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# AN AGENT-BASED MODEL OF SUPPLY CHAIN COLLABORATION: INVESTIGATING MANUFACTURER LOYALTY

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## ABSTRACT

Collaboration is considered to be a key driver to supply chain success. However, the ideal collaboration practice is difficult to achieve. Firms' strategy and behaviour in supply chain collaborations are identified as the main reasons for supply chain failure. To study this problem, we use an agent-based model which represents two-stage supply chains, consisting of customers, manufacturers, and suppliers. The firms exist in a two-dimension supply chain strategic space defined by efficiency and responsiveness. In this paper, we examine the effect of manufacturer loyalty on supply chains' performance in an innovative products market from system perspective. Measuring the supply chains fill rate and number of surviving supply chains in the market, the results indicate that manufacturer loyalty at intermediate levels does not seem to guarantee supply chain success in a market of innovative products, unless it is very high or does not exist at all.

**Keywords**: agent-based modelling, collaboration, supply chain, loyalty

## 1 INTRODUCTION

Supply Chain Management (SCM) practices are a fundamental determinant of business success. It shifts the conventional perspective from firm competition to supply chain competition. This point of view makes collaboration between firms in supply chains crucial in achieving supply chain success (Chopra and Meindl, 2007; Christopher, 2000; Lee, 2004). However, many firms have failed to establish successful collaborations leading to ineffective and inefficient SCM practices (Barratt, 2004; Cao and Zhang, 2011; Holweg et al 2005; Lambert and Cooper, 2000).

According to supply chain literature, collaboration between firms is achieved by maintaining long-term partnerships and a single supplier. Collaboration strategies in SCM are believed to optimise the supply chain's competitive advantage. Long term collaboration is believed to promote better communication between firms and accelerate the innovation process (Boddy et al 1998). Meanwhile, a single sourcing strategy for long term collaboration can minimise uncertainties in the supply side (Kraljic, 1983) and lead time to market (Christopher, 2000), because it can reduce the opportunity for the emergence of competition (Lee, 2004). These claims are supported by examples of best practices in SCM, which are practiced by successful companies, such as Toyota and Benetton.

Despite the benefits of these collaboration strategies, the implementation of these approaches may lead to supply chain failure. Some reasons for this could be that these partnership strategies do not suit all supply chains. Several findings, such as Anderson and Jap (2005), Burke et al (2007), Leeuw and Fransoo (2009), Squire et al (2009), and Sun and Debo (2014), argue that this approach does not always lead to a better supply chain performance. Furthermore, researchers in strategic management, such as Porter (1997), suggest that single sourcing does not encourage supplier to improve their performance.

This study aims to obtain a better understanding of collaboration strategies and its effect on the supply chain overall. Collaboration is a critical issue in supply chain practice, particularly in comprehending collaboration failures. This problem is difficult to observe by using an empirical approach, hence we propose to use an agent-based model (ABM). The use of ABM to study collaboration in supply chains is still limited to date. Studies that use ABM to study SCM issues focus primarily on software architecture than supply chain analysis, such as Barbuceanu et al (1997), Parunak et al (1998), Barbuceanu (1999), García-Flores et al (2000), Jiao et al (2006), Kwon et al (2007, 2011), and Siebers and Onggo (2014). In addition, ABM research that has addressed collaboration issues in SCM, such as Zhu (2008) and Chen et al (2013), only focuses on a single supply chain. They do not examine the supply chains at market level, taking a system perspective.

The work presented in this paper is part of a PhD project that aims to study competition and collaboration in supply chains. A previous paper (Arvitrida et al 2015) presented the modelling approach of this work. It provided the conceptual model of this study and provided several preliminary results for the face validation. The paper does not discuss the effect of particular collaboration behaviour on the supply chain. The current paper focuses on collaboration strategies and more specifically examines how firms' behaviour in implementing supply chain collaboration strategies affects supply chains at a market level. The main hypothesis examined in the model is that collaboration between firms in the supply chain improves the supply chain performance considered from a market level perspective. A two-echelon supply chain is modelled, including customers, retailers and suppliers. The model assumes a simplified strategic landscape where the agents (customer, retailer, supplier) attempt to reach the best strategic fit on two dimension (criteria) responsiveness and efficiency (Chopra and Meindl, 2007). We adopt a theory-driven approach to develop the model and observe the emerging outcome as a result of the agents' intrinsic behaviour. We examine collaboration at market level, taking a system perspective. This is a novel approach that has not been implemented by previous studies in SCM literature.

