural change that SFL wants to avoid so that it will not lose its contracted customer relationships.
2. The customers' interactions and consequently the emergent results from the auction might have another set of effects. First, the contract customers may continue being satisfied with their relationships with SFL (as they are), while spot customers may also want to negotiate long-term contracts to access more reliable transport. Then major transformations in the structure of the SFL's network may happen as SFL forms new long-term relationships, i.e. new contract customer relationships.
3. Another situation happens when the customers' interactions and consequently the emergent results from the auction, progress as SFL had planned in advance. SFL continues having contract customers as before, while the excess wagon capacity is organized through the auction by forming new spot customer relationships.

> The structure of the network is changed in this case but not as radical as the above two possible situations.

Still, the connection between the endogenous change trigger of this case and the consequent transformations of the network structure is not a straightforward one because of the highly interdependent relationships in business networks and will be moderated by different "moderator" factors. It is the outcomes of actors' interactions in the online auction that lead to reorganization of the network. I propose that the customers' demand volume, their willingness to take risks and flexibility in delivery time of shipments (represented as "time flexibility") – collectively called "*market composition*"- are three moderating factors that may influence the transformation of the SFL's network structure. These factors are relevant because they are the basis of the customers' responses to the SFL's initiative, the way the spot customers interact in the auction system (according to common general assumption of traditional economics) as well as customers' decision on the mode of exchange with the SFL. The moderating effect of these three aspects and their overall implication –as the market composition- are explored through ABM and simulation in various experimentations.

4.2.1.2 SFL-ABM Definition

The process of the agent-based modelling of this case starts by defining its main building blocks, agents and the environment.

Agents

The definition of agents, their specific attributes and their behavioral rules of interaction are defined based on the specifications of the data available from the description of the cases as well as the theoretical ideas of INA in general. These also include a set of rules on how the agent can affect the environment and vice versa (Gilbert, 2008). It is important to note that, these definitions involve high levels of abstraction, but enough details are incorporated to capture the theoretical phenomena of interest and gaining fruitful insights - guided by the causal model.

The agents (the autonomous and heterogeneous entities) of the SFL-case are the customers (contract customers and spot customers) and the SFL itself. These business actors are autonomous, may have different characteristics and are interacting with each other either directly through the experimental online auction system of the SFL or indirectly through the influencing (and being influenced by) the overall condition of the market. Each agent type may have a different rule for making decision on how to interact with others within the market.

The three types of agents introduced above (the SFL, contract customers and spot customers) are the agents of this ABM. For practical reasons relevant to the model implementation and the specific modeling platform used (please see the model implementation section, which comes next), I decided to explicitly model two groups of agents, contract customer agents and spot customer agents. SFL itself is implicitly considered in the model through the *environment* the rather than being defined as an agent.

Customer agents have specific demand and delivery time preferences. One group of agents are the contract customers, whose demands and delivery times mentioned in their contracts with SFL, need to be honored. Another share of potential customer agents are spot customers, which have no contract and varying demand volume. These spot customers are the potential users of the simulated auction. A set of variables and parameters are defined in Table 2 for presenting the features of the agents, which are the main features of the agents.

According to INA, the spot customers' interactions in the auction system and the prices they get, may influence the SFL's relationship with its original contract customers because of their embeddedness in an inherently interdependent business network (Håkansson et al., 2009; Håkansson & Snehota, 1995). Depending on the auctions' wining prices and the features of the contract customers, these set of customers may decide to terminate their contracts with SFL to buy cheaper wagons in the auction system (although with higher delivery uncertainties). Spot customers, on the other hand, may end-up having positive experience with SFL's services through the auction and decide to establish contracts with the firm and develop more stability in their actions and interactions. These emergent shifts between the two modes of exchange with customers, may lead various changes in the structure of the network.

Table 2. Customer agents' parameters and variables

	Parameters	Definition
Parameters	Demand class (D)	Three classes of demand exist that represent a range of demand values per week for the customer i: Low, medium and high demand levels
	Contract price ($P_{Contract}$)	The price of a wagon for a week for the customer i if it is a contract customer.
	Desired arrival time	Each customer has a desired arrival time for its weekly shipments on a specific day of the week
	Time Flexibility class (T_F)	Defines how much delay customer i can tolerate in receiving its weekly shipment. The higher the T_F, the more delay is tolerated.
	Risk aversion (R)	Represents the customer i's willingness in taking risks. The higher is the R, the lower is the customer's willingness to take risks
	Cost of road contract per wagon (P_{road})	The cost of sending a shipment volume equivalent to one wagon, on the road for customer i
	Penalty cost of late arrivals per day	The penalty cost incurred by customer i for one day of delay in sending its shipment
	Positive experience threshold	A spot customer perceives its transaction experience with the SFL positive when its winning bid amount is less than this Positive experience threshold
	Evaluation threshold	The number of weeks after which the agents start evaluating their relationships with SFL and consequently may want to shift from contract to the spot market or vice versa. The value differs for different customer depending on their demand volume and R. E.g. a contract customer with low demand volume and low R waits less than a contract customer with high demand volume and high R, for deciding on the termination of its contract with SFL
	Contract customers' tolerance (T_C)	A contract customer considers the termination of its contract with SFL if it observes that during the Evaluations threshold weeks in the past, in T_C % of the auction rounds, the average winning bid were lower than the price it paid for its contracted transportation.
Variables	Costs	The total costs incurred by customer i in a week (transportation cost + penalty cost of the week)
	Type	represents the type of the customer agent: contract customer or spot customer
	Bid amount (P_{Bid})	The amount of bid per wagon that spot customer i decides for its required wagons in each auction run
	Demand	The exact number of wagons that customer i needs for one week. It is constant for contract customers but may change weekly for a spot customer within its range of demand class

Environment

Environment implicitly captures the SFL's activities as the auctioneer. The features of the environment were designed based on both the case specifications and the theoretical backgrounds (while trying to balance the simplicity and descriptiveness of the model). For the case of SFL, the features of the environment in which the agents are embedded include the general features of the market (Table 3) as well as the specifications of the weekly auctions (Table 4).

Table 3. Parameters of the market

Parameters	Definition
Number of auctions per week	The number of auctions that are held by SFL each week. Each auction corresponds to one train departure in the following week.
Number of contract customers ($N_{contract}$)	The number of customers with whom SFL has contracts for weekly deliveries with specific amount and specific delivery time (train departure)
Number of spot customers (N_{spot})	The number of spot customers in the market. They are potential customers. They may manage to buy wagons from SFL in a week which leads to a transaction with SFL.
Number of wagons of each train departure	Total number of wagons in a train departure (on a day)
Number of wagons available in auction for each train departure	Total number of available wagons in each train departure after assigning the wagons of the contract customers. This number of wagons are initially available when an auction starts.

Table 4. Parameters of weekly auction

Parameters	Definition
Minimum bid amount (P_{min})	The minimum amount of bid possible for the auction
Buy-now price (P_{buynow})	If a spot customer wants to avoid the auction, it can offer the buy-now price for a wagon before the auction is closed and as long as free wagons are available.
Delivery date	The day of the week on which the train departure corresponding to this auction arrives at the destination (the shipments delivery date)

The Overall processes of the Model

Clarifying the ideas of the agents and the environment of this case, the model itself is next designed to represent how all the agents are connected to each other, how they interact with each other and with the environment and all the mechanisms involved in the emergence of macro-level outcomes from these micro-level specifications. This step of the process was initiated by drawing flowcharts of the agents' activities and the operation of the market in each period, as well as how the interactions of the agents and their outcomes can be related to the operating mechanisms of the market.

The important part of the modelling process is the consideration of the causal model as the starting point. The model has to be designed in a way to be able to capture the elements of the causal model; the change process, the market compositions aspects and more importantly, the outcomes have to be interpretable in terms of the changes in the structure of the SFL's network.

Moreover, each variable of the causal model needs to be operationalized so that it can be interpreted/measured in the ABM. The interpretations and definitions of the model variables as well as the interactions and the agents' features must be grounded in the literature, the empirical setting of the case or the expert opinions. E.g. network structural changes defined as "[…] variation over time in the underlying pattern of relationships that bind a given set of actors." (Madhavan et al. 1998, P441) are interpreted from the ABM results when contract customer relationships are terminated or new spot customer relationships are formed, hence a restructuring or reorganization of actor links within the network is implied (Abrahamsen & Håkansson, 2012; Andersson & Mölleryd, 1999; Guercini & Runfola, 2012; Halinen et al., 1999; Mattsson, 2003).

Again, the flowcharts of the model design were constantly revised and eventually restructured during the phase of model implementation into the SeSAm platform. Hence, iterative processes were followed in order to be able to implement the model into the platform and make it work. These sometimes led to addition or deletion of certain variables, parameters, agents' decisions and interaction rules, etc. in an iterative and explorative process.

SFL has four train departures each week (with one departure in a day). For each departure, first the contracted wagons are assigned to the contract customers (which pay the fixed price of $P_{Contract}$ according to their contract). The rest of the wagons of each departure is available to spot customers in their corresponding auction (there is one auction per departure). Spot customers, upon arrival to the auction have two decisions to make. First, they should decide which auction (departure) to enter (and bid) and second how much to bid in the auction. The decision is made based on the customer's willingness to take risks (of not winning enough wagons) (The parameter R, see Table 2) and their flexibility in the delivery time of their shipments (The parameter T_F, see Table 2). To avoid bidding and guaranteeing achieving the demanded number wagons, the spot customers has the option of paying the Buy-now price (P_{BuyNow}) before the auction is closed (as long as there are free wagons available). If any spot customer fails to get its demanded wagons, it needs to send its shipments on road for a particular price (P_{Road}). The following price hierarchy is assumed:

$P_{min} \leq P_{bid} \leq P_{BuyNow} < P_{Road}$

If the customer wins wagons in the auction on its offered P_{bid}, it will pay this price for the wagons which may be higher than the contracted price of wagons ($P_{contract}$). Spot customers' incentive for attending the auction market is to buy transportation services with prices lower than P_{road}, which is what they would pay for road transport per load equivalent to one wagon (Shahin Moghadam et al., 2018).

The above decisions refer to one week of business interactions. Each week starts by assigning the wagons of the contract customers for the corresponding train departures of the next week. Then the auctions open and the rest of the available wagons are put into auction and spot customers have the opportunity to bid for their demanded number of wagons (D). When a spot customer identifies at least one relevant auction (which match its delivery time preference), it decides whether to start bidding or just pay the buy-now-price. The agents are modelled in a way that only those agents which are not willing to take risks at all and are not flexible in delivery time of their shipments, immediately pay the P_{buynow} and get the wagons (if enough wagons are available). Others, hand in a sealed bid of the number of wagons they need with the price that they are willing to pay for them (P_{bid} per wagon). The agents calculate their bids based on the following formula:

$$P_{bid} = \left(R \times \frac{1}{N_{RelevantAuctions}} \times P_{buynow}\right) + P_{min}$$

Hereby, R is the *risk aversion* parameter and $N_{RelevantAuctions}$ is the number of possible auctions, which the customer can attend. The amount of bid is adapted only depending on the number of auctions left to attend and not on the previous experience of the agents in the auctions. When fewer auction opportunities are left to attend, the amount bid is higher.

When the auctions are closed, the bids are sorted and wagons are allocated to the highest bids until no more wagon is left (a combinatorial matching auction). Finally, the agents are notified about the results (the number of wagons that they won).

After a specific number of weeks of observing the different auctions (*Evaluations threshold* parameter), contracted customer agents based on their characteristics can leave their contracts and spot customers can establish contracts (if the capacity allows for it). It is assumed that contract customers based on their characteristics may decide to cancel their contracts if they observe that during the *Evaluations threshold* weeks in the past, in 80 % of the auction rounds, the average winning bid were lower than the price they paid for their contracted transportation. Cancelling contract results in joining the spot market. However, following the current research in the networked industry (Håkansson et al., 2009), the decision for changing business relations as manifested in contracts is not only depending on potentially volatile prices, but is influenced by many other factors. I have mapped this by defining different decision rules for each contract customer based on its characteristics. For example, the decision rules are defined in a way that contract customers with higher risk aversion and higher demand volumes hesitate longer before leaving their contracts and in a way, they are representatives of relationships with more strength. All assumptions are primarily derived from empirical case data collected during the FutureRail project.

Scholars studying the different methods of trade and exchange, have compared the use of auctions and traditional face-to-face negotiations (Kaufman & Carter, 2004; Radkevich et al., 2008; Yu et al., 2015). The face-to-face negotiations -although different from long-term business relationships- compared with the auctions, might be more similar to the long-term relationships in terms of being tightly coupled exchanges. In line with INA, Yu et al. (2015) argue that substantive measures such as price, revenue and profit are not the only criteria for selecting the exchange mode and more subjective measures are often considered as well.

Risk and the previous experience in the business exchange are the non-price attributes that may affect the customers' choice of exchange mode (staying in the auction vs. negotiating contracts), (Radkevich et al., 2008; Schlaegel, 2015; Yu et al., 2015; Zhong & Wu, 2006). Accordingly, in this thesis, it is assumed that the customer's risk aversion and emergent experiences with the firm affect its decision to negotiate long-term contracts with the focal firm. As was explained as one of the parameters of customers, the positive experience perception is defined as achieving an average wagon cost of less than *Positive experience threshold* in a week for a certain number of weeks. For example, the customer's experience in a week is positive if it manages to achieve an average wagon cost of 1800 per unit or less. Depending on the *risk aversion* parameter of the customer, if it had positive experience in a certain percentage of the previous weeks, it will negotiate contracts with SFL and if there are enough wagons available, the negotiations will end up in the customer becoming a contract customer. Figure 9 shows an overview of a customer agent's behavior. For the sake of simplicity and readability, this figure does not include the details on contract customer agents' decision on whether to join the auction or on spot customer agents' decision on whether to establish contracts. These decisions are summarized as the evaluation-step in the Figure 9 (Shahin Moghadam et al., 2018).

Considering the above assumptions, the effects of different characteristics of the spot market and the composition of customer agents on the number of newly formed customer links and terminated customer links and the contracts share of wagons after 52 weeks of interaction are studied in different simulation runs in each experiment.

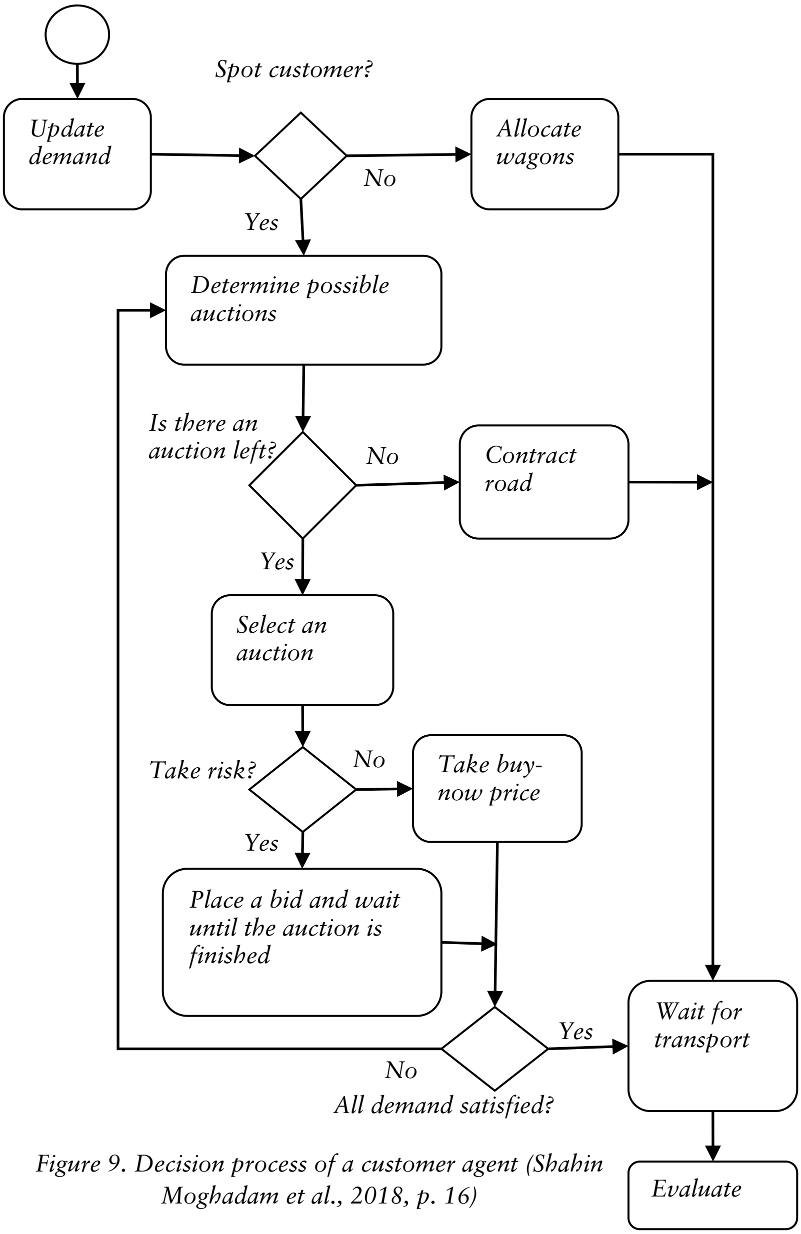

Figure 9. Decision process of a customer agent (Shahin Moghadam et al., 2018, p. 16)

4.2.2 Model Implementation

This step involved translating all the model specifications above into computerized models in a software platform of SeSAm to create the artificial business societies of agents. As was elaborated in the methodology chapter Agents, resources and world are the main entities of this platform. Agent types (spot customers and contract customers) are defined under the Agent entity in SeSAm. For each agent type their set of variables are defined. These variables include the ones defined in the model description section as well as technical variables and parameters added to the model so that the simulations work.

The two types of agents introduced above (contract customers and spot customers) are the agents of this ABM. When it comes to modeling these agent types and implementing the model in the software platform, their representation may vary depending on the platform as well as the modeler's choice. When implementing my agents into the SeSAm, I decided to model two groups of agents, contract customer agents and spot customer agents. Since SFL merely sets the online auction system and is not actively involved in further interactions with the customers, its features and decision do not change during the auction and in different periods. The SFL mainly sets the contextual condition for the interactions of the customers and does not get any influence during the auction from the customer agents. Hence, for practical reasons I decided to model two types of agents, contract customers and spot customers. SFL features and decisions are incorporated into the model as the contextual features of the auction market.

For each agent type and based on its corresponding flowchart, the reasoning of the agent is modelled. This is done as a behavior activity graph in SeSAm (Reasoning Engine). The model involves a set of activity boxes connected with conditional arrows guiding the steps which the agent must follow. Inside each activity box, a set of implementations are modelled representing what a single agent does in that activity box. Figure 10 is a screenshot of the modeling space of the customer agents of this ABM in the SeSAm platform.

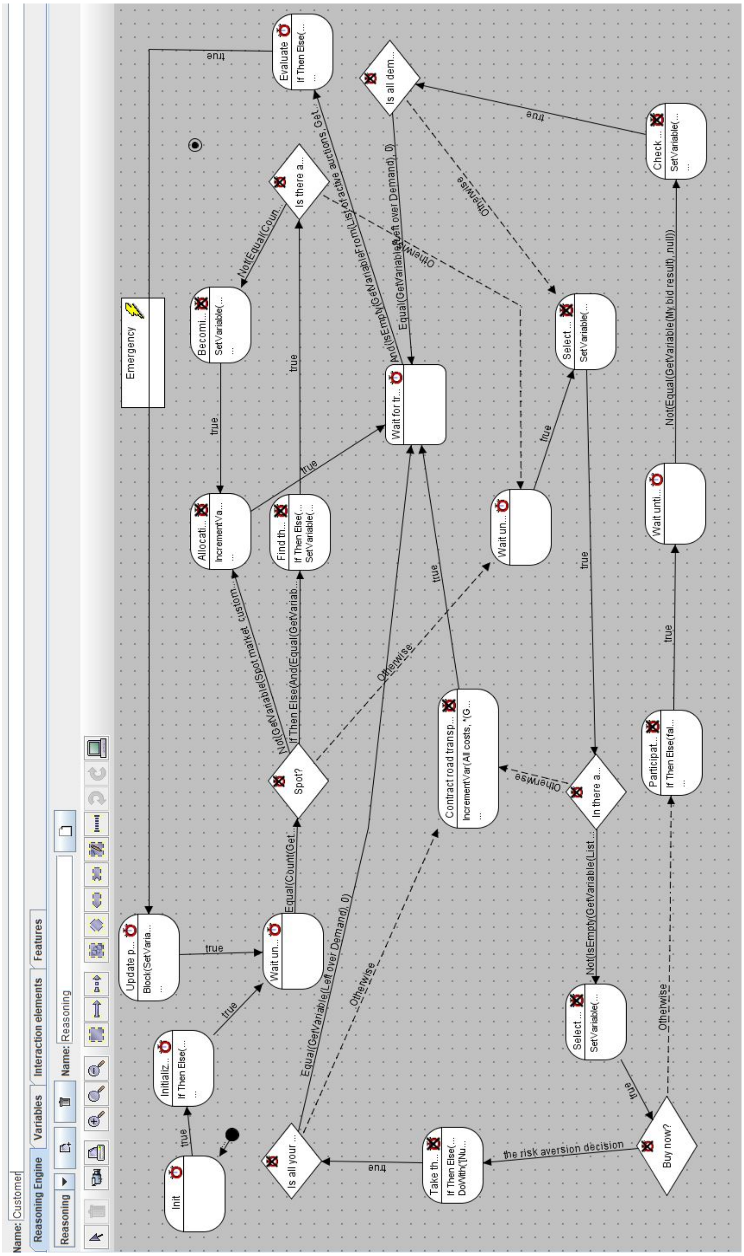

Figure 10. Customer agents' Reasoning Engine

The environment of the agents, i.e. the market context in which the agents interact, were modelled under the *World* entity in SeSAm. Again, the variables and parameters that are global to the model (rather than being agent-types' specific features) and represent the environment specifications are defined under *World* entity. Moreover, the general functioning of the market, which was initially depicted in flowcharts, are then implemented into the model in terms of activity boxes and arrows. Figure 11 is a screenshot of the modeling space of the operating mechanisms of the auctions of this ABM in the SeSAm platform. Each auction itself is modeled as a *Resource* object in SeSAm.

Further specifications of the model and more practical issue of the model implementation will not be explained in this document. However, the SeSAm model files will be available and are self-explanatory in terms of the practical model implementation in the platform.

The above implementation processes are accompanied by the long process of model verification to ensure that the model is operationally right and works in the right way as intended. Please refer to the chapter 3 on methodology for details of the verification processes followed in this thesis.

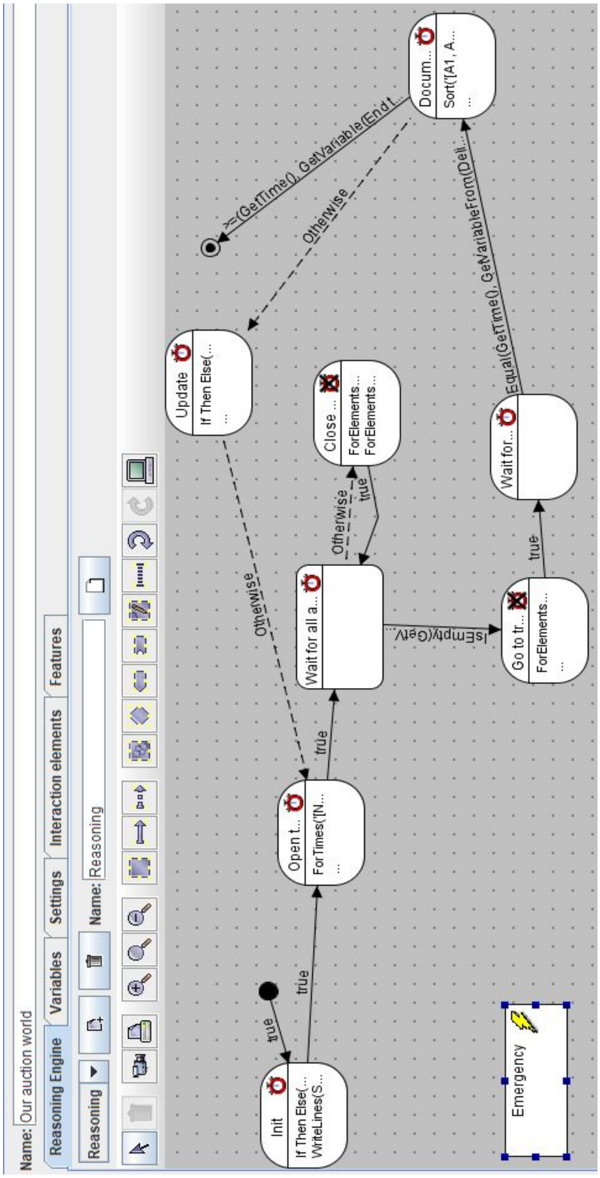

Figure 11. The auction market

4.2.3 Model Analysis

4.2.3.1 Sensitivity Analysis & Parameter Setting

Parameters. The environment features and the agents' features are fed into the model as parameters and variables of various types; they may be defined as numerical values, Boolean, lists of numbers, lists of strings, etc. In the following paragraphs the initial value of the parameters are presented. For these initial parameter values, most of them are chosen based on empirical setting and expert opinion. For the rest, the sensitivity analysis is applied.

Each simulation, runs over 52 weeks (equivalent to one year) with four auction rounds per week on different days of the week. Each auction corresponds to one train departure. Each train departure contains 19 wagons, so each week there are 76 wagons available for transportation. I assume that contract customer agents fill 50% of the wagons each week (38 wagons) at the beginning of the simulation run. The rest of the wagons are available to be bought by customer agents in the spot market attending the corresponding auction. The parameter values of the auction and the market are presented in Table 5.

Three levels of demand volume are defined for the customer agents. The demand volume determines how many wagons an individual customer agent needs to use per week (D). Demand levels 1, 2 and 3 respectively correspond to customers' required number of wagons between intervals [1,6], [7,12], [13,19]. The actual demand volume of spot customers is initially set to a random value within these intervals in a simulation run.

Table 5. Parameter values of the market and the auctions

Parameters	Values
Number of auctions per week	4
Number of contract customers ($N_{contract}$)	5
Number of spot customers (N_{spot})	25
Number of wagons of each train departure	19
Minimum bid amount (P_{min})	800
Buy-now price (P_{buynow})	1600

The contract customers' demand volumes are fixed in all scenarios and in each simulation run. A customer agent has an individual *risk aversion* parameter ∈ {0,0.25,0.5,0.75,1}. Hereby, the lower the number, the lower is the risk aversion, with R=0 meaning that the customer agent is not risk averse at all and R=1 meaning that the customer agent will try to avoid risk completely.

Table 6. Customer agents' parameter values

Parameters	values
Demand class (D)	$D \in \{1,2,3\}$
Contract price ($P_{contract}$)	1500
Desired arrival time	Can be one day of the week
Time Flexibility class (T_F)	$T_F \in \{1,2,3,4\}$
Risk aversion (R)	$R \in \{0,0.25,0.5,0.75,1\}$
Cost of road contract per wagon (P_{road})	1900
Penalty cost of late arrivals per day	100
Positive experience threshold	1800
Contract customers' tolerance %	80%
Evaluation threshold	Varies depending on D and R of the customer

Time Flexibility (T_F) of customer agents expresses how much the agent is able to cope with delays for goods arriving at the destination with respect to the preferred arrival time. Agent's T_F determines the number of auctions it can attend ($N_{RelevantAuctions}$). As the preferred arrival date for customer can be any of the arrival days corresponding the four auctions of the week, they will find different sets of the auctions of that week relevant according to their timing preferences ($N_{RelevantAuctions} \in \{1,2,3,4\}$). Customer agents with lower T_F have less auction options to attend. The T_F parameter has a qualitative value defined by a four-level system, in which the lowest value (1) represents a highly inflexible customer that cannot accept any discrepancy between preferred arrival time and the train's actual arrival time. That means that if the agent fails to acquire the wagons for a specific day, it has to use road carriers for shipping its cargo. The highest value of T_F

(4) represents a customer agent that can absorb 3 days of delay for the delivery of its shipment and hence is very flexible. Thus, the agent may enter auctions for all trains of the week, as all are relevant ($N_{RelevantAuctions}$ = 4). Nevertheless, the customer agent has to incur a penalty cost of 100 units for each day of delay. The values of T_F and R are initialized according to the respective experiment setup and not changed during a simulation run. The values of the rest of the parameters are provided in Table 6.

In order to reduce complexity and produce results that could be made sense of, I restrict the experiments to transportation between one origin and one destination only – yet varying customer characteristics. This of course is a simplification, but a necessary one to make the experimental scenarios intelligible.

Sensitivity analysis. As explained in the methodology chapter, sensitivity analysis involves the systematic changing of parameters over a range of values and checking the robustness of the outcomes. Because of the high computational demand of performing a complete sensitivity analysis, as suggested by North & Macal (2007), I limit this possible range to certain variables and parameters of interest with limited number of test values, trying to mostly test for extreme values of the parameters. This sensitivity analysis contributes to verification, validation and to the parameter setting of the model. By testing the extreme values of the selected parameters, I can identify the bugs of the implemented ABM and any aberrant and inexplicable behavior of the model, hence verifying it. The robust behavior of the model in different values of the selected parameters also adds to the validity of the model. For the base line parameter values, most of them are chosen based on empirical setting and expert opinion. For the rest, the sensitivity analysis helps for a deeper understanding of the dynamics of the system and choosing the values for which the dynamics relevant to this research outcome of interest (structural changes) could be observed. Moreover, in this case, most of the selected parameters of interest are also the moderating factors of the causal model. Hence, the sensitivity analysis incorporates parts of the experimentations (based on the causal model) that are needed to answer the research questions of the study as well.

The selected parameters are tested in different scenarios with different parameter setting. The rest of the parameters hold the same values as presented above. A table similar to Table 7 is used to structure the sensitivity analysis of the selected parameters. The table merely presents a sample of the settings, which were tested for the SFL-ABM of the thesis. For example, in a scenario called "T007" the parameter settings for the selected parameters are as follow:

- N_{spot}=15
- Demand volume of spot customers is randomly generated from the demand levels of 1 or 2 and then kept unchanged for the rest of the simulation
- *R* of contract customers are randomly generated unchanged for the rest of the simulation
- *R* of all spot customers are equal to 1
- T_F of the spot customers are randomly generated and kept unchanged for the rest of the simulation
- *D* of the spot customers are randomly generated in each period
- P_{buynow} =1600

Table 7. The guide to sensitivity analysis

Scenarios	Spot customers				Contract customers		Auction
	N_{spot}	R	TS	D	R	D	P_{buynow}
T001	15	random	random	random	random	random	1600
T003		All 0.75					
T004		All 0					
T005		All 0.25					
T006		All 0.5					
T007		All 1					
T008		random	all 1				
T009			all 2				
T010			all 3				
T011			all 4				
T020				all 2			
T021				All 1			
T022				all 3			
T [...]	5	random					
T [...]	20						
T [...]	10						
T [...]	15					All 1	
T [...]	10						1500
T [...]	10						1700

The sensitivity analyses performed according to the table above showed some dependencies among the parameters and the outcomes of the simulations, specifically in terms of changes in the structure of the network.

