Optimal strategic alliance in multi-echelon supply chains with open innovation

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Abstract

The concept of open innovation in supply chain management has emerged from the necessity for the free flow of knowledge and learning in supply chains. The relationship between innovation and the supply chain can be studied quantitatively and quantitatively. Although the qualitative aspects of supply chain innovation have been studied extensively, the quantitative supply chain research is still in its infancy. In this study, a game-theoretic approach is proposed to examine several possible coalition strategies in a four-echelon supply chain consisting of a supplier, manufacturer, wholesaler, and retailer. A solitude model is used to probe the role of learning in quality improvements, and experimental design is conducted to evaluate all possible supply chain coalition strategies between echelons. The novelty of this study is the comprehensive evaluation of knowledge sharing strategies in collaborative supply chains. The results confirm the Delta model with a coalition among a supplier, manufacturer, and retailer is the best strategy, and the manufacturer's leadership in creating a coalition with a wholesaler and a retailer is the most profitable strategy in a four-echelon supply chain.

Keywords: supply chain; game theory; Nash equilibrium; coalition; open innovation; knowledge sharing.

1. Introduction

It has been almost half a decade since the first definitions of the supply chain (SC) were introduced. The early stages of SC management emphasized the synchronization between machines and humans in assembly lines (Jain et al., 2010). The critical idea behind the early definitions was to underscore the importance of collaboration and integration between members within the SC (Scott & Westbrook, 1991). As the concept nurtured over time, several barriers, including process-oriented or structural complexities, were identified, and information technology solutions such as cloud-based systems were developed to address these problems (Fawcett et al., 2008). However, the issue of globalization and the transformation of SCs from a single chain to global networks has brought about new challenges such as trust-building, collaboration, and knowledge management (Busse et al., 2016).

In the past few years, the importance of an efficient alliance between SCs has been discussed (Flynn et al., 2010), and several factors affecting a collaborative SC were meticulously investigated (Hudnurkar et al. 2014). Conversely, there is no specific finding that elaborates on the most productive cooperation between SC members. The following research envisages a four-echelon SC consisting of a retailer, supplier, wholesaler, and manufacturer (see Figure 1). The subsequent study assesses the different forms of dual and trio collaboration between members considering advertising costs, demand, and product quality. As shown in Figure 1, there is also a decentralized form where each associate performs independently.

Insert Figure 1 Here

The cooperation between supply chain members can produce a great deal of knowledge. This information can help managers nurture their product life cycle faster through innovation. It also benefits shared members to increase their productivity by spending less on R&D efforts. Several studies have investigated various benefits of open innovation. Brunswicker & Chesbrough (2018) have studied the advantages and drawbacks of open innovation adaption in firms. Leckel et al. (2020) have also proposed a framework to increase the potential for collaboration in small to medium-size enterprises through open innovation. However, in this study, the knowledge sharing factor has been contemplated in the trio and dual collaborations to emphasize on the importance of open innovation and learning in global SCs. This study will conceivably aid managers to have a better insight into outsourcing projects. Figure 2 presents the open innovation and SC collaboration research questions and agenda undertaken in this study.

Insert Figure 2 Here

The rest of this paper is organized as follows. Section 2 provides an exhaustive literature review and basic preliminaries on different aspects of SC collaboration. Section 3 presents the proposed methodology and assumptions. Section 4 describes the proposed member models, leadership models, coalition models, and the decentralized model. Section 5 demonstrates the numerical example and results, including the leadership and coalition model results. The findings are integrated into the Delta model proposed by Hax & Ii (2003). Section 6 presents our managerial insights, and Section 7 includes conclusions and future research directions.

2. Basic concepts and literature review

In this section, a comprehensive review of different aspects of SC collaboration and the use of game theory in multi-echelon SCs is provided. This study is beneficial in finding the gap and the novelty of this study.

2.1 Supply chain collaboration

Collaboration is a valuable strategy for helping organizations resolve issues regarding quality, R&D, and value-creation (Wagner et al., 2002). Cao & Zhang (2011) uncovered the nature of SC collaboration and explored its impact on firm performance based on a model for collaborative advantage. Although there are innumerable risks in making business relationships, yet there is a great chance of aiding advantages such as faster product development cycle, lower R&D costs, product quality enhancement, and sensible operational costs (Walter, 2003). It is suggested that collaboration can reduce or diminish SC challenges and improve productivity in organizations (Holweg & Pil, 2008). Collaboration is defined as an effort to move towards common goals with appropriate mutual admiration (Xu & Beamon, 2006).

From an economic viewpoint, collaboration in SC results in better demand forecasting, which ensures lower inventory costs and better logistics management in the long run (Pashaei & Olhager, 2015). SC collaboration and coordination can result in supportive action improvements if formed properly. Presume a cooperative SC where wholesalers cooperate for a common target. They would probably share their marketing costs and reduce operation costs (Stevens & Johnson, 2016). Discussing the learning perspective of cooperation in SCs, the phenomenon is highly advantageous in sharing knowledge and risks by partaking common resources and objectives (Herczeg et al., 2018). The open innovation definition emerges If firms are assisted with knowledge from outsourcing companies, a paradigm represented by Chesbrough (2003). This paradigm is a strategic solution for success in small and medium-sized companies (Chesbrough & Appleyard, 2012; van de Vrande et al., 2009). Although there is no precise assurance according to the functionality of open innovation (Felin & Zenger, 2014), it's clear that knowledge sharing is beneficial in cooperative SCs and it could be used as a tool for helping an SC grow faster in a competitive environment. This factor is considered in the payoff function proposed in this study as a trio SC alliance.

SC collaboration studies have grown substantially in the past two decades. Cheng (2011) has studied the impact of proper information sharing in achieving competitive advantage and cost reduction. Other studies have stressed the importance of planning in a collaborative SC due to environmental uncertainties. Table 1 illustrates a summary of the recent findings regarding cooperative SCs.

Insert Table 1 Here

2.2 Game theory and supply chain

It has been almost half a decade since the core findings of game theory were proposed by (Nash, 1950). Discussing the SC perspective of game theory, research has recently conducted to solve the issue of poor quality supplied raw material to a manufacturer in a cooperative green SC (Kang et al., 2019). Similarly, an effort has been put on making a reasonable integration between SC members for a sustainable, long term relationship using game theory (Babu & Mohan, 2018). The theory has provided adequate flexibility in discussing different components affecting SC's profit. As an instance, advertisement costs were discussed in a reversed logistic two-echelon SC (Hua et al., 2019). A recent study has discussed the issue of pricing strategies in a two-echelon SC where retailers and manufacturers cooperate in boosting their profit (Taleizadeh & Sadeghi, 2019). The idea has also been employed in forecasting and decision making in an uncertain situation. Considering an undetermined, multi-stakeholder SC, a framework has been suggested to optimize the overall profit (Gao & You, 2019).

Generally, a game consists of at least two rational players who have sufficient information about the rules of the game. They take the best possible option as their optimal strategy. As Nagarajan & Sošić (2008) state, a set of these strategies creates equilibrium. Managers implement equilibriums in decision making, especially in uncertain situations where there is no precise knowledge about competitor's possible reactions regarding an action taken in the game.

