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HOW DO COMPETITION AND COLLABORATION AFFECT SUPPLY CHAIN PERFORMANCE? AN AGENT BASED MODELING APPROACH

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ABSTRACT

Supply chain collaboration is considered to be the main driving force of supply chain success. In practice, however, ideal supply chain collaboration is difficult to achieve. In particular, a factor that is presumed to hinder collaboration is competition between firms. Even though several studies suggest that competition benefits supply chains, other studies come to the opposite conclusion. In order to address this issue, this paper proposes an agent-based modeling approach to understand how competition and collaboration between firms affects supply chains in the market in which they operate. The model represents customers, manufacturers, and suppliers collaborating and competing in a supply chain strategic space. Preliminary results presented in this paper are reported for the purpose of illustration. These show that it is the bounded-rationality of each agent that drives the emergent outcomes, and that the market structure is determined primarily by competitive behavior and not by demand.

1 INTRODUCTION

In this study we apply an agent-based modeling (ABM) approach to model business competition and collaboration in supply chains. In doing so we adopt a theory-driven approach to modeling, rather than an empirical approach., So, instead of analyzing a specific supply chain market in detail, we provide a simple representation of the strategic landscape and use it to understand how individual firm behavior, in terms of competition and collaboration, influences the whole system.

This study aims to understand how competition and collaboration affect supply chains as a market system. This involves characterizing the success and failure of individual firms, both manufacturers and suppliers. This issue is hard to observe in the real world, but it is a critical issue in supply chain management (SCM) practice, particularly in understanding failures in supply chain collaboration. We expect that the knowledge obtained from this study will be beneficial for managers to understand better the impacts of their strategic relations with their supply chain partners as well as the impacts of their competitive behavior.

This research has three main objectives. The first one is to develop an agent-based model for exploring competition and collaboration in supply chains. Secondly, to understand the impact of alternative collaboration and competition strategies on supply chain performance. Lastly, to identify strategies that lead to a better supply chain performance and enhance individual firm and market competitiveness. This paper focuses on the model that has been developed to address these objectives (objective 1).

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The intended contribution of this work is to provide a new perspective for understanding the implications of supply chain collaboration under competition at a market level. This has not been investigated by previous studies in SCM which tend to focus on a single supply chain. Also, our simple model is expected to be able to act as a building block to study more complex and real supply chains. This work aims to encourage academics, business managers, and market regulators to invest time in studying the impact of competitive behavior and collaboration in supply chains.

We organize this paper into three main parts. In the next section, we discuss the problem as it is addressed in the literature. Then, we describe our modeling approach. We outline the conceptual model of the problem and the design of the computer model. Finally, the last section presents and discusses some preliminary results from the model.

2 PREVIOUS WORK ON SUPPLY CHAIN COMPETITION AND COLLABORATION

2.1 Competition and Collaboration in Supply Chains

SCM is a set of techniques and practices for managing supply chains — a term to describe a network of firms, including suppliers of raw materials, manufacturers, warehouses, retailers, and logistics service providers, who work together in replenishing the orders of end consumers (Simchi-Levi, Kaminsky, and Simchi-Levi 2000; Chopra and Meindl 2007). In the strategic management literature, particularly in business process management, supply chain activities are considered to be the core business process (Childe, Maull, and Bennett 1994; Montreuil, Frayret, and D'Amours 2000). This means that business strategy in manufacturing industries is driven by the supply chain strategy.

As SCM practices are a crucial determinant of business success, particularly in manufacturing industries, this has implications for the meaning of competitive advantage. It turns the conventional view from firm competition into supply chain competition. This perspective makes collaboration between firms in supply chains vital if they are to develop supply chain competitiveness and achieve SCM success (Christopher 2000; Lee 2004; Chopra and Meindl 2007). However, many firms have failed in establishing appropriate collaborations within their supply chain. This failure results in ineffective and inefficient operations (Lambert and Cooper 2000; Barratt 2004; Holweg et al. 2005; Cao and Zhang 2011).