The remainder of this paper is organised as follows. Section 2 describes the agent-based model, including the conceptual and computer model. Section 3 explains the experiments and shows some preliminary results of the effect of a manufacturer's collaboration behaviour, which is manufacturer loyalty to supplier. Section 4 discusses the results presented in section 3. Finally, section 5 concludes the paper.

## 2 THE AGENT-BASED MODEL OF COLLABORATION IN SUPPLY CHAINS

In this section, the model applied to this study is described. We adopt the conceptual modelling framework introduced by Robinson (2014), which specifies the following elements of a conceptual model: the model contents, inputs or experimental factors, outputs, assumptions and simplifications of the model. In this work, the model content incorporates the main features of the ABM North and Macal (2007) and Robertson and Caldart (2009) describing the model's scope and level of detail.

The contents of the model consist of the agent, the environment, the interaction, and the behavioural rules (Figure 1). Three types of agents are simulated in this model: suppliers, manufacturers and customers. They are located in a two-dimensional environment of supply chain's strategic position to represent the level of responsiveness and efficiency. Responsiveness, that is described as *y-axis,* is represented as the level of innovation from a customer's view and manufacturing flexibility from the firm's perspective. Meanwhile, efficiency, depicted on the *x-axis*, reflects the price and product value from the customer's point of view and operational expenses from the firms' viewpoint. Within the landscape, two infeasible areas are set to reflect the limits to the competitive space. It represents strategic positions where a product with a relatively high level of innovation and manufacturing flexibility, it is impossible to have a very low price (or cost) and product value, and vice versa.

The interaction and collaboration behavioural rules are characterised as follows. Customers create links with a manufacturer, which represents the decision to purchase the manufacturer's product. At the same time, manufacturers create links with suppliers, which reflect the partnership decision. Manufacturers have a *loyalty* to represent the probability of selecting the same supplier for the next collaboration. Suppliers also have *loyalty* to the manufacturer. It represents the probability that suppliers will imitate the manufacturer's strategic movement to maintain their current partnership. As with manufacturer agents, suppliers have a *maximum number of relationships with manufacturers*. It delineates a situation where suppliers can supply more than one manufacturer. The software used in this study is NetLogo and the computer representation of the agent-based model is presented in Figure 1.

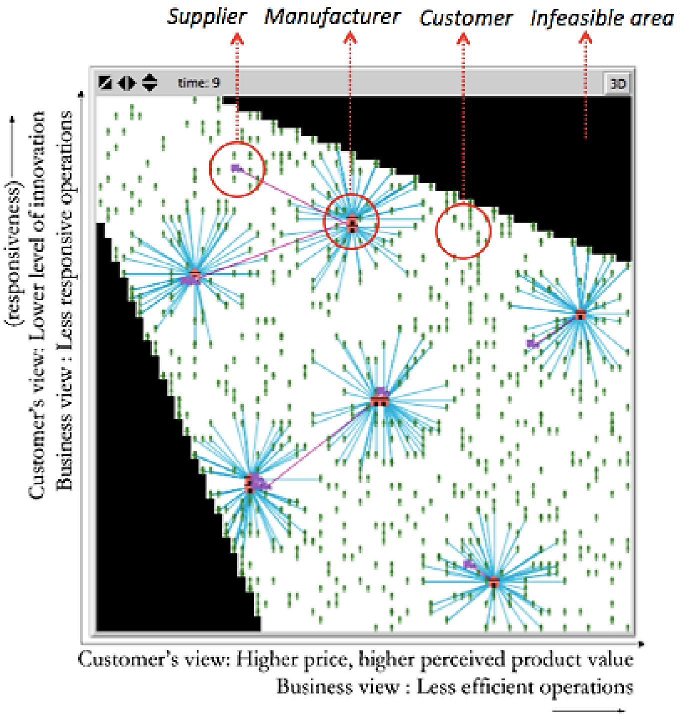


**Figure 1** *The representation of the model (revised from Arvitrida et al 2015)*

The key inputs or experimental factors of the model are the collaboration strategy rules. They are the *duration of collaboration* between a manufacturer and a supplier, and the *manufacturer maximum number of sourcing*. The *duration of collaboration* represents the length of partnership between manufacturers and suppliers, and the *maximum number of sourcing* reflects the manufacturer's maximum number of suppliers allowed to collaborate with.