Some of these dependencies are described and analysed in the following sections.

4.2.3.2 Experiments

According to the causal model of this case, the experimentations and corresponding scenarios must be focused on understanding the influence of market composition on the structural changes in the SFL's network. To accomplish such a purpose, I perform two sets of experimentations. One is exploring the influence of isolated parameters referring to each of the three dimensions of market composition; spot customers' demand level, their risk aversion and time flexibility. Parts of the sensitivity analysis contribute to this set of experiments. Based on the results of this sets of experimentations, another set focuses on their combined effect (as the market composition) on network structural change process.

Considering the parameter values in the parameter setting section above, I design different experiments by varying the value of the parameter of interest (each of the three dimensions of the market composition) while keeping the rest of the parameter values unchanged. Each simulation run corresponds to 52 weeks of interactions among agents. To account for the randomness in the results, each experimentation with a scenario is repeated for 100 times.

Three main steps are followed in each of the subsections below to illustrate and discuss the results.

First, considering the definition of structural changes in this thesis, the number customer relationships being created or terminated are a measure to makes sense of the amount of restructuring happening in the network in terms of the actors' patterns of connectedness. In the SFL-case, those contract customers relationships that initially existed but after the introduction of the auction system, the customers decide to change their mode of exchange with SFL and join the spot market, are the customer relationships that are terminated. The number of these types of relationships being terminated is recorded in the experimentations as the "number of customer shifts to auction".

Moreover, as was explained before, some spot customers who have exchanges with SFL mainly through the auction system, depending on the changes that eventually emerge in the context of their interaction over the periods following the introduction of this online auction, may decide to have more long-term relationships with SFL and become a contract customer. This situation is about the formation of new business relationships for the SFL and hence is signaling structural changes that may emerge in the network. The number of these types of relationships being created is recorded in the experimentations as the “number of new contracts”.

In each simulation run, the two values of the “number of customer shifts to the auction” and the “number of new contracts” are recorded. The results of the 100 repetitions of each experimental setting are presented in box plots. The number of customer relationships being created and terminated are shown in the same plot but with different colors to help with a better comparison of the two.

Second, the sum of the number of created and terminated customer relationships under each experimental setting are illustrated as “Total number of modified links” in a separate plot to show the general extent of the structural changes that emerge in the network in each experimental setting.

Third, for better understanding of the structural changes that emerge under each experimental setting and more insightful comparisons, I also record the contracts’ share of wagons that SFL has after 52 weeks of introducing the auction system under each experimental setting. The contracts’ share of wagons is the percentage of the SFL’s wagons’ capacity that are filled through contracted customer relationships. This specific outcome is important to be compared alongside the corresponding emergent structural changes, since it addresses the cannibalization concern of SFL in terms undesirability of losing its contracted customer relationships. The recorded values of the contracts’ share of wagons for each run (52 weeks of auctions system operating) repeated for 100 times are then presented in box plots.

Finally, the differences between the experimental settings are examined through statistical tests. The output data of the experiments do not follow Normal distribution, hence a non-parametric statistical test -Kruskal Wallis with 0.05 significance level- is used for evaluating the results. The statistical analyses are conducted in SPSS.

Experiments with Isolated Parameters

The effect of spot customers’ demand volume

In a first set of experiments, I explore the effect of spot customers’ demand volumes on the emergent structural changes. Three different extreme case experiments are tested, where all the spot customers have respectively low (level 1), medium (level 2) and high (level 3) demand volumes. The demand volume of the customers seems to have an effect on the number of customer links of each type being created or terminated as well as on the contract customers' share of the firm's total customer-base.

Figure 12, shows the box plots of the results of 100 simulation runs of 52 weeks of the auction system's functioning, in terms of variables: the "number of shifts to the auction" (relationships terminated) and "number of new contracts" (relationships created), under three different extreme case experiments. In these experiments all the spot customers have respectively low (level 1), medium (level 2) and high (level 3) demand volumes. The two (dependent)variables of interest are shown in the same plot but with different colors to help with a better comparison of the two. A Kruskal Wallis statistical test, with 0.05 significance level confirmed the significant differences in the distribution of the results between the three demand settings.

As can be seen in the plots, in networks with spot customers who have higher demand volumes (moving to the right in the plots), less customer relationships are terminated or created. In settings where spot customers have higher demand volumes, there are less tendencies for these customers to have contracted exchange with SFL. Moreover, less contracted customers are provoked to terminate their contracts and start arm-length exchanges with SFL through the online auction system (Figure 12).

These observations can be explained by two main processes. First, when spot customer agents bid for a higher number of wagons (when they have high demand levels), it is less probable that they receive all of the demanded wagons (the free train space is filled with fewer number of customers but with larger demand and the rest will not win anything). As long as they have unfulfilled demand for wagons, they continue bidding in the upcoming auctions of the week (if the auctions match their delivery time preferences) but with higher prices as their opportunities for finding relevant auctions reduce as time goes by. Hence, higher demands and auction prices lead to a less positive experience of the auction for the spot customer. Consequently, less (or no) new contracts are established. On the contract customers' side, higher auction prices stimulate fewer shifts from contracts to the spot market. Second, when the demand volume of customers are higher, among those few spot customers who might manage to fulfill their demands on the auction (and gain positive experiences) and might be willing to establish new contracts with the focal firm, fewer number would get the chance to have contracts with the firm. That is because it would be harder to match a high demand with the limited capacity of each of the trains, i.e. their negotiation to form contracts with the focal firm would not succeed, as the SFL might not be able to offer them enough capacity in one train departure.

Figure 12. The effect of spot customers' demand level on the number of new contracts and the number of terminated contracts

The general extent of the structural changes that emerge in the network in each experimental setting is illustrated in a separate box plot in Figure 13. The plot shows the sum of the number of created and terminated customer relationships under each spot-customers' demand setting. A Kruskal Wallis statistical test, with 0.05 significance level confirmed the significant differences in the distribution of the results between the three demand settings. As the results show and in accordance with the plots above, structural changes of the network are more sever when the demand volumes of spot customers are lower.

To further illustrate the implications of such structural changes in terms of cannibalization effect that concerns SFL, the contracts' share of wagons in each setting are presented in Figure 14. In setting where spot customers have lower demand volumes, contracts' share of wagons increase, as many spot customers would like to have contracted relationships with SFL. The higher structural changes in theses settings as discussed above can explain this level of contracts' share of the wagons. Although there may also be some contracted customers which are terminated, still, the shifts from auction setting to contracts is high enough to increase the share of contracted wagons. The Kruskal Wallis statistical test, with 0.05 significance level confirmed that the different distributions of the contract share of wagons in different demand settings. The difference is more significant between the settings with high demand volumes (level 3) and settings with lower demand volumes (level 1 and level 2).

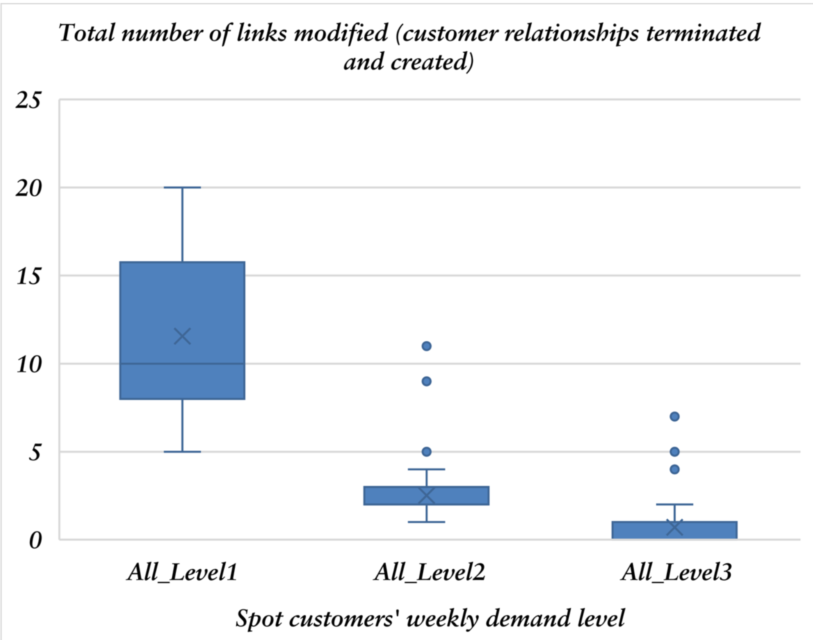

Figure 13. The effect of spot customers' demand level on the total number of customer relationships modified

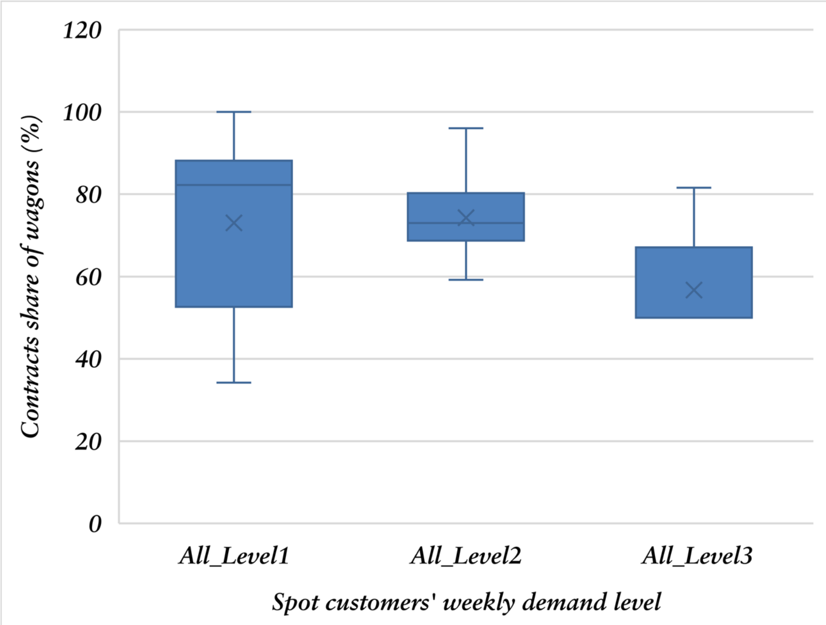

Figure 14. The effect of spot customers' demand level on contracts' share of wagons (Shahin Moghadam et al., 2018)

The effect of spot customers' risk aversion

For better clarification and comparison, five extreme cases are considered to test the effect of spot customers' *risk aversion* (*R*) where all spot customers have the risk aversion parameter equal to 0, 0.25, 0.5, 0.75 and 1 respectively. Considering the bidding function of spot customers, it is expected that the existence of customers who are highly risk averse, would lead to higher auction prices and hence less chance of contracts being terminated.

The non-parametric statistical test of Kruskal Wallis, with 0.05 significance level was conducted and showed the differences between experimental settings with different levels of *risk aversion*. The results of 100 simulation runs (repetitions) of 52 weeks of the auction system's functioning, in terms of variables: the "number of shifts to the auction" (relationships terminated) and "number of new contracts" (relationships created), are depicted in the box plots in Figure 15. A Kruskal Wallis statistical test, with 0.05 significance level confirmed the significant differences in the distribution of the results between the risk aversion settings. The statistical analysis in SPSS on the pairwise comparison shows that difference between settings are significant specifically the differences *between* settings with low risk averse customers (R=0 and R=0.25) *and* settings with higher risk averse customers (R=0.5, R=0.75 and R=1).

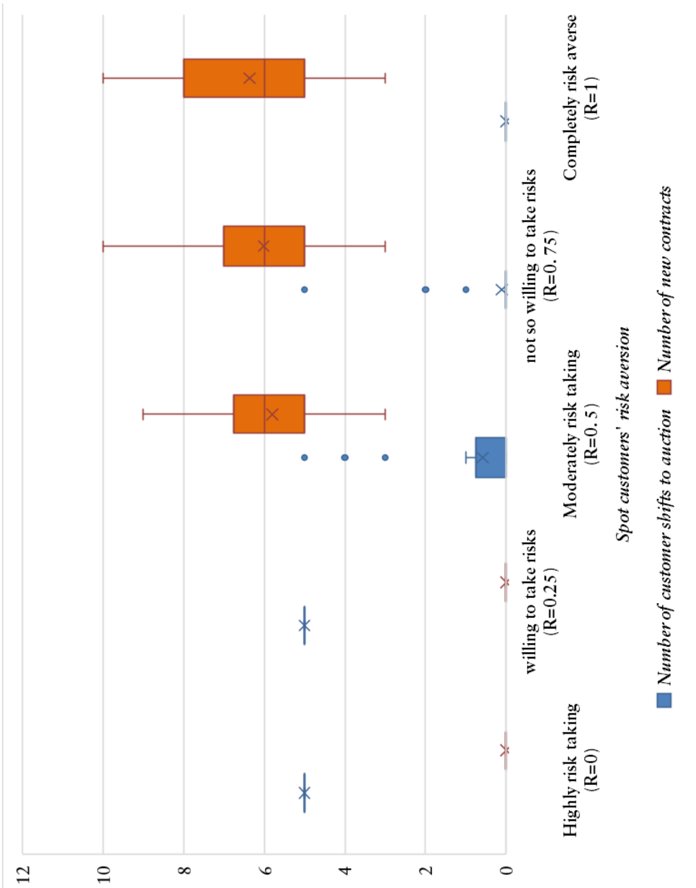

Figure 15. The effect of spot customers' risk aversion level on the number of new contracts and the number of terminated contracts

As can be seen in the plots, in networks with spot customers who are moderately or highly risk averse (R=0.5, R=0.75 and R=1), many new contract relationships are created and much less already-existing contracts are terminated, compared with settings with low risk averse customers (R=0 and R=0.25), i.e. customers who are more willing to take risks when bidding in the auctions.

The decision rules of the spot customers are defined in a way that low risk averse customers (R= 0 or 0.25) do not establish contracts. As expected, in a spot market where all customers are not risk averse or have low risk aversion (risk aversion parameter - R= 0 or 0.25), the emergent results of auctions – i.e. low winning wagon prices- lead to termination of old contract relationships (all 5 contract customers have moved to the auction market- see the "number of shifts to auction" of the R=0 and R=0.25 settings plots in Figure 15). Hence, in a market with spot customers that accept high levels of risk (customers with low risk aversion), the firm will probably lose all its contracted relationships.

The general extent of the structural changes that emerge in the network in each experimental setting is illustrated in another set of box plots in Figure 16. The plot shows the *sum* of the number of created and terminated customer relationships under each spot-customers' risk aversion setting. A Kruskal Wallis statistical test, with 0.05 significance level confirmed the significant differences in the distribution of the results between the settings and more specifically (based on the pairwise comparisons in SPSS) *between* settings with low risk averse customers *and* moderately or highly risk averse ones. As the results show and in accordance with the plots above, structural changes of the network are slightly more in networks with rather risk-averse spot customers.

To further illustrate the implications of such structural changes in terms of cannibalization effects that concerns SFL, the contracts' share of wagons in each risk aversion setting are presented in Figure 17. In line with the experiments on structural change variables discussed above, pairwise comparison of different settings shows that this effect seems to be significant specifically in a situation with very low risk averse customers (R=0 or 0.25) and a situation with medium to high risk averse customers (R=0.5, 0.75 or 1) (pairwise comparisons in a non-parametric test with zero p-value and 0.05 significance level). The test do not confirm a significant difference in the final contract share between situations where all spot customers risk parameter are 0.5, 0.75 or 1 (I.e. customers willingness to take risks is not high) (Shahin Moghadam et al., 2018).

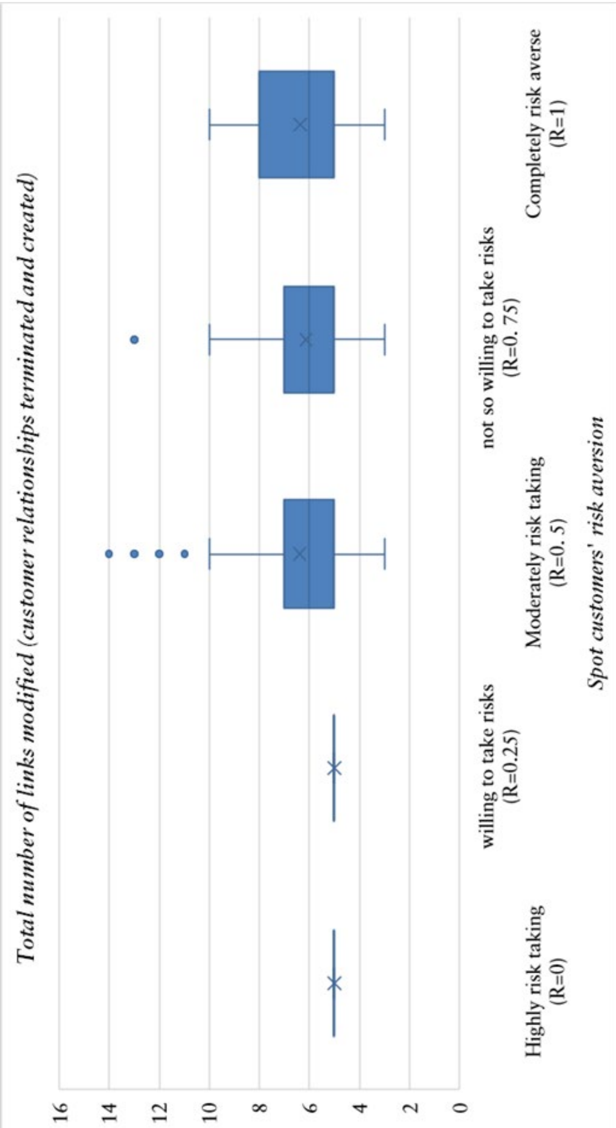

Figure 16. The effect of spot customers' risk aversion on the total number of customer relationships modified

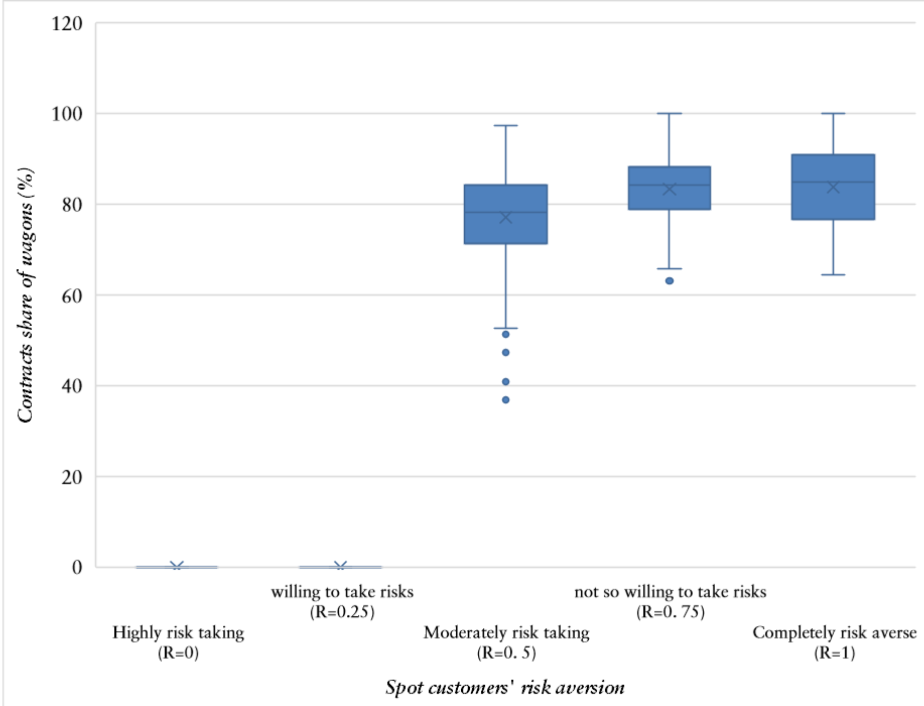

Figure 17. The effect of spot customers' risk aversion on contracts' share of wagons (Shahin Moghadam et al., 2018)

A conclusion could be that the risk aversion level of the customers in the spot market can have an effect on the structural changes that emerge in the network as well as the contracts' share of wagons. When the spot customers are avoiding risk, the calculated auction wining prices are high enough not to provoke contract customers to leave their contracts. Still, the winning prices turned out to be low enough for the auction customers to leave a positive experience and encourage negotiation of contracts, specifically for spot customers who are avoiding risks involved in operating in the auction market (Ibid.). Generally the structural changes may not be sever or too radical, as under different settings usually only a limited number of customers (whether contracted ones in the low risk aversion settings, or spot customers in the high/moderate risk aversion settings), modify their links with SFL.

The effect of spot customers' time flexibility

The effect of the spot customers' flexibility in the delivery time of their shipments is tested in four extreme cases, where all the spot customers have a certain level of *Time Flexibility* (*TF*= 1,2,3,4). Lower *TF* values mean that the customers are more sensitive to delays, i.e. is less flexible with regard to the delivery of shipments and hence cannot tolerate any delay in delivery. Hence, it is expected that existence of less flexible customers would lead to higher auction prices

Figure 18, shows the box plots of the results of 100 simulation runs (repetitions) of 52 weeks of the auction system's functioning, in terms of variables: the "number of shifts to the auction" (relationships terminated) and "number of new contracts" (relationships created), under four different extreme case experiments. A Kruskal Wallis statistical test, with 0.05 significance level confirmed the significant differences in the distribution of the results between the four delivery Time Flexibility settings. Consequently, less contracts would be terminated.

As can be seen in the plots, customers with more delivery time flexibility (*TF*=3 and *TF*=4) seem to stimulate more termination of currently-existing contracts. The pairwise comparisons show that the results in terms of relationships terminated and created are not the same when spot customers are highly flexible versus when they are less flexible in the delivery time of their shipments.

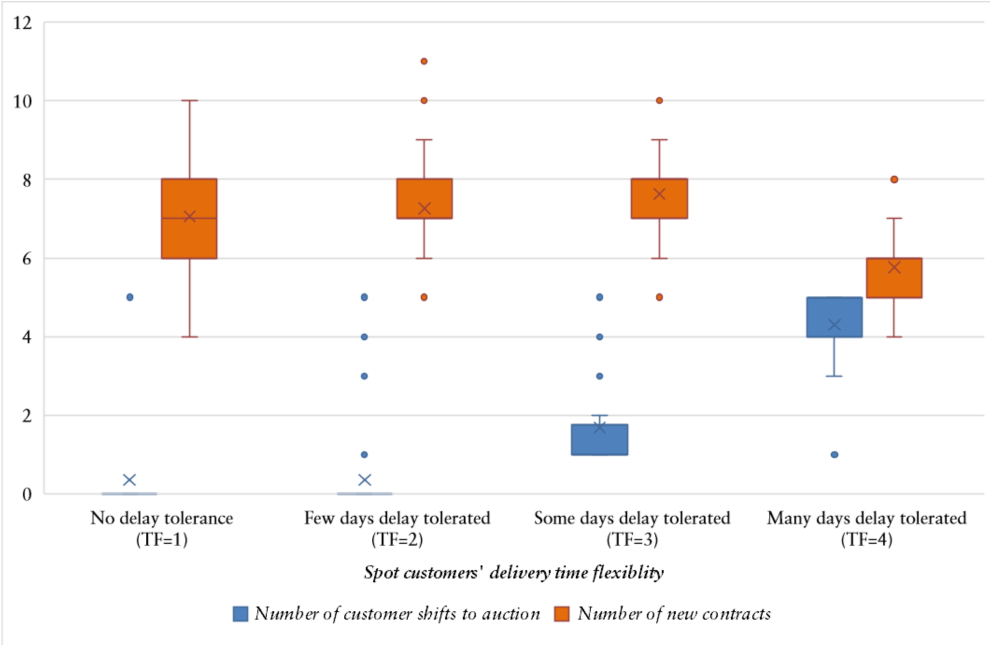

Figure 18. The effect of spot customers' delivery time flexibility on the number of new contracts and the number of terminated contracts

Figure 19 shows the total number of links modified, i.e. the general extent of the structural changes that emerge following the introduction of the online auction system. As shown above, with more time flexibility of the customers, more shifts to the auction are simulated and hence structural changes increase. According to pairwise comparisons in SPSS, the structural changes of the settings are specifically different between lower levels of time flexibility (*TF*=1 and *TF*=2) and higher levels of it (*TF*=3 and *TF*=4).

In terms of contracts' share of wagons (Figure 20), according to a non-parametric statistical test of Kruskal Wallis, with 0.05 significance level, the differences between the settings with different *TF* parameter values seem to be significant. The results of pairwise comparisons indicate a significant difference in situation in which all the spot customers are highly flexible in their delivery times (*TF*=4) compared with a market with less flexible customers (*TF*=1, 2, 3) with regard to delivery times (Shahin Moghadam et al., 2018).

In situations where spot customers have lower time flexibility in delivery of their shipments, the wining prices in the auction seem to be high enough, not to stimulate termination of current contracted relationships (see Figure 18). Still the auction prices are good enough to leave a positive experience for some of the spot customers and stimulate new contracts for the focal firm. When the delivery time flexibility of customers are high (*TF*=4), the contracts' share of wagons are lower compared to the markets with *TF*=1,2,3. When the market contains customers with high delivery time flexibility (that can tolerate delays), the initially low auction prices provoke a shift from contracts to auction. However, at the same time some satisfied spot customers will also establish new contracts, which in the end mitigates the effect of terminated contracts and causes the contract customers' share not to differ significantly from what it used to be.

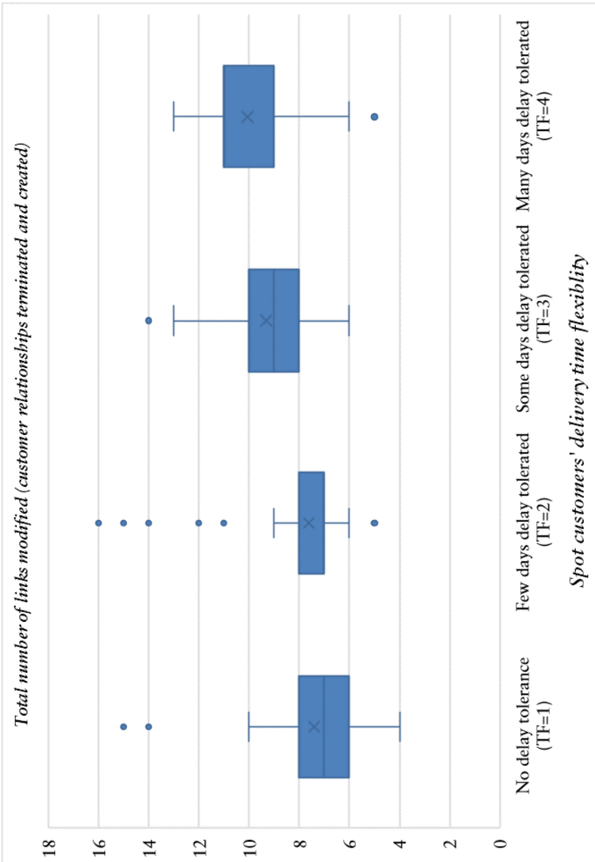

Figure 19. The effect of spot customers' delivery time flexibility on the total number of customer relationships modified

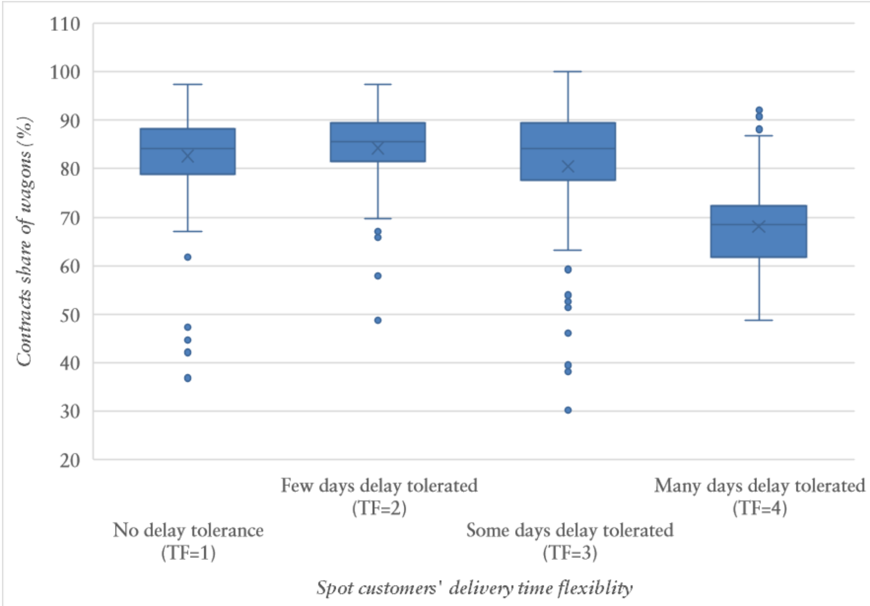

Figure 20. The effect of spot customers' time flexibility on contracts' share of wagons (Shahin Moghadam et al., 2018)

Experiments on the Combined Effect of the Parameters - Market Composition

The experiments on the isolated parameters above showed that risk aversion, demand volume level and time flexibility of customers can affect the outcome of interactions for the SFL in terms of changes in the structure of its network. Next, the combined effect of these parameters on the outcome is investigated by categorizing the spot customers in to two classes (see Table 8). A spot customer may belong to one of the two classes presented in Table 8. This analysis corresponds to clustering the customers according to the characteristic parameters whose variations were shown to affect the total number of modified customer links (the sum of terminated and created relationships) (in the previous sections).

Table 8. Customer types and their characteristics parameter values

Spot customer class	Class 1	Class 2
Time Flexibility	3, 4	1, 2
Risk Aversion	0.5, 0.75, 1	0, 0.25
Demand level	1	2, 3

Class 1 spot customers have a combination of risk aversion, demand level and time flexibility level, which seem to cause larger changes in the structure of the network. Class 2 spot customers with their certain combination of characteristic parameter values, seem to stimulate less changes in the network structure.

To examine the interaction effect of the parameters investigated in the previous section, I investigate the structural changes of the network under different market compositions. Market composition is defined as different configurations of the shares each spot customer type in the market, e.g. a situation with 20% of spot customers being class 1 and the rest being class 2, represents a specific market composition. In different settings, to define each class of customers, the values of each parameter is randomly chosen. For example, if a Class 1 spot customer needs to be generated, its *Time Flexibility* is randomly chosen from [3,4] and its *Risk Aversion* parameter is randomly chosen from [0.5, 0.75, 1]. Different experimentations with different percentages of each customer type are designed accordingly. The five experimental settings that are defined and tested are presented in Table 9.