A factor presumed to deter supply chain collaboration is competition. Competition may enhance the uncertainty level both in upstream and downstream markets. Supplier competition, for example, has been empirically proven to produce higher transaction costs for the manufacturer (Walker and Weber 1987). This drawback is also supported by numerical results from theoretical models that show a high potential for quality distortion from the supply side (Altug and van Ryzin 2013). Moreover, researchers who work on Total Quality Management, such as Walley (1998), demonstrate that competition provides fewer opportunity to reduce variations in lead time and quality.

On the other hand, the strategy implemented in supply chain collaboration may also contribute to supply chain failure. The most debatable issue in supply chain collaboration is around the value of establishing long-term partnerships. This strategy is the basic approach in SCM to improve and optimize supply chain competitiveness over the long term. It can secure the supply flow and price (Kraljic 1983), and reduce the lead time to market (Christopher 2000). In other words, it can be an enabler to achieve better supply chain performance (Boddy et al. 1998; Lee 2004). This notion is also supported by SCM best practices, such as Toyota and Benetton, which demonstrate that these strategies lead them to gain better profit.

However, long-term partnerships do not suit all supply chains. Several findings, such as Anderson and Jap (2005), Burke, Carrillo, and Vakharia (2007), Leeuw and Fransoo (2009), Squire et al. (2009), and Sun and Debo (2014), suggest that this approach does not always provide a better supply chain performance.

In SCM and social science, competition and collaboration have been viewed from different perspectives. Most SCM researchers, such as Christopher (2000) and Lee (2004), claim that supply chain performance will be much better if businesses are able to develop long term collaborations, particularly with the supplier. This approach reduces the opportunity for the emergence of competition. However, in social science, competition has been regarded as beneficial to improve business competitiveness. It supports corporate success (Porter 1985, cited in Richardson 1993) and provides better value to the customer (Stucke 2013). It also enhances innovation that leads to a better company profitability (Anderson and Jap 2005).

2.2 The Agent-based Modeling

Agent-based modeling (ABM) is a simulation approach that is inspired by the intelligence of organisms in making decisions in biological science. The agent in the approach represents entities, which are independent, but interact with others. This modeling approach has become popular since it can be applied in a wide variety of problem situations. Moreover, supported by the advancement of computational capability, its application is getting more widespread (North and Macal 2007).

To date, simulation has been widely used in SCM research, but most of the simulations employ either discrete-event simulation (DES) or system dynamics (SD) modeling. The use of ABM in SCM research is limited. Where ABM has been applied to the SCM context, it is mostly conducted through computer science research, such as Barbuceanu, Teigen, and Fox (1997), Parunak, Savit, and Riolo (1998), Barbuceanu (1999), García-Flores, Wang, and Goltz (2000), Jiao, You, and Kumar (2006), Kwon, Im, and Lee (2007, 2011), and Siebers and Onggo (2014). These works tend to focus on the software architecture rather than supply chain analysis. Also, even though several ABM studies have addressed collaboration issues in SCM, such as Zhu (2008) and Chen et al. (2013), they only focus on a single supply chain and do not investigate supply chains from a system perspective.

Research that examines the effect of competition within and between supply chains on supply chain collaboration and performance using an ABM approach has not been carried out. Most SCM and ABM research separates collaboration and competition issues into different studies. Thus, this study tries to provide new insights on the effects of competition on collaboration and performance, both for the academic literature and for business practice.

3 THE MODEL

This work uses ABM to simulate competition and collaboration for two-stage supply chains that consist of suppliers, manufacturers and customers. We examine how collaboration and competition between firms, which is competition between suppliers and between manufacturers, impacts on supply chain performance at the market level. In doing so we consider the strategic fit of the firms in the supply chain to the dimensions of responsiveness and efficiency (Chopra and Meindl 2007). In other words, this supply chain strategic perspective determines whether they are responsive or agile supply chains, and efficient or lean supply chains. These strategies represent not only the supply chain competitiveness, but also the required capability of companies along the supply chain to achieve their goals.