The outputs of this model represent the performance of the supply chains at market level. It is assessed by *supply chains fill rate* and the *number of supply chains in the market*. The *supply chains fill rate* is measured by dividing the number of customers served by the total number of customers in the system. Meanwhile, the *number of supply chains in the market* represents the number of supply chains that can survive in the market. For instance, if an experiment ends with only one surviving supply chain, it indicates that the collaboration approach pursued does not promote competition in the market. The reader is referred to Arvitrida et al (2015) for the further detail. The summary of the conceptual model of this study is presented in Table 1.

**Table 1** *The conceptual model (revised from Arvitrida et al 2015)*

| **Model contents**<br>**(Scope and Level of Detail)** |
|---|
| **The agent:**<br>Customers, manufacturers, and suppliers. |
| **The environment:**<br>Two-dimensional strategic space defined as the degree of efficiency and responsiveness. |
| **The interaction:**<br>Each customer creates a link with a manufacturer, and each manufacturer makes connection/s (collaborations) with one or several suppliers. |
| **The collaboration behavioural rules (autonomy):**<br>*CUSTOMERS*<br>Each customer selects a manufacturer in accordance with its preference presented by its position.<br>*MANUFACTURERS*<br>Each manufacturer selects a supplier based on its preference presented by its position, within a probability of manufacturer loyalty to the supplier/s.<br>*SUPPLIERS*<br>Suppliers have a probability of loyalty to the manufacturers and maximum number of relationship with manufacturers. |
| **Inputs / Experimental Factors** |
| **Collaboration strategy:**<br>1. The duration of collaboration between supplier and manufacturer, and<br>2. Manufacturers' number of sourcing. |
| **Outputs** |
| 1. Supply chains fill rate, and<br>2. Number of supply chains in the market. |

## 3 EXPERIMENT AND PRELIMINARY RESULTS

In this study, we simulate supply chains that operated in a market of innovative products, such as automobile and high technology devices. A thousand customer agents are randomly located within the environment of the model. Their position in the grid represents their unique preference to buy a product from a manufacturer. They are set to have a very limited degree to compromise with their preference to decide which manufacturer is most suitable to supplying their taste or requirement preferences. They will only create a link with a manufacturer if the manufacturer stays within their radius of compromise measured from their position in the 2-dimensional space. In this experiment, the radius is defined as 10% of the diagonal distance of the strategic space. They are also situated to have no loyalty to the manufacturer, so they will select another manufacturer if it is closer to their preference than the previous one.

A limited number of manufacturers and suppliers are assigned in the simulation. Ten manufacturer and ten supplier agents are set to collaborate and compete with each other. The *duration of collaboration* is homogenously situated to be short-term partnership, which is defined as four ticks. A tick reflects the time unit in which a firm can change its strategic position by one grid. We consider that one tick represents three months, so that the length of collaboration is set by one year. Manufacturer and supplier who cannot manage to find a firm for collaboration will die after they have exceeded a limit to loss, which is defined as four ticks or a year.

A single-sourcing supply chains is applied to the relationship between manufacturer and supplier. It means that a manufacturer is only allowed to collaborate with one supplier. This rule also applies to the suppliers, which are limited to have only one link with manufacturer. In this situation, the supplier agents are programmed to have no loyalty to the manufacturer, so they will move to approach another manufacturer instead of following the strategic movement of the currently linked manufacturer.

In this paper, we focus on analysing the effect of *manufacturer loyalty* to the outputs. This variable is a representation of manufacturer trust to work with the supplier. The value is defined at five levels (or scenarios) of loyalty as a probability: 0%, 25%, 50%, 75%, and 100%. These values are selected to represent these following loyalty degrees: very disloyal (0%), not very disloyal (25%), so-so (50%), not very loyal (75%), and very loyal (100 %). These scales are chosen empirically to observe the effect of different firms' level of loyalty on the model outputs. The variation of the variables for the scenarios is summarised in Table 2.