Recent research has underlined SC sustainability. Inter-organizational systems were highly suggested as a solution for SC collaboration. However, scholars need to investigate the structural aspect of a collaborative SC deeply regarding the vague vision of potential collaborative profit. This paper studies a leader-follower relationship alongside a collaborative relationship in a four-echelon SC to make a better understanding of the members' cooperation. Mahdiraji et al. (2015) indicate the best responses are represented in Equation (1), presuming a two-player game:

$$B_i(S_{-i}) = \{S_i: U_i(S_i, S_{-i}) > U_i(S_i', S_{-i});\ \forall s_i \in S_i\} \tag{1}$$

B_i	Player i best response
(S_i, S_{-i})	The strategy chosen by the players
$(i, -i)$	Two players of a game
$U_i(S_i, S_{-i})$	Utility or payoff when a player opts strategy

Following that, the Nash equilibrium is defined as Equation (2).

$$\begin{cases} U_1(S_1, S_2) = f(S_1, S_2) \\ U_1(S_1, S_2) = f(S_1, S_2) \end{cases} \rightarrow \begin{cases} \dfrac{dU_1(S_1, S_2^*)}{dS_1} = 0 \rightarrow B_1(S_2^*) = f_1(S_2^*) \\ \dfrac{dU_2(S_1^*, S_2)}{dS_2} = 0 \rightarrow B_2(S_1^*) = f_2(S_1^*) \end{cases} \tag{2}$$

Note that (U), (S), and (B) indicate the payoff function of a player, the strategies or decision variables of each player, and the best response of each player, respectively. The formula has been widely used in various cases where different players search for the best response in the game. Table 2 illustrates the recent SC problems solved using game theory.

Insert Table 2 Here

The manufacturers' and retailers' issues have been regularly discussed in recent years. Although each of the aforementioned studies is novel, there is no overall investigation regarding the influence of suppliers, retailers, manufacturers, and wholesalers on each other in a real SC. Wholesaler's role is critically important in SC. However, these studies have ignored the impact of this element on SC profit. Discussing the focus point of findings in Table 2, demand and price were the greatest criteria that scholars have probed in recent years. Whereas the impact of knowledge and quality were less investigated. Makowski et al. (2017) have emphasized the importance of price on demand. They argue price can cause irreparable damage to demand, and SC managers need to prioritize their pricing strategy. Discussing the marketing influence on SC performance, Green et al. (2012) show the importance of marketing on SC's strategic alliance, and Ellram et al. (2019) emphasize the controversial role marketing departments play in the industrial inter-organizational relationships. Lastly, the direct impact of quality on SC nurturing has been discussed in the past few years. Findings state that improvements in quality assist managers in making better relationship decisions with each other and create information flow along with the SC (Narasimhan & Nair, 2005). Also, customer satisfaction is dramatically increased regarding the balance between proposed quality and price (Chen et al., 2017). The literature review depicts how scholars have used the standard game theory model in various cases. However, in this research, the importance of knowledge flow in supply chains has been considered. Therefore, in collaborative SC, where members share knowledge, a new variable has been added to the profit equation. To assess the impact of knowledge sharing and open innovation on SC overall profit. Knowledge sharing and innovation boost the quality of the products. Thus, this variable is used in the cooperative supply chain analysis. This overview has never been used before, and the authors believe that further researches on the financial risks of open innovation on supply chains are highly beneficial in saving money in organizations. Considering the role of demand function on supply chain members profit function, best responses and as a result of their relevant model, any slight changes in demand function, alternates objective function, constraints, and decision variables of decentralized, leadership, and coalition conditions. In this research to address the role of open innovation and knowledge sharing on the quality of the products, some major changes have been applied in the demand function as the contribution of this section. First of all, quality has been added as the third variable in the Cobb-Douglas based demand function comparing to previous literature that focused only on one (e.g. Abad, 1994) or two (e.g. Mahdiraji et al, 2015) variables including price and marketing. Moreover, the effect of the quality emanated from open innovation and knowledge sharing has been added in the demand function as correlated parameters of quality elasticity as a novel idea. Any increase in knowledge sharing results in a positive effect on quality elasticity and as a result increase in demand. By these two main changes, the objective function of all four members of the supply chain, their best responses, and as a result of their decentralized, leadership, and coalition models are completely changed. Thus, all designed models are novel compared with similar researches. Furthermore, in studied literature, a dual coalition between two members is studied (e.g. Mahdiraji et al, 2014) and trio coalitions are more recent approaches used in this research to profound and evaluate all possible vertical integrations of supply chain members. This paper uses a four-echelon SC and focuses on marketing costs, price, demand, and knowledge alongside each other to find the best coalition between SC members in a collaborative and non-collaborative game. Table 3 presents the main contributions and novelty of this study compared with similar studies on supply chain collaboration and open innovation.

Insert Table 3 Here

3. Methodology and assumptions

Assuming a four-echelon SC with a supplier, manufacturer, wholesaler, and retailer, the following section demonstrates the connection between various SC levels. Furthermore, the demand function and payoff equations are formed using a DOE experiment, and a numerical example is solved to determine the ideal collaboration. Realistic assumptions such as shortages are considered for the wholesalers and manufacturers. It is also assumed that each SC works independently from other members by default. This case discusses a four echelon SC with limited levels consist of one member since this research is searching for the functionality of cooperation.

Suppliers are at the first level in SC, and they are mainly responsible for the quality of the final products. Therefore, this stage needs a technological enhancement to offer a fair price to the manufacturer and assist them with providing financial needs to stock quality raw materials. Moving to the next level, manufacturers need to present their products to the market. Thus, they offer a wholesale price and accept orders up to the inventory quantity since they may be charged with shortage costs from wholesalers. Afterward, there is a game-changing relationship between the wholesalers and the retailers since several threats may be posed due to the chance of losing market share, competitor arrivals to the market, and shortages. These two require a large appropriation of marketing costs and to bargain for the best selling price. The aforementioned relationship is depicted in Figure 3.