We study the level of competition and collaboration based on the relative positioning of firm performance in terms of responsiveness and efficiency. Responsiveness is reflected as the level of innovation from a customer's perspective and lead time from the firm's standpoint. Meanwhile, efficiency is represented as price and product value from the customer's view and operational costs from the firms' perspective.

The model has been developed incrementally, starting with the simplest representation possible and then adding detail until the key facets of the problem domain have been characterized. This follows the model development approach of start small and adds (Pidd 2004). This practice can also be an effective way to verify the model thoroughly. Thus, as suggested by Robinson (2014), the code is built using small or simple steps, then tested and documented at each phase.

The proposed model is summarized in Table 1. The conceptual model describes the inputs (or experimental factors), the outputs, the contents of the model, assumptions and simplifications. For the model contents, it covers the agents' type, the environment, the interaction between agents and the behavioral rules or autonomy of each agent. The structure of the conceptual model is adopted from Robinson (2013), by incorporating the main features of ABM defined by Macal and North (2013), and Robertson (2003).

Table 1: The conceptual model.

Inputs / Experimental Factors	**A. Collaboration strategy:** 1. The duration of collaboration between supplier and manufacturer, and 2. Manufacturers' number of sourcing. **B. Competition behavior:** Competitive with acquisitiveness, or not competitive.	
Outputs	1. Supply chain revenue, and 2. Supply chain service level, which is represented by fill rate.	
Model contents	**Scope**	**Level of detail**
	The agent	Customers, manufacturers, and suppliers.
	The environment	Two-dimensional strategic space that reflects the relative supply chain capabilities or competitiveness on efficiency and responsiveness.
	The interaction	**Vertical interaction (between different types of agent):** Each customer creates a link with a manufacturer and a manufacturer makes connection/s (partnerships) with one or several suppliers. **Horizontal interaction (between similar agents):** Manufacturers and suppliers compete with the others by attracting new customers (for manufacturers) and new manufacturers (for suppliers) who have not been linked with them. Because firms do not account for or predict how other firms will move, this interaction reflects their bounded-rationality toward understanding competitors' strategic movement.
	The behavioral rules (autonomy)	**CUSTOMERS** Each customer selects a manufacturer in accordance with its preference presented by its position in the environment and within these parameters: 1. Willingness to compromise, and 2. Loyalty toward manufacturer. **MANUFACTURERS** <u>A. Competition-related rules:</u> Tolerance to loss Manufacturers compete with each other unless they have reached their tolerance to loss; once manufacturers cannot manage to find any supplier to collaborate with, they will die. <u>B. Collaboration-related rules:</u> Each manufacturer selects a supplier in accordance with its preference presented by its strategic position and within these parameters: 1. Willingness to compromise, and 2. Loyalty toward its supplier/s. **SUPPLIERS** <u>A. Competition-related rules:</u> Tolerance to loss. This parameter is identically applied as manufacturers' tolerance to loss; once suppliers cannot manage to find any supplier to collaborate with, they will die. <u>B. Collaboration-related rules:</u> 1. Loyalty towards manufacturers, and 2. Maximum number of relationship with manufacturers. **GLOBAL RULES** All agents select the closest firm/s within their willingness to compromise.
Simplifications	1. The two dimensional supply chain strategic fit is the basis of competition and collaboration. It represents the relative strategic position of capabilities or competitiveness of manufacturers and suppliers. 2. Price of finished goods is linearly proportional to the efficiency level of the manufacturers. 3. Loyalty of manufacturers and suppliers reflects the level of trust for the collaboration commitment.	
Assumptions	1. Customers have consistent preference basis for all the time (i.e. they do not move). However, they can adjust their preference within their willingness to compromise. 2. Manufacturers determine the duration of collaboration since it is a common practice in reality.	