**Table 2** *The scenarios of the experiment*

| | **Probability of manufacturer loyalty** | **Scale representation** |
|---|---|---|
| Scenario 1 | 0% | *Very disloyal* |
| Scenario 2 | 25% | *Not very disloyal* |
| Scenario 3 | 50% | *So-so* |
| Scenario 4 | 75% | *Not very loyal* |
| Scenario 5 | 100% | *Very loyal* |

Each scenario is run for 50 replications with 1000 ticks for each replication. We assume a tick represents three months to allow a firm to change their strategic position slightly, so 1000 ticks is equal to 3000 months or 250 years. This time period is considered to be a sensible extreme duration to allow us to analyse the performance and survivability of the supply chains in the simulated market. Common random numbers are used in the simulations in order to reduce the variations of the simulation outputs (Robinson, 2014). It means that the similar streams of random numbers are applied for all scenarios. This approach can also be applied to reproduce the simulation results for allowing further investigation.

We use descriptive and inferential statistical analysis to interpret the simulation results. Boxplots are employed to obtain descriptive patterns of the results, and confidence intervals are used to infer the significant difference between scenarios.

### 3.1 Boxplot Analysis

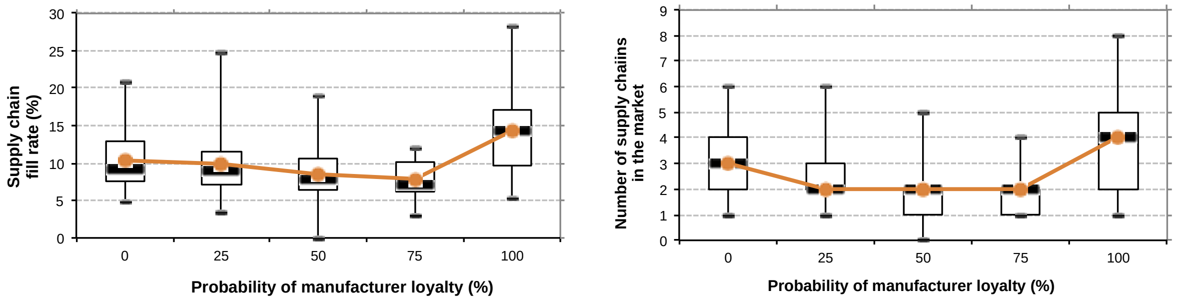
Boxplot analysis allows us to describe the data characteristics of the outputs. As shown by Figure 2, the boxplots shows that there is a pattern for the effect of *manufacturer loyalty* to both *supply chains fill rate* and *number of supply chains in the market.*

Figure 2a indicates that the median and the mean of *supply chains fill rate* have a slight U pattern as the probability of *manufacturer loyalty* increases. In scenario 1 (*manufacturer loyalty* is 0%), the median of *supply chains fill rate* is 9.3% and the mean is 10.47%. Then, both values gradually decrease as the probability of *manufacturer loyalty* increases up to 75% (scenario 4). The values rise to 14.3% for the median and 14.37% for the mean when the *manufacturer loyalty* is 100% (scenario 5). In the last scenario, the model provides the highest outputs comparing to other scenarios.

Meanwhile, the median and the mean of the *number of supply chains in the market* also depicts a slight U shape (Figure 2b). Both the median and the mean of the output decrease from 3 supply chains to 2 supply chains, from scenario 1 to scenario 2 (*manufacturer loyalty* is 25%). The values do not change until the *manufacturer loyalty* is 75% in scenario 4. In the last scenario, both values increase to 4 supply chains.

The variation of the simulation outputs can also be observed by looking at the tall of both boxplots. The charts show that the highest variations of both outputs are in scenario 5, where 100% of *manufacturer loyalty* is applied. The first scenario provides the second highest variation, while the others (scenario 2, 3, and 4) reveal the same values of the outputs.

In general, the boxplots indicate that 100% of *manufacturer loyalty* has the greatest effect to both *supply chains fill rate* and "the number of supply chains in the market", and 0% of *manufacturer loyalty* provides the second highest outputs. It also implies that scenario 2, 3, and 4 provides no different effect to the simulation outputs.