Insert Figure 3 Here

Predominantly, demand has widely been discussed in SC literature as a determinate and indeterminate factor. The function of this research has been borrowed from the well-known Cobb-Douglas equation used by innumerable scholars in recent years (Abad, 1994; Mahdiraji et al., 2015). That said, the formula has been extended in the trio coalition by adding “information flaw” criteria for a better insight into the SC in a real collaborative environment. Chesbrough (2003) has indicated that open innovation allows supply chain members to outsource their assets for various financial, human resources, and operational purposes to boost the overall quality of goods in the long term. Hax and Ii (2003) have also shown the direct impact of knowledge sharing on quality improvement. Consistent with these conclusions, we have added a new variable to the standard Cobb-Douglas equation previously used by Abad (1994) and Mahdiraji et al. (2015) and reconstructed Equation (3). Abad (1994) employed negative behavior of price (P) in the demand function as $K.P^{-\alpha}$ where α determines the negative effect of price elasticity on demand, and K denotes the scaling parameter of demand. In addition, Mahdiraji et al. (2015) used the price and advertising costs (C) in the demand function as $K.P^{-\alpha}.C^{\beta}$ where β represents the positive effect of advertising costs on demand. In this research, we have added a new factor as quality in the demand function and reconstructed the demand function as follows:

$$D = K.P_r^{-\alpha}.C_m^{\beta}.V^{\gamma} \tag{3}$$

The reseller's selling price to the customer is indicated as p_r, while the price elasticity with a reverse effect on the overall equation is shown as α. This factor is negative due to its inharmonious impact on demand. The marketing costs alongside with the elasticity are shown as C_m and β, respectively. The boost of quality V has the same positive effect on demand function; therefore, its elasticity is aligned with demand increase as γ. As mentioned earlier in Figure 3, the SC is assumed to allow for shortages. Furthermore, it is assumed that each member acts rational, and SC managers are looking for balancing their annual income and forced marketing costs. Therefore, the price is enormously more significant than marketing costs since it is the main source of money-earning per Equation (4).

$$\alpha - \beta > 1 \tag{4}$$

Furthermore, marketing managers need to plan for the annual marketing budget regarding strategic goals per Equation (5).

$$0 < \beta < 1 \tag{5}$$

Any SC faces several fixed and moving costs to produce a good with definite quality between 0 and 100 per Equation (6).

$$\begin{aligned} &1 < \alpha \\ &0 < \gamma < 1 \end{aligned} \tag{6}$$

Quality is an important criterion in choosing one product but comparing this factor to price and marketing costs, customers preferably choose products at a lower price since it is the most decisive factor in customers' buying pattern presented by Equation (7).

$$\begin{aligned} &\alpha - \gamma > 1.05 \\ &\beta - \gamma > 0.05 \end{aligned} \tag{7}$$

Eventually, it is assumed that manufacturers can boost product quality up to 5 times per Equation (8).

$$0 < v < 5 \tag{8}$$

Table 4 presents a list of the parameters (P) and variables (V) used in this study. Finding the optimal value of all the above-mentioned variables is one of the objectives of this research.

Insert Table 4 Here

4. Proposed models

4.1. Member models

All members in the SC are seeking the most suitable strategy to increase their overall profit in the long term. Therefore, considering the notations given in Table 4, SC members participate in collaborative and non-collaborative games in the following section to find out the most profitable cooperation strategy. Retailers are subject to inventory and setup costs in the SC and earn sufficient income by offering a product to the customers and replenishing their reorder points. However, retailers need to balance their order quantity with the wholesaler's maximum inventory and represent their products considering their stock. Thus, the retailer's payoff function can be represented with Model (9) presented in Table 5.

Insert Table 5 Here

Although wholesalers are forced to undertake setup costs from the manufacturer and are in pose of shortage costs in different circumstances, they can boost their overall profit by giving sufficient order to the manufacturer. Also, wholesalers need to deal with their stock limitation along with selling price to the retailer, which is presumed to be higher than the retailer's selling price with Model (10) presented in Table 6.

Insert Table 6 Here

Manufacturer plays a crucial role in SC since they are responsible for transforming the raw materials received from the supplier(s) and deliver the final product to the consumer(s). Note that due to the balance between incoming raw materials and the final product, no bullwhip effect is considered in the profit function. Moreover, manufacturers are responsible for branding their products. Therefore, a precise marketing budget is allocated to other members annually with Model (11) presented in Table 7.

Insert Table 7 Here

Suppliers are in charge of providing high-quality products due to their crucial role in extracting standardized raw material. Similar to other SC members, they burden inventory costs and are have limited inventory with Model (12) presented in Table 8.

Insert Table 8 Here

4.2. Leadership model

Regarding the findings above and the payoff functions for each SC member, the leader-follower game is formulated in Models (13) to (16) presented in Table 9. Considering four members in the SC, four leadership scenarios are possible. In each possible scenario, one member acts as a leader and the rest as followers. For each situation, the objective function and the constraints are formulated as follows.

- ***Objective function:*** For each leadership game, the objective function is to maximize the payoff/profit function of the leader based on models presented in Equation (9) to (12);
- ***Best responses:*** The best responses of each follower are considered as rational constraints for the leader. These responses have been emanated from the root of the first derivation of the profit functions of the followers. As a case in point, the best responses of the retailer are (P_r^*) and (Q_r^*), and they have resulted from the root of the derivation of the retailer's profit function towards P_r and Q_r. For the manufacturer, C_m^*, V^*, Q_m^*, b_m^*, and P_m^*; for the wholesaler, Q_w^*, P_w^*, and b_w^*; and for the supplier, P_s^*, have been calculated correspondingly. All derivations and roots were emanated by MATLAB software.
- ***Feasible Constraints:*** These constraints are obtained from Models in Equations (9) to (12).

Insert Table 9 Here

4.3. Coalition models

Due to the nature of cooperation, operational costs are highly reduced since SC members share their assets and resources. The main challenge in cooperative SC is the amount of knowledge flow in the relationships. Assume a medical manufacturing company that needs help with filling medicine in proper packages sensitive to light and heat. They may align with a supplier and share resources and revenues. Although the companies must be mindful of strict laws on information sharing and trade secrets, the SC could benefit from this mutually beneficial partnership. In this study, we assume the SC may increase the quality elasticity as the result of the knowledge sharing (in the range of 1.2 to 1.5), and the demand function will change accordingly as Equation (17).

$$1.2 < KNS\ (k) < 1.5$$
$$D = K.p_r^{-\alpha}.C_m^{\beta}.V^{\gamma * k}; \quad (17)$$

In a possible coalition, the relationship between the wholesaler and the manufacturer ignores the possible shortage since the demand is planned based on the production level. Such coalitions are highly dependent on the close market analysis between the manufacturer and the wholesaler who choose the most appropriate market. As an illustration, a new gadget like drones needs a comprehensive market assessment to launch successfully. Imagine an information technology company that makes global government dashboards. Besides their location on the Delta model, such companies have limited wholesalers, and they need to make a close relationship with their retailers around the world to promote and support the technological functionalities. Thus, the retailer-wholesaler cooperation, if made appropriately, requires a bigger budget for marketing and promotions. A high-technology company like a pharmaceutical company may cooperate with suppliers to take advantage of high-quality standard raw materials. However, in such a case, coopetition is inevitable, a phenomenon that makes enemies out of partners.

A medicine producer then needs to choose an appropriate market for its products. Therefore, wholesalers and retailers need to study the market together and share the capacity of the manufacturer. As an instance of trio cooperation, an arms producer company like Lockheed Martin is unable to present their products to open markets. Moreover, they need a close relationship with suppliers for R&D to create new products. As Hax and Ii (2003) indicate in their Delta model, these companies have locked the business in, and it seems hard for other companies to achieve such knowledge in a short time. In other words, they have obtained a trio coalition between supplier, manufacturer, and wholesaler. The classic agriculture business is decentralized, and those with better prices and differentiated products have a higher chance of selling their products.