The key experimental factors in this study are the collaboration strategy and competition behavior. Collaboration strategy involves the "duration of collaboration" between a supplier and a manufacturer, and "manufacturers' number of sourcing". Meanwhile, competition behavior represented in this study is acquisitiveness, which reflects the desire to earn more revenue on an ongoing basis. For instance, manufacturers change their strategy by incrementally moving towards nearby customers that are currently not buying from them. The manufacturers have no way of assessing the effect of moving towards a new customer, but due to acquisitive, they will always attempt to gain new customers. In doing so, they may lose some of their current customers to another manufacturer. In a similar way, suppliers move to try and gain collaborative relationships with new manufacturers by moving towards the closest manufacturer with whom they do not collaborate.

The outputs or the responses of this model relate to the main goal of supply chain collaboration and competition, which is maximizing the supply chain's profit. However, since our model does not represent the details of operational decisions and costs, supply chain revenue is used as a proxy for supply chain success. Further, supply chain fill rate is used as a simple measure of supply chain service level. This is calculated as the number of customers served divided by the total number of customers in the system.

Three types of agent are modeled in this study: customers, manufacturers, and suppliers. Suppliers compete with each other to attract manufacturers to cooperate with them, while manufacturers are trying to optimize their market share by attracting customers. These behaviors are dynamic since manufacturers and suppliers tend to change their relative position towards competitors over time. The position of the collaborating companies reflects their supply chain competitiveness as well as their performance.

All the agents act in the two-dimensional environment of efficiency and responsiveness (Figure 1). These dimensions can be interpreted from two different perspectives: customer preference from the customers' viewpoint, and individual firm and supply chain competitiveness from the perspective of the manufacturers and suppliers. Within the environment there are two infeasible areas that reflect the limits to the competitive landscape. So, for a product with a relatively high level of customization, variety or innovation, it is impossible to have a very low price (or cost) and product value, and vice versa.

From the customers' perspective, the *x*-axis represents the product's price. A product that is further to the right will be more expensive, but will also provide more value to the customer. Within limits, customers can choose to purchase products that are cheaper or more expensive than their preferred price or value. Meanwhile, the *y*-axis reflects the customers' perception of how innovative the product is. Innovation increases when moving down the axis. Again, customers can choose to purchase products that are more or less innovative than their preference, but within limits. The customers' willingness to choose products that do not exactly match their preferences is represented by a "willingness to compromise".

From the firms' standpoint, the *x*-axis delineates the operational efficiency (further to the left is more efficient), and the *y*-axis represents operational responsiveness (closer to the bottom is more responsive).

Two types of interaction are simulated in the model. The first interaction is vertical interaction between different types of agent. It is represented by links between customers and manufacturers, and connections between manufacturers and suppliers. The other interaction is horizontal interaction that reflects competition between similar agents (manufacturer-to-manufacturer and supplier-to-supplier). These autonomous interactions are described by the following rules. Customers create links with a manufacturer which represents the decision to purchase the manufacturer's product. In doing so the customers decide which manufacturer is most appropriate for supplying to their preference with a particular degree of willingness to compromise (Figure 1). Customers also have loyalty that represents a probability of choosing the same manufacturer as selected previously.

Meanwhile, manufacturers create links with suppliers which represent the decision to collaborate with each other. They collaborate with suppliers while they compete with each other. The duration of the collaboration with the selected supplier is determined by the manufacturers. The manufacturers' preference is to select suppliers who are more responsive and efficient than their capability; this enables the manufacturers to supply customers according to their strategy for efficiency and responsiveness. As with the customer agents, manufacturers also have a "willingness to compromise" and "loyalty" towards suppliers. The "willingness to compromise" feature allows manufacturers to work with suppliers who are less responsive and efficient than their capability (Figure 1), and the "loyalty" represents the probability of manufacturers working with the same supplier for the next collaboration. Manufacturers who cannot manage to find suitable suppliers will die after they have exceeded their "tolerance to loss" (number of ticks the manufacturer can survive without a supplier).