***a*** ***b***

**Figure 2** *Boxplots of the model outputs with a line of mean values for all scenarios of manufacturer loyalty. a) Supply chains fill rate. b) Number of supply chains in the market*

## 3.2 Confidence Intervals for Multiple Comparisons

Confidence intervals are constructed with 10% level of overall significance in order to infer whether there is a statistically significant difference between scenarios. If the confidence interval includes zero, it can be concluded that there is insignificant difference between the scenarios. Since ten confidence intervals are developed for the comparisons, Bonferroni inequality is used to adjust the level of significance outputs (Robinson, 2014). In other words, the individual level of significance for each confidence interval is 10/10 = 1%.

With 90% confidence intervals, the *manufacturer loyalty* provides almost similar pattern as the boxplots for *supply chains fill rate*. As shown by Table 3, scenario 5 (100%) is significantly different from other scenarios for all individual comparisons. It provides the highest value of *supply chains fill rate*. Scenario 1 (0%) also has significant difference from the others, but it is indifferent with scenario 2 (25%). It has higher *supply chains fill rate* comparing to scenario 3 (50%) and 4 (75%), but it is lower than scenario 5. Scenario 2 (25%) is significantly different from scenario 4 and 5, but it is insignificant with scenario 1 and 3. It provides higher *supply chains fill rate* than scenario 4, but it is lower than scenario 5. Scenario 3 (50%) is only significantly different from scenario 1 and 5. It has lower *supply chains fill rate* than scenario 1 and 5. Lastly, the *supply chains fill rate* in scenario 4 (75%) is significantly lower comparing to scenario 1, 2, and 5.

**Table 3** *Confidence interval comparison of supply chains fill rate between all scenarios of manufacturer loyalty (presented in percentage, with overall confidence interval ≥ 90%)*

| **Scenario** | **2**<br>***(25%)*** | **3**<br>***(50%)*** | **4**<br>***(75%)*** | **5**<br>***(100%)*** |
|---|---|---|---|---|
| **1**<br>***(0%)*** | **(-1.44, 2.81)**<br>*No difference* | **(0.29, 3.69)**<br>*Scen.1 (0%) > Scen.3 (50%)* | **(0.89, 4.29)**<br>*Scen.1 (0%) > Scen.4 (75%)* | **(-6.65, -1.15)**<br>*Scen.1 (0%) < Scen.5 (100%)* |
| **2**<br>***(25%)*** | | **(-0.66, 3.28)**<br>*No difference* | **(0.14, 3.67)**<br>*Scen.2 (25%) > Scen.3 (75%)* | **(-7.37, -1.79)**<br>*Scen.2 (25%) < Scen.5 (100%)* |
| **3**<br>***(50%)*** | | | **(-0.97, 2.16)**<br>*No difference* | **(-8.44, -3.34)**<br>*Scen.3 (50%) < Scen.5 (100%)* |
| **4**<br>***(75%)*** | | | | **(-8.98, -4)**<br>*Scen.4 (75%) < Scen.5 (100%)* |

A similar approach is used to infer the difference between scenarios for the *number of supply chains in the market* (Table 4). In general, scenario 5 (100%) provides a significantly higher *number of supply* *chains in the market* than other scenarios, particularly when it is compared to scenario 2, 3, and 4. It is considered to be only insignificantly different when it is compared to scenario 1. Scenario 1 (0%) is only significantly differential from scenario 3. It generates more *number of supply chains in the market* than scenario 3. Finally, insignificant difference between scenarios is concluded for the remaining comparisons.

**Table 4** *Confidence interval comparison of number of supply chains in the market between all scenarios of manufacturer loyalty (with overall confidence interval ≥ 90%)*

| **Scenario** | **2**<br>***(25%)*** | **3**<br>***(50%)*** | **4**<br>***(75%)*** | **5**<br>***(100%)*** |
|---|---|---|---|---|
| **1**<br>***(0%)*** | **(0, 2)**<br>*No difference* | **(0, 2)**<br>*No difference* | **(1, 2)**<br>*Scen.1 (0%) > Scen.4 (75%)* | **(-2, 0)**<br>*No difference* |
| **2**<br>***(25%)*** | | **(0, 1)**<br>*No difference* | **(0, 1)**<br>*No difference* | **(-2, -1)**<br>*Scen.2 (25%) < Scen.5 (100%)* |
| **3**<br>***(50%)*** | | | **(0, 1)**<br>*No difference* | **(-3, -1)**<br>*Scen.3 (50%) < Scen.5 (100%)* |
| **4**<br>***(75%)*** | | | | **(-3, -2)**<br>*Scen.4 (75%) < Scen.5 (100%)* |