It is expected that, when the majority of customers in a market belong to Class 1, the introduction of the auction system (the endogenous change trigger) lead to larger structural changes in terms of the number of customer relationships created or terminated. Moreover, this larger number of modified customer links often implies more contracts' share of wagons and a move away from having low shares of contracts- the cannibalization consequence of the auction that SFL would like to avoid. On the other hand, it is expected that when the majority of spot customers are initially Class 2 customers, the auction system triggers lower levels of change in the patterns of actors' connectedness in the network. This may involve. Each experiment is run for 100 times and the results are presented in various box plots similar to the analysis in previous subsections.

Table 9. Scenarios representing different market composition regarding the market share of each spot customer class

	Setting 1	Setting 2	Setting 3	Setting 4	Setting 5
Customer Class 1 share of the market (%)	0	20	52	80	100
Customer Class 2 share of the market (%)	100	80	48	20	0

Figure 21 shows the number of terminated and created customer relationships under each experimental setting (a specific combination of Class 1 and Class2 spot customers). A non-parametric statistical test of Kruskal Wallis, with significance level of 0.05 is applied and shows that differences between some settings are significant. According to pairwise comparison of the settings, when there are more Class 2 spot customers in the network (Setting 1 and 2), there are shifts from contracts to the auction system, implying that the cannibalization effect happens when the already-existing contract customers of SFL decide to change their mode of exchange with SFL into a rather arm-length one. This effect is reduced when there are more Class1 spot customers than Class 2. E.g. Figure 21 shows that in Setting 3, where 52% of the spot customers are of Class 1, the shifts to auction are less than Setting 1 and Setting 2. Then with even more percentage of Class 1 spot customers in Setting 4 and Setting 5, there are no shifts to the auction system and the cannibalization effect is minimized.

In terms of the number of new contracts being formed, it can be seen in Figure 21 that more percentage of Class 1 spot-customers imply higher number of new contract customer relationships being formed (there are less new contracts in Setting 1 and Setting 2 compared to the other three settings with more Class 1 customers).

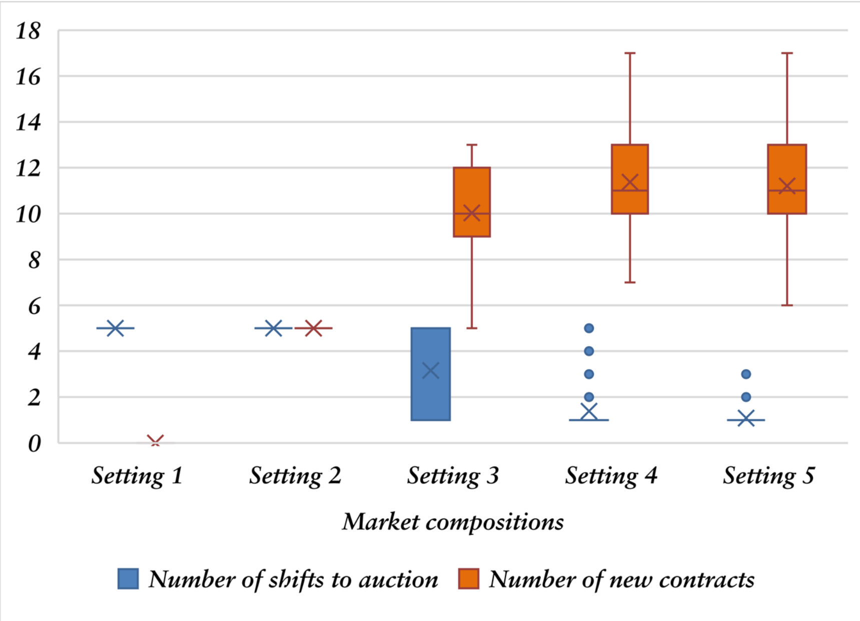

Figure 21. The effect spot-market composition on the number of new contracts and the number of terminated contracts

The total numbers of modified customer links representing the total structural change happening in the network under each market composition are shown in Figure 22. A Kruskal Wallis test, with significance level of 0.05 of confirms the differences in the distribution of the results in different experimental settings. The pairwise comparisons indicate that difference are significant between Setting 1, Setting 2 and the rest of the settings. i.e. if there are at least 50% class 1 spot customers in the network (e.g. in Settings 3,4 and 5) then, the level of structural changes is relatively high and not significantly different between the settings. However, the structural changes are the lowest when there are no Class 1 spot customer in the network and it is relatively moderate in Setting 2 where there are more Class 2 customers but still a few Class 1 customers exist as well.

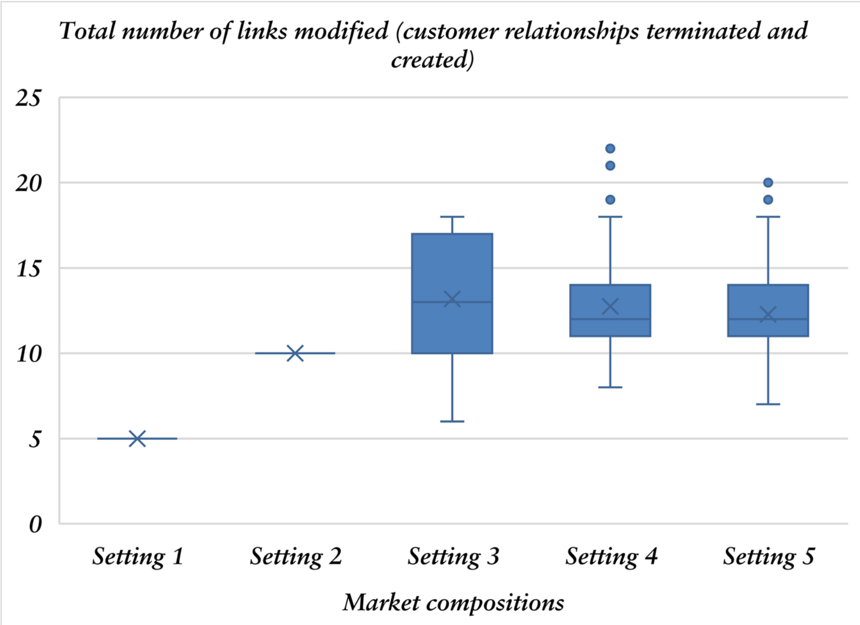

Figure 22. The effect of spot market composition on the total number of customer relationships modified

For exploring the contracts' share of wagons achieved in each setting, the results are illustrated in Figure 23. A Kruskal Wallis test, with significance level of 0.05 of confirms the differences in the distribution of the results in different experimental settings. The contracts' share of wagons in Setting 4 and Setting 5 where the majority of the spot customers are of Class 1, are not significantly different but there are differences between the other settings. The existence of more Class 1 spot customers, imply higher percentage of contracts' share in wagons. In Setting 1 and 2 the structural changes have progressed in the direction of loss of contracts' shares of wagons, i.e. cannibalization effect. In markets with higher shares of Class 1 spot customers (customers with smaller demands, higher risk aversion and more delivery time flexibility), the auction prices are high due to risk aversion of the spot customers and less contracts are terminated. Moreover, spot customers have better experiences with SFL since they have low demand volumes and better chance of finding a relevant auction (due to their higher delivery time flexibility). Hence there many of them who are willing to negotiate contracts and can achieve a better matching with the free wagon spaces (due to low demand volumes), and lead to more new contracts being established. This means that most of the structural changes are the result of new contract relationships being formed. Even under Setting 3 where there are almost equal levels of the two classes of customers, there are some contracts being terminated but more new ones are also being created which keep the contracts' share of wagons high after 52 weeks of the auctions' functioning.

However, since Class 2 spot customers are not very risk averse, the auction prices that they generate are low and thus can cannibalize on the focal firm's current relationships with its contract customers. These spot customers themselves also are not willing to form stable contracts with SFL or even if they are, they cannot get good matches with the free wagon spaces due to their higher demand volumes. Hence, in a market where the majority are of Class 2 types (Settings 1 and 2), there is more chance that contracts are ended and very few new ones are formed, hence leading to low changes in the structure and lower levels of contracts' share of wagons (cannibalization effect).

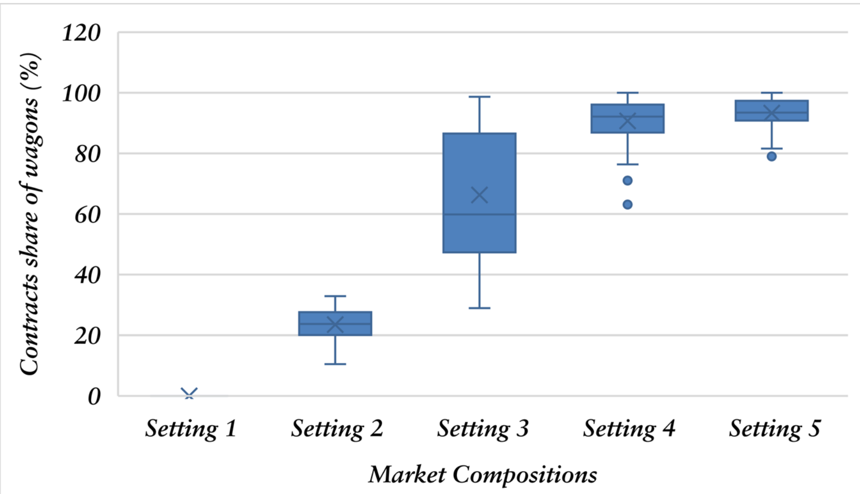

Figure 23. The effect of spot market composition on contracts' share of wagons

The changes that happen in the structure of the SFL's (focal firm's) network are illustrated in Figure 24, where it is shown that how customer links are being created or terminated in different experimental settings compared to the structure of the network before establishing the auction system.

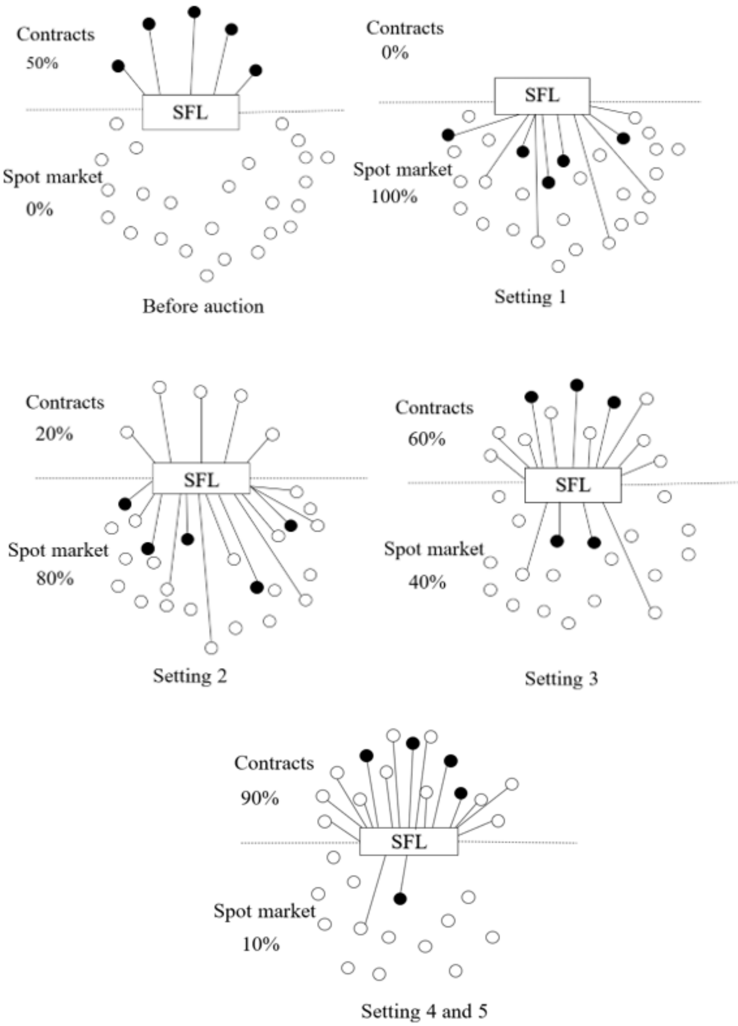

Figure 24. Changes in the network structure with different spot market compositions (Black circles and white circles represent original contract customers and spot customers respectively).

5 Case 2. The Food Supply Network

This chapter goes through the second part of the explorative phase of the thesis, focusing theoretically on structural changes that emerge in business networks in response to an exogenous trigger. The theoretical approach in this chapter allows for consideration of more complexities, heterogeneous business actors and their interdependencies. For better understanding, the context of a food supply network comprising of various supply chains under sustainability pressures is chosen to be investigated in this case. The sustainability pressures coming from shifts in consumers' attitude and increased demand for environmentally sustainable products is chosen as the specific exogenous trigger, simultaneously affecting a wide range of business actors in the supply network, stimulating various types of reactions (i.e. decisions on adopting sustainability) with no individual business actor in control of the process. Hereafter, the second case will be called FSN-Case. The model specifications of its corresponding ABM (called FSN-ABM) include different types of business actors and their behaviour and are based on common knowledge of the field and the theoretical assumptions of INA relevant to the purpose of this research. This chapter covers these specifications, the model implementation and the experiments conducted by the FSN-ABM.

5.1 Background on the Context of Sustainable Supply Networks

For the second part of this research, in this chapter, I theoretically approach the research questions to explore the emergent structural changes of the business networks that arise from exogenous triggers. Supply networks and their sustainability are chosen as the context in which I anchor my theoretical exploration. As explained in the Chapter 1, this context is specifically relevant since adoption of sustainability in business networks is considered as a change process by INA scholars and hence is a relevant dynamic context for exploring network changes. Moreover, this process involves high levels of interdependencies among business actors and the sustainability of the network depends on the aggregation of various actors' responses to certain adoption pressures. The connectivity of business networks and their actors make the results of these aggregated outcomes, non-linear and emergent.

Since supply networks are the links between consumption and its impacts (WWF living planet report, 2018), consumers' behavior and more specifically their demand for sustainable products can have a significant role on the supply side of the networks and business actors' interactions.

Against this background, here I consider customers' sustainable demand as an important exogenous trigger for business actors to adopt sustainability. In other words, exogenous pressures from the end customers' demand on sustainable products imposed on supply networks comprising of various actors in various tiers of the supply chain push the business network actors –with no individual actor in control of the process- to adopt sustainable business practices. Then, considering the research questions of this second part of the thesis, business actors' responses to this pressure and the consequent restructuring of the network that arises from these interactive responses are of interest:

1. What are the possible implications of end-customers' increased demand for sustainable products for the structure of a supply network?
2. What moderating factors may influence the process and its outcomes?

Moreover, both sides of this setting – the consumers and the business actors present in the supply networks- are the agents within a Complex Adaptive System (CAS). Each may have different characteristics, attitudes and behaviors (heterogeneity). They are autonomous and capable of making decisions based on their features and are constantly interacting with each other (directly/indirectly). These interactions when viewed from a macro-level are self-organized and no one single agent (not any individual consumer or any individual firm within the supply networks) is in control of these interactions. The agents' interactions at the micro-level (customers' shopping behavior as well as supply network firms' interactions with each other and with the customers) are constantly shaping the context of interaction through feedbacks. Over time, macro-level patterns of interaction are generated, e.g. certain customers' shopping behavior may lead to certain transformations in the supply networks.

I model a set of supply networks corresponding to the production, delivery and consumption of a specific type of food product (but under different brands). The supply network of this specific food product contains a set of farmers, a set of wholesalers (which can be viewed as producers) and a set of retailers selling the products to a set of customers with varying levels of demand on the price and sustainability level of the product.

Consumers have different preferences with regard to the price and sustainability level of the product they buy. In this research, customers with demand for sustainable products are referred to as "Green customers" while others are called "Brown customers". Retailers are the main business actors in the supply network who get to be in direct contact with the end customers and partly understand their demand preferences.

This choice of actors, although may not be realistic for many supply chains (as there are often more types of business actors are involved), I need to acknowledge that the purpose of the model is not to reproduce reality, but to theoretically explore some of the dynamics and mechanisms involved in the structural changes of the network. Hence the level of details included into my model are chosen in a way to allow us to capture some the theoretical properties of the supply network of interest, within the boundaries of research questions of the thesis and purpose avoiding further unnecessary complications.

Based on the observed shopping behavior of the customers, a retailer may decide to make modifications in the type of products it sells with the aim of gaining more profit. The literature informs us that business actors are dependent on each other's resources and hence, their relationships are setting limitations on their activities, objectives and the extent of change they can apply to those. Although, it is realized that in today's supply networks, retailers are often the actors in the position of power (e.g., Marfels, 1992; Olsen, 2011), but the sustainability issues have added to the complexities involved in the interdependent context of supply networks. The retailer's sustainability is highly dependent on the sustainability of its directly/indirectly connected partners along the chain. Hence, the extent to which the retailers of the supply network in this research, can adapt themselves to the requirements of the end customer is dependent on the types of wholesalers and farmers with whom the retailer works. Depending on the retailers' requests for changes in the level of the sustainability of the offered products, wholesalers and farmers would need to modify their activities accordingly. With increasing demand on sustainable products among customers, these interdependencies and business actors' interactions and consequently the structure of the supply network would change as retailers, wholesalers and farmers eventually would have to adopt sustainability in order to conform to the consumers' pressures. This transformation process with the increased demand of sustainable products is explored with an ABM in this study.

5.2 Research Design

The general steps followed to achieve the purpose of this study and answering the research questions are presented in Chapter 3 on methodological considerations That general framework is the basis for the way the following sections are structured to illustrate the research process for this second case of the thesis, FSN-Case. The specific research questions were formulated during the explorative phase of the thesis (please see section 3.1. in the methodology chapter) through an iterative process of immersing into the literature. Meanwhile, in the modeling phase, the corresponding causal model of the case is designed and presented in the next section. The causal model, which is an abstract representation of the purpose of this thesis' inquiry and research questions of this case, is a key element and the basis for building the corresponding ABM of the FSN-case.

5.2.1 Model Definition

5.2.1.1 The Causal Model

Adopting the INA and Complexity perspective and based on the specific research questions of the FSN-Case, a causal model is designed which is then my point of reference in implementing the FSN-ABM and following experimentations. A preliminary version of the model was first designed based on the literature and the theoretical framework of the thesis, including a set of independent, dependent and moderating factors.

It is important to note that, since this part of the thesis is mainly theoretical with no specific empirical data, the causal model of this case and the consequent experimentations were developed in a highly explorative process. Starting from an initial causal model and sets of hypotheses to be tested, the causal model was eventually developed further after observing different results. When trying to understand and explain certain observed dynamics or patterns of outcomes from testing various hypotheses, we came about other hypotheses to be tested to understand and explore the target and its behavior better. The causal model explained below is the outcome of this iterative process of theoretical exploration.

The supply network under study comprises of a set of farmers, wholesalers and retailers which form multiple supply chains within the wider supply network and supply the demands of the end customers (see Figure

25). In a demand-driven supply network, it is the customers' demand that drives the business actors' decisions in the supply network. From the INA perspective, then shifts in the consumers' demand toward sustainable products, is an exogenous change trigger for the business actors to adapt their activities accordingly and overtime leads to certain implications for the network. The main outcome of interest in such a context is the structural changes that happen in this network as a result of the greening of customers' demand.

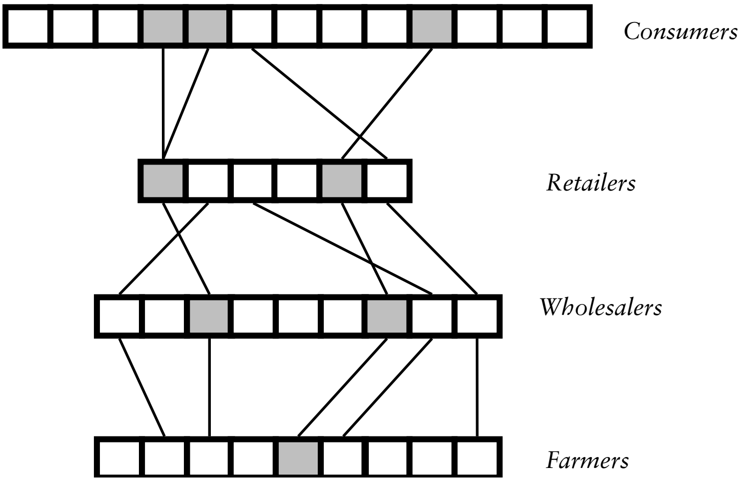

Figure 25. The schematic representation of the supply networks in this study-Coloured customers have sustainable demand and coloured business actors represent actors who have adopted sustainability

Hence, customers' greening demand- the independent variable of the causal model, represented, as the increasing share of end customers who want to buy sustainable products is the exogenous trigger imposed on supply network's actors to adopt sustainability. However, the customers' actual purchasing behavior may be different depending on the availability of the products offered in the retail stores. E.g. if a customer prefers to buy a type *i* product, but there are no retailer who sells product *i*, then the customers will go for the most similar product type to its main preference which is also available in the market.

The shifts in the consumers' demand characteristics are fed into the supply network (in this case mainly through the retailers who are in direct contact with the consumers) and may be translated into retailers' strategizing to modify the type of product they are offering and so a change process is initiated. The business relationships and interactions drive this process and its outcomes (Håkansson & Snehota, 1995). Then the supply networks' connectivity is the mechanism through which the change would spread to other relationships within the supply network (leading to *connected change* rather than *confined change*, in terms of Halinen et al., 1999). For a retailer to be able to adapt and change its strategy, it needs to reorganize its partner networks or negotiate changes in their activities. All these initiate a set of interactions among (business and also non-business) actors. In Complexity perspective terms, this eventual transformation is a self-organized and bottom-up process, in which the business actors' interactions in the supply network context and the feedback effects of the consumers' sustainable behavior, may modify the patterns of connectedness and the actors' sustainable orientations and hence reorganize the activities, resources and actors as well as their interdependencies (Mattsson, 2003). This transformed pattern of connectedness, i.e. network's structural changes are the dependent factors in the causal model (Figure 26).

Again, it is important to acknowledge an important feature of the described CAS. Although the link between the greening customers' demand and the structural changes of the network in Figure 26 is drawn as a one-way arrow, the process underlying it, is not straightforward and unidirectional. With reactions and interactions going on among business actors and also between the demand side and supply side of the network, actors are simultaneously affecting their own context of interaction. Hence, while they change the structure of the network, the network structure is also influencing their further interactions.

The structural changes of the network as the outcome of interest in this case, comprise of a set of measures that are observed, recorded and analyzed at the end of each experiment. These measures are:

- Supply network's greening level: the percentage of retailers, which have adopted sustainability –i.e. have gone "green".
- The number of terminated supply chains (as a straightforward measure of the changes in the structure of the network): the frequency of changing partners (retailers restructuring their supply chains by connecting to a new wholesale and farmer)

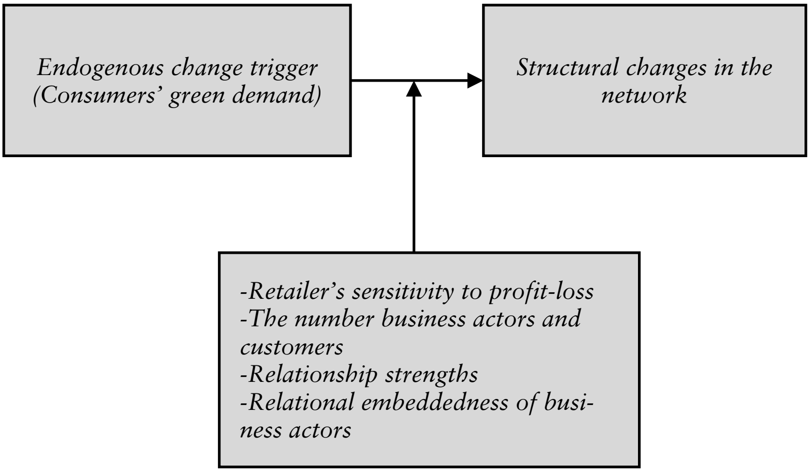

Figure 26. FSN-case causal model of structural changes

Since, this system of interconnected interactions represent a CAS, for a better understanding of the transformation processes illustrated above, the effect of certain moderating factors on the process outcomes are investigated (Figure 26). The moderating factors presented and discussed in this research are among many that were tested in an iterative exploration done with the model and are identified as more insightful by the researcher to be discussed.

- Retailers' sensitivity to profit-loss. When the customers' demand shifts towards more sustainable products, customers begin changing their preferred retail store and in this way retailers' profit may be positively or negatively affected. The negative influences may be so high that the retailer will decide to change its strategies and sell a different type of product. The tolerance of a retailer for this negative influence is called sensitivity to profit-loss. The higher the sensitivity of the retailer to profit-loss, the less loss of customers are tolerated. In other words, higher share of transformed customer demands are needed, until a retailer with less sensitivity to profit-loss decides to change its strategies. Comparing and contrasting different supply networks with different levels of retailers' sensitivity to profit-loss, in terms of the output measures of interest, can be insightful.

- The number of different types of business actors and customers' existing in the market. E.g. one can ask how the emergent network restructuring may be different in a network where there are much more customers on average per retailer (the ratio of the number of customers to the number of retailers) than a supply network where there are fewer customers on average per retailer.
- The strength of the relationships between various pairs of partners (retailer-wholesaler relationships and wholesaler-farmer relationships). Relationship strength is generally an important factor identified by INA scholars in business networks. Due to costs of constantly changing partners, there are often tendencies to develop long-term business relationships (Gadde & Matsson, 1987). Moreover, established and stronger business relationships increase the chances of trusting in each other and adapting to the partner's requests (Hallén, Johanson & Seyed-Mohamed, 1991; Håkansson & Prenkert, 2004; Håkansson & Snehota, 1995). I.e. "adaptation and learning among counterparts depends on the level of interaction between the actors involved" (Vildasen & Havenid, 2018, P. 154)
- Relational embeddedness of the actors in the supply network. The relational embeddedness within the literature often points to the intensity of the exchange between actors in the network which can be a source of learning (Granovetter 1985, 2005, Gulati & Gargiulo,1999, Tate, Ellram & Gölgeci, 2013). Similarly here, by relational embeddedness we mean the varying levels of the strength of the actor's relationships (retailers with wholesalers and wholesalers with farmers). It may be insightful to explore how networks in which actors have different composition of strong and weak ties with their suppliers may behave differently in response to the customers' demand pressure. For example, how the results may be different when the retailer (wholesaler) has strong relationships with all its possible wholesalers (farmers) compared to a situation in which the retailer (wholesaler) has strong relationship with only one of its possible wholesaler (farmer) partners.

In the next subsections, the details of the FSN-ABM are further explained to give better understanding of how the above factors are implemented, measured and tested.

5.2.1.2 FSN-ABM definition

The process of the agent-based modelling of this case starts by defining its main building blocks, agents and the environment. The following model specifications are theory-driven in a way that they are in line with common understanding of the field, and based on literature relevant to the purpose and research of this research within INA and Complexity perspective, as well as the causal model above. The fit between model assumptions and the theoretical lenses adopted in this research, please see subsection 5.2.3.1. of this chapter.

The Environment

The main setting in which the agents of this ABM are interacting are the "market segments" where each market segment represents a specific range of product price and sustainability (offered by suppliers and desired by customers). Figure 27 shows the assumed and simplified market segments for the specific product of this model. For example, *Segment 4* are products (brands) with medium price and low sustainability. The qualitative values of *low*, *medium* and *high* have numerical equivalents when it comes to model implementation. Depending on the agent types, the numerical values of each price level varies. For example, if we are considering the segments of the wholesalers, the price level is about the price that wholesalers ask from their retailers for supplying a specific product type (PR_W). Clearly, for each *segment i*: $PR_{i,F} \leq PR_{i,W} \leq PR_{i,Ret}$ (where F, W & Ret, stand for Farmers, Wholesalers & Retailers respectively).

First, this structure represents the context for shopping behavior of customers, in a way that each customer is mainly interested in buying from a retailer who is operating in one of these segments (sells a product in that segment).

Second, the type of products that each farmer, wholesaler and retailer offers to its buyer are also categorized through this structure. For example, a retailer may be operating in *segment 9*, meaning that it sells products (a brand of a specific product type) which are expensive and highly sustainable. Alternatively, a farmer may operate in *segment 3*, meaning that the types of products it sells to wholesalers are low-priced and highly sustainable. There can be more than one retailer, wholesaler or farmer in each segment.

Price				
High	7	8	9	
Medium	4	5	6	
Low	1	2	3	
	Low	**Medium**	**High**	***Sustainability level***

Figure 27. Representation of the operating segments of business agents and customers' preference

Being interested in the greening process of the supply networks, the segments with low levels of sustainability are called *Brown* (*Segments 1, 4* and 7), and the rest of the segments are called *Green*. In practice, considering the sustainability levels of the *segments* [2,5,8] and *segments* [3,6,9], *segments* [3,6,9] are *Greener* than *segments* [2,5,8]. However, in this thesis, this difference does not have any significant implications and both series of segments are called *Green*. Each retailer, wholesaler and farmer may be operating in any of the green or brown segments. However, for a retailer to operate in a green segment, it needs to have at least a green wholesaler or farmer in its supply chain (depending on the level of retailer's sustainability). For example , in order for the retailer to be able to offer a product with the highest level of sustainability possible (e.g. *segments 3, 6 or 9*) , both the wholesaler and farmer of the supply chain need to be supplying products with the high sustainability (they both need to be located at *segment 3,6 or 9*)

The number of customers (N_c), the percentage of Green customers (*GC%*), the number of retailers (N_{Ret}), wholesalers (N_W) and farmers (N_F) are other parameters specifying the environment for agents' interactions.

Agents

There are four agent types in FSN-ABM. Each type consists of autonomous and heterogeneous entities which can have direct or indirect interactions with certain other agent types. The agent types are customers, retailers, wholesalers and farmers.

Customers

Customer agents are the non-business actors on the demand side of the supply network. The customers in this setting are assumed to be willing to fulfill their demand of a specific product type (e.g. apple). However, they prefer to buy a brand within a specific price and sustainability range. If there exists a retail store which sells the product with those specification, the shopping is done. Otherwise, depending on the weight (value) that the customer assigns to different levels of price and different levels of products' sustainability, the customer will choose the next best product option which is available in a retail store (Figure 28) . The main feature that distinguishes different customers from each other is their preferred product segment. Depending on whether it is a low-sustainability *segment* or not, then customer is then called *Brown* or *Green*.