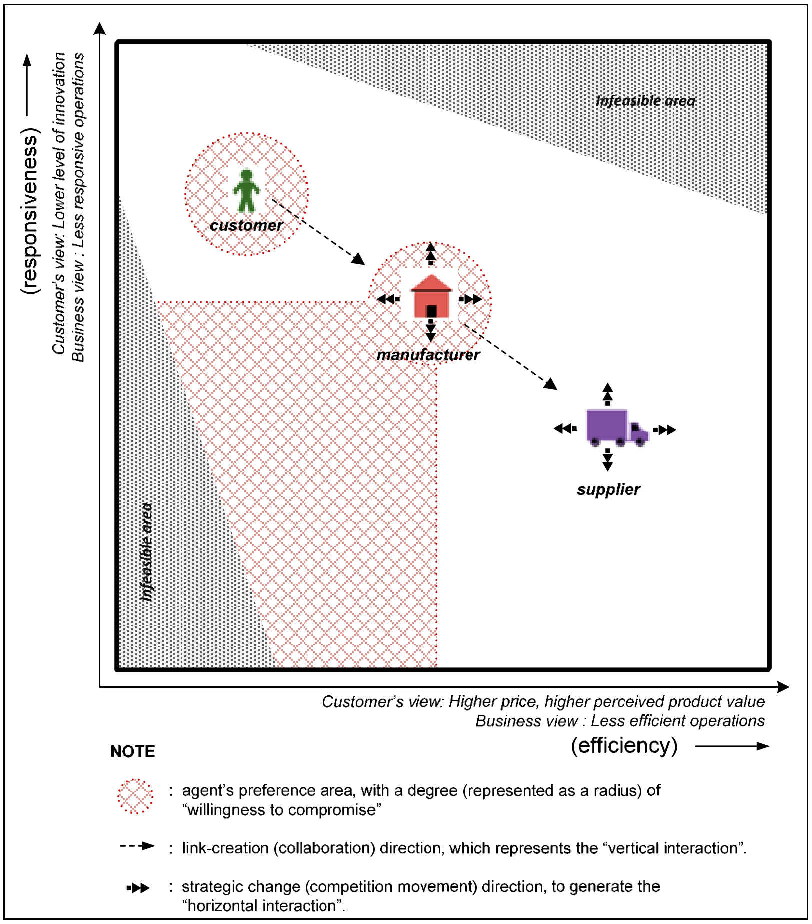

Figure 1: The diagrammatic representation of the model.

Lastly, suppliers are characterized by "loyalty" towards manufacturers, and "maximum number of relationships" with manufacturers. The "loyalty" represents the probability that suppliers will follow the manufacturer's strategic movement so that they can maintain their current relationships. The "maximum number of relationships" reflects a situation where suppliers can supply more than one manufacturer. Once a supplier is linked with several manufacturers, it has to choose to which manufacturers it will remain loyal.

These variables simulate an environment that is subject to complexity and uncertainty in both the upstream market and the downstream market. The upstream market complexity is characterized by the characteristics and bounded-rationality of suppliers and the downstream market uncertainty is represented by customers' preferences and competition between manufacturers.

The model includes several assumptions. For example, we assume that customers have a consistent preference for all time (i.e. they do not move). We also assume that the manufacturers lead the supply chain collaboration with their suppliers, since their bargaining position is higher.

The programming language used in this study is NetLogo. We selected the platform since it is relatively simple to use whilst still providing sufficient features for developing this model (Railsback, Lytinen, and Jackson 2006; Wilensky 2013). It has a simplified programming language and graphical interface that enable a modeler to develop an ABM without needing to learn a complex programming language. In addition, much publishable research has been carried out with NetLogo. An advantage of NetLogo is that it is freeware and can be run in most operating systems. Figure 2 shows the NetLogo representation of the model for this study.