Table 10 presents various coalition formations in a four-echelon SC as models presented in Equations (18) to (23). In this regard, based on the best responses for each member (or coalition), the optimal value for each decision variable has been derived upon the root of the first-order derivation by MATLAB software (similar to the leadership modeling section). Next, these equations are solved by LINGO nonlinear global optimization package to obtain the optimal values. Subsequently, these values have been used in the profit functions for each player.

Insert Table 10 Here

4.4. Decentralized model

The last form of collaboration in SC occurs by decentralization, where there is no cooperation between members (see the equations presented in Table 11). In this scenario, the best response from all members has been used to solve the model with LINGO nonlinear global optimization package.

Insert Table 11 Here

5. Numerical example and results

We constructed a payoff function for each level and designed and applied 17 (2^4+1) experiments by considering a central point and full/fractional factorial design of the experiment. Hence, 17 (2^4+1) experiments were emanated. We considered leadership, coalition, and decentralization and studied knowledge sharing and open innovation effects based on the models in Section 4. The possible outcomes of open innovation were studies by comparing leadership and decentralization with coalition because the coalition considers the open innovation and knowledge sharing effects on the quality of the product. Given the unavailability of real-world data, supply chain performance for 17 experiments under different possible coalition strategies was discussed. The main objective is to study the benefits of knowledge sharing and open innovation on the overall supply chain profits. The reliability of the results is dependent on the analysis of all possible situations of the designed models as presented in Table 12. Based on Table 12 the authors studied all possible experiments according to the demand function parameters, including k, α, β, and γ. As previously mentioned the possible range of α, β, and γ is determined in equations (3) to (8) and for k presented in equation (17). The extreme values of these four parameters build (2^4) different conditions. In this research, all of these possible situations alongside with one central point is analyzed to illustrate the behavior of the designed models. Thus all feasible areas as presented in Table 12 are studied and analyzed to validate the designed models in decentralized, leadership, and coalition situations. In addition, other non-significant parameters were considered in Table 13 to solve different alignments using LINGO nonlinear software package. We should note the Debug command of the models is tested with LINGO software by activating the Global Optimal Solver. The debugging process confirmed the feasible solution in all models. Moreover, the global solver emanated global optimal solutions for all designed models demonstrating that the concavity of the models is valid and reliable.

Insert Tables 12 and 13 Here

5.1. Leadership section results

Table 14 presents the results for each leadership scenario utilizing the parameters and constraints on the follower-leader equations in Section 4.2. The results for SC's overall profit in all experiments according to different leader-follower games are exhibited in Figure 4.

Insert Table 14 and Figure 4 Here

Table 15 presents the results of pairwise comparisons for the leadership section upon paired t-test. As shown in Table 15, the manufacturer is the most advantageous leader in this scenario. However, this does not apply to all industries. Note that, (0) indicates that the leadership comparisons of two members are not significant for SC overall profit with a 90% confidence level in the t-test. Moreover, (1) and (-1) denotes that the leadership of one member leads to more and less profit for the SC, respectively.

Insert Table 15 Here

5.2. Coalition section results

Based on the models presented in Section 4.3, alongside the experimental design, results have been presented in Table 16. Note that the experiments are designed based on parameters of the demand function, including K, α, β, k, and γ; hence, 2^{5-1} (fractional factorial design) experiments are produced. By adding a central point, a total of 17 experiments are employed. Figure 5 illustrates the SC overall profit based on all possible coalitions with regards to all experiments.

Insert Table 16 and Figure 5 Here

Table 17 shows that the optimal coalition to reach the highest profit is the cooperation of the manufacturer, wholesaler, and retailer. The status of all possible scenarios and coalitions are illustrated in Table 17 (according to the t-test results with a 90% confidence level). Note that (0) indicates that the comparisons of two coalitions are not significant for SC overall profit with a 90% confidence level. Moreover, (1) and (-1) denotes that one coalition leads to more and less profit for the SC, respectively.

Insert Table 17 Here

5.3. Decentralized section results

The results of the decentralized SC are presented in Table 18 based on equations presented earlier in Section 4.4. Note that the experiments are designed based on parameters of the demand function, including K, α, β, and γ; hence, 2^4 (full factorial design) experiments are produced. By adding a central point, a total of 17 experiments are employed.

Insert Table 18 Here

Considering manufacturers leadership as the optimal scenario in the leader-follower games, and considering manufacturer-wholesaler-retailer (MWR) as the optimal coalition in the cooperative games, and by considering the results of non-cooperative games, a comparison of SC overall profit has been provided in Table 19. The pairwise t-test comparison among the three scenarios presented in Table 19 shows the MWR coalition scenario makes the highest profit for the SC. Furthermore, there are no meaningful differences between the decentralized and the manufacturer-leadership scenarios. Figure 6 illustrates the comparisons of SC overall profit for the optimal scenarios in all 17 experiments.

Insert Table 19 and Figure 6 Here

6. Managerial insights

Organizations must consider inbound and outbound knowledge flows to survive during uncertain times in a turbulent environment. We show knowledge flow and open innovation are essential ingredients for improving productivity and profitability in supply chains. Hax and Ii (2003) proposed the Delta model to help organizations with an adaptive management process for coping with environmental uncertainties. The Delta model depicted in Figure 7 provides a comprehensive and integrated strategy development process with four unique features, including linking strategy with execution by employing adaptive processes with aggregate and granular metrics complemented with experimentation and feedback. The adaptive process involves collaboration between supplier, manufacturer, and wholesaler. Consider the classic decentralized model where players with more competitive prices and differentiated products can sell more products. Note that the trio coalition (MWR) scenario has been recommended for the supplier-manufacturer coalition (SM), the manufacturer-wholesaler coalition (MW), the wholesaler-retailer coalition (WR), the supplier-manufacturer-wholesaler trio coalition (SMW), and the manufacturer-wholesaler-retailer.

Insert Figure 7 Here

The global supply chain environment is experiencing unprecedented times due to natural disasters such as Coronavirus pandemic or political crises such as Brexit. We showed that the MWR strategic coalition provides higher profits for the supply chain compared to decentralization or other forms of cooperation. Manufacturers can take advantage of this finding and revisit their strategic decisions by adopting joint decision making with their partner retailers and wholesalers. Our study also suggests companies should spend less on R&D and invest more in knowledge sharing with their outsourcing allies.

Furthermore, customers are a great source of knowledge for quality improvement. The Hax Delta model suggests that managers need to innovate by learning from their customers and share knowledge with their retailers. Besides numerous advantages of knowledge sharing and outsourcing, practicing managers should be mindful of the pitfalls in cooperative partnerships. Cultural clashes, the lack of strategic alliance between two companies, differences in systems and processes, and lackluster synergy between companies are among the most probable causes of failing partnerships. Research shows the importance and the necessity of improving inbound-outbound processes and gathering knowledge from outside the supply chain. Open innovation can save time, reduce R&D budget, decrease marketing costs, and ultimately improve productivity and profitability. The conventional wisdom of low cost and differentiation may not be adequate during uncertain times in turbulent environments. Practicing managers should consider adopting win-win open innovation and knowledge sharing practices with their supply chain partners.