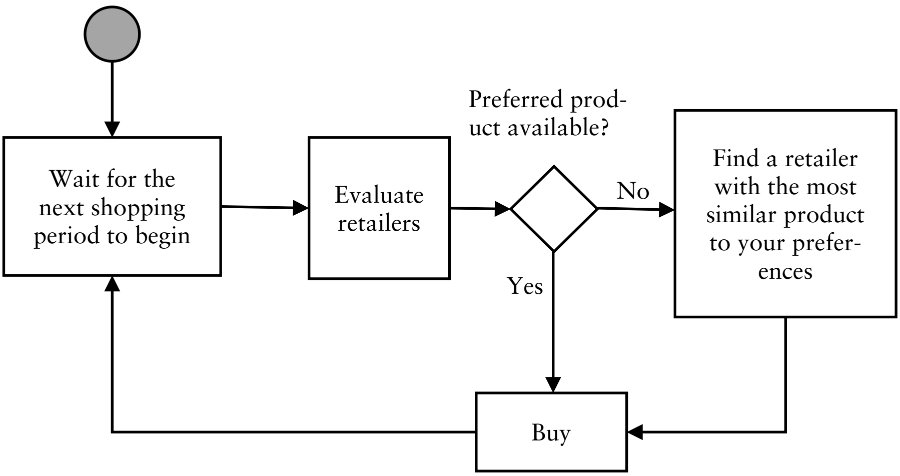

Figure 28. Customers' decision process

In this model the loop of market is not closed. In other words, the customers' budget is external and not taken into account explicitly in the model. Hence, the customers simply purchase products without actually spending an explicit monetary resource.

Retailers

Retailers are business actors in the supply network which are in direct contact with the customers. Depending on the price and sustainability of the product (e.g. apple) that they offer they occupy certain segments. The retailer agents' variables and parameters are presented in Table 10. The parameter values are the same across all retailers.

Base on the parameters and variables defining the features of each retailer agent, there is also a set of decision rules defined for them. Figure 29 illustrates a summary of the processes that a retailer agent goes through in each period. After the consumers' shopping, a retailer examines its profit. If the profit-loss is large enough, then the retailer decides to change its strategy. Then depending on the strength of its relationship with its wholesaler, it decides on whether a restructuring of its supply chain is needed for changing its segment or not. Then requests for adaptations are sent to the relevant wholesalers and the retailer waits for responses and acts accordingly. The details of each of the decisions above which are four main behavioural mechanisms for each retailer, are explained below:

1. **When to change strategy** (move to another segment). A retailer evaluates its profit periodically. If the profit is zero or has decreased more than the retailer's tolerance (Sensitivity to profit loss-SPL), the retailer considers change of its segment.
2. **What is the next strategic move** (the next segment to try to move to). This is the retailer's moving mechanism and defines the next segment that the retailer will try to move to. Considering the illustrated 3×3 structure of the segments in Figure 27, it is assumed that each retailer in each period can move at most one-step to its neighbouring segments. E.g. a retailer which is currently *in Segment 4* and due to high profit loss would like to change its strategy and sell products in a different segment, can choose to move in one the three following directions:
    - The retailer may move downward from *Segment 4* to *Segment 1*, i.e. it decides to decrease the price of its products.
    - The retailer may move upward from *Segment 4* to *Segment 7*, i.e. it decides to increase the price of the products sold.

- The retailer may move to the right from *Segment 4* to *Segment 5*, i.e. it decides to sell a more sustainable product but at the same price

Table 10. Parameters and variables of a retailer agent

	Parameters & variables	Definition
variables	Segment	Retailer's offered product type
	Number of customers (n)	The number of customers whose demand was fulfilled by this retailer at the beginning of the current period
	Profit per unit (p_{Ret})	The profit per unit of the product depends on the selling price and the costs that retailer incurs includes the buying cost of the product from the corresponding wholesaler and costs of retailing operations: $p_{Ret}=PR_{i,Ret}-C_{Ret}-PR_{j,W}$ $PR_{i,Ret}$: *the selling price of the retailer currently occupying Segment i* $PR_{j,W}$: *the selling price of the wholesaler currently occupying Segment j* C_{Ret}: *Retailing costs per product unit (See below)*
	Total profit (P_{total})	Total profit of the retailer in each period $P_{total}=p_{Ret}\times n$
	Supply chain	The specific wholesaler and farmer with which the retailer is in a relationship
	Relationship strength (RS)	RS represents the strength of the retailer's relationship with each of the existing wholesalers at each period (the value may be different for each existing wholesaler)
	Next strategy	The segment to which the retailer decides to move to, after the evaluation of the changes in its profit in each period
	Number of zero-profit periods with adaptation	The number of consequent periods in which the wholesaler has adapted to the retailer's request but there has been no profit generated in those periods.
Parameters	Retailing costs per product unit (C_{Ret})	The operation costs of a retailer for each unit of the product and is assumed to be the same for all retailers
	Sensitivity to profit loss (SPL)	The allowed percentage drop in the retailer's profit from last period to the current period. If the percentage-decrease in the retailer's profit is less than this amount, the retailer does not change its strategy (stays in the current segment)
	Strategic choice threshold (ST)	The percentage decrease in the retailer's profit which affects its next choice of segment (please see the Retailer's moving mechanism).
	Bankruptcy threshold	If the number of consequent periods in which the retailer's profit stays zero, reaches this value, the retailer goes bankrupt (it is removed from the network).

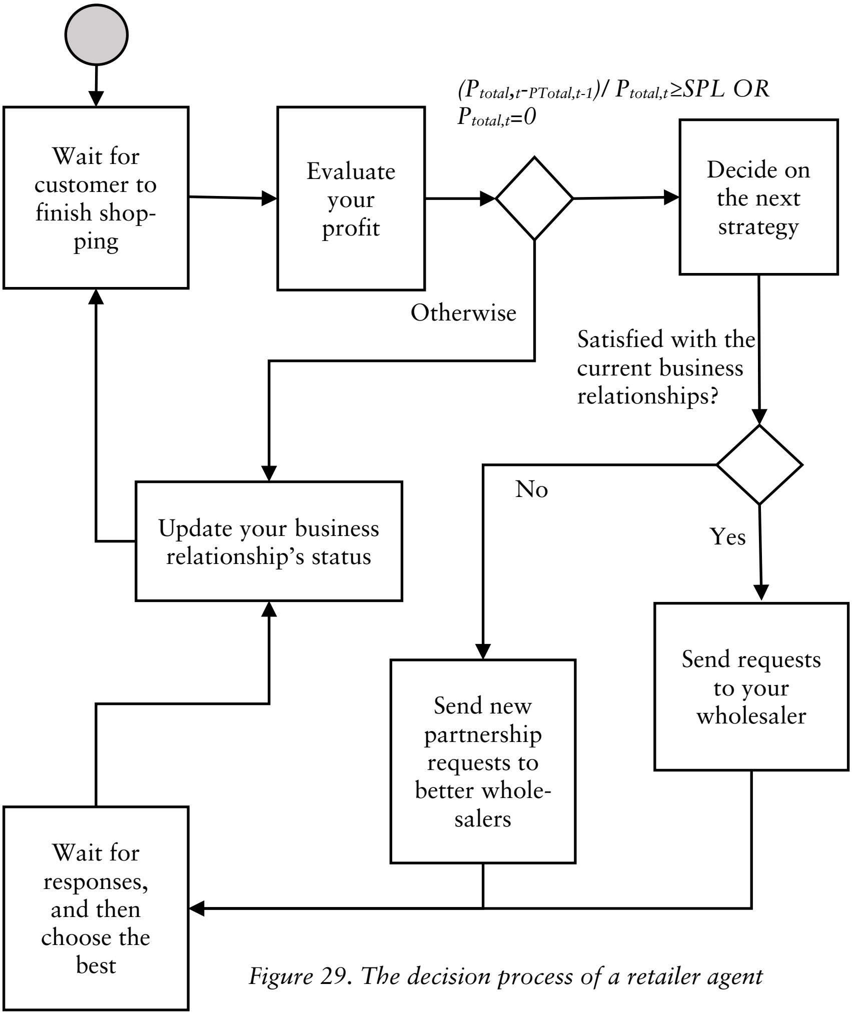

Figure 29. The decision process of a retailer agent

Which one to choose depends on the largeness of profit loss. Moving to the right between segments (i.e. selling a more sustainable product but at the same price range) is a more challenging strategic step for the retailer than moving vertically (merely adjusting the price of the product). With more sever profit losses the chance of choosing to change the segment more radically (through horizontal movement) is higher (Table 11). The move to the right is clearly more challenging to accomplish since the retailer cannot do it unless it can convince its wholesaler and farmers to also move to the right (offer a more sustainable product). E.g. if the profit loss is less than *ST* with *a*% chance, the retailer decides to move upward, with *b*% decides to move downward, with *c*% chance to the right and with *d*% chance, it decides to move to the left.

Table 11. Relative probabilities of a retailer choosing its next strategic move

Next strategic candidate	↑	↓	→	←	
If $(P_{Total\ (t-1)} - P_{Total\ (t)}) / P_{Total\ (t-1)} < ST$	a%	b%	c%	d%	$a \geq d \geq b \geq c$
Otherwise	a'%	b'%	c'%	d'%	$c' \geq a' \geq b' \geq d'$

Generally, when profit-loss is low (but still high to stimulate retailer's change of segment), retailer mainly prefers to increase the price (upward move) or keeping the price constant but reduce the product's sustainability level. On the other hand, if the profit-loss is high, retailer gives higher priority to improving the sustainability of the offered product (a radical move to the right).

3. **How to evaluate the relationships' status**. This mechanism involves the process in which the retailer updates its relationship strength (*RS*) with its wholesaler. The following rules are applied:
    a. Any period of routine interaction with no request for changes among partners, increases the *RS*.
    b. A positive response of the wholesaler to the retailer's adaptation request, increases the *RS* and negative responses decrease the *RS*.
    c. If in spite of constant positive responses received from the wholesaler, i.e. if the "number of zero-profit periods with adaptation" variable is more than a threshold- see Table 10), the retailer's profit did not improve, the strength of the relationships is dramatically decreased.

    The *RS* of a relationship between a retailer and a wholesaler is symmetrical, meaning that they both have the same interpretation of the strength of their relationship. E.g. if the retailer considers the strength of its relationship with its wholesaler having the numerical value of *RS*, the wholesaler assigns the same value to its relationship to the retailer. *RS* values can be within a predefined range.

4. **When to restructure the supply chain.** The retailer during its existence, if it decides to change its strategy (move to another segment) and if the strength of its relationship with its wholesaler partner has become too low that there are better partner candidates available, then the retailer decides to restructure its supply chain by terminating the relationships and sending partnership request to other available and potentially better wholesalers.
   e.g. Imagine that a retailer can connect to one of the three wholesaler options of W_1, W_2 & W_3 and it is currently connected to W3. Moreover the {5,5,4} are the strength of the retailer's relationship with each of the mentioned wholesalers respectively. The retailer's relationship with its current wholesaler (W_3) is weaken over time to a value of 4. Now, if the retailer wants to change its segment, this current wholesaler is not the best possible option anymore. Hence, the retailer decides to restructure its supply chain by terminating the current relationships and forming a new supply chain with one of the other available wholesalers (the ones with higher relationship strength).
5. **Calculations of the sustainability level of a retailer's product.** Retailer is assumed not to produce any product itself. Hence, the sustainability of the product that it offers, depends on the sustainability of the products produced in its supply chain by its corresponding farmer and wholesaler. The numerical value of sustainability of the retailer's product depends on the sustainability of its wholesaler and farmer and is chosen to be the average and rounded up value of the sustainability of the wholesaler and the farmer. E.g. if the sustainability level of the wholesaler's product is high (3) but the farmer is still producing in an unsustainable way -low sustainability (1)- or vice versa, the sustainability of the final product offered to the customer will be medium (2).

As explained above, the main purpose of the retailer guiding its movements, is improvements in its profit and avoiding any large decreases in the total profit. If the retailer has been operating with no profit for a specific number of consequent periods (see Bankruptcy threshold in Table 10), then it goes bankrupt.

Wholesalers

Wholesaler agents in this model are also business actors in the supply network, who are in direct contact with the retailer agents and farmer agents. Similar to retailers, depending on the price and sustainability of the products that they offer they occupy certain segments. In the model, there exist active and inactive wholesalers, where the former are currently in a supply chain and have business relationships while the latter wholesalers, do not have any active relationship. Each wholesaler may receive adaptation requests from its retailer during the lifetime of their relationship. Adaptation requests are requests from the retailer for wholesaler to adapt its operations, in terms of the price of their products or their level of sustainability. For example, if the retailer is trying to change its strategy by moving to a more sustainable segment (a strategic movement to the right), it needs its supply chain partners to become more sustainable (move to the right). The wholesaler may then accept or reject the request. The wholesaler agents' variables and parameters are presented in Table 12.

Apart from the parameters and variables defining the features of each wholesaler agent, there are also a set of decision rules defined for them. Figure 30 illustrates a summary of the processes that a wholesaler agent goes through in each period. If the wholesaler has received a request, it first transfers the request to a farmer. This choice of farmer depends on the strength of the relationship of the wholesaler with its current farmer. After transferring the request, then the wholesaler decides whether it want to adapt its own operation or not. Then a response is sent back to the retailer based on the response received from the farmer and the wholesaler's own decision on adapting.

Table 12. Parameter and variables of a wholesaler agent

	Parameters & variables	Definition
Variable	Segment	Wholesaler's offered product type
	Profit per unit (p_W)	The profit per unit of the product depends on the selling price and the costs that the wholesaler incurs: $p_W = PR_{i,W} - C_W - C_{Suts,W} - PR_{j,F}$ *Where,* $PR_{i,W}$*: the selling price of the wholesaler occupying Segment i* $PR_{j,F}$*: the selling price of the corresponding farmer occupying Segment j* C_W*: Wholesaling costs per product unit (See below)* $C_{Suts,W}$*: Sustainable wholesaling cost per product unit (See below)*
	Supply chain	The specific retailer and farmer with which the wholesaler is in a relationship
	Relationship strength with retailers (RS_{W-Ret})	Represents the strength of the wholesaler's relationship with each of the existing retailers at each period
	Relationship strength with farmers (RS_{W-F})	Represents the strength of the wholesaler's relationship with each of the existing farmers at each period
	Inertia (In_W)	Represents the wholesaler's tendency to avoid changes. Higher In_W means lower chance of adaptation in the business relationship. With increase in the received requests for adaptations from its retailer, the inertia eventually decreases. In_W values are within a range of [Min. In_W, Max. In_W]
	Number of zero-profit periods with adaptation	The number of consequent periods in which the wholesaler's farmer has adapted to the wholesaler's request but there has been no profit generated in those periods.
	Next strategy candidate	The neighbouring segment to which the wholesaler decides to move to in response to its retailer's request.
Parameters	Wholesaling costs per product unit	The operation costs of a wholesaler for each unit of the product
	Sustainable wholesaling cost per product unit ($C_{Suts,W}$)	Offering sustainable products is costly. Offering Medium sustainable products imposes less cost on wholesalers than highly sustainable products (i.e. this cost is proportional to the sustainability level of the segment in which the wholesaler is operating)

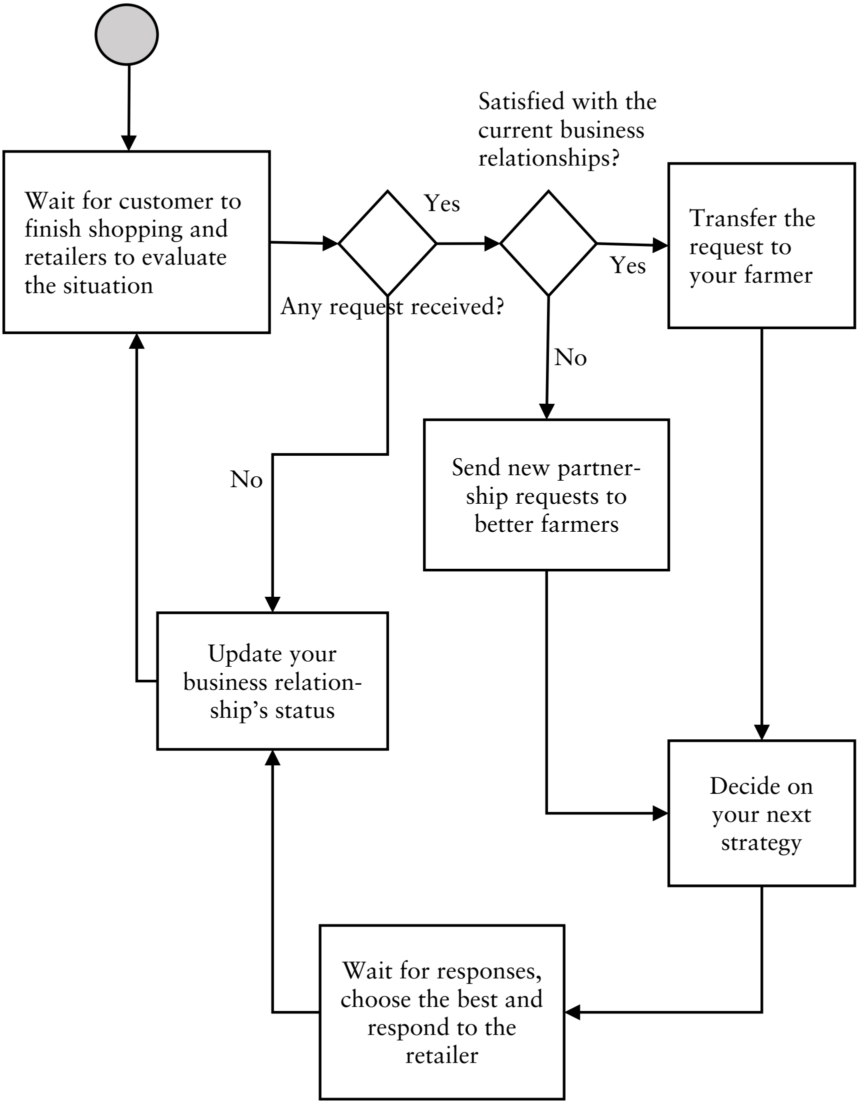

Figure 30. The decision process of a wholesaler agent

The details of each of the decisions above which are three main decision mechanisms for a wholesaler are explained below:

1. **How to respond to the retailer's request for adaptation.** This mechanism itself involves two steps:
   a. When the wholesaler receives a request from its retailer, it transfers the request to the farmer.
   b. Based on its own inertia and the strength of its relationship with the retailer, it may decide to change its segment or not, in a way that may be in line with the retailer's request. The higher the strength of their relationship and the lower the wholesaler's inertia, the higher will be the chance of positive adaptation to the retailer's request.

   This decision combined with the decision received from the farmer in response to the wholesaler's request, form the final response of the wholesaler to its retailer.
2. **How to evaluate the status of its relationships with its retailer and farmer.** The strength of the wholesaler's relationship with its retailer (the status of the relationship) is updated according to the mechanisms explained above for the behaviour rules of the retailer.

   The same set of rules as the ones applied to the relationship between retailer and wholesaler, are also applied to the relationship between wholesaler and farmer. The same holds for the same interpretation of the wholesaler and farmer of the status of their relationship.
3. **When to change its farmer.** When responding to the retailer's request, the wholesaler needs to also interact with its farmer to prepare a response to that request. If over time, the strength of the wholesaler's relationship with its farmer have decreased so much that there are other better potential farmer candidates available, then the wholesaler will try to change its partner and choose a farmer with which it has a better relationship strength. If the wholesaler succeeds in changing its farmer, then clearly, part of the supply chain of the corresponding retailer is changed too.

Farmers

Farmer agents in this model are business actors in the supply network, who are in direct contact with the wholesaler agents. Similar to retailers and wholesalers, depending on the price and sustainability of the products that they offer, they occupy certain segments. In the model, there exist active and inactive farmers, where the former is currently in a supply chain and have business relationships while the latter, do not have any active relationship. Each farmer may receive adaptation requests from its wholesaler during the lifetime of their relationship. Adaptation requests are requests from the wholesaler for the farmer to adapt its operations, in terms of the price of their products or their level of sustainability. Here, the price of the farmers' products can be seen as a proxy for quality of the product. The farmer agents' variables and parameters are presented in Table 13.

Table 13. Parameters and variables of a farmer agent

	Parameters & variables	Definition
Variable	Segment	Farmer's offered product type
	Supply chain	The specific retailer and wholesaler with which the farmer is in a relationship
	Relationship strength with whole-salers (*RS*)	Represents the strength of the farmer's relationship with each of the existing wholesalers at each period
	Inertia	Represents the farmer's tendency to avoid changes. Higher inertia means lower chance of adaptation in the business relationship. With increase in the received requests for adaptations from its wholesaler, the inertia eventually decreases.
	Next strategy candidate	The neighbouring segment to which the farmer decides to move to in response to the wholesaler's request.
	Sustainable farming cost per product unit ($C_{Suts,F}$)	Offering sustainable products is costly. Producing Medium sustainable products imposes less cost on the farmer than Highly sustainable products (i.e. this cost is proportional to the sustainability level of the segment in which the farmer is operating)

When receiving a request from a wholesaler, the farmer decides whether to adapt accordingly or not (Figure 31). The main behaviour mechanisms of the farmers are as follows:

1. **How to respond to the wholesaler's request for adaptation.** Based on its own inertia and the strength of its relationship with the

wholesaler, it may decide to change its segment, in a way that may be in line with the wholesaler's request. The higher the strength of their relationship and the lower the farmer's inertia, the higher will be the chance of positive adaptation to the request.

2. **How to evaluate the status of its relationships with its wholesaler.** The relationship status represented as Relationship Strength with the wholesaler is updated according to the mechanisms explained for the wholesaler agents.

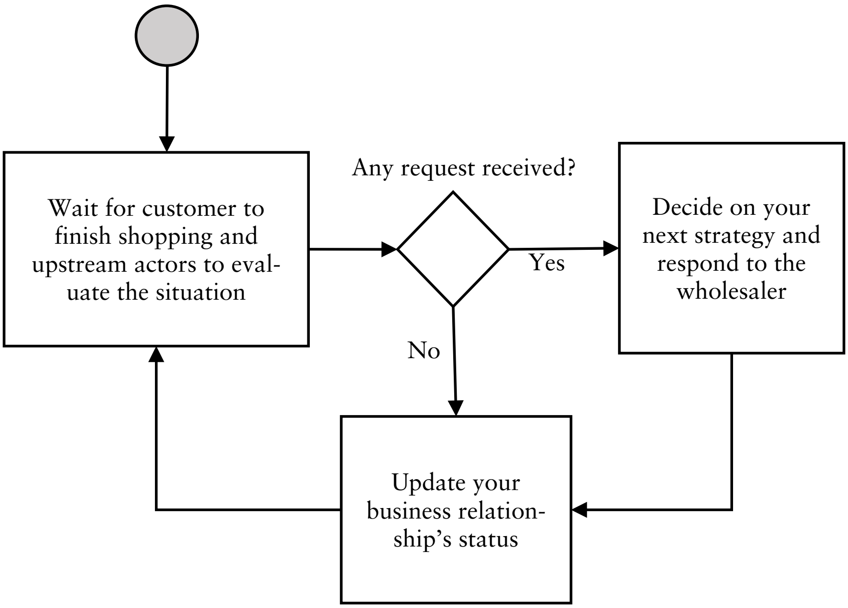

Figure 31. The decision process of a farmer agent

The Overall Processes of the Model

Clarifying the ideas of the agents and the environment of this case, the processes of the model are designed next to represent how all the agents are connected to each other, how they interact with each other and with the environment and all the mechanisms involved in the emergence of macro-level outcomes from these micro-level specifications. This step of the process was initiated by drawing flowcharts of the agents' decisions, their interactions and how all these in connection work and lead to operation of the supply network.

The important part of the modelling process is the consideration of the causal model as the starting point. The model has to be designed in a way to be able to capture the elements of the causal model; the change processes of customers' demand and supply network's restructuring.

Each variable of the causal model needs to be operationalized so that it can be interpreted/measured in the ABM. Similar to the above specifications of the agent types, the interpretations and definitions of the model variables that define the interaction processes of the agents as well as the agents' features must be grounded in the literature of the adopted theoretical perspectives of this research. E.g. network structural changes defined as "variation over time in the underlying pattern of relationships that bind a given set of actors" (Madhavan et al. 1998, P. 441) are interpreted from the ABM results when retailers restructure their supply chains by connecting to a new wholesaler and farmer- Or, when a wholesaler, changes its farmer partner in order to be able to adapt to its retailers' request. Then, a restructuring or reorganization of actor links within the network is implied (Abrahamsen & Håkansson, 2012; Andersson & Mölleryd, 1999; Guercini & Runfola, 2012; Halinen et al., 1999; Mattsson, 2003).

Again, the flowcharts of the model design were constantly revised and eventually restructured during the phase of model implementation into the SeSAm platform. Hence, iterative processes were followed in order to be able to implement the model into the platform and make it work.

The FSN network in this model comprises of four main layers representing the customers, retailers, wholesalers and farmers. On the supply side, there are a number of retailers, wholesalers and farmers as the business actors in the supply network. They all initially are operating in *Brown* segments (*Segments 1, 4* and *7*) supplying products which have low levels of sustainability and different price levels. Each retailer has a corresponding supply chain including one wholesaler and one farmer. In this model, it is assumed that there are the same number of wholesalers and farmers in the network. All retailers have a supply chain but not all farmers and wholesaler, i.e. there exist at least one farmer and one wholesaler who are not actively involved in a supply chain ($N_{Ret} \geq N_{W(or\ F)}+1$).

On the demand side, there exist customers who have preferences for specific product types (specific segments). Initially, all customers are Brown meaning that they prefer products with low sustainability levels.

Hence, they initially choose a retailer and fulfil their demand, depending on their preference.

Each period in this model corresponds to all of the following actions:

- The act of customers' shopping
- The business actors' evaluation of their situation based on the results of customers' shopping
- Business actors' interaction, consolidating or restructuring their relationships

At some point in time, $N_c \times GC$ (N_c: the number of customers, GC: the share of green customers) of N_c customers go *Green*, meaning that now their preferred products lie somewhere in segments with medium and high sustainability level (*Segments 2,3,5,6,8* and *9*). Although in the period following the shift in customers' demand, there exists no *Green* retailer, still the customers need to fulfil their demand with the closest available product type (retailer) based on their evaluation function. E.g. a customer, whose main preference is a product of type 9, may go to a retailer in *segment 7* for his/her shopping. It is also assumed that if there are more than one retailer in the chosen segment of the customer it will choose one of them randomly. Moreover, in this situation the customer is assumed to be loyal, meaning that if in the next period, it still decide to fulfil its demand from the same segment as before, and if the previous retailer is still there (along with other possible retailers in that segment), the customer will choose that retailer again (please refer to Figure 28 for the summary of the process that each customer goes through in each period).

Hence, after the shift in the customers' demand towards more sustainable products, the retailers may face changes in their profit since some customers changed their retailer. If there is a large decrease in the profit of a retailer compared to the previous period, then retailers' strategy change is triggered (see the subsection on retailer agents above). Otherwise, the retailer continues as before (so do its wholesaler and farmer) waiting for the next period. Hence, a number of retailers may stay still while others may consider a change in their segments (please refer to Figure 29 for illustration of a summary of the processes that a retailer agent goes through in each period).

A retailer, who has decided to change its segment, will first decide on the content of its next strategy, i.e. the neighbouring segment to which it wants to move. To accomplish this strategic move, the retailer will need its supply chain partners to adapt their strategies as well. Change of strategy (moving to a neighbouring segment) for any type of business agent in this model is about one of the following changes: increasing/decreasing the price of the product or increasing /decreasing the sustainability level of the product.

The retailer then evaluates its relationship with its wholesaler in terms of its strength. If the current wholesaler is still the available option with highest *RS*, the retailer sends the adaptation request to its own wholesaler. However, if their relationship is not in a good status (low *RS*), the retailer considers the restructuring of its supply chain. Then the adaptation requests are sent to a number of other wholesalers who are available (i.e. not already active in another supply chain) and with which the retailer has the highest *RS* value.

Then a number of wholesalers have received adaptation requests from retailers and it is time for them to consider a response to these requests (see figure 30). These wholesalers are either already in a supply chain or have received partnership requests from retailers who are considering restructuring their supply chains:

1. Those wholesalers who have a request form their own retailer, first needs to transfer it to their farmer. The wholesaler first evaluates the *RS* its relationship with its current farmer. The assumption is based on the fact that more adaptation happens in stronger business relationships. If the farmer is the best available option in terms of *RS*, the wholesaler then sends the adaptation request to its farmer. Otherwise, the wholesaler considers restructuring of its relationship by finding a new farmer. These wholesalers then behave similar to the next group of wholesalers below (number 2). However, those wholesalers who transferred their retailer's request to their own farmer, they then evaluate the possibility of adapting their own products according to the request. Their own decision on adaptation (which is about where to change their segment or not) is made based on the decision mechanism of response mentioned in the subsection of wholesalers agents above and is based on the wholesalers Inertia and the strength of its relationship to the retailer. When the decision is made, the wholesaler then waits for the farmer's response.
2. Those wholesalers, who have new partnership requests, do not consider adaptation but they look for farmer partners to connect

with in order to prepare a supply chain generation response to the retailer. Hence, partnership requests are sent out to the farmers with whom the wholesalers have the best relationship (in terms of higher *RS* value).

Similar to wholesalers, there are also a number of farmers who have received adaptation and partnership requests from wholesalers, these requests are then considered by those farmers to be responded to (see Figure 31). These farmers are either already in a supply chain or have received partnership requests from wholesalers:

1. Those farmers who have received an adaptation request from their wholesalers, go through the same decision mechanism as wholesalers above to decide on whether to change their segments or not. The decision depends on the farmer's Inertia and its strength of relationship with the wholesaler.
2. Those farmers who have new partnership requests, need to choose to respond positively to one of them. The wholesaler with which the farmer has had the best relationship (highest *RS*) in the past, is chosen.

Upon receiving responses from the farmers, the wholesaler evaluates them to choose the best one and offer the whole package to their retailer. A response which fulfils the retailer's request and brings the highest Profit per unit (p_W) for the wholesaler is chosen and sent to the retailer.

The retailer also chooses among the responses it has received. A response which brings the highest Profit per unit (p_{Ret}) for the retailer is chosen. Responses are not necessarily favourable to retailers' expectations. For horizontal movements (changes in the products' sustainability), the wholesalers and farmers' responses may hinder the retailers' movement. For vertical movements (changes in the price of the product), the retailer will move anyway, since it is about its own offered price to the customer. However, depending on the wholesalers and farmers responses this may imply lower p_{Ret} for the retailer.

The features of the supply chains including the links between business actors and their strength are then updated according to the mechanisms explained in the previous section on Agents (see Section 5.2.1.2.2). The period is then ended. Hence, by the end of each period, various business agents *may* hold a new segment and new actor relationships. It is important to note that, unlike the first case, no centralized perspective of any agent type is in focus or control of the interactions of other agents. All agent types follow their own paths of decision processes with no central control. I.e. the supply network is self-organizing itself. Figure 32 summarizes the main processes of the agents' interaction in one period.