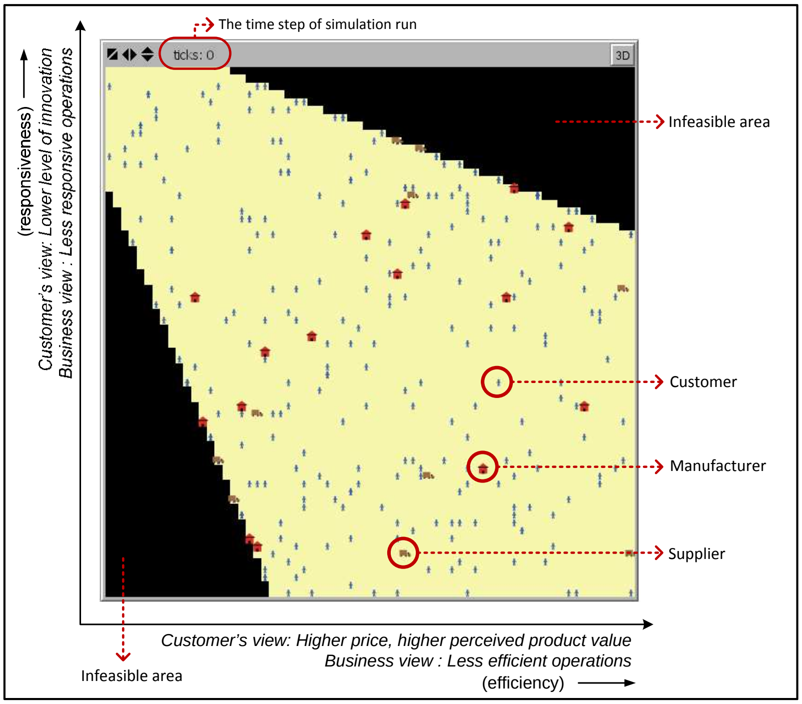

Figure 2: The computer model – in its initial condition.

4 MODEL DEVELOPMENT AND PRELIMINARY RUNS

The computer model was developed in two stages. In the first stage we only modeled the interaction of manufacturers and customers. In the second stage we added the suppliers.

Model verification and validation was carried out during model development to ensure that the emergent behavior of the first stage model is plausible. For instance, a classical spatial competition model that is introduced by Hotelling (1929) was used for the face validation. Simulating two manufacturers (Figure 3 A) with a very high "customer willingness to compromise" and a very low "customer loyalty", the resulting behavioral pattern of this model shows a similar behavior to that is predicted by Hotelling's model. The firms move to occupy almost the same strategic position (Figure 3 B).

We increase the complexity of the model by adding more firms (Figure 3 C). The simulation reveals that the firms converge at multiple locations to create several concentrated markets (Figure 3 D). A similar pattern is generated in every run of the model, with different numbers of firms and different combinations of customers. It implies that the firms' competitive behavior plays a significant role in forming the market structure. In other words, market structure is created by the competitive behavior of the firms which are boundedly-rational, and not by the customers.

Two performance measurements are employed to analyze the model: the mean revenue of all manufacturers in the system and the aggregate service level. A manufacturer's revenue is defined as the number of customers that are linked to the manufacturer. The mean revenue is calculated by averaging all the manufacturers' revenues in the model. The service level is interpreted as the percentage of the customer demand that is fulfilled. It is calculated as the number of customers served (linked to a manufacturer) divided by the total number of customers in the system.

Employing these performance metrics, preliminary analysis of the effect of "customer willingness to compromise" and "customer loyalty" is conducted. Experiments are performed with 256 simulations (128 scenarios with two replications for each) that are run for 3,000-ticks. A tick has no specific meaning in terms of time, but represents the smallest period in which a firm can move its strategic position by one grid space. This might represent a week, month, quarter or year, say, depending on the nature of the market being simulated.

The experimental factors are varied as follows. The “customer willingness to compromise” is varied into two extreme values that are 10% and 90%. Since this factor is considered as a radius measured from the customer’s position, the selection process is set in two different modes: random firm selection (anywhere in the radius) and closest firm in the radius. “Customer loyalty” is also varied to two extremes, 10% and 90%, representing the probability of choosing the same manufacturer as selected previously. The number of manufacturers is set at 5 and 20 firms. They are set in two conditions: under competitive environment (i.e. moving in the space) and without competitive behavior (i.e. manufacturers do not move). For manufacturers who have no customer, they are assigned in two types of rules: they die and they do not die. Lastly, the number of customers is assigned into two values, 40 customers – to represent low demand, and 500 customers - to represent high demand.