7. Conclusion

The concept of open innovation has emerged to emphasize the necessity of learning in SCs. This research investigates a four-echelon SC consisting of a retailer, wholesaler, manufacturer, and supplier. Several possible alliance scenarios between echelons are examined using a game-theoretic approach. Also, a solitude model is discussed to probe the role of learning in quality improvements. Three possible scenarios were assumed, including leader-follower (for dominant market or players), decentralization (non-cooperative situation), and coalition (for cooperating based on open innovation).

For each scenario, the payoff function of SC members was calculated, and 17 experiments were designed through experimental design. The results indicated that in leader-follower circumstances, manufacturer leadership is most beneficial. Furthermore, for the coalitional situation, the MWR coalition among manufacturer-wholesaler-retailer is most beneficial supported by statistical tools and pairwise comparisons. Indeed, the MWR coalition has been recognized as the final optimal scenario by comparing it with optimal leadership, optimal coalition, and non-cooperation conditions. Although the Delta model suggests the SMW coalition as the best solution for SC members, this study shows that manufacturers are still the best leader in making the most profit for the SC and creating the most influential coalition.

It is highly suggested that scholars investigate the financial dimensions of SC cooperation with further constraints to make a broader determination of profitable alignment strategies. Moreover, researchers may probe the same SC structure with a depth of multiple members in each stage. It is conspicuous that cooperation has several benefits for stakeholders in the long run. However, to make this phenomenon in practice, trust contracts, financial issues, among many other structural issues, should be studied in the future.

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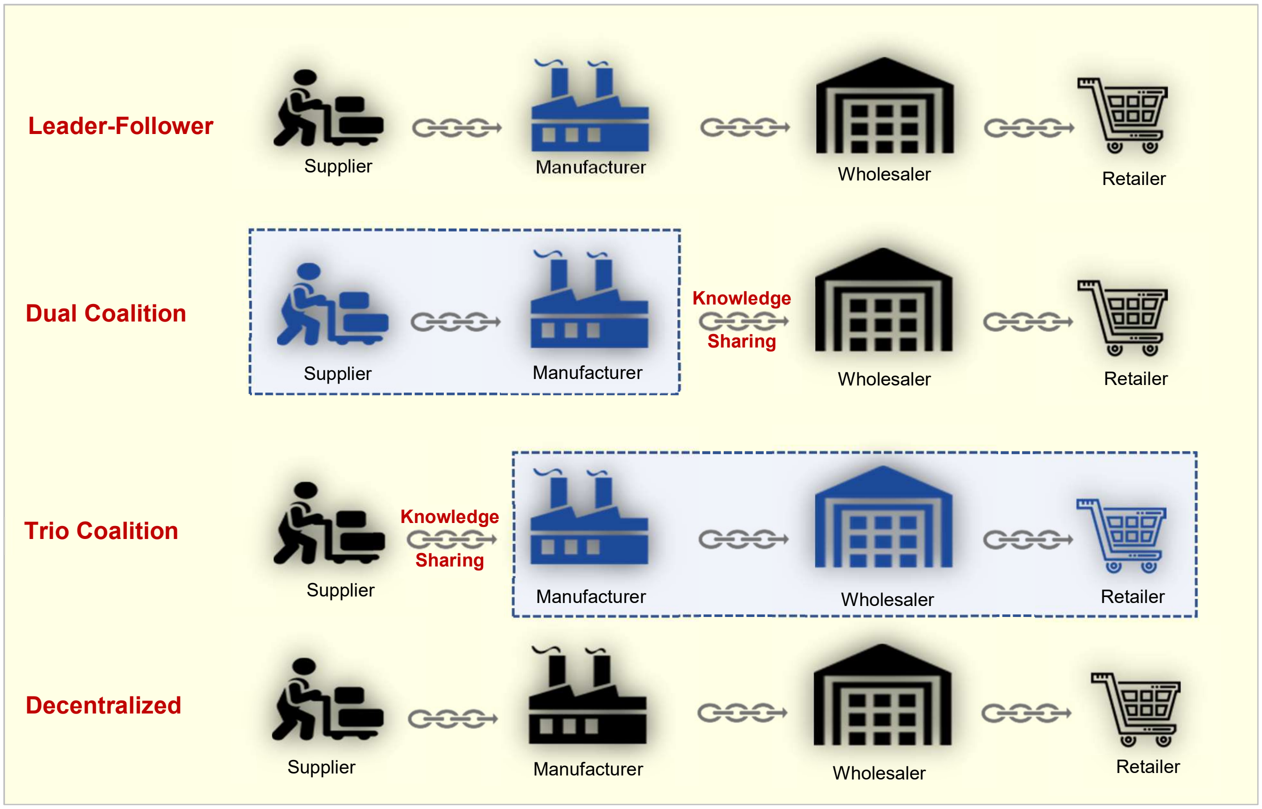