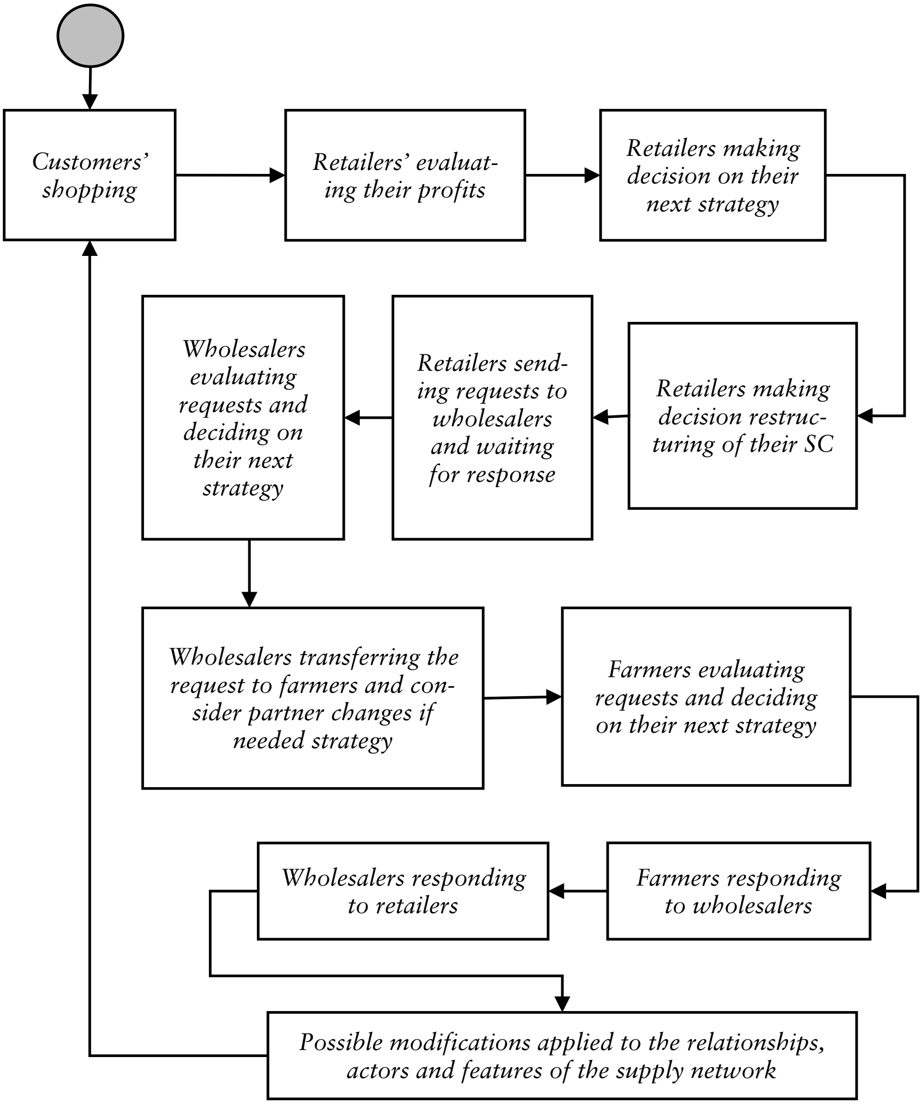

Figure 32. The process of the FSN in one period; different activities are done by different agents.

Considering the model above, then the factors affecting various parts of this model, which are the causal model factors, are studied by repeating these processes under various simulation experimental settings, each for 52 periods.

5.2.2 Model Implementation

This step involved translating all the model specifications above into computerized models in a software platform of SeSAm to create the artificial societies of supply side and demand side agents. As was elaborated in the methodology chapter, agents, resources and world are the main entities of this platform. Agent types (customers, retailers, wholesaler and farmers) are defined as agents in SeSAm. For each agent type their set of variables and parameters are defined. These include the ones defined in the model description section as well as technical variables and parameters added to the model so that the simulations work.

There is a visual space to draw the reasoning of each agent type (Reasoning Engine). For each agent type and based on its corresponding flowchart, the reasoning of the agent was modelled. The model involves a set of activity boxes connected with conditional arrows guiding the steps which the agent must follow. Inside each activity box, a set of implementations are modelled representing what a single agent does in that activity box. Figure 33 is a screenshot of the modelling space of retailer agents of FSN-ABM in the SeSAm platform, presented as an example.

The environment of the agents, i.e. the context in which the agents interact (the network), are modelled under the world entity in SeSAm. Again, the variables and parameters that are global to the model (rather than being agent-types' specific features) and represent the environment specifications are defined under world entity. Moreover, the general functioning of the network, which was initially depicted in flowcharts, are then implemented into the model in terms of activity boxes and arrows. Figure 34 is a screenshot of the modelling space of the operating mechanisms of the demand and supply network of FSN-ABM in SeSAm platform. There are no *Resource objects* defined in the implementation of the model in this case.

Further specifications of the model and more practical issue of the model implementation will not be explained in this document. However, the SeSAm model files will be available and are self-explanatory in terms of the practical model implementation in the platform.

The above implementation processes are accompanied by the long process of model verification to ensure that the model is operationally right and works in the right way as intended. Please refer to the chapter 3 on methodology for details of the verification processes followed in this thesis.

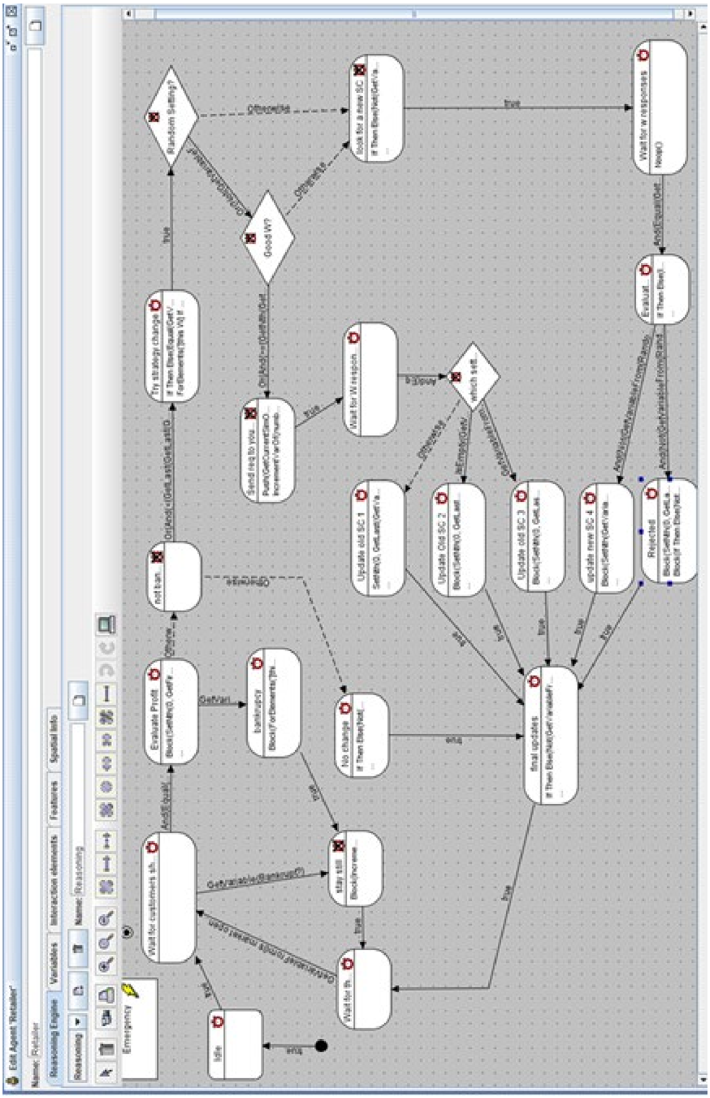

Figure 33. The screenshot of retailer agents' modeling space

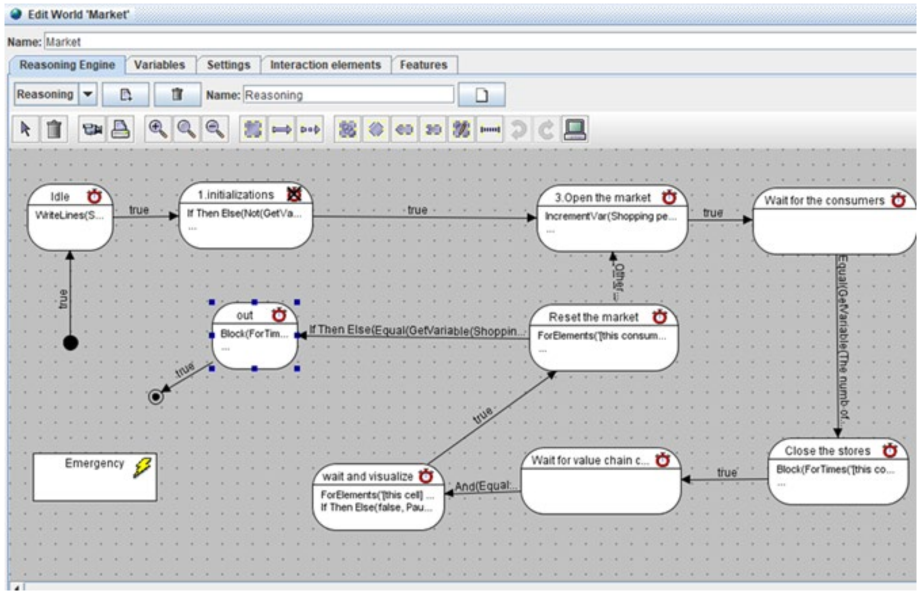

Figure 34. The screenshot of the modeling space of the supply network

5.2.3 Model Analysis

In the following subsections, first as part of the model validation process, the model assumptions are grounded in the literature. Then, I continue by setting the parameters of the model and explaining the sensitivity analyses conducted for this model. Some of the results of the sensitivity analysis which are relevant to explore the relationships of the causal model and other related experiments are presented and analyzed.

5.2.3.1 Validation of Model Assumptions

For better clarification on the validity of the model and its assumptions and consequently the results of the model that will be discussed later in the chapter, in Table 14 we explicitly back up the most important assumptions of the model by referring to and grounding them in the relevant literature.

Table 14. Model assumptions grounded in the literature

General scope	Model assumption	Related literature
Interdependencies		
Adaptation	Retailers' change of strategy being dependent on its supply chain actors	- Andersson & Mölleryd (1999) ("Interorganizational networks are both the means and outcomes of the firms' strategic change actions, providing both opportunities and constraints". P. 292) - Network paradoxes (Håkansson & Ford, 2002)
	Adaptations within Retailer-wholesaler and wholesaler-farmer relationships	- Håkansson & Prenkert (2004) (adaptation and learning among counterparts depends on the level of interaction between the actors involved) - Brennan & Turnbull (1999) - Held (2013) (Adaptation as one of businesses dancing mechanism)
	Adaptations within Retailer-wholesaler and wholesaler-farmer relationships Wholesalers' and farmers' choice of retailers' request to consider	- Fonfara, Ratajczak-Mrozek & Leszczyński (2016) (Adaptation as the source of transformation) - Schmidt, Tyler & Brennan (2007) (There may be both tangible such as revenue gain and cost reductions and intangible such as gaining new skills, strengthening of bonds benefits in adapting within buyer-supplier relationships) - Thilenius et al. (2016)

General scope	Model assumption	Related literature
Relationship strength and adaptation		
The reciprocal relation between the strength of the relationships and the adaptation	Wholesalers and farmers responses to adaptation requests depends on the strength of their relationships	- Guercini & Runfola (2012) (Consolidating or substituting) - Hertz (1999) (Increasing integration, establishment of relationships) - Gadde & Mattsson (1987) (There is tendency for long term relationships because of the costs of developing new business relationships) - Hallén et al. (1991) - Held (2013) (The partners are constantly updating their mental models of each other after each interaction - Halinen & Tähtinen (2002) (Investments and adaptations causing some sort of “stickiness” of a relationship over time)
	Increasing with adaptations of the actors within the relationship and with routine interactions. Decreasing with resisting change an adaptation within the relationship and limiting the other partner's actions.	
	The retailer considers restructuring of its supply chain when the strengths of its current relationships drop too much over time.	
	A Wholesaler changing its farmer partner when the strength of its current relationship drops too much over time.	
Relationship termination and Integration based on its strength	A Wholesaler changing its farmer partner (in order to be able to adapt to the retailer’s request)	- Thilenius et al. (2016) (Sometimes adaptations cannot be done without interfering with relationship of others. P319) - Held (2013) (Relationships may terminate because of the dynamics of market conditions which may affect the attractiveness of the current partner while giving rise to better alternatives. All these being examples of business dancing mechanisms)
	Too much adaptation with no positive outcome, leading to reduction of the RS, moving towards changing partners to avoid lock in	Kamp (2015)

General scope	Model assumption	Related literature
Inertia		
Inertia	Wholesalers and farmers responses to adaptation requests	- Tura, Keränen & Patala (2019) (Network as the potential source of inertia) - Halinen et al. (1999) - Harrison & Easton (2002) (Change minimization mechanism)
Structural change		
Retailers restructuring their supply chains	When a retailer terminates its current relationships with a wholesaler and develop a new supply chain, a structural change has happened	- Madhavan et al. (1998) ("[...] variation over time in the underlying pattern of relationships that bind a given set of actors". P. 441) - Reorganization of actor links (Abrahamsen & Håkansson, 2012; Andersson & Mölleryd, 1999; Guercini & Runfola, 2012; Halinen et al., 1999; Mattsson, 2003)

5.2.3.2 Parameter Setting and Sensitivity Analysis

The features of the agents' environment and the agents themselves are fed into the model as parameters and variables of various types; they may be defined as numerical values, Boolean, lists of numbers, lists of strings, etc. In the following paragraphs, the main parameter values and initial values of certain variables are presented (Table 15 is a list of these parameters and variables).

For these values, some are chosen based on common understanding of the context, reasonability and in a way that they are in line with the theoretical perspectives adopted. Here most of the times, and specifically since the purpose of modelling is not the reproduction of a real world supply network but rather exploring some of the theoretical properties of an abstract supply network, it is not the exact numerical values that matters, rather the relative values of the parameter and variables need to be accounted for. These are explained below in more details.

The values of some of these parameters and (initial values of) variables, are chosen based on sensitivity analysis which also contribute to verifying the model and getting more insights into the functioning of the explicit and implicit mechanisms of the modelled supply network. These are those parameters and variables shown in Table 15 where a number of values are tested for them.

Table 15. The main parameter values and initial values of certain variables

	Variables and parameters	Tested values for the purpose of sensitivity analysis
1	Number of periods of interactions in a simulation run	-
2	Parameters and variables needed for costs and profit calculations of the business agents (including agents' costs of operation and the price features of the segments)	-
3	The possible range of values for Relationship Strength variables	-
4	The possible range of values for Inertia variables	-
5	Wholesalers' and farmers' probabilities of adaptation to requests (depending on the *RS* and Inertia values)	-
6	Retailer's probabilities of choosing a neighboring segment to move to	-
7	Strategic Threshold (*ST*)	{20%, 50%, 80%}
8	The percentage of green customers (*GC*%)	{10%, 20%, 50%, 80%, 100%}
9	Retailer's sensitivity to profit-loss (*SPL*%)	{10%, 15%, 20%, 30%, 40%, 50%}
10	Number of customers	{50, 200, 300, 500}
11	Number of retailers	{10,11,12,13,14,15,20}
12	Number of wholesalers (and farmers)	{15,20,25}
13	Initial relationship strengths for all relationships	{1,3,5,7,9}

Parameters and initial variable settings

1. Each simulation involves repeating the cycle for 52 periods. This number of periods can correspond to one year and various experiments have shown that 52 periods is enough for the output patters to show up and converge.
2. A set of parameters defining the agents' and environment's features are those needed for cost and profit calculations. They also involve the selling price of the products at each level of the supply network and for each segment. Retailers, wholesalers and farmers operate in 3×3 market with 9 *segments* (niches). However, for each agent type the corresponding price of the products are different. Specifications of the segments for each business agent type also involve defining numerical values for the sustainability levels. For all agent types, Low, Medium and High sustainability, correspond to numerical values of 1, 2 and 3 respectively. The qualitative levels of the prices of each segment for each agent type are represented as Low, Medium and High in Table 16 with their corresponding numerical values in the model to allow for cost and profit calculations of the agents. E.g. if a retailer is operating in *Segment 8*, it means that the price of its products per unit is 16 and their sustainability value is 2.

   The retailing costs of the retailer agent per product unit (C_{Ret}), the wholesaling cost of the wholesaler agents (C_W) and the production cost of the farmer agents (C_F) are set to 1.

   For wholesaler and farmers, the sustainability costs are proportional to the sustainability level of the product. Offering products with low sustainability does not impose any sustainability costs. For products with medium and high sustainability levels costs with values of respectively 1 and 2 exist.

   All these values are chosen in a way that for all agent types, even in the worst case, it will be feasible to supply (assuming that they will be bought by upstream agents). E.g. a wholesaler operating in *Segment 3* and being in a relationships with a farmer at *Segment 7* is incurring the most costs (sustainability cost + high buying cost of the product form its farmer) while also selling the product at the lowest price. The profit is at its minimum but still non-zero:

$p_W = PR_{i,W} - C_W - C_{Sust,W} - PR_{j,F}$ $\qquad$ $p_W = 10 - 1 - 2 - 6 = 1$

Table 16. The numerical prices of the products of each agent type associated with each price level

	Price level of a segment		
	Low	Medium	High
Retailers' segments	14	15	16
Wholesalers' segments	10	11	12
Farmers' segments	4	5	6

3. Retailers, wholesalers and farmers have a variable keeping track of the strength of all their possible relationships (for each pair of retailers and wholesalers and each pair of wholesalers and farmers). It is assumed that these variables can take integer values in [1,10] range, 1 being the weakest relationships and 10 representing the strong one. The starting values for each pair of relationships are one of the moderating factors which will be analyzed later in the chapter. A situation in which all relationships are initially weak (newly formed) is decided as the base setting.
4. Wholesalers and farmers as business actors inherently resist change as much as possible. It is assumed that their Inertia variables can take integer values in [1,3] range, 1 being the lowest resistance and 3 representing the highest. The initial values of this Inertia variable for all farmers and wholesalers are set to maximum.
5. The mechanisms of wholesalers' and farmer's decision making on whether to adapt to the request or not (see the subsection on these agent types), are also specified with certain numerical probability values which depend on their Inertia and strength of their relationships (RS). The following values are assumed for both agent types in a way that the higher the RS and the lower the Inertia the

higher is the probability of adapting to their partner's preferences (See Table 17). E.g. if the strength of a wholesaler's relationship with its retailer is 5 and its Inertia has reached the value of 2, then there is a 25% chance that the wholesaler behaves according to the retailer's request.

Table 17. Wholesalers (farmers) adaptation probabilities depending on Inertia and RS values

		Relationship Strength (RS) Values		
		[1,3]	[4,7]	[8,10]
Inertia Values	3	10%	15%	35%
	2	15%	25%	50%
	1	25%	30%	70%

6. The mechanism controlling the retailer's decision on its next strategy depends on the amount of lost profit from previous period and its current position (see subsection on Retailer agent type). Depending on the current segment of retailer, there are certain probabilities for choosing each of the neighbouring cells.

Sensitivity Analysis

As explained before in the methodology chapter and Case 1, sensitivity analysis involves the systematic changing of the parameters over a range of values and checking the robustness of the outcomes. This sensitivity analysis contributes to verification, validation and to the parameter setting of the model. For the base line parameter values, most of them are chosen based on theoretical perspectives and expert opinion. For the rest, the sensitivity analysis helps for a deeper understanding of the dynamics of the system and choosing the values for which the dynamics relevant to this research outcome of interest (structural changes) could be observed. A few of these selected parameters of interest are also factors of the causal model. Hence, the sensitivity analysis incorporates parts of the experimentations (based on the causal model) that are needed to answer the research questions of the study as well. The results of their corresponding experiments are focused on, in the next subsection.

The selected parameters are tested in different scenarios with different parameter setting. The rest of the parameters hold the same values as presented above.

The main parameter on which we have done sensitivity analysis are:

1. **The percentage of green customers (*GC%*).** This parameter represents the share of customers who will shift their demand from Brown segments to *Green* segments during the simulation. This parameter is actually an important factor of the causal model and the main trigger that initializes the processes of change that this research is focusing on. Hence, it is decided that no single base line value be defined for it. Instead, almost every experimental setting that will be conducted with this model, are repeated under five different values of *GC%*: 10%, 20%, 50%, 80% and 100%.
2. **Sensitivity to profit-loss (*SPL*).** The extensiveness of the customers' greening is the main trigger for retailers and more generally the supply network to react. Since, it is affecting the profit of the retailer. E.g. if the *SPL* of a retailers is 30%, it means that when enough customers change their preferences so that the retailer's profit is reduced by 30% or more (because of losing those customers), then the retailer decides to change its segment. Hence, the extensiveness of the shift in customers' demand alongside the tolerance of the retailers for changes in their profit (before they finally decide to act upon it) seem to influence the retailers and consequently the whole network responses. Sensitivity analysis on this parameter of retailer agents is conducted on a number of values, including extreme ones. Then a baseline value under which the model does not act too aberrantly and seem to offer a setting for the dynamics of interest is chosen.

   Other parameters and initial variable values being the same, we tested the behavior of the model under different values of Sensitivity to Profit-Loss. The outcomes in terms of the percentage of green retailers and the number of terminated supply chains (structural changes in the supply network) were as expected. With less sensitivity to profit loss (higher *SPL* parameter values), less retailers went green. Generally, the retailers are less motivated to move, so the chance of requiring supply chain adaptation and consequently supply chain restructuring are lower. The interaction effect of various values of *SPL%* parameter with *GC%* parameter and the initial strength of the relationship in the network are further discussed in the next section on Experiments.

3. **Strategic choice threshold (*ST*).** This parameter of retailer agents guides the general direction of the agents' movements. Considering that with at least *SPL%* drop in the profit the retailer decides to move, then if the drop is at least *ST%*, the retailer is more likely to make radical changes (e.g. going to the right, i.e. going green). Hence, under the same *GC%* and *SPL%*, lower *ST%* mean more retailer are likely to move more radically.
   The baseline value should be balanced in a way that, with low *GC%* less retailers be likely to move radically while, at higher *GC%*, more retailers are willing to move radically. Moreover, at moderate levels of *GC%*, both radical and more incremental changes are equivalently probable. This parameter is also a bit pointing to the heterogeneity of the retailers' behavior. At lower *GC%* and higher *GC%* the retailers are more homogenous in terms of the direction of their strategic change while in moderate *GC%*, more heterogeneity is probable in terms of the varying adopted strategies.
   Three values of this threshold are tested ({20%, 50%, 80%}). The results were as expected so we avoid going through their details here.
4. **The initial number of different agent types.** Everything else being equal, we tested the sensitivity of the model different values of the number of different agent types existing in the network (see Table 15). The results of these are discussed in the next section as certain interaction effects are identified and deserve more discussions

The baseline setting are decided to have the following features presented in Table 18 (The rest of the parameters such as wholesalers' decision making probabilities and the defining parameters of the ranges of the segments are as described in the previous subsection):

Table 18. The baseline values

Parameter/variable	Baseline value
Number of customers	200
Number of retailers	10
Number of wholesalers (farmers)	15
Percentage of green customers	15
Sensitivity to profit-loss	0.15
Strategic choice threshold	0.5
Initial relationship strengths for all relationships	1

5.2.3.3 Experiments

Considering all the parameter and variables of interest various combinations of the parameters and variables are tested. Every single one of them contributed to the theoretical exploration of the model and specifically to the researcher's understanding of many of the explicit and implicit mechanisms of the agents' interactions. The following results and discussion are chosen from those experiments based on their explicit relevance to the research questions and the causal model of this case. The stylized facts elicited from the results apply to the supply network of the case illustrated in this research. The purpose is to explore some of the theoretical properties of this abstract model of the supply network case and illustrate the type of insights achievable with the specific methodology of this research.

To control for randomness, the initial configuration of the network links (i.e. the initial supply chains including the Retailer-wholesaler-Farmer triads) are random but set constant for all simulation runs and all experimental settings. However, the initial position of the business agents in the segments are randomly selected (from {1,4,7}- the brown segments) in the beginning of each simulation run. The initial distribution of the customers in the segments is also random. The same holds for when they go green, i.e. their preferred segment, is modified to a randomly selected green segment and then held constant for the rest of the simulation run.

Each simulation run involves repeating the agents' interactions for 52 periods. Due to the presence of random factors and specifically the probabilistic decision making of agents in various decision mechanisms (e.g. the retailer's choice of next strategy or the wholesaler's chance of accepting an adaptation request), each experimental setting is repeated for 80 times. The results are then shown as box plots. For some results (periodic patterns), the mean of these 80 runs are also discussed but generally since the outcome values do not follow the Normal distribution, most of the results are presented in terms of box plots for a valid comparison.

The presentations of the experiments' results are structured in two main parts. First, a set of causal model factors which are mainly related to the "demand side-supply side" interface are discussed. These include the sensitivity of the retailers to profit loss as well as the number of different agent types. The share of green customers ($GC\%$) is present in all experiments. Hence, this first set of experiments are generally about how the intensity of the change trigger and retailers' tolerance to loss of profit may affect the results. I.e. they involve factors that somehow influence the processes through which the exogenous trigger (shift in customers' demand towards green products) are captured, interpreted, and acted upon by being transformed into endogenous triggers in the supply network.

The second part of the experiments are focusing on those factors of the causal model which are mainly about the features of the supply network (supply side of the case) on which the exogenous trigger is imposed. This set of experiments are about the factors that may affect the processes, through which the business actors respond to the triggers, spread the effects and adapt. Consequently, their interactions over time may restructure their supply chains and the whole supply network in general.

In all the following experiments four main outputs are represented and discussed in different plots for various experimental settings. These include:

- *The level of supply network's greening:* this value shows the percentage of retailers who went green after 52 periods of agents' interactions. It is important to note that, retailers' greening is about them moving from Brown segments {1,4,7} to any of the Green segments {2,3,5,6,8,9}. Since each experimental setting is repeated for 80 times, this value is represented in boxplots and different settings are then compared.
- *The process of supply network's greening:* this process is illustrated in terms of the average percentage of *Green* retailers in each period (the average over 80 repetitions of the simulation under the same parameter settings). Observing the variations in this value under each experimental setting over 52 weeks, can then gives us insights

on how fast the retailers' greening happens. Moreover, illustrating this process for different settings in the same chart, let us compare the settings and explore whether under certain settings, the greening of the supply network proceeds faster.

- *The number of restructured supply chains:* total number of terminated(restructured) supply chains is the main factor measuring the structural changes that happen in the supply network. It represents the sum of the number of supply chains (a retailer-wholesaler-farmer triad) that broke down during the 52 weeks. I.e. these are the retailers who had to restructure their supply chain and connect to a new pair of wholesaler-farmer. The total number of these structural changes over 52 periods are illustrated in boxplots (of a sample of 80 repetitions of the same parameter setting)
- *The process of structural changes in the network*: *The number of restructured supply chains* explained above merely offers an aggregated account of the total number of supply chains which were restructured after 52 weeks of agents' interactions. I complemented that with a more processual account of the network's structural changes. Considering that each parameter setting was repeated for 80 times, the average number of restructured supply chains in each period is illustrated over time. The observed curves of different experiments can give insights to the processes of the structural changes that happen in each setting and comparisons between settings can be made. Certain settings may have more sever restructuration in earlier periods while these changes may start slower in another setting. Then, exploring the observed patterns and their potential reasons are followed.

A shared factor among all the four plots explained above which are presented in the following subsections, is the simultaneous presentation of results under different levels of green demand. Considering the role of the customers' greening (as the independent factor of the causal model), any experimental setting includes the results of a specific combination of parameter and variables under five different percentages of green customers, with the *GC* parameter values of {10%, 20%, 50%, 80%, 100%}. For example, the focus may be on the influence of retailer's sensitivity to profit loss on the total number of structural changes that happen in the network. Then in one plot the output measure (the sum of restructured supply chains) is illustrated under two variables: 1) different levels of green demand and 2) different levels of retailers' sensitivity to profit loss. I.e. a multivariate analysis is offered in the plots where one can see the output values of the total number of restructured supply chains under each level of green demand and each level of retailers' sensitivity to profit loss.

At the end of each sets of experiments, the stylized facts derived from them are posited.

Demand Side- Supply Side Interface

Retailers' sensitivity to profit loss

As discussed in the sensitivity analysis section, both the extensiveness of the customers' demand shift to green products and retailers' interpretation of this shift (*SPL*) influence the results. For the purpose of sensitivity analysis six different values of *SPL* were tested and the verified the model. Here, for better presentation and discussion of the results we limit the analysis to four main values of *SPL* {10%*SPL*, 15%*SPL*, 30%*SPL*, 50%*SPL*} (see Table 19). For example, 15%*SPL* (which is also the baseline value of the parameter) means that if a retailer realizes at least 15% reduction in its profit compared to previous period, it considers changing its strategy.

Figure 35 shows the level of supply networks' greening which is measured with the percentage of green retailers by the end of 52 periods of agents' interaction. The chart also illustrates the interaction effect of retailers' sensitivity to loss of profit with the percentage of green customers in the network.

The general expected trend under each level of green demand (GC%) is the decrease in the supply network's greening with lower sensitivity of the retailers to the loss of profit. The observed reduction is specifically significant between higher sensitivity levels (10%SPL, 15%SPL & 30%SPL) when there are less green customers in the networks (i.e. 10%, 20% and 50% GC) meaning that when green customers are not dominant, slight differences in the tolerance of retailers to profit loss in a network, lead to different levels of supply network greening. This is specifically the case when the sensitivity of retailers are higher.

Table 19. SPL experimental settings

Experimental settings	Description	Sensitivity to Profit-Loss
10%SPL	A retailer considers changing its strategy (segment) if it has lost at least 10% of its profit since last period	Very high
15%SPL	A retailer considers changing its strategy if it has lost at least 15% of its profit since last period	High
30%SPL	A retailer considers changing its strategy if it has lost at least 30% of its profit since last period	Moderate
50%SPL	A retailer considers changing its strategy if it has lost at least 50% of its profit since last period	Low
Shared parameter values:	200 customers, 10 Retailers, 15 wholesaler and 15 farmers. All relationships are initially weak with the same strength.	

When the green percentage of customers are the dominant group (e.g. 80% *GC* or 100% *GC*), then networks with highly sensitive retailers (i.e. networks with 10%SPL and 15%SPL retailers' sensitivity) perform similar in terms of the supply network's greening. However, networks with retailers who are less sensitive, may perform differently depending on the sensitivity of their retailers.