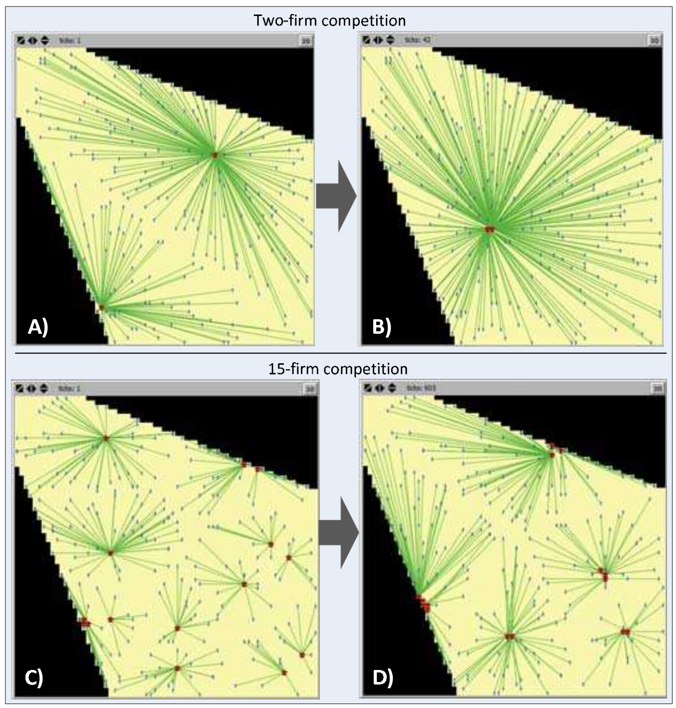

Figure 3: Example of emergent behaviors from the first stage model.

The results of these experiments indicates that a higher “customer willingness to compromise” tends to lead to higher revenues for firms and a better aggregate service level for the whole market. The high “customer willingness to compromise” means customers buy the goods they need even though the available goods do not fully suit their preferences. When the “customer willingness to compromise” is lowest at 10%, the modal service level is 15%, and the modal revenue is 2.9. Meanwhile, with the “customer willingness to compromise” at 90%, the service level is always 100% and the modal revenue is 100.

High “customer loyalty” does not always have a positive impact on manufacturer revenues and service level. The reluctance of customers to switch to another manufacturer means that competition among firms is of limited benefit. Both the low (10%) and high (90%) “customer loyalty” generates a modal revenue of 100 and a modal service level of 100%. It implies that ‘customer loyalty’ has no significant effect on supply chain performance in the scenarios modeled.

Having developed the first model to the point that the behavior and the results seem plausible, the second model was then produced by adding the supplier agents (as shown in Figure 4). In this version of the model the customer behaviors are similar to the previous model, but they can only select a manufacturer that has collaborated with a supplier. The manufacturers select suppliers in a similar fashion to the way customers select manufacturers, that is, through a "willingness to compromise" and "loyalty". The manufacturer moves to attract customers in the same way as in the first model, but their ability to supply customers is now influenced by the ability to link with suppliers. The suppliers move around the strategic space in order to attract manufacturers, applying the same greedy approach; trying to attract the nearest manufacturer with whom they are not working.