Figure 1. Different collaboration forms

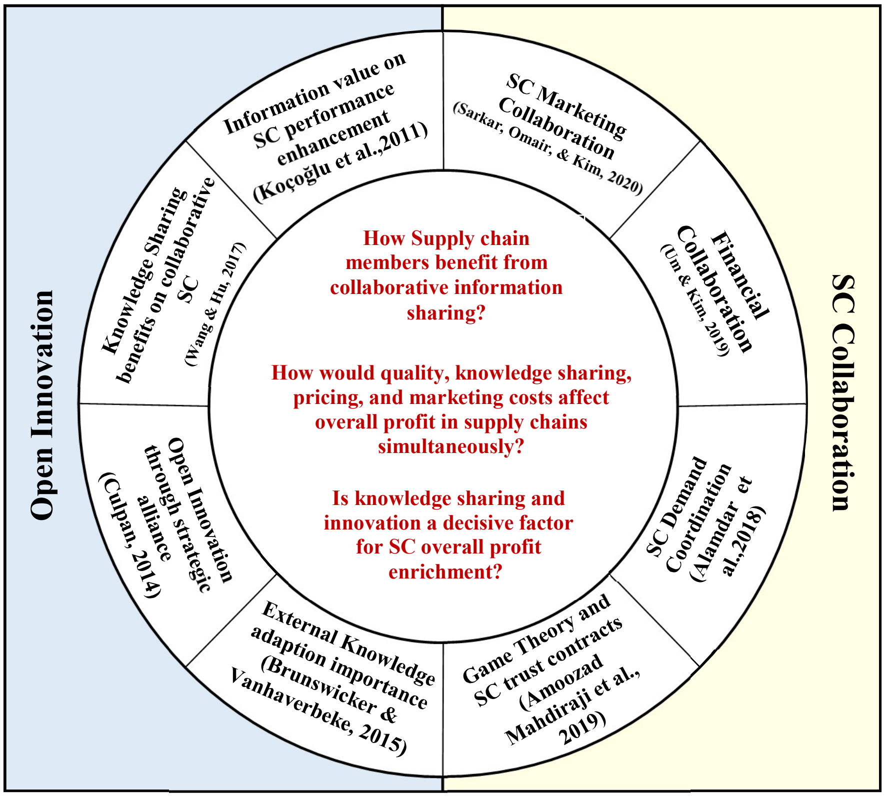


Figure 2. Research agenda

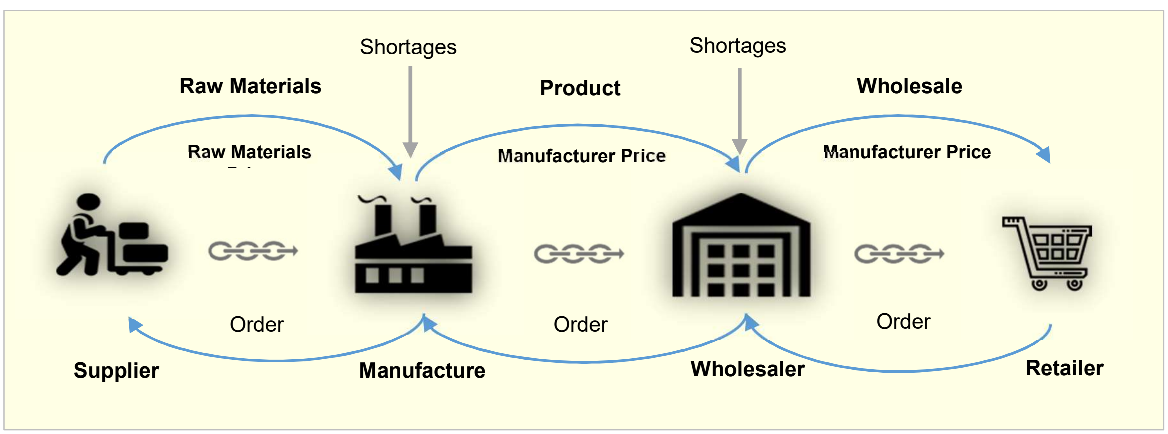


Figure 3. Four echelon supply chain trade-off

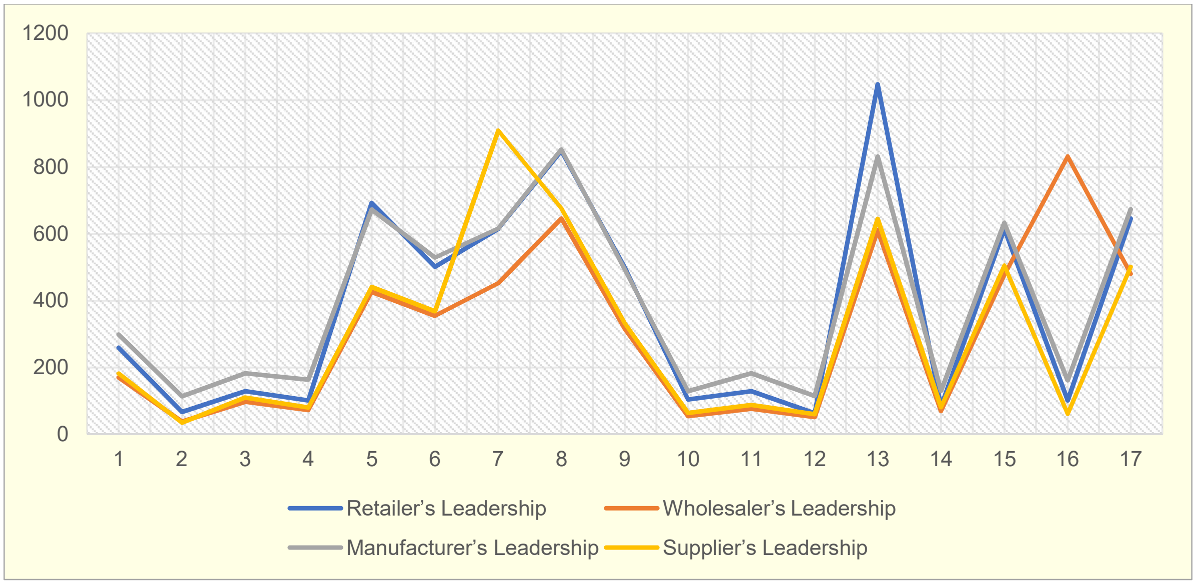


Figure 4. Supply chain overall profit behavior for various leadership roles

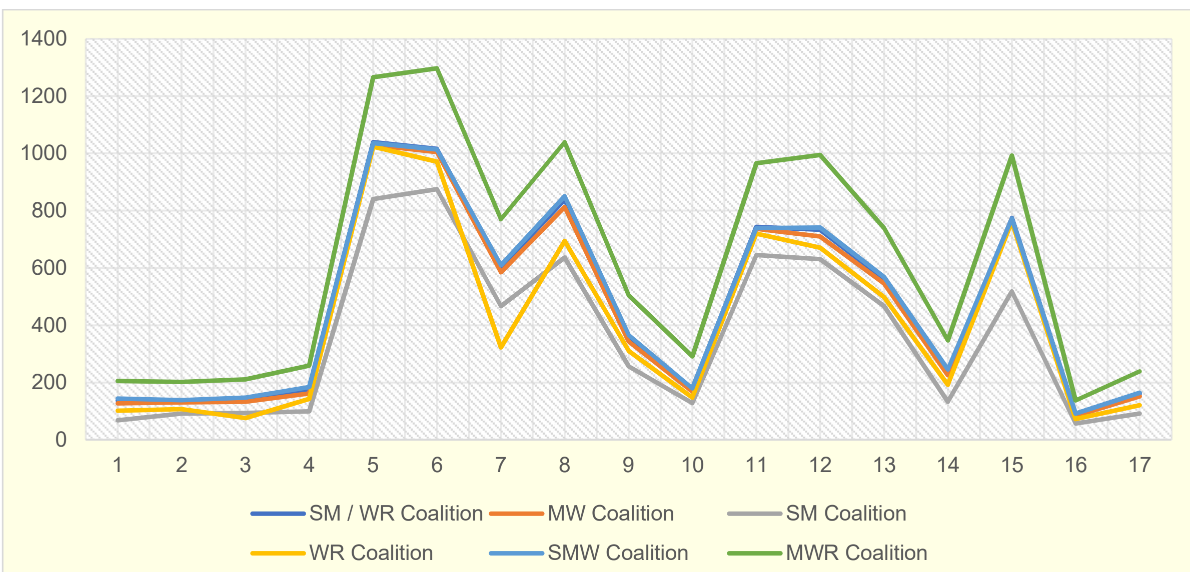


Figure 5. Supply chair overall profit behavior for various possible coalitions

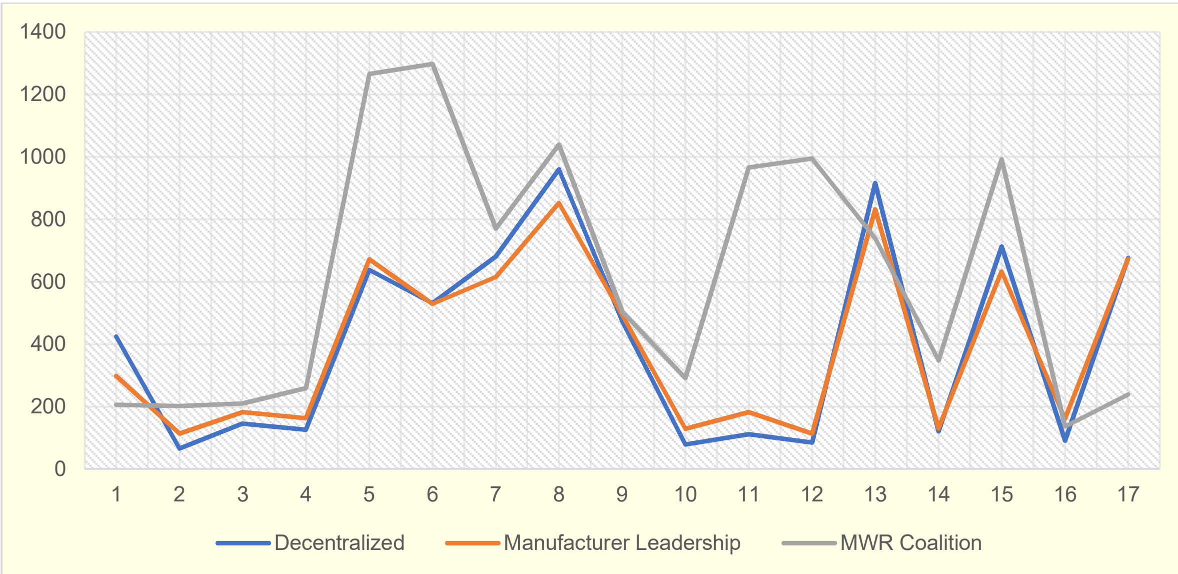


Figure 6. Supply chain overall profit for optimal scenario

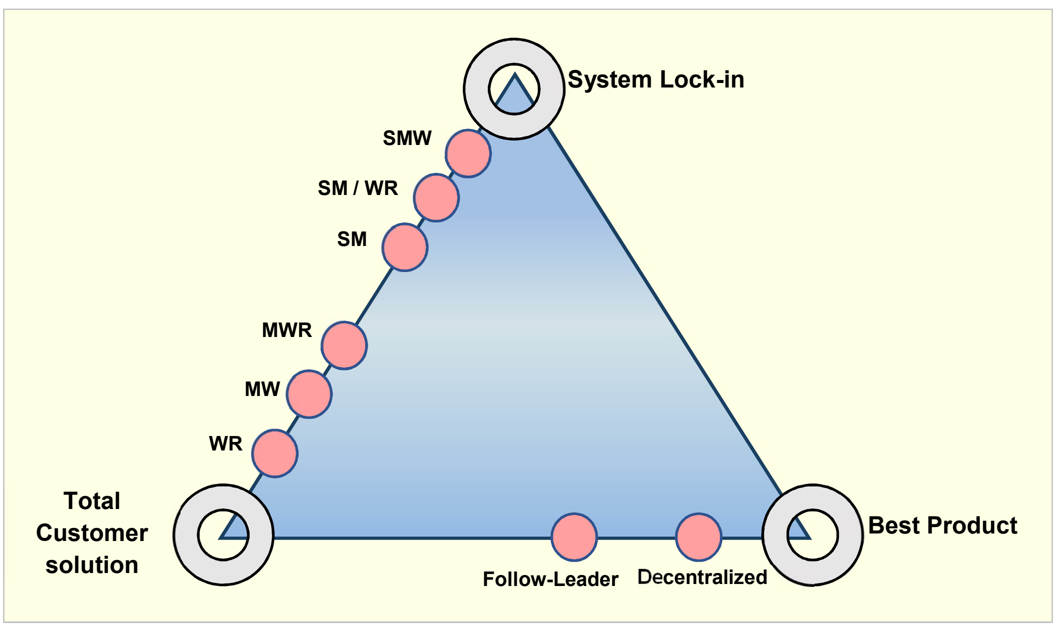


Figure 7. Delta model (Hax and Ii, 2003) with a coalition

Table 1. Recent collaborative supply chain studies at a glance

Author	Focus	Findings
(Ramanathan & Gunasekara, 2014)	Sustainability	Collaborative planning and decision making support SC sustainability and success in the long term
(Qu & Yang, 2015)	Contracts	Trust and uncertainty was found as a decisive factor in making collaboration with peers
(Sancha et al., 2016)	Sustainability	Despite the importance of supplier assessment, having a collaborative relationship with them improves SC profit in long term
(Long, 2017)	Digitalization	Data-driven computational experiments were suggested as a framework to reduce the possible risks of collaboration in SC
(Bustos & Moors, 2018)	Sustainability	Information flow and innovation were suggested as effective solutions in food industry collaborative SC
(Zhang & Cao, 2018)	Structure	Using a structural equation model, authors attempted assessing the impact of culture in making SC integration easier
(Koberg & Longoni, 2019)	Sustainability	Crucial factors affecting a sustainable global SC were analyzed through literature review
(Allaoui, Guo, & Sarkis, 2019)	Sustainability	A decision-making structure is designated to overcome with possible social and environmental issues regarding SC alliance

Table 2. Recent game-theoretic supply chain problems

Author	Focus	Method/Tools	Players	Findings
(Nagurney & Yu, 2012)	Competition	Nash equilibrium	overall	An oligopolistic competition for fashion SCs in the case of differentiated products considering environmental issues is investigated
(Zhang & Liu, 2013)	Marketing	Stackelberg	Supplier, Manufacturer, Distributor	The cooperation is profitable in green SCs considering a three echelon SC.
(Yin, Nishi, & Zhang, 2013)	Demand-Quality	Stackelberg	Manufacturer, Supplier	Coordination in an SC where there is one manufacturer and several suppliers were discussed and further proved with numeral examples