This result was expected since more sensitivity of retailers to loss of profit implies that with even little shift in the customers' demand from brown product to green ones, more retailers are likely to be affected enough to be stimulated to consider changing their strategy. In terms of the relations, in the causal model of the case, we can see that more greening of customers' demand implies more greening in the supply network. Still the sensitivity of the retailers to profit loss affects the level of greening of the network with increasing green demand of the customers. The increasing greening of the network is more visible when the retailers are more sensitive to loss of profit. The sensitivity to profit loss may be partly related to the size of the retailers. Then in networks with larger retailers, large levels of customers' greening are needed for the supply network's adaptation towards sustainability.

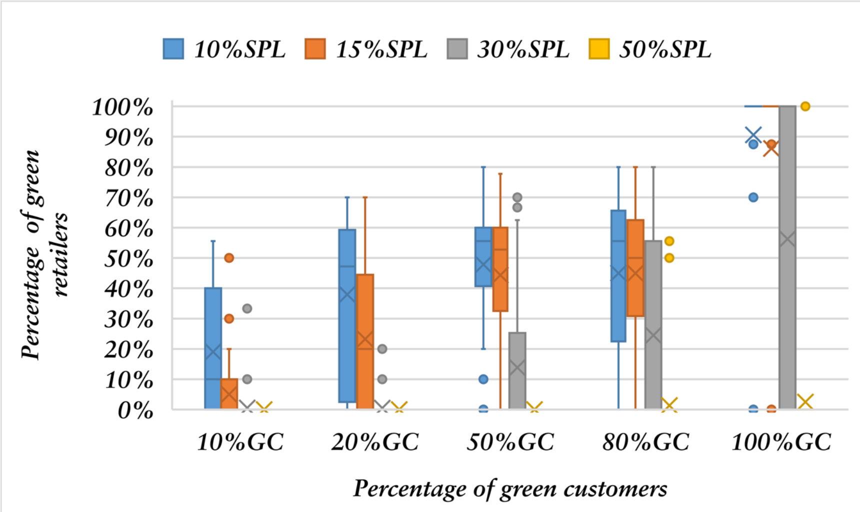

Figure 35. The level of supply networks greening by the end of 52 periods, under different shares of green demand and different levels of retailers' sensitivity to profit loss

Figure 36 further illustrates the periodic average percentage of green retailers over 52 periods. Each chart compares the greening process of networks with different levels of retailers' *SPL*, under a specific level of green demand (*GC%*). The relative slope of the curves is the main focus here and not exactly the differences in the level of green retailers. The slope of the curves gives us an idea of the rate of greening over time in different experimental settings. The final values of percentage of green retailers should not be the focus of analysis in these charts, because they are merely illustrating the mean of non-normally distributed values over 80 simulation runs, and do not offer a complete view of all runs.

A similar analysis holds for restructuring happening in the networks with different levels of retailers' sensitivity to profit loss (Figure 37). Even with high levels of green demand, if the sensitivity of the retailers to loss of profit is low, then less retailers are triggered to adapt and less structural changes are then expected in this case.

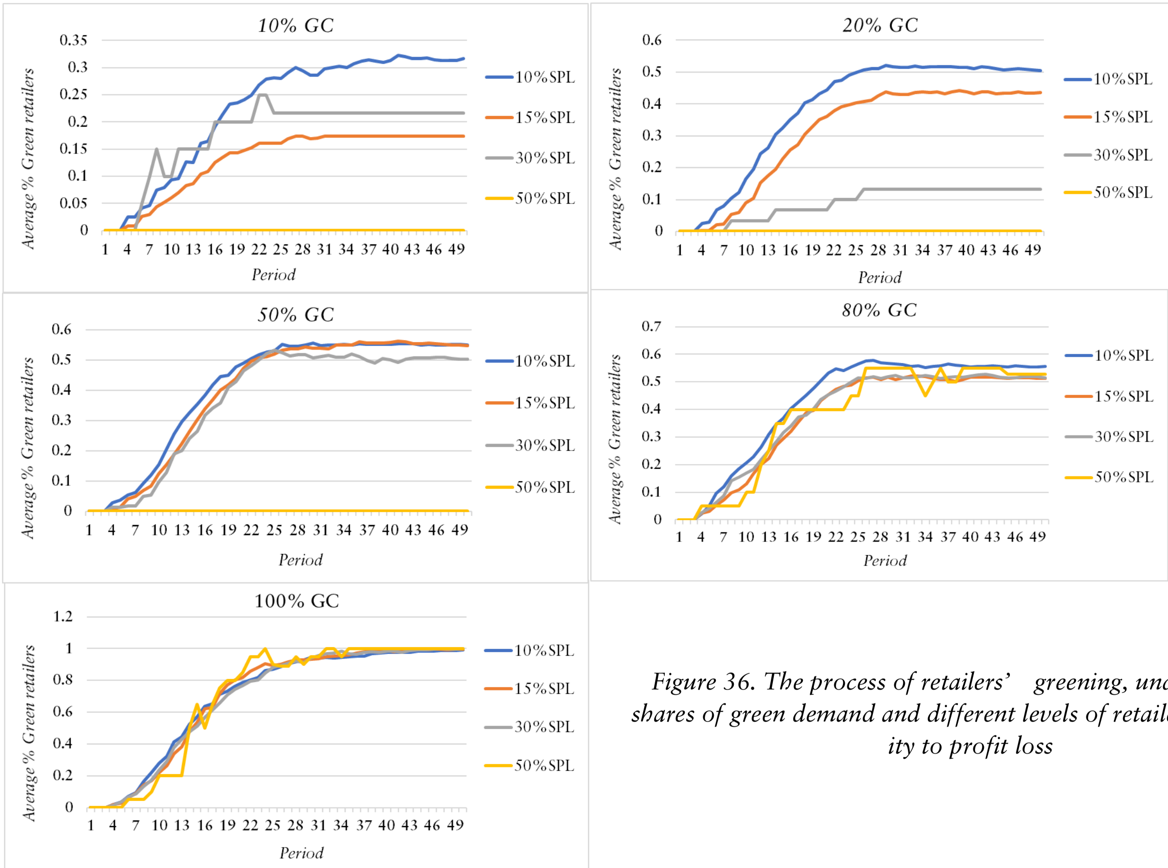

Figure 36. The process of retailers' greening, under different shares of green demand and different levels of retailers' sensitivity to profit loss

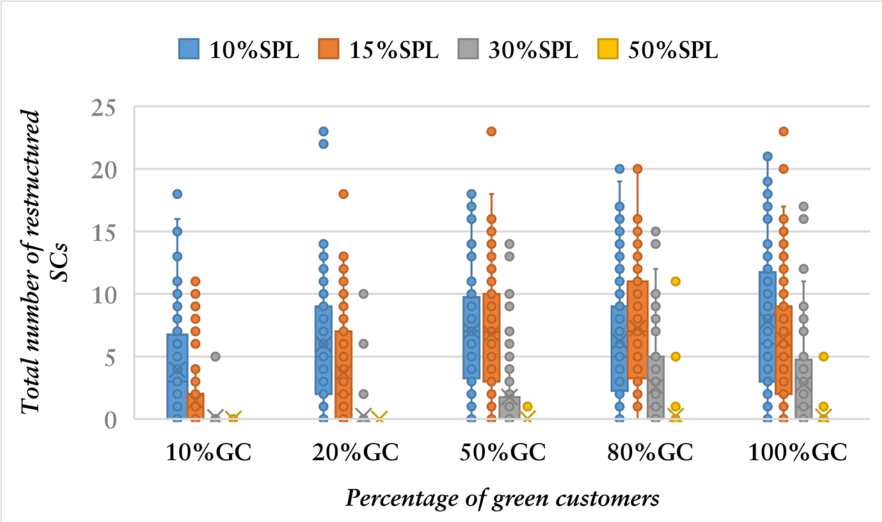

Figure 37. Total number of supply chain restructuring by the end of 52 periods, under different shares of green demand and different levels of retailers' sensitivity to profit loss

Stylized fact: In networks with less sensitive retailers to profit loss (which may be associated with the size and profitability of the retailer), increase share of green customers, has lower impact on the greening of the supply network and the amount of restructuring happening in the network. Moreover, in networks with less sensitive retailers to profit loss, the process of greening proceeds at a slower pace.

The number of customers, retailers, wholesalers and farmers in the network

Considering the parameter settings of the baseline model, as part of the sensitivity analysis the results under different network settings (various number of customers, retailers, wholesalers and farmers) are studied. The general trend of increasing network greening and restructuring) with increasing pressure of green demand (*GC%*) is observable in all experimental settings (although there are situations in which the greening level of the network and its restructuring are not significantly different between two values of *GC%* , e.g. 50% and 80% green customers).

The results show that with increasing number of customers, the supply network's greening (the percentage of green retailers) decreases (Figure

38), under a specific level of green demand. This is explained by the fact that, with higher number of customers, there are on average more customers for each retailer in the network, then small changes in the customers' demand towards green products, are not affecting the retailers' profit enough to stimulate their adaptation and change of strategy. Even if a few retailers are initially stimulated to adapt and then succeed, the amount of profit loss that their movement cause for other retailers is often not too critical to cause further movements of retailers of the network.

The high variation in the greening of the retailers in settings with 300 and 500 customers (the grey and yellow boxes of the chart in figure 38), show that even when 50% and 80% of the customers are green, still there are high chance that no greening happens in the network (among 80 simulation runs there are some of them in which no retailer goes green). Only when all the customers are green that the push of green demand is high enough (everyone prefers non-brown product) that initial movements of the few retailers can keep stimulating further need for adaptation among other retailers as well.

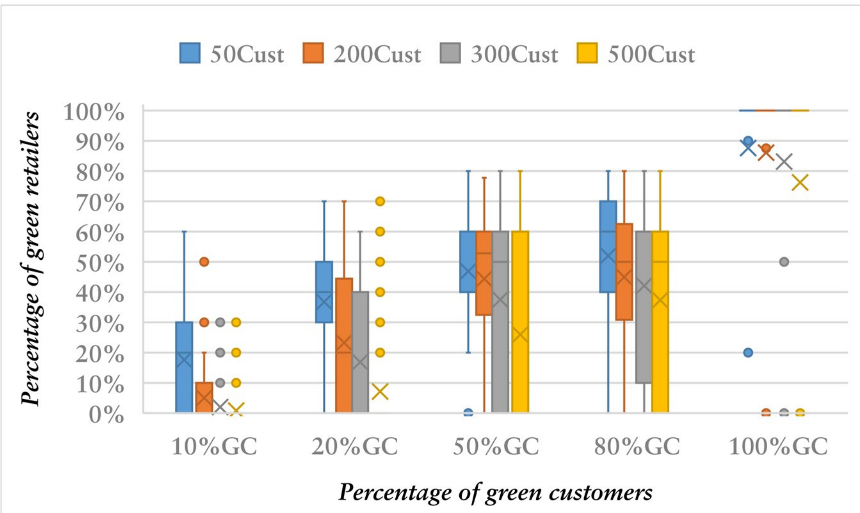

Figure 38. The level of supply networks greening by the end of 52 periods, under different shares of green demand and different number of customers in the network

The same analysis is applicable to the observed results of the supply network restructuring (Figure 39). At lower levels of *GC%* networks with less customers face more restructuring than a network with smaller customer size as more retailers are affected by the greening of customers' demand. The differences between networks with different number of customers diminishes as the green demand increases. This happens because the customers' pressure is big enough to stimulate more retailers.

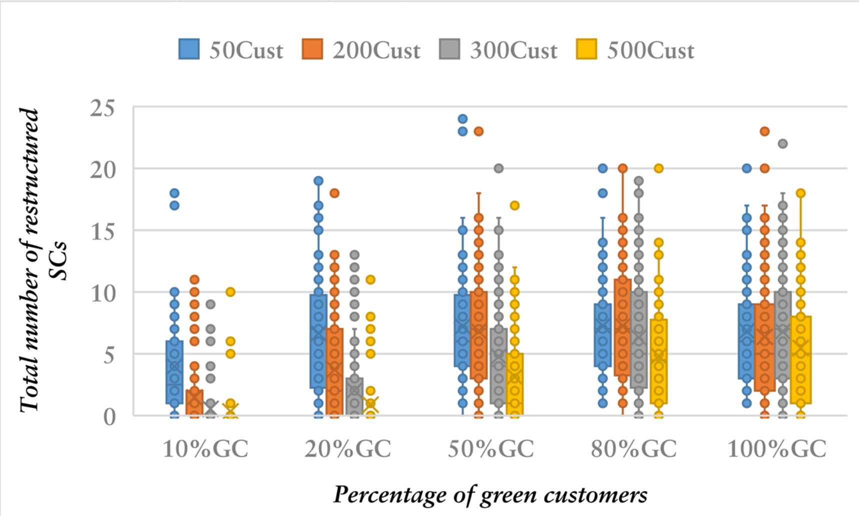

Figure 39. Total number of supply chain restructuring by the end of 52 periods, under different shares of green demand and different number of customers in the network

This conjecture on the explanation of the observed outcome, can lead us to consider the possibility of the ratio of the number of customers to the number of retailers, being an influential factor. Hence, I hypothesized that with higher ratios (more customers on average for each retailer), low levels of green demand, cannot be sufficient to stimulate enough retailers to adapt. To explore this, in another set of experiments the number of customers is held constant (to the baseline value) and then I vary the number of retailers with 5 values of {10 (baseline), 11, 12, 13, 14} (considering that the number of wholesalers and farmers are 15, the maximum possible number of retailers can be 14). It is expected that since in the network with more retailers (e.g. 14), the ratio is smaller than a network with less retailers (e.g. 10), the greening of the network and its restructuring should be more (in lower percentage of green demand) as, the customers' greening is more likely to affect the profit of more retailers.

Figure 40 shows the results of experiment with settings of five different values for the number of retailers (including the baseline value of the parameter)[5]. The percentage of the retailers' who go green does not vary significantly between the settings (which also means that more retailers go green in networks with higher number of retailers).

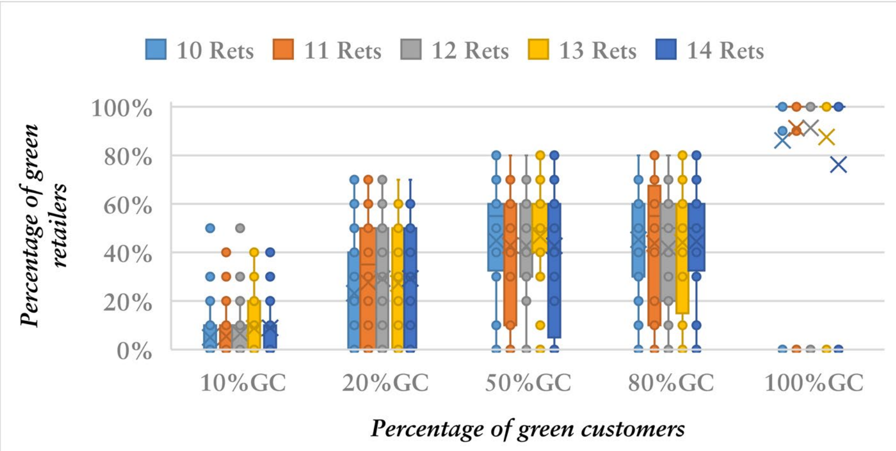

Figure 40. The level of supply networks greening by the end of 52 periods, under different shares of green demand(GC) and different number of retailers in the network (15 wholesaler and farmers)

Figure 41 shows the supply network restructuring of different experimental settings. As the number of retailers (and hence supply chains) are different in each setting, in order to be able to compare the settings better, the average number of terminated supply chains per survived retailer is depicted (instead of the sum of all restructurings). The differences between the settings under low levels of green demand are not significant. In higher levels of green demand (50%, 80% and 100%) I start to see a decreasing pattern of the network restructuring. This is contrary to what was expected from my hypothesis on the effect of the ratio of the number of customers to the number of retailers. If my conjecture was right, then I should

[5] To save space and for better representation of the results, the short for of "Retailer" in the form of "Ret" is used in the diagrams of these sections.

have seen that in networks with more retailers (lower ratio), there were more greening among retailers and more restructuring of the network.

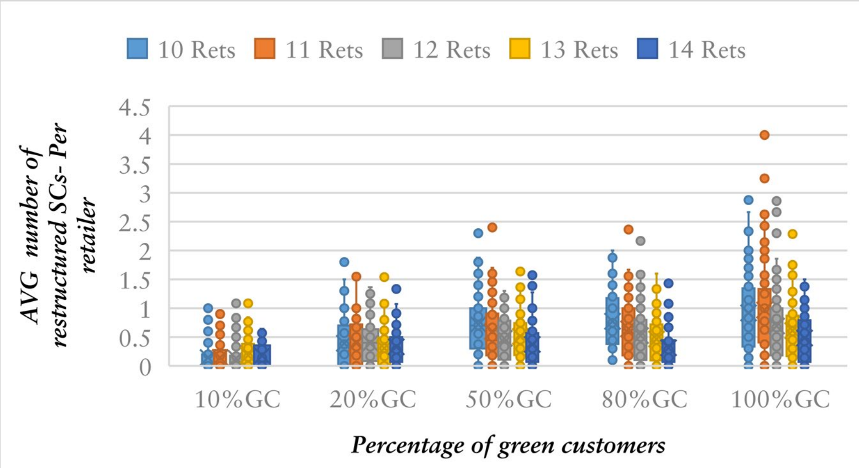

Figure 41. The average number of restructured supply chains per retailer by the end of 52 periods, under different share of green demand and different number of customers in the network (15 wholesaler and farmers)

To explore the reason of this behaviour, I followed the retailer agents of the model in different settings and realized that as was expected from my conjecture, in the setting with 14 retailers, more retailers were affected by the green customer demands. In other words, there were more retailers being stimulated to adapt to the changed demand of customers. However, they often did not manage to change their segments as much as expected because they were being limited by their supply chains, since in these settings the number of available wholesaler options are limited (a network with 15 wholesalers, 15 farmers and 14 retailers, imply that 14 of the wholesalers and farmers are already in a relationship and only one wholesaler and one farmer is available). I.e. even most of the retailers decide to change their segment and also restructure their supply chains by connecting to a new set of partners, at each period at most one of them can do so, because only one wholesaler and farmer are available. Figure 42 depicts the average number of triggered retailers (those retailers who have lost profit more than they can tolerate- *SPL*) in each period, under the baseline parameter values of 15 wholesalers (and farmers), *SPL*=0.15 and 200 customers.

Considering the mechanisms through which the greening of the customers' demand affects the retailers, it is clear that the number of customers, retailers and the retailer's sensitivity to profit loss are the three most important factors defining the average number of retailers being triggered to change their segments. The low values of the average number of triggered retailers in the later periods is not due to bankruptcies, i.e. there are at least half of the retailers who are still active in the final periods.

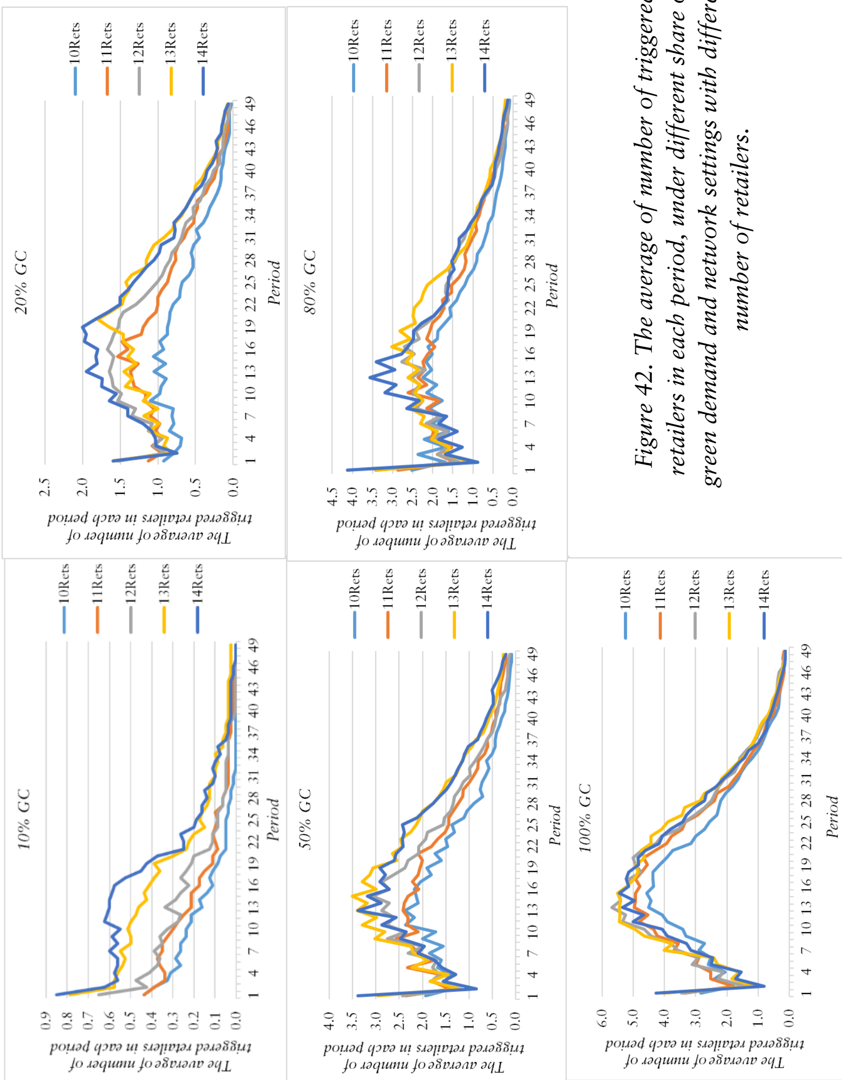

Figure 42. The average of number of triggered retailers in each period, under different share of green demand and network settings with different number of retailers.

Figure 42 shows the higher number of stimulated retailers when the green demand is higher and when there are more retailers in the network. Specifically, at higher levels of green demand (50%-100% *GC*), one should notice the maximum average number of stimulated retailers. E.g. in 80%

GC, the maximum number of simulated retailers for a network with 10 retailers is about 2.5 and for a network with 14 retailers is about 3.5. Considering that there are only 15 wholesalers (and 15 farmers) in the network, at any period of a network with more retailers, there is a higher chance that the number of retailers who want to change the supply chains (i.e. their wholesaler) is more than the number of available wholesalers. Hence, the restructuring that happens in a period is less than what is expected for example from a network with higher number of available wholesalers. I.e. the low availability of the partners is hampering the structural changes and a retailer may need to keep working with the same wholesalers for some time even if the strength of the relationships is not good. That is the reason for observing lower structural changes even when the ratio of the number of customers to the number of retailers (which represents the number of stimulated retailers) is lower (in the setting with 14 retailers).

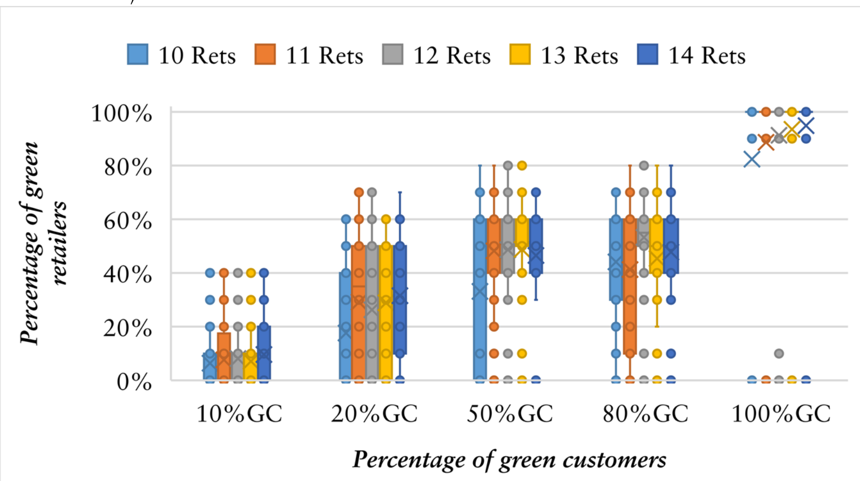

Figure 43. The level of supply networks greening by the end of 52 periods, under different share of green demand and different number of retailers in the network (20 wholesalers and farmers)

These observations naturally lead us to the next set of experiments on the influence of the number of wholesalers (and farmers) in the network, while already giving us an idea of the interaction effects existing between the number of customers, retailers, wholesalers and farmers in the network which may affect the emergent changes in the network. Next, I repeat the above experiments with varying number of retailers (varying ratio) while changing the number of wholesalers and farmers to 20 (instead of 15). This time giving the retailers of the network, enough available wholesalers and farmers and see whether the expected pattern of increased greening and restructuring happens with decreased ratio or not.

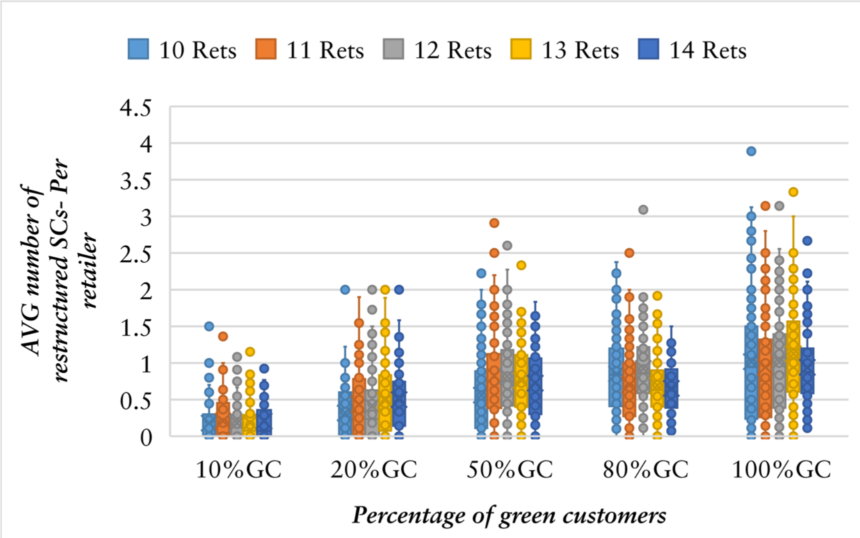

Figure 44. The average number of restructured supply chains per retailer by the end of 52 periods, under different share of green demand and different number of customers in the network (20 wholesaler and farmers)

The differences in terms of the percentage of the network's greening is similar to the settings with 15 wholesalers and insignificant (Figure 43). In terms of the network restructuring (Figure 44) I do not anymore see the decreasing number of restructurings in network with more retailers because now most of the retailers who may want to move in one period (which in the worst case, happens in a network with 14 retailer and 100% *GC*, is maximum 6 retailers) may manage to do so because there are 20-14=6 available wholesalers (and farmers) in each period. Still, unlike the initial conjecture on the effect of the ratio of the number of customers to the number of retailers, no significant difference between these setting is observed. My initial conjecture then only holds for settings with largely different ratios. In test with constant number of retailers and varying number of customers, the settings I tested have very different ratios values

(5, 20,30 and 50 - see Table 20) while in settings where I varied the number of retailers, the differences between the settings is not significant (14.3, 15.4, 16.7, 18.2 and 20) (if there are enough available wholesaler in the network).

Stylized fact: keeping other conditions the same, there are interaction effects between the number of customers, retailers, wholesalers and farmers which may influence the extent of restructurings and greening that we observe in the network. When the ratio of the number of customers to the number of retailers in a network is very different from another network, then the network with higher ratio may face less restructuring with greening of the customers' demand. However, when the ratio of the number of customers to the number of retailers in a network is not very different from another network, the two networks face similar levels of restructuring if there are enough wholesalers and farmer options available in the network. Otherwise, the number of wholesalers works as a limiting factor, and can lead to less restructuring in the network with less available wholesalers and farmers (generally a smaller number of wholesalers and farmers).

Varying the number of customers	50/10=5	200/10=20	300/10=30	500/10=50	
Varying the number of retailers	200/14=14.3	200/13=15.4	200/12=16.7	200/11=18.2	200/10=20

Table 20. The ratio of the number of customers to the number of retailers

Supply Side Interactions

As explained in previous sections on model specifications, the initial strength of the relationships in the supply network on which the change trigger (the customers' demand shift) is imposed, is a main factor in the decision making of various business actors involved in the model. I.e. the strength of the relationships of the business network is the important factor affecting the interactions and possible adaptations happening in the supply side in response to changes imposed from the demand side. Moreover, it gives us the opportunity of exploring the consequences of various combinations of these relationships' strengths on the change process that the network goes through. How actors' responses to the shifts in customers demand may lead to emergence of different results if the supply network comprises of weak (or newly formed), strong (long-term) or moderate relationships? What if retailers (wholesalers) have strong relationships only with a very few numbers of wholesalers (farmers) (which can be interpreted as the relative positions of the wholesalers vis-à-vis each other as possible suppliers of a specific retailer). In the following paragraphs, these questions are explored.

Initial strength of business relationships

A basic assumption of the model is that all pairs of actors, i.e. retailer-wholesaler links and wholesaler-farmer links, are initially weak, and homogenous meaning that initially all relationships have the same strength. The weak strength of a relationship is numerically represented in the model with the minimum value of the *RS* parameter (*RS*=1). To understand how different results may emerge if the initial values of the relationship strengths are different, a set of experimental settings are defined and tested. Other than the baseline value of *RS*, four other values of [3,5,7,9] are tested in four different experiments (Table 21).

Figure 45 and 46 illustrate the supply network's greening (percentage of green retailers by the end of 52 interaction periods) and the total number of restructuring happening in supply chains under various percentages of green customer demand. The general pattern of increase in greening of the supply network in response to the greening of the customer demand with various initial strength of the actors' relationships is observable. However, the differences between the supply network's greening of networks with different initial *RS* are not significant. However, if we consider the process of greening (in Figure 47), it becomes clear that although by the end of 52 periods of agents' interactions in all settings and under certain level of green customers, networks reach approximately similar levels of greening, but the rate at which these greening emerges in the supply networks depends on the strengths of the relationships in the supply network.