## 4 DISCUSSIONS

Both the boxplots and confidence interval analysis indicate that very loyal manufacturers (when *manufacturer loyalty* is 100%) can lead to better supply chain performance in the market. The *supply chains fill rate* is significantly higher compared to collaboration with less manufacturer loyalty. It also generates more supply chains in the market compared to the other scenarios. This outcome is consistent with the concept of achieving supply chain collaboration success believed by most supply chain experts, such as Chopra and Meindl (2007), Christopher (2000), Lee (2004), Simchi-Levi et al (2000). They claim that a firm's trust, represented by loyalty in this study, is critical to support collaboration in supply chains to achieve a better performance and resilience.

However, disloyal manufacturers (when *manufacturer loyalty* is 0%) also provide a better *supply chains fill rate* and *number of supply chains in the market* as opposed to the in between degrees of manufacturer loyalty. Even though the outputs are lower than the results of 100% *manufacturer loyalty*, it is significantly higher than having a moderate degree of loyalty.

This result is counterintuitive with the current SCM concept of achieving supply chain success through collaboration achievement. A possible explanation for this could be that when all manufacturers in the market are disloyal with the suppliers, it can support a perfect competition environment that benefits the supply chain as a system. In other words, extreme loyalty (0% and 100%) can enhance the performance of all supply chains to serve the market.

In general, these results suggest that the firms' collaborative behaviour affects the supply chains in the market. It contributes to the overall service level of all supply chains in the market, represented by the *supply chains fill rate*, and the number of supply chains who can survive in the market. We consider that a higher *supply chains fill rate* is better for the market because more demand can be fulfilled. Meanwhile, the more supply chains that can survive in the market do not always represent a better performance for the market. However, this measure is useful to understand how the number of supply chains is decreased during the simulation run. The shrinkage of this output in the simulation represents the number of supply chain collaboration failure in the market. Moreover, if the simulation ends where only one supply chain survives in the market, it suggests that the behavioural rules implemented to the simulation potentially leads to a monopoly situation. If this occurs, it indicates that market intervention may be required to prevent it from happening.

## 5 CONCLUSIONS

An agent-based model of collaboration in supply chains has been developed in this study. An experiment on supply chains of innovative products is performed to examine the effect of manufacturer loyalty to the supply chains fill rate and number of supply chains in the market.

The preliminary runs of the model show that the manufacturer loyalty affects market performance, in terms of the supply chains fill rate and number of supply chains in the market. If manufacturers are perfectly loyal to the supplier, by choosing the same supplier every period, it would lead to a higher supply chains fill rate and a higher number of supply chains in the market. On the other hand, when a manufacturer has no loyalty to the supplier, the supply chains fill rate and number of supply chains in the market are notably higher compared to when a manufacturer has a moderate degree of loyalty. These results are contradictory with the current concept of SCM even though very loyal manufacturers generate better supply chains fill rate and more number of supply chains in the market rather than very disloyal manufacturers.

The experiments performed in this paper consider only one aspect of supply chain collaboration in the market, supply chain loyalty. As a next step we plan to consider further aspects of collaboration and competition behaviour, including the distance of manufacturer strategic movement, supplier loyalty, and the supplier's maximum number of relationships. The results are also analysed by disregarding the interaction between collaboration factors, such as *duration of collaboration* and *number of sourcing*. A similar analysis is also under way considering supply chain competition. Varying the model content, such as supply and demand characteristics, will also be simulated in the future in order to gain a better understanding of collaboration in the supply chain. Moreover, several case studies will be used to test the model.

The model presented in this study represents the strategic space and firm behaviour in a very simplified fashion. However, it can be extended to address more supply chain issues, such as collaboration in functional products market, to study the market at a system level. Moreover, incorporating a learning capability for each agent and providing alternative measures of performance could enrich the model.

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