(Yue & You, 2014)	Demand-Information	Stackelberg	Supplier, Manufacturer, Costumer	A follow-leader game from the manufacturer perspective is investigated, and as a result, two case studies were implemented to confirm the functionality of the model
(Mahdiraji, Govindan, Zavadskas, & Hajiagha, 2014)	Price, Marketing	Nash equilibrium	Supplier, Manufacturer, Retailer	An unlimited three echelon SC is envisaged, and as the result of the non-collaborative game and two collaborative scenarios, the decentralized SC was found to perform worse
(Alaei, Alaei, & Salimi, 2014)	Marketing	Stackelberg, Nash equilibrium	Manufacturer, Retailer	Cooperative and non-collaborative SCs consist of manufacture and multiple retailers are studied to find an optimal solution to reduce advertising costs
(Huang, Wang, Zhang, & Pang, 2016)	Price	Generic algorithm and GT	Supplier, Manufacturer, Retailer	A game theoretic-generic algorithm model is suggested to overcome troubles caused by greenhouse gases.
(Taleizadeh & Noori-daryan, 2016)	Price-Inventory	Stackelberg	Supplier, Manufacturer, Retailer	The optimized Stackelberg model is proposed to help SC members achieve more profit and to have better inventory planning
(Nishi & Yoshida, 2016)	Demand	Stackelberg	Manufacturer, Retailer	Using the Stackelberg game, a multi-period bi-level SC under demand uncertainty is optimized
(Chua, Vasnani, Pacio, & Ocampo, 2018)	Price	Stackelberg	Manufacturer, Supplier	Collaboration between manufacturer and supplier was suggested in a leader-follower game to overcome with customization phenomenon in production
(Raj, Biswas, & Srivastava, 2018)	Price, Sustainability	Stackelberg	Supplier, Retailer	A buyer-seller scenario is discussed to overcome with greening costs considering social responsibility
(Xiao, Zhou, Zhong, & Xie, 2019)	Marketing	Stackelberg	Manufacturer, Retailer	Two advertising policies were suggested in a collaborative two-echelon SC
(Mahdiraji et al., 2019)	Demand	Nash equilibrium	Supplier, Retailer	The collaboration in the form of Three contract forms, i.e., rebate, buyback, and flexible SC was investigated, and the rebate was found to be the most remarkable one
(Sepahi Chavoshlou et al., 2019)	Demand, Sustainability	Nash equilibrium	Government, Manufacturer	Developed a model that analyzes the effect of customer's opinions on the strategic outcomes. This research is seeking for the best strategy selection and improved payoff.