Table 21. Initial RS experimental settings

Experimental settings	Description	Strength of the relationships
All [1]	All potential relationships of the network are initially very weak (*RS*=1)	Very low (newly formed relationships)
All [3]	All potential relationships of the network are initially weak (*RS*=3)	Low
All [5]	The Initial strength of all potential relationships of the network are moderate (*RS*=5)	Moderate
All [7]	Initially all potential relationships of the network are relatively strong (*RS*=7)	High
All [9]	Initially all potential relationships of the network are very strong (*RS*=9)	Very high (developed relationships)

Shared parameter values: 200 customers, 10 Retailers, 15 wholesaler and 15 farmers, 15% sensitivity to profit loss

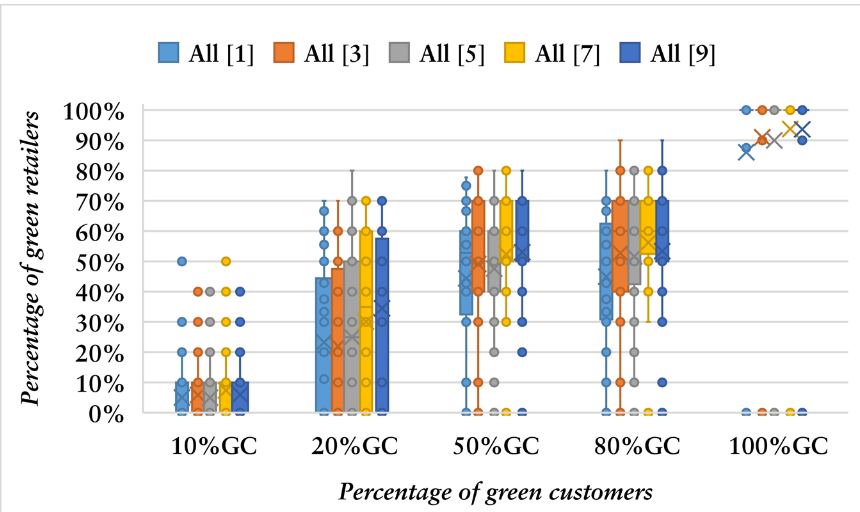

Figure 45. The level of supply networks greening by the end of 52 periods, under different shares of green demand and different initial strength of the relationships in the network

Figure 47 illustrates that networks with stronger relationships are much faster in adapting to the shifts in the customers' demand. Weaker ties between the partners in the supply network hamper and slow down the retailers' adaptation to the customers' demand since, the chance of partners' adaptations to the change requests are lower. Hence, it takes longer for networks with weak relationships to adapt to the customers' demand. The stronger relationships instead, proceed faster in this process.

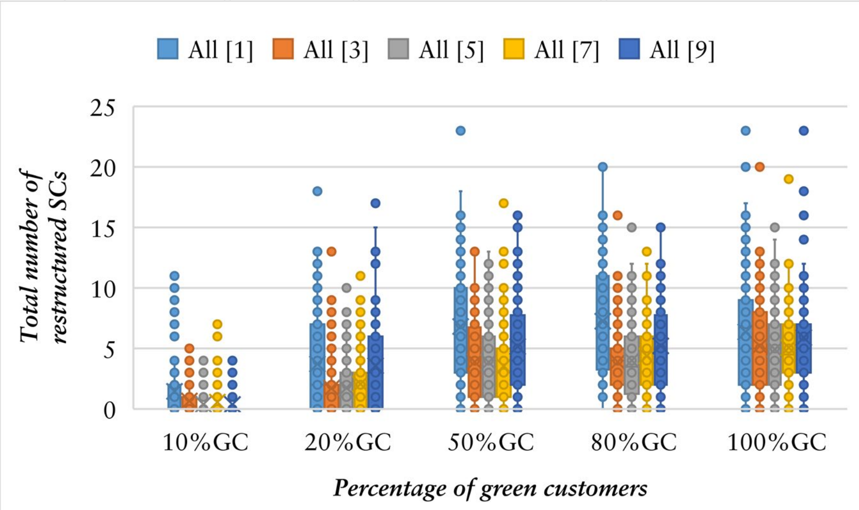

Figure 46. The total number of restructured supply chains by the end of 52 periods, under different share of green demand and different initial strength of the relationships in the network

Network structure also changes more when more customers go green (Figure 46). In all initial *RS* settings of {1,3,5,7,9} the restructuring of the network is significantly wide spread when green customers are dominant (more than 50% *GC*) compared to the restructuring of the network with less green customers. The differences between settings in terms of the network restructuring are not significant either, except for the setting in which the relationships are initially weak (*RS*=1). In this setting as expected, weak relationships lead to more structural changes in the network. This outcome could be expected since with weaker relationships, the chance of adaptation of the supply chain partners to the retailers' request is lower, hence over time, retailers need to restructure their supply chains more frequently, to find partners with which they can adapt to the customers' changed demand.

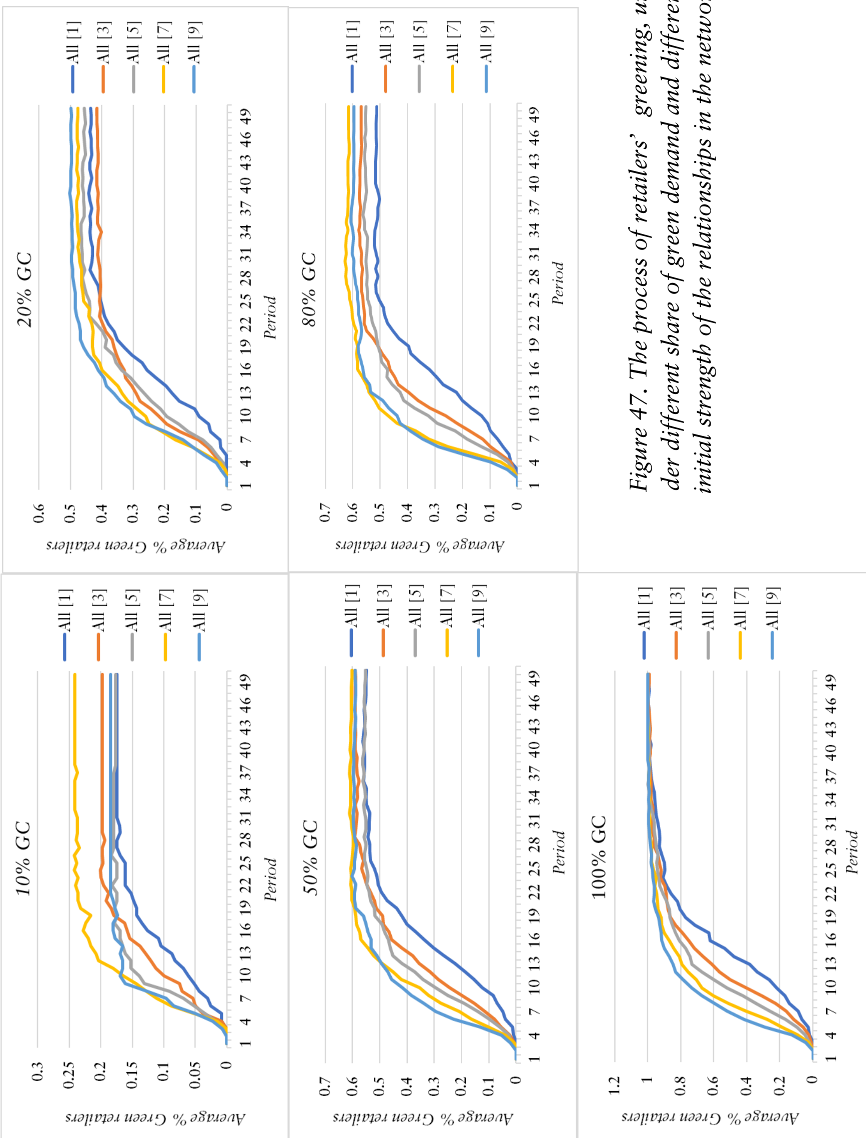

Figure 47. The process of retailers' greening, under different share of green demand and different initial strength of the relationships in the network

For a better understanding, Figure 48, shows a general pattern of the restructuring of supply chains over time. The setting with very weak initial relationship strengths, there are more changes in the structure of the network specifically in the earlier periods (compared to the rest of the settings), until the supply chains begin to settle and consolidate their relationships.

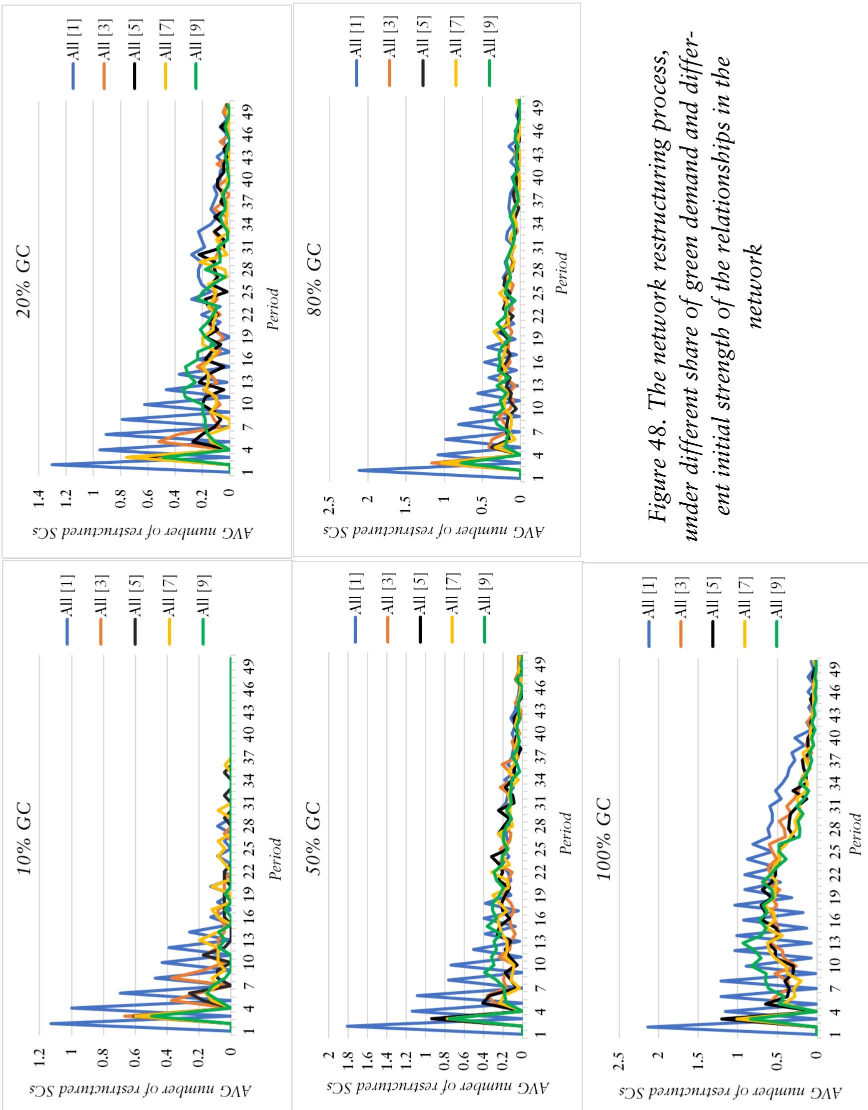

Figure 48. The network restructuring process, under different share of green demand and different initial strength of the relationships in the network

Stylized facts: In terms of the hypotheses of the causal model, the above results show that more pressure from customers' green demand (higher *GC%*) lead to more restructuring of the supply network and higher percentages of green retailers in the network. The role of the initial strengths of the relationships of the network as the moderating factor does not significantly affect the level of supply network's greening, rather it makes a difference in terms of the rate at which retailers' go green (adapt to the customers). With stronger relationships, the supply network becomes green at a faster rate. Moreover, networks with very weak relationships may go through more restructuring to adapt to same level of green customer demand.

Relational embeddedness of business actors

So far it has been assumed that the strength of the relationships of a single business agent are initially the same (and under the baseline setting, also low) with all possible partners. One can think of the baseline setting where all relationships are weak and not developed, as a setting in which the business actors are not relationally well embedded (Tate et al., 2013). On the other side, if the initial relationship strengths are all high for all possible relationships, then the agents are highly embedded in the network. However, other possible relational settings which may also be closer to reality, can be thought of, if we assume that a business actor has strong and well-developed relationships with only a few suppliers. These settings are explored in this subsection in terms of the outcomes of interest in this research. Four different settings are designed in a way that each retailer agent initially has one best, two best, $N_W/2$ best and N_W best relationships with its possible wholesalers (N_W is the number of wholesalers in the network). For example, considering the initial baseline settings of all other parameters and variables, when the simulation starts:

- A retailer (wholesaler) may have a relationship strength of 5 with one of the wholesalers (farmers) and 1 with the rest of wholesalers (farmers) of the network
- A retailer (wholesaler) may have a relationship strength of 5 with two of the wholesalers (farmers) and 1 with the rest of wholesalers (farmers) of the network

- A retailer (wholesaler) may have a relationship strength of 5 with seven (almost half) of the wholesalers (farmers) and 1 with the rest of wholesalers (farmers) of the network (*Half best-[5]* setting)
- A retailer (wholesaler) may have a relationship strength of 5 with all of the wholesalers (farmers) of the network (this setting was tested in the previous subsection).

Each of the above settings are tested below to explore possible differences in the emergent changes of the network.

Figure 49 shows the greening percentage of the retailers under each relational embeddedness setting with specific shares of green customers in the market. Other than the general pattern of increasing network greening with more green customers in each setting, the settings are not significantly different in terms of the level of supply network's greening.

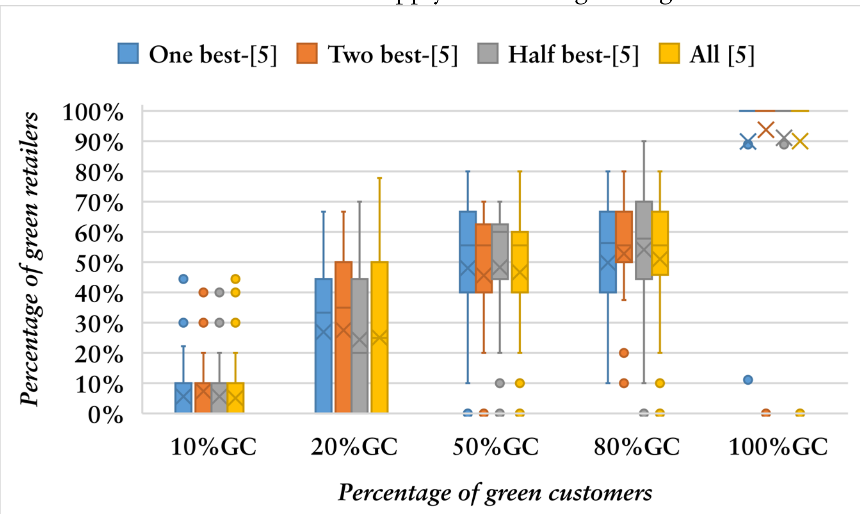

Figure 49. The level of supply networks greening by the end of 52 periods, under different share of green demand and network setting with different initial relational embeddedness

Figure 50 compares different settings in terms of the restructurings that happen in the network. The structural changes in networks where the retailers (and wholesalers) have a few strong relationships (*One best-[5]* and *Two Best-[5]* settings) by the time the customers' demand go green, are less than networks where there are many strong relationships (*Half* *best[5]* and *All [5]* settings). The differences are more visible when there are more customers going green. To understand the reason of this behaviour of the network, the average periodic restructuring of the networks over 80 repetitions of 52 periods of interactions in the network are shown in Figure 51 for various levels of green customers.

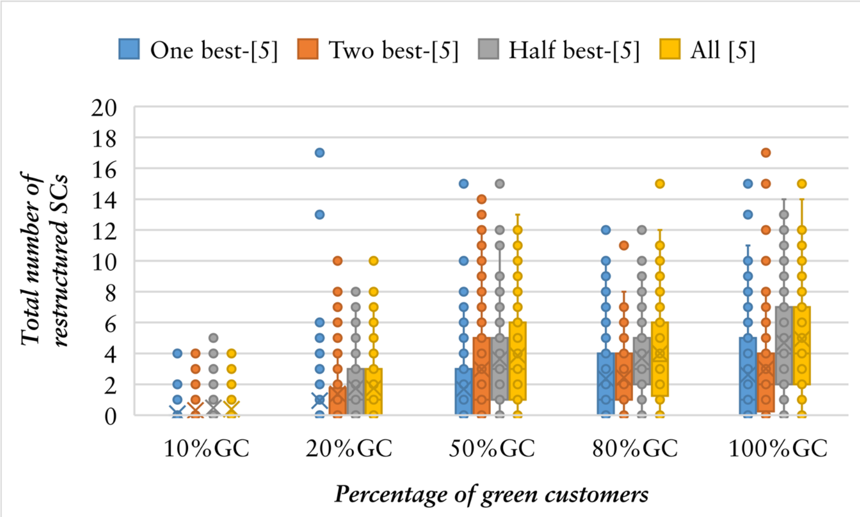

Figure 50. The total number of network restructurings by the end of 52 periods, under different share of green demand and network setting with different initial relational embeddedness

Following the agents under each setting and in line with the patterns observed in Figure 51 in settings with a few numbers of initially strong relationships, retailers start any possible restructuring of their supply chains in a slower process. The strength of those one/two best relationships of the retailers with wholesalers is relatively higher than the retailers' relationship strength with other wholesalers. For some periods following the greening of the customers' demand, the retailers keep working with those best wholesalers and try to negotiate their adaptations in line with the retailers' change of strategy (segment). Only after getting some resistance from those wholesalers and when the strengths of those relationships are low enough that the retailer may finally restructure its supply chains. This process can be interpreted from charts in Figure 51 where the number of terminated supply chains is low in early periods and starts to vary more as time proceeds in later periods.

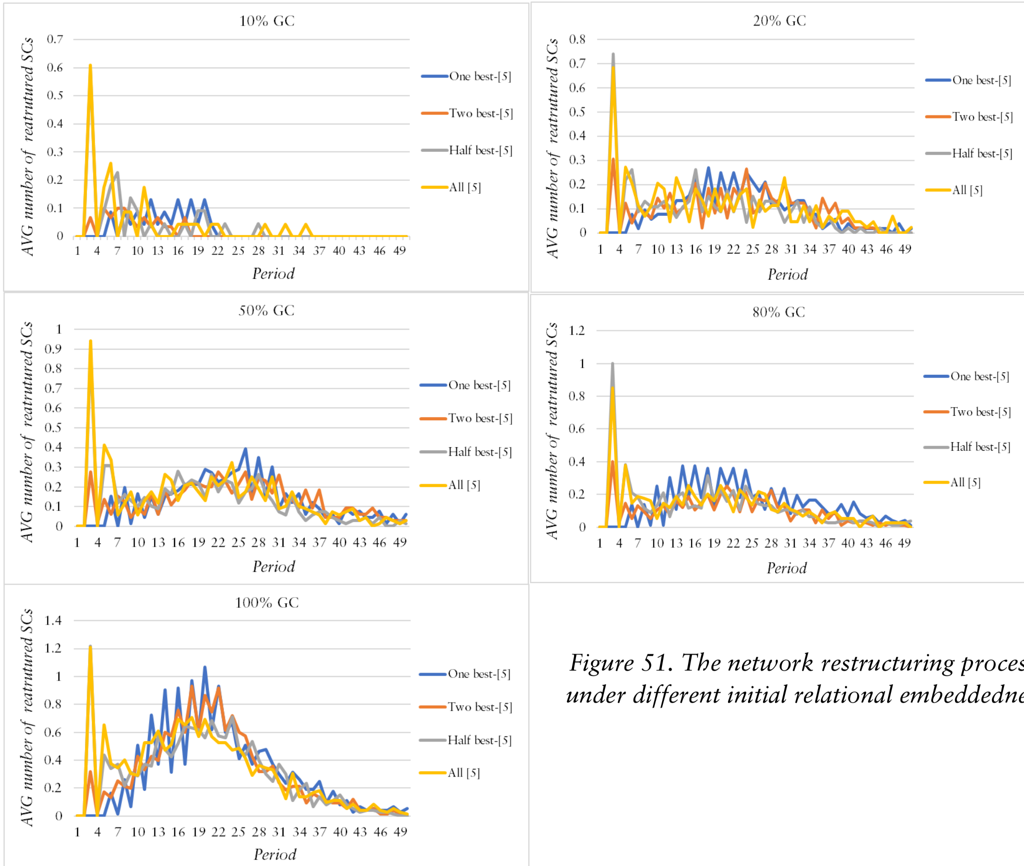

Figure 51. The network restructuring process, under different initial relational embeddedness

For settings with more strong relationships (in settings *Half best-[5]* and *All [5]*), the network behaves differently. The retailers initially have strong relationships with many wholesalers. Any resistance to adaptation from the retailers' current wholesalers, lowers the strength of the relationship in a way that the retailer then has better other wholesalers to connect with (remember the mechanism of changing partners where the retailer restructure its supply chain any time that it realize it can have a stronger relationship with a wholesaler other than the current one). In other words, many initially strong relationships of the retailers, put the corresponding wholesalers in a competitive position vis-à-vis each other. This process makes the supply chains volatile since the retailers keep changing their supply chains more often in order to be able to form stronger relationships and adapting to the customers' demand. Hence, the supply networks restructuring is more in these kinds of networks.

Then looking at the average percentage of green retailers over time, following the greening of demand in Figure 52 confirms the above explanation since the process of greening seem to be slightly faster in networks with only a few initially strong relationships. The higher number of strong relationships in settings *Half best-[5]* and *All [5],* makes the network more volatile and hence the retailers are slower in adapting to the customers' demand since some time is wasted by constant changes of partners before starting to settle.

Stylized facts: The networks in which the business actors have many strong relationships do not have different levels of greening from the networks in which the actors have a few strong relationships. However, they may reach a specific level of greening at a slower pace. Moreover, the networks with many strong relationships go through more restructuring to adapt to a certain level of customer's greening. Most of the restructuring of these networks happen in earlier periods following the customers' demand shift towards green products, while in networks where retailers have only a few strong relationships, the major restructurings happen in later periods.

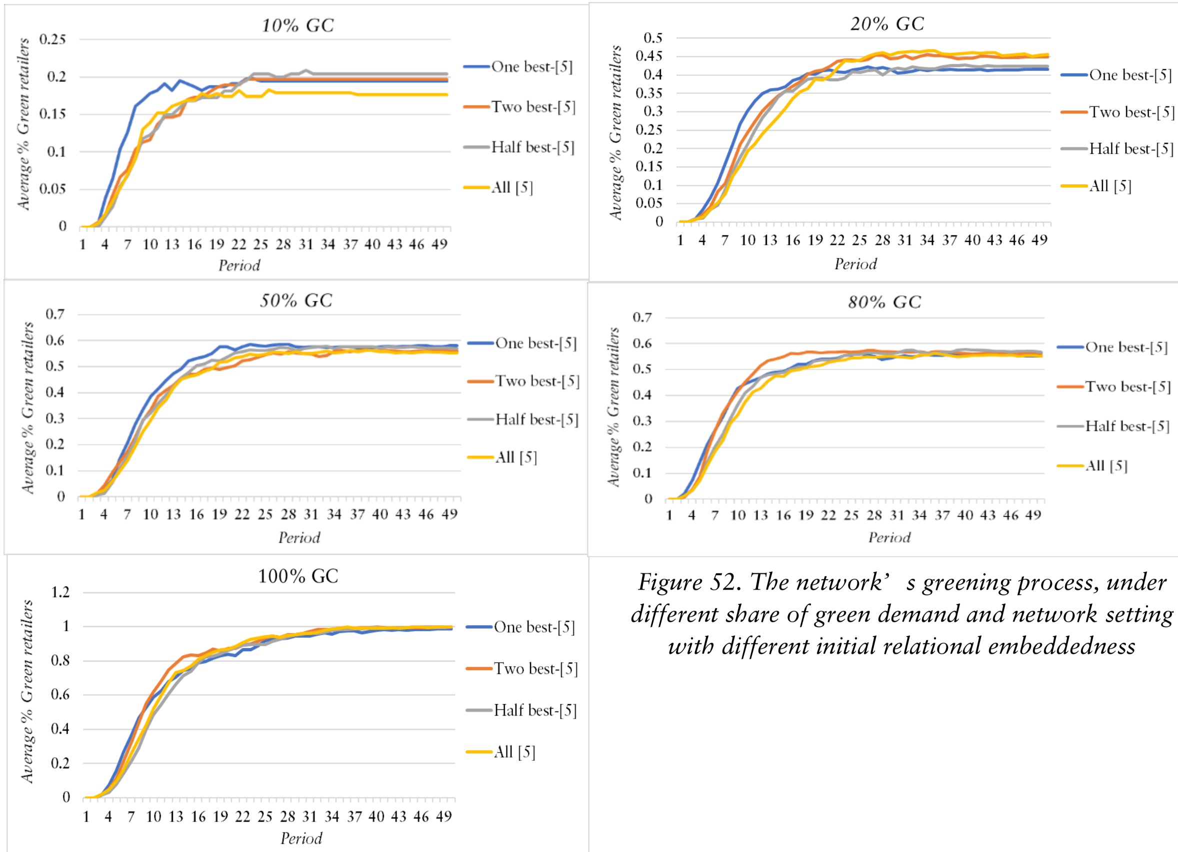

Figure 52. The network' s greening process, under different share of green demand and network setting with different initial relational embeddedness

6 Discussion & Conclusions

6.1 Discussions and conclusions

As indicated earlier in the thesis, the purpose of this research has been to better understand the structural changes that emerge in business networks in response to the endogenous and exogenous triggers.

Given this setting and as elaborated in the Introduction chapter the following research questions are formulated:

1. How can the structure of a business network evolve over time as a result of endogenous and exogenous change triggers?
2. What moderating factors may influence the process and its outcomes?

Departing from Industrial Network Approach (INA) and dynamics in business networks, due to connectedness and interdependencies between business actors and relationships, actors' responses to certain triggers may lead to the emergence of changes in the network structure. Each actor may be directly or indirectly affected by these triggers. Then depending on its perception of the trigger, actors respond and react to these triggers or their effect through interacting with others (e.g. Abrahamsen et al., 2011; Corsaro & Snehota, 2012; Kragh & Andersen, 2009). These responses may be in the form of adjusting their business ties. The connectivity and interdependencies existing in business networks then invoke further responses of the actors (Halinen et al., 1999). Hence, changes may spread to various levels of the network (other individual actors, dyads or the whole network) and affect actor bond, resources ties and activity links in those levels (Hulthén & Mattsson, 2010). For an integrated understanding of all these actor responses and interdependencies and the structural changes that arise, one needs to adopt perspectives which can account for the simultaneous influence of these complexities, connected influences (directly/indirectly) coming from various actors and relationships and the feedback effects that emerge.

Adopting the Complexity perspective, the above specifications of interactions in business networks and their dynamics can be viewed as Complex Adaptive Systems(CAS) comprising of a set of connected autonomous components (business actors) who are constantly interacting with each other and adapting to their environment (the business network context) (e.g., Easton et al.,1997; Wilkinson, 2006; Wilkinson and Young, 2013).

Adopting this perspective, I can then view the structural changes of a network as the macro-level phenomena that emerge from micro-level actor responses and interactions in non-linear and self-organized processes (Schelling, 1978).

Departing from INA and Complexity perspective, I approach the purpose of the research -understanding business network dynamics- by building Agent-based Models of business network and exploring their dynamics in different computational experiments. Agent-based Modelling and simulation is the common methodology adopted to study CASs in various scientific fields. The reason is that the underlying assumptions of this methodology match the features of CASs.

In this thesis, I approach the research questions of the thesis in two parts and focus on the structural changes of business networks in two cases. Building on the theoretical foundations of the thesis, two Agent-based computational models are developed in which I explore some of the theoretical properties of the two cases by formalizing the assumptions of the system in those models and testing them through computational experiments The results of the experiments assist me in answering the research questions of the thesis and fulfilling the purpose of the research.

In the following paragraphs I refer back to my research questions and discuss them based on the results of theoretical explorations conducted with the help of computational experiments. Given the empirical (the SFL case) and theoretical (the food supply network case) context delineated in this thesis and the theoretical lenses of INA and Complexity Perspective, I propose that the following patterns and structural changes emerge in those networks. Also, beyond these prepositions and as was also the case in the analysis section of each case, the following results are accompanied with potential explanations. Since, the identified outcomes and patterns have *emerged* or more specifically are generated by the mechanisms that are implemented in the model, the model itself and the mechanisms underlying it are explaining the outcomes. Some of these explanations are more evident from the beginning while others are achieved by more follow-up exploration and experiments conducted with the model. All these are the contributions of the methodological approach that is adopted in this thesis.

6.1.1 Research question 1

How can the structure of a business network evolve over time as a result of endogenous and exogenous change triggers?

In this thesis I have illustrated that, due to the business actors' embeddedness (Halinen & Törnroos, 1998) in the highly interactive network of relationships, actors' responses to various triggers, lead to different levels of structural changes in the network. I.e. patterns of the actors' connections in the network may change because actors' interactive responses over time may lead to establishment of new ties and termination of old ones. These changes emerge in a rather non-linear and self-organized processes that may not be easily predictable in advance.

In both cases of the thesis, through my ABMs I illustrate that certain changes in the structure of the networks can be explained by viewing business networks and actors' interactions in terms of the assumption within INA and Complexity Perspective. This is a generative type of explanation meaning that through formalizing some empirical and theoretical assumptions in my ABMs, I *generate* structural changes in the business network (Epstein, 2006). The explanations (which are basically some of the specification of the model and mechanism of the network) may not be the best explanations, still through the model I can theoretically explore them further, identifying the structural changes that emerge under different situations.

Departing from INA and Complexity perspective and partly based on the empirical data, certain elements and assumptions of the business networks are already known. We know that business actors are embedded in a highly interactive and interdependent context (e.g., Halinen & Törnroos, 1998; Tate et al., 2013). We know that certain events such as actors' strategizing or network-external pressures can trigger business actors' responses, these responses may be changes at various levels (actor, relationship and network) and aspects (resources, actors and activities) of the business network (Abrahamsen & Håkansson, 2012; Halinen et al., 1999). Literature within INA inform us about the possible actor response mechanism in business networks (e.g., Abrahamsen & Håkansson, 2012; Easton & Lundgren, 1992; Harrison & Easton, 2002). More importantly, by adopting INA and Complexity perspective, we know that business network's connectivity can lead to further responses and interactions within the network.

What we do not know much about, is the aggregate outcome of various actors' responses specifically the outcomes in terms of changes in the structure of the network through dynamics processes that arise from the actors' interactive responses. This thesis adds to the knowledge within INA on actors' responses (e.g., Easton & Lundgren, 2002). Knowing single actor responses to change (triggers) is not enough for understanding business network dynamics. Considering the connectedness and embeddedness of these responses, dynamics in business networks arise from non-linear interactions of those responses over time.