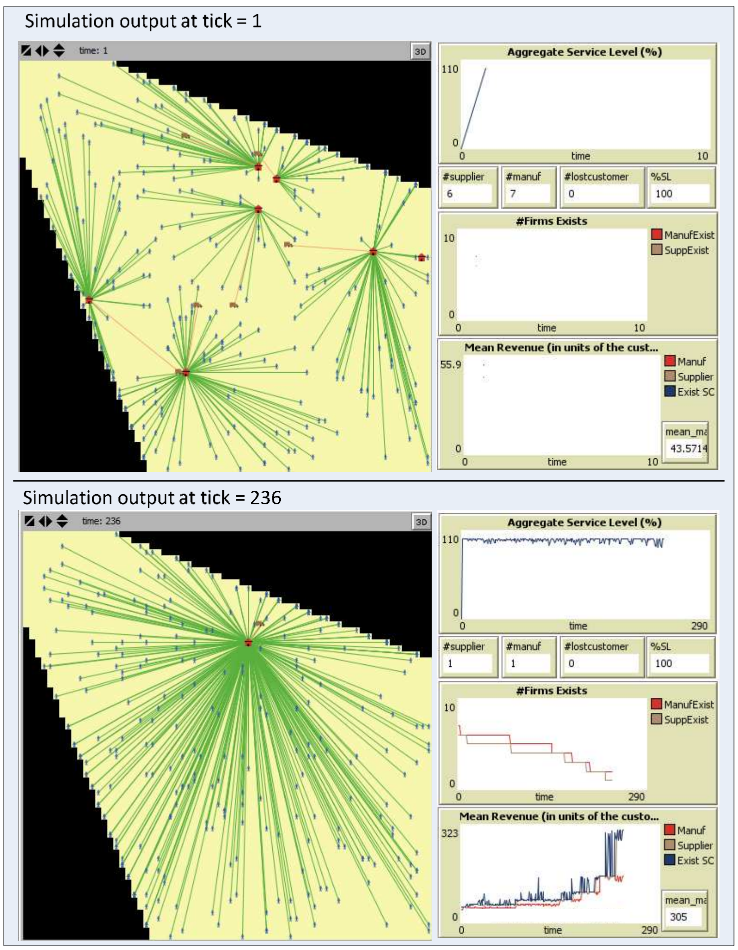

Figure 4: Example of emergent behaviors from the second stage model.

As with the previous stage, the simulation runs show a similar pattern in the formation of the market. Both manufacturers and suppliers converge to compete in concentrated areas.

An extension to the model is for firms who have no customers or firms to collaborate with to die. Under this rule, if all the firms follow the same rules (they are homogeneous), in the long term this can lead to a monopoly situation. It implies that if all firms have a similar competition behavior, in the end one firm comes to dominate. Also, it shows that acquisitive competition makes supply chain collaboration less beneficial in enhancing supply chain performance and survivability in the market.

5 CONCLUSIONS

An agent-based simulation model of a simplified supply chain is developed in this study. The model represents competition and collaboration in a multi-firm strategic space. The bottom-up approach and individual-interaction focus in ABM allow the modeler to analyze the strategic interactions between customers, manufacturers and suppliers.

The preliminary runs of the model show that it is the bounded-rationality of each agent that drives the emergent outcomes. Market structure is determined primarily by competitive behavior and not by demand. Moreover, once acquisitiveness is applied to each agent, it enhances the uncertainties in supply and demand market. This situation can lower the advantages of collaboration, market service level and even lead to monopoly. The limitation of the model in this study is that it represents the strategic space and firm behavior in a very simplified fashion. However, it can be extended to address more supply chain issues inform a system perspective. Moreover, incorporating a learning capability for each agent and providing alternative measures of performance could enrich the model.

This paper focuses on the development of the model and explaining its constructs. The preliminary runs reported illustrates how the model works. In the next stage of this work we will run more experiments to identify different competition and collaboration interventions that improve supply chain performance at market level. We will also complete the testing of the model through a calibration of the ABM against a series of real-world case studies. We then aim to use the model to understand how different behaviors lead to different supply chain outcomes. In particular we will allow one manufacturer agent to behave differently from the others. This will represent the intention of a manufacturer to gain competitive advantage by differentiating itself from the other manufacturers. This differentiation can be represented by setting different parameter values (e.g. for willingness to compromise and collaboration length) or by allowing a manufacturer to 'mutate' by suddenly and randomly making a strategic leap to another part of the strategic space.

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