A few scholars have focused on this level of aggregation and identified certain emerging patterns such as integration or substitution of relationships in networks (Guercini & Runfola, 2012), loosening or reinforcement of the network structure (Madhavan et al. 1998), expansion, strengthening, churning and shrinking of networks (Ahuja et al., 2012). Still we do not know much about the contingencies involved. Moreover, obviously due to the methodological challenges involved in accounting for the interdependencies between various actors' responses, most studies consider a limited number of actors and relationships and often have the perspective of a focal actor within its direct business network. The methodology adopted in this research allows me to go beyond these limitations both in terms of the number of actors, relationships and interdependencies that I capture in my models and in terms of the extent of structural changes that emerge depending on different contextual factors (addressed in the second research question). The issue is approached in two parts in this thesis, through first, an empirically-grounded Agent-based Modelling of a railway operator (SFL) and second, an abstract Agent-based Model of a supply network.

Endogenously triggered structural changes

In the first part of the thesis, SFL's new online auction is considered as the endogenous trigger- a trigger arising from the business actors' strategizing to improve its position within the network. The new auctions system provokes various customer responses in the SFL network of (potential and current) customers. According to INA scholars, actors' intentionality is a force of change and dynamics within business networks (Halinen et al., 1999) which in this case is manifested as a result of SFL's strategizing to enhance its profitability and position within the network. Modelling such a CAS, through my ABM, I show that due to SFL's embeddedness in its business network involving various customers, the introduced auction system, and the consequent *interactive* responses of the customers lead to termination of its current customer relationships or establishment of new ones. This is in line with the focus of Halinen & Törnroos (1998) on embeddedness of actors, relationships and micronets functioning as forces of change.

The heterogeneity of the customers and their responses to this trigger and how each response sets the context for the reactions and interactions of the other customers, determine the process through which the network changes emerge. The interactions of spot customers attending the auctions in a non-linear way, have feedback effects on the interaction setting of those customers as well as their context of interaction with contract customers. These feedback effects are actually the manifestations of two main forces of change underlying business network dynamics, often discussed by INA scholar; embeddedness and connectivity (e.g. Halinen et al., 1999; Halinen & Törnroos, 1998). These interactions, specifically manifested in the prices achieved in the auctions, can over time, create conditions under which the contract customers tend to leave their contracts and join the auction market. Hence business relationships are terminated. The interactions can also lead to conditions under which spot customers are willing to have contracts, hence, new business relationships can potentially be created. Network structural changes the SFL case, in line with the common perspective adopted by other INA scholars is captured by termination or creation of business relationships. The structure of the SFL's network changes when new customer relationships are formed after the introduction of the auction system or when the old customer relationships end. Any of these responses, interactions and changes, at the same time, set the context for further interactions and responses happening in later rounds of the auctions. The model accommodates this circularity of change, when changes in the relationships, lead to changes in the network and vice versa (Halinen et al., 1998). These multi-level flows of dynamics, although acknowledged by INA scholars, are often difficult to capture systematically with case studies specifically when more actors and interdependencies are involved. Formalization of these interdependencies in the ABM of this case and the bottom-up approach underlying this methodology, allows investigation of the circularity of change in the network.

The findings show that, certain features of the interaction context of the customers, lead to emergence of different levels of structural changes in the network. Some conditions leading to larger structural changes in terms of the number of business relationships being created or terminated. These will be further addressed in the second research question.

Exogenously triggered structural changes

In the second part of the thesis, in the abstract model of a food supply network involving a number of retailers, wholesalers and farmers, the shifts in end customers' demand toward sustainable products is focused on as the exogenous trigger- a trigger arising from outside of the defined network boundaries, simultaneously affecting a large number of business actors with no focal business actor organizing the interaction processes.

This thesis adds to the current knowledge of the field in two aspects. First, this rather industry-level perspective in studying business network dynamics is not so common within INA scholars. Multiple levels of embeddedness are being considered simultaneously in this case of the thesis; actor-network, dyad-network, micronet-macronet (Halinen & Törnroos, 1998). Retailers, wholesalers, farmers are all embedded within their supply chains and are capable of decision making. Each pair of connections between that exist between a retailer and a wholesaler and between a wholesaler and a farmer are actually embedded withing their corresponding supply chain (supply triad) and the whole supply network. Then, each supply chain is nested in the overall supply network of the case and its dynamics have implications for the dynamics of the supply network and the lower level relationships and actors within other supply chains. This multilevel approach is possible due to the methodology adopted. Second, end-customers are rarely considered within the business network studies. Demand shifts are acknowledged as exogenous change triggers (Madhavan et al., 1998) but their influences and interactions with business actors are not being considered systematically within INA studies. However, here I adopt an extended view of the supply network and directly take into account the end-customers' influence and their interactions with the supply-side.

The most direct response to changes in the end-customer's demand (exogenous trigger) is retailers' making decision on whether to adapt according to the demand or not. Adopting INA, we know that retailers' embeddedness in business networks (in this theoretical case, this is manifested in terms of the retailer's supply chain involving a wholesaler and a farmer), while generating opportunities, also can be restricting in terms of the retailers' access to resources and the freedom to change partners, activities and resources (Håkansson & Ford, 2002). Hence, retailers' adaptation to end-customers' demand depends on wholesalers' and farmers' responses in terms of adopting more sustainable practices. Although the paradox of opportunities and restrictions that relationships of a firm introduce to it, is well-acknowledged by INA scholars, however, its implications are not explicitly focused on in most studies on business network dynamics (an example of some exceptions being Abrahamsen & Håkansson (2012)). That is the case specifically becasue a focal firm in its network and a limited number of relationships are commonly focused on (e.g., Chou & Zolkiewski, 2012; Guercini & Runfola, 2012; Kamp, 2005). The model of supply network in this thesis, systematically captures such a paradox and can offer a better understanding of the network dynamics by consideration of wider sets of interdependencies.

By making explicit certain theoretically-grounded assumptions, through formalizing them in an ABM, I generate (*explain*) certain levels of structural changes in the network. The model can capture certain mechanisms of business actors' interaction in supply networks which lead to changes in the network structure. With increasing pressure of end-customers' demand shift towards sustainable products, the supply networks may to restructure in order to adapt to the customers' demand. A possible mechanism leading to such restructuring can be as follow: upon perception of the changes in the end-customers' demand, the retailers may decide to adapt in order to stay profitable. Their adaptation is contingent upon their interactions with wholesalers, and wholesalers' interactions with farmers. Each of these actors may respond differently to the adaptation requests imposed on them. Consequently, supply network's actors' interactive responses, collectively and in a non-linear way, with various feedback effects *over time*, cause current supply chain links being broken and new ones being formed. I.e. structure of the supply network changes. All parts of this mechanism are well-known to INA scholars and their various discussion; actors' responsiveness, reactions, interactions, adaptations, network connectivity and multi-level interdependencies (e.g. Håkansson et al., 2009; Håkansson & Snehota, 2017). However, there are a few who actually investigate them and study how this whole mechanism plays out in network dynamics.

The extent of changes which then emerge may vary depending on certain factors, some settings leading to more restructuring than others, under a specific level of change in customers' demand. This will be elaborated later in this section.

Apart from making explicit certain theoretical assumptions that generate structural changes in the network as a result of actors' responses to exogenous triggers, the mechanism of the influence of exogenous triggers can be pointed out in the results as well. INA scholars indicate that often, the exogenous triggers when received and responded to, are actually transformed to some sorts of endogenous triggers (Halinen et al., 1999; Hertz, 1999) and start to internally invoke actors' responses. The model in this thesis illustrates this mechanism of influence, formally and hence informs INA literature in this regard. The pressure of customers' green demand as the exogenous trigger, is imposed on a number of retailers. With retailers' perception of this collective trigger, then more individual endogenous triggers are created by retailers' responses to the shifts in customers' demand. The retailers' perception of these exogenous triggers, determines the type of reactions they show.

The retailer may consider the pressure too high or insignificant and then act accordingly. If the retailer conceives the exogenous pressure as critical, then it initiates further changes through strategizing and changing its segment. This points to an example of processes through which exogenous change triggers are transformed to endogenous ones when responded by the actors and then further changes are invoked. The endogenous triggers which are initially the retailers' strategizing for changing their segments and improve their lost profit, then invok further responses, interactions among the retailer and other business actors on the supply side of the network. These actor interactions are in the form of adapting to partners, terminating the current partnerships and forming new supply chains.

Therefore, under the influence of an endogenous trigger, heterogeneous business actors respond and react. But then due to their embeddedness in a highly connected and interactive network, these reactions and their effect are not isolated. In terms of Complexity perspective, the actors' responses and interactions are the micro level specifications of the system and over time, lead to emergence of changes in the wider network level (macro). Like the first case, in this CAS, then the micro level interactions of the actors are constantly setting the context of further interactions (pointing to the circularity of the change in networks). Then in a non-linear path they lead to emergence of macro level changes in the structure of the whole network.

The fit between the theoretical framework derived from INA and Complexity perspective, with the observed patterns of outcomes from the formalized computational models of the cases, shows the usefulness of the methodology adopted. Developing my models by formalizing the basic theoretical assumption of INA and Complexity perspectives, i.e. the mechanisms, I systematically have generate structural changes in networks (i.e. offered possible explanations) in various computational experiments. In other words, the developed models have captured the complexities of the business actors' interaction in the network as a CAS and can explain the structural changes that emerged in the network.

I can further use the model for theoretical exploration purposes and explore further theoretical properties of business networks as CASs. These explorations are partly conducted in the two cases of this thesis specifically when addressing the second research question. With those models then I start to go deeper in the change processes by exploring the implications of some of these theoretical assumptions and how the process of structural changes in those networks behave differently if those assumptions are changed. Hence, to achieve the purpose of the research and addressing the second research question of the thesis, some the theoretical explorations are then conducted.

6.1.2 Research question 2

What moderating factors may influence this process of change and its outcomes?

There are studies within INA who have identified some actor responses to change (e.g., Easton & Lundgren, 1992; Harrison & Easton, 2002; Veal & Mouzas, 2011; or generally how actors act and network when facing changes (e.g. Abrahamsen & Håkansson, 2012). However, our knowledge of the implications of these responses specifically at the network level is limited. Again, some INA scholars have identified some empirical patterns of change in the network structure which are inherently the implications of interactive responses of actors, such as relational paths of integration and substitution (e.g., Guercini & Runfola, 2012), reinforcement/integration of the networks and weakening/change of the networks (e.g., Andersson & Mölleryd 1999; Madhavan et al. 1998), other patterns of structural change (e.g., Pardo & Mitchel, 2015) or analysis of changes identified in ARA aspects at different levels (e.g., Hulthén & Mattsson, 2010). Still, we have limited understanding of the emergence of such patterns, specifically in terms of the factors that can influence them, their severity and extent of influence or their pace/rate of occurrence. In this thesis, in addressing the second research question I have focused on some of these kinds of factors and their influences.

The moderating factors that I focus on are actually some of the theoretical assumption underlying the modelled networks, which I decided to explore their consequences. Here specifically the contribution of the methodology adopted becomes more visible as it allows systematic experimentations to theoretically explore assumptions and their impacts on the structural changes of the network as the complex phenomena of interest.

Findings discussed above, point out that by viewing business networks as CAS, I can systematically model certain mechanism through which actors' interactive responses to endogenous and exogenous triggers lead to various extents of changes in the structure of the network. To address the second research question, then in both cases I use the model to theoretically explore the implications of some of the underlying assumptions of the models which correspond to specifications of the business actors and their context of interaction.

Generally, the assumptions underlying the processes of structural changes triggered endogenously or exogenously, can be divided in to two interconnected sets of mechanisms that guide the actors' responses and interactions. A set of mechanism are about how a trigger is perceived by the actors in terms of its criticality and significance. Another set of mechanisms follow the assumption that the actors have conceived the trigger as significant and now they should respond. These sets of mechanisms control the actors' responses and processes of interaction, which involve certain individual actor features or certain specifications of the relationships existing among actors or some general conditions of their context of interaction. In each case of the thesis a set of these mechanisms are chosen and further explored to gain better insights into the processes through which the structural changes emerge in the network.

Perception of the change trigger's significance

In the case of the food supply network, the focus is on a set of theoretical assumption of the model which guide both the perceptions of the retailers of the significance of the customers' changed demand and also mechanisms that affect the supply network actors' responses and interactions. Through the computational experiments conducted , I show that the retailers' sensitivity to profit loss as well as the number of each types of supply chain actors (retailers, wholesaler and farmers) make a difference in the network restructurings that are emerging, mainly through affecting the perceptions of the retailers of the significance of customers' greening demand. Certain status of these mechanisms cause situations where the exogenous trigger (customers' greening demand) is perceived more severely by many retailers. These factors are referring to heterogeneity in the web of actors and their compositions which according to Hulthén & Mattsson (2010) are among the main sources of dynamics in distribution networks.

Still, these factors and their influences on the network dynamics are hardly explored by INA scholars. This thesis adds to our understanding of the influence of these network specifications on the emerging dynamics by adopting ABM and simulation.

When there are fewer *Green* customers than *Brown* customers, differences in the level of retailers' sensitivity to profit-loss in two different supply networks lead to different levels of network greening and structural changes. The increasing greening of the network with increasing number of *Green* customers is more visible when the retailers are more sensitive to loss of profit. Put in other words, in networks with less sensitive retailers to profit loss (which may be associated with the size and profitability of the retailer), increasing the share of green customers, has lower impact on the greening of the supply network and the amount of restructuring happening in the network. Moreover, as was expected, the greening process of the supply network is slower in networks with less sensitive retailers to profit-loss. The sensitivity to profit loss may be partly related to the size of the retailers. Then in networks with larger retailers, large levels of customers' greening are needed for the supply network's adaptation towards sustainability.

The number of customers, retailers, wholesalers and farmers are other factors which are shown to affect the extent of influence of customers' greening on the retailers' perception of the severity of the change and consequently the restructuring of the supply network.

Generally, the ratio of the number of customers to the number of retailers in the network, is an influencing factor for the emergent changes in the network. Networks with very different ratios, face different levels of structural changes when there are fewer *Green* customers than *Brown* customers, i.e. when customers' greening is not yet widespread. With more and more greening of customers' demand, the differences between networks with different numbers of customers and retailers diminish.

In networks where there are on average many customers per retailer (high ratio), less structural changes emerge compared to networks where there are few customers for each retailer (low ratio). This is because in the former, the greening of customers' demand does not affect the retailers' profit enough to stimulate their adaptation and change of strategy. Even if a few retailers are initially stimulated to adapt and then succeed, the amount of profit loss that their movement cause for other retailers is often not too critical to cause further movements of retailers of the network. Hence, less structural changes emerge in the network.

However, if the ratios of the number of customers to the number of retailers of two networks are not very different, those networks face similar levels of restructuring (i.e. the ratio is not a significant factor in the process) if there are *enough* wholesalers and farmers in the supply network. In other words, for the organizing to take place the requisite variety must be reached (Ashby, 1956). If there not enough wholesalers and farmers in the network, an opposite trend is observed. The number of wholesales and farmers then works as a limiting factor and can lead to less restructuring in the network with less available wholesalers and farmers. I.e. in networks with more retailers and specifically when green demands are higher (higher *GC%*), although more retailers are stimulated by their profit-loss to adapt to the customers' greening, but due to low availability of supply chain partners -wholesalers and farmers- only a few of those stimulated retailers manage to adapt. Hence, less restructuring than what was expected is observed in the network.

To sum up, retailers' sensitivity to profit-loss as well as the interaction effect between the number customers, retailers, wholesalers and farmers existing in the supply network, are among the factors that influence the perception of the supply networks' actors of the severity of the greening of customers' demand and hence their adoption of sustainability and consequently the structural changes that emerge in the network. When the retailers' sensitivity to profit loss is high and there are few customers on average per retailer (low ratio of the number of customers to the number of retailers) and the number of wholesalers and farmers existing in the network are enough then, many retailers are stimulated to adapt to the customers' demand by adapting their supply chains (transformation of exogenous trigger to endogenous triggers). Moreover, the structural changes of the supply network are also more sever.

Actors' responses and interaction processes in the supply network

In the SFL-case, the composition of the market to which the SFL's new online solution is introduced is the specific mechanism to study. The composition of the network is about the *actor-level* features of the customers, existing in the network of SFL. These features include the size of their demand, their risk aversion and sensitivity of their preferred delivery time of their wagons. These actually stand as one set of assumptions underlying the formalized networks which I chose to study their implications for the emerging change process and its outcomes. A set of computational experiments, then show that various shares of customers with specific levels of demand, risk aversion and time sensitivity, lead to different patterns of structural changes in the network under the endogenous trigger. I.e. the market composition in terms of the types of (potential) customers existing in network in which SFL is embedded has a moderating effect on the extent of structural changes that emerge from the actors' interactive responses to the auction system (endogenous trigger of the case).

Two sets of experiments are conducted. The findings of the first set of experiments on isolated parameters, show that the demand volume of spot customers, their risk aversion and their flexibility in the delivery time of their shipments influence the extent of structural changes that SFL face after introducing its new auction system:

- structural changes of the network are more sever when the demand volumes of spot customers are lower. A reason identified is that in a network with spot customers who have low demand volumes there are more new contracts being formed (customers with higher demand volumes have to spread their demand between different auctions - train departures - which lead to emergence of higher auction prices and lower willingness/possibility to establish long-term contracts with SFL). Moreover, the emergent low auction prices stimulate the termination of many of the already-established contract relationships.
- structural changes of the network are slightly more in networks with rather risk-averse spot customers. With more risk-averse customers, the emergent auction prices are not low enough to stimulate termination of many contract relationships. Still, the spot customers' interpretation of the auction is good enough for risk-averse customers to start forming contracts with SFL and reducing the uncertainties.
- structural changes of the network are more in networks with customers who are more flexible in the delivery time of their shipments. More flexibility leads to lower auction prices and stimulate termination of already established contracts, still the prices are good enough and stimulate some spot customers to establish contracts with SFL.

These initial results led to identification of two possible clusters of customers in terms of their characteristics of demand volume, risk aversion and delivery-time flexibility. I.e. further exploration of the model leads to a new hypothesis to test: in a network comprising of customers with lower demand volumes, higher risk aversion and more delivery-time flexibility, SFL faces more sever structural changes. The results of experiments show that in networks where this class of customers are the majority, the structure of the network in terms of changes in its ties, alters more.

Hence, the findings illustrated certain mechanisms in interactive responses processes of customers exist that depend on the actor-level features of the customers. These factors, more specifically the composition of the customers in the market -in terms of the features of the customers- moderate the processes through which customers' interactive responses affect the structure of the SFL's network connections.

In the case of the food supply network, a set of underlying assumptions are tested to understand their implications better. These are related to the context in which retailers, wholesalers and farmers are embedded and hence controls their response decisions to each other and their interactions. Specifically, I focus on the relational context of the actors' interaction and the strength of their relationships by the time the customers' demand shifted towards green products. Business relationships and interaction although are principal and well- recognized elements underlying business network's dynamics (e.g., Abrahamsen & Håkansson, 2012; Halinen et al., 1999; Halinen & Törnroos, 1998), but we need more systematic exploration of their features and implications for the network. This work informs INA on possible impacts of more relational features of the relationships on an aggregate level. More specifically the relational embeddedness of the actors in terms of the strength of their relationships are focused on. Tate et al. (2013) in a rather theoretical study, have focused on a similar aspect -within environmental supply chain literature- however, they explore its implications on the diffusion of environmental practices in the networks and propose some hypothesis in this regard, rather than exploring their implications for the dynamics of supply network and their structural changes. Hence, this thesis can also add to their study by expanding their focus further.

The computational experiments conducted in this research show that this feature of their context of interaction can influence the change process (e.g. in terms of the rate of the change) and its outcomes (in terms of the amount of restructuring that happens in the network).

The role of the initial strengths of the relationships of the network as the moderating factor iss explored. The findings across various settings of relationship strength show that the share of *Green* customers is the most important factor to the supply network greening and the extent of emergent changes. Under the same level of green demand, the final supply network's greening does not vary significantly between networks with relationships of different strengths. If we suppose that supply network's greening is to some extent similar to diffusion of environmental practices in supply networks, the results of this research are different from Tate et al. (2013)'s proposition. They propose that supply networks similar to the ones explored in this thesis, are expected to have *moderate* diffusion. The findings of ABM experiments here show that under some circumstances – in this case, the green demand of end customers- the initial strength of business relationships in a supply network does not significantly affect the amount of diffusion that emerge but they can influence the pace of diffusion.

With stronger relationships, the supply network becomes green at a faster rate, since adaptation requests of upstream partners have a lower chance of being positively responded to in weaker relationships. For the same reason, networks with very weak relationships may go through more restructuring to adapt to same level of green customer demand. Differences in the restructuring happening in networks with different initial strengths of ties, are diminished if all customers have gone *Green*.

The relational setting of the actors' interactions is further explored by considering the influence of the *number* of strong relationships that the actors initially have, when the demand-shift happens. Findings show that in supply network setting where each actor has many strong relationships, the processes of actors' responses, interactions and adaptations following the change of customers' demand proceed slower than a network setting where the actors have only a few strong relationships. The explanations offered for any of the observed patterns are in line with the theoretical perspectives adopted. E.g. relevant to the mentioned results on the number of strong relationships that actors have in the supply network, it is realized that many strong relationships have some sort of a non-productive influence, limit the actors' freedom of change and slow down the process of change in the network. This is in line with the network paradox proposed by (Håkansson & Ford, 2002) when they say the relationships of the business actors have both enabling and restricting effects on the actors.

To sum up, certain actor-level features of the business actors in the network (in the first case-SFL) as well as relationship-level and network-level features (in both SFL and food supply network case) of context of actors interaction in the supply network are shown to have an influence on actors' responses and consequently the extent of structural changes that may emerge in networks in reposes to endogenous and exogenous triggers.

In the case of SFL, customers' demand volume, risk-aversion and delivery time flexibility are shown to be influencing factors. Moreover, the influence of composition of the market in terms of the share of different types of customers with different features are explored and shown to be significant.

In the case of the food supply network, the initial strength of the relationships in the supply network as well as the relational embeddedness of the retailers in terms of the number of strong ties that they initially have, influence their responses, the pace of supply network's greening and the consequent structural changes that emerge in the network.

Apart from the theoretical propositions elicited from the simulation results offered above, another contribution here -in relation to the case of the food supply network- is the consideration and modelling of both the supply and demand side and their interactions. Specifically, it is illustrated that how the changes in the end customers' demand can have implications for the business interactions in the supply network. This perspective is often rare within the field where the majority of research is focused on only the business actors and their interactions. To enhance our understanding of the business network dynamics within INA perspective, scholars need to extend the boundaries of the networks and specifically acknowledge the supply-demand interface and its implications for the business network and its interactions. This change in perspective can be methodologically challenging. In this thesis, I have shown that by viewing business networks as CASs and adopting the ABM and simulation, we can capture more interactions and complexities of the business networks when studying their dynamics.

Specifically, within INA, there are few scholars that have focused on structural changes within larger scales of networks -involving more actors and relationships- and they have mainly focused on mergers and acquisitions (e.g., Dahlin & Havila, 2007; Kamp, 2005). Their analyses seem to be limited to counting the number of relationships terminated or created or new actors that join the network or go bankrupt. Not so much is comprehensible from those studies in terms of the mechanisms underlying those widespread structural changes, their dynamics and influencing factors. This is expected considering the methodological limitations of approaching dynamics in such networks. This thesis shows the potential of

ABM methodology in capturing and exploring the dynamics of such networks.

Contributions of this methodology to the field as have been illustrated above, point to the kind of perspective that one can adopt when approaching business network dynamics. As elaborated in the chapter two on Theoretical Backgrounds, INA scholars approach business network dynamics from two points of departure. From a relational view, business networks can be considered as merely a context for business interactions and their embeddedness. Then, the components of the network such as the actors, their relationships and their dynamics are central. From the structural perspective, business networks can be considered as structural entities. Then, the change is an independent variable and its implications for the network structural features are central (Eiriz & Carreiras, 2018; Dahlin and Havila, 2007; Dahlin & Thilenius, 2006; Knoben et al., 2006). With the bottom-up approach that ABMs offer, one can systematically consider the network both as the context and as the structural entity and gain deeper insights into the mechanisms underlying the network dynamics. This opportunity has been exploited and illustrated in this thesis.

6.2 Challenges, Limitations and Future Research

During the processes of design, implementation and analysis the ABMs of this thesis, I faced a number of challenges that most of them are the challenges that are often associated with agent-based models in general.

First, in both cases of SFL and food supply network -where the former is empirically grounded while the latter is theoretically grounded- the main challenge was to find the balance between simplicity and complexity of the models. Too simple models fall short in offering insights to the dynamic processes and may end up modelling only linear processes with no feedbacks- which then one might be able to approach them even without agent-based modelling. With too complex models, other than the challenges in the design and implementation of the model, consideration of too many parameters and feedback loops can lead to problems in analyzing the output data since tracing back the model outputs and trying to explore and understand the mechanisms that initially gave rise to those outcomes becomes almost impossible.

In both ABMs I tried to simplify the reality while incorporating enough complexity and feedback effects so that some levels of dynamics emerge in which I could further explore the implications of the assumptions. A major measure guiding the level of simplifications that I adopted in my models, has been the research questions. Model details and complexities were chosen in a way to make sure that the research questions could be fruitfully approached and explored. For example, in the SFL case, both *contract* customers' and *spot* customers' decisions are highly simplified. *Contract* customers when deciding to end their contracts with SFL and joining the auction, merely decide based on their demand volume, risk aversion and the observed auction prices. In reality, counterparts of a long-term relationship have many more decision factors to consider before ending the relationship, specifically more relational factors. Similar simplifications are made for *spot* customers' decision making as well, when the computational spot customers in my model are distinguished from one another and bid merely based on three actor-level parameters; their demand volume, risk-aversion and delivery time flexibility.

Many simplifications are also made when modelling the food supply network of the second case. The structure of the market delineated in terms of two factors of price and sustainability level, in which retailers, wholesalers and farmers are embedded as well as end-customers choosing their retail stores based on merely these two factors is one of them.

The decisions on balancing simplicity and complexity of the models are closely related to the model validation as well. The simplifying assumptions are chosen in a way to make sure that they are in line with the empirical and theoretical settings of the cases and are valid on face, trying to avoid ad hoc assumptions. The Table 14 in Section 5.2.3.1 of the previous chapter where the theoretical grounding of the model assumptions is illustrated was part of the effort to avoid ad hoc and arbitrary assumptions and model inputs. Moreover, considering the purpose of this thesis being theoretical exploration, as explained in chapter three, subsection 3.3.2.3, this approach to validation is acceptable, still can be improved.

Clearly the type of assumptions that I have chosen to incorporate into my models have restricted the kind of results and conclusions that I could arrive at with my ABMs. To address some of the limitations of model outputs arising from the level of abstraction adopted in the ABMs of this thesis, the models can be extended in future by adoption of more realistic assumptions. For example, in the SFL case, more relational elements can be incorporated in agents' decision making, such as the strength and status of the SFL's relationships with *contract* customers. In the case of the food supply network, the end-customers' purchasing behaviors is rather static, homogenous and simplified with a valuation function that only considers the price and sustainability level of the products. This can be enhanced by incorporating more heterogeneity in end-customers' decision rules, similar to the studies within Consumer Behavior literature.

Moreover, in the current model of the food supply network, the greening of demand is introduced into the model and acknowledged by the retailers in a rather discrete way. I.e. in all experimental settings it is assumed that suddenly in the second period *GC%* of the customers go *Green* and this percentage then stays constant for the rest of the simulation run. However, in reality the shift of customers' demand towards green products happen in a continuous way. Hence, the potential extension of the model can include the greening of customers' demand as a process, starting with a low *GC%* in the early periods of a single simulation run and then increasing this percentage with a specific rate during the same simulation run in later periods.

On the supply side of the network, one can also extend the model by incorporating more heterogeneity among retailers, wholesalers and farmers. Now the only distinguishing factors of the retailers is their market segments (i.e. the price and sustainability level of the products they sell). Other features such as willingness to invest in sustainability and the size of their network (i.e. the extent of their access to wholesalers) can be included in the model as well. Decision rules of the retailers, wholesalers and farmers such as when to change partners, accept requests, etc. are now homogenous within each actor group. More heterogeneity can be introduced in these decisions for each actor group as well.

A second challenge in the research process with my ABMs has been the difficulty involved in analyzing the results. Sometimes due to the complexities of the models (although many simplifications were adopted in the assumptions), I faced the issue of epistemic opacity of agent-based models (Grune-Yanoff & Weirich, 2010; Miller, 2015) and had difficulties in tracing back certain emergent outputs and explaining them. In such cases, the models were run step by step and many agents were closely monitored and different intermediate values of variables were stored and analyzed in order to understand the reasons. For example, I faced this challenge when trying to understand the influence of the number of customers and retailers on the outputs (in previous chapter). Following certain initial experiments, I arrived at a hypothesis that in networks with lower *ratio* of the *number* customers to the *number* of retailers, more structural changes would emerge. However, further test results showed an opposite trend. To explore the reason then I engaged in further experimentations and finally realized that the number of wholesalers and farmers are moderating the results that I was expecting to see and led to a different pattern of outcomes.

Challenges similar to the one above, are the intrinsic part of the theoretical exploration that one does with ABMs, and are actually the process through which one can get deeper insights to the mechanisms involved in emergence of certain results in the system.

Third and related to the challenge above, ABMs often generate large amount of data where the researcher should then know how to use and analyze them to address his/her research questions. Various charts, diagrams, tables, methods of statistical analysis and data representations need to be considered. More specifically, the challenge is then the communication of the results with the reader and most importantly the description of the processes of analysis that were followed. As also stated by Miller (2015), my experience of working with the model and my understanding of its mechanisms as the researcher/modeler is very different from the readers' understanding of the model. I achieved my understanding in an incremental process spanning over months of working and experimenting with the models and their assumptions. Then describing these insights in a systematic way that can be comprehensible by readers of this thesis and probably most importantly since my audience are mainly INA scholars with low or no previous knowledge on this novel methodology, has been very challenging. Related to this issue is also the general current weakness of agent-based modelling community in coming up with a standard way of communicating the model, its specifications and analysis- although recently many advances have been introduced in the community, e.g. ODD Protocol (Grimm et al., 2020).

A limitation of the modelling processes followed in this thesis is related to the results that are discussed considering only a limited number of values for each parameter of the models. I.e. the attained results and analysis are only valid in the context similar to the ones delineated based on the specific theoretical assumptions that I have adopted and for the specific range of parameter settings to which the sensitivity of the results are tested. A complete exploration of the parameter space is missing for the models in this thesis, mainly due to resource-intensiveness of the process. Consequently, the explanations offered for the observed outcome patterns are *candidate* explanations that are *sufficient* to generate certain regularities in the systems that I focused on, and not necessarily the only and the best explanations.

Another limitation of this thesis is the lack of empirical data. ABMs within the business network field are best when they are complemented with case studies (Prenkert, 2012). Then the results and analysis are more insightful. Then both the model input and outputs could be validated based on empirical data. Hence, an obvious path for future research, can be exploration and validation of the theoretical proposition elicited from ABMs of this thesis and specifically the ones for the case of the food supply network, with empirical data.

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