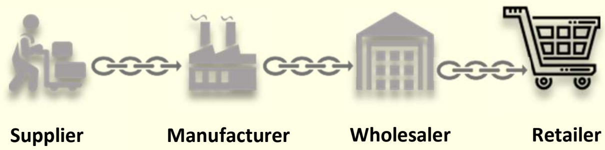
Table 3. Research contributions

Aspect	Previous researches focus	Proposed research novelty
Supply chain collaboration	• Seller-buyer coordinations • Demand and price evaluation • Supply chain marketing cooperation • Definite dual or trio collaboration evaluation	• Comprehensive cooperative contracts assessment • Strategic insight on different coalitions
Open Innovation	• Qualitative study • Risk and benefit assessment	• Quantitative analysis • Experiment on all possible coalitions between supply chain members

Table 4. Parameters and variables

Sign	Type	Concept	Description
K	P	Demand's constant	$K > 0$
C_V	P	Quality Improvement Cost	Number
α	P	Price Elasticity	$\alpha > 1$
γ	P	Quality Elasticity	$\gamma > 0$
k	P	Knowledge sharing parameter	$1.2<k<1.5$
β	P	Marketing Elasticity	$0 < \beta < 1$
J	P	Product Handling Cost Share from Price	Percentage
D	P	Annual Demand	Quantity
λ	P	Demand / Production Rate	Percentage
C_{Sw}	P	Wholesaler's Setup Cost per order	Currency
C_{ss}	P	Supplier's setup Cost per setup	Currency
C_{sr}	P	Retailer's ordering Cost per order	Currency
C_{sm}	P	Manufacturers' setup cost per production	Currency
C_{bm}	P	Manufacturer's Shortage Cost per unit	Currency
C_e	P	Suppliers Extraction Cost per unit	Currency
C_{bw}	P	Wholesaler's Shortage Cost per unit	Currency
Q_w	V	Wholesaler's Order	Quantity
b_w	V	Wholesaler's Shortage	Quantity
p_w	V	Wholesaler's Price per unit	Currency
p_m	V	Manufacturer's Price per unit	Currency
Q_m	V	Manufacturer's Order	Quantity
b_m	V	Manufacturer's Shortage	Quantity
C_m	V	Marketing Costs per unit	Currency
V	V	Quality Improvement	Scale
p_s	V	Supplier's Price per unit	Currency
p_r	V	Retailer's Price	Currency
Q_r	V	Retailer's Order	Quantity

Table 5. Retailer member model



Retailer's Payoff Function: Retailer's profit= ((Retailer's price)*(customer demand))-(inventory costs)-(setup cost)-(wholesaler's price)
Constraint: demand; retailer's price greater than wholesaler's price

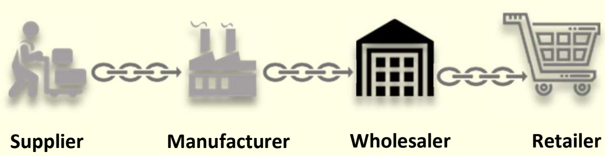
$$max\,profit\ R = (p_r \times D) - \left(j.P_w \times \frac{Q_r}{2}\right) - \left(C_{sr} \times \frac{D}{Q_r}\right) - (D \times P_w)\,;$$

Subject to:

$$D = K.p_r^{-\alpha}.C_m^{\beta}.V^{\gamma};\tag{9}$$

$\alpha > 1;$	$0 < \gamma < 1;$	$1 < V < 5;$
$\alpha - \beta > 1;$	$\beta - \gamma > 0.05;$	$P_r > P_w;$
$0 < \beta < 1;$	$\alpha - \gamma > 1.05;$	

Table 6. Wholesaler member model



Wholesaler's Payoff Function: Wholesaler's profit= ((wholesaler's price)*(retailer's demand))-(inventory costs)-(shortage costs)-(setup cost)
Constraint: demand; wholesaler's price greater than the manufacturer's price

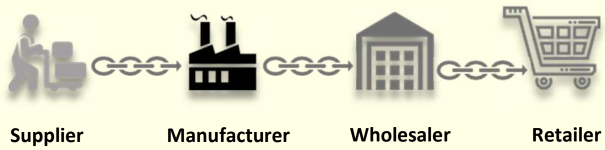
$$max\,profit\ W = (p_w \times D) - \left(j \times P_m \times \frac{(Q_w - b_w)^2}{2Q_w}\right) - \left(C_{sw} \times \frac{D}{Q_w}\right) - \left(C_{bw} \times \frac{b_w^2}{2Q_w}\right) - (D \times P_m)\,;\tag{10}$$

Subject to:

$$D = K.p_r^{-\alpha}.C_m^{\beta}.V^{\gamma};$$

$\alpha > 1$	$0 < \gamma < 1;$	$1 < V < 5$
$\alpha - \beta > 1$	$\beta - \gamma > 0.05;$	$P_w > P_m;$
$0 < \beta < 1;$	$\alpha - \gamma > 1.05;$	$1 < V < 5$

Table 7. Manufacturer member model



Manufacturer's Payoff Function: Manufacturer's profit= ((Manufacturer's price)*(wholesaler's demand))-(inventory costs)-(setup costs)-(shortage costs)-(quality costs)-(marketing costs)-(production costs)
Constraint: demand; Manufacturer's price greater than supplier's price

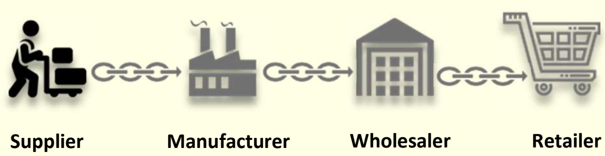
$$max\,profit\;M = (p_m \times D) - \left(\frac{C_{bm}.b_m^2}{2\lambda_m Q_{rm}}\right) - \left(j.P_s \times \frac{(\lambda_m Q_{rm} - b_m)^2}{2\lambda_m Q_{rm}}\right) - \left(C_{sm} \times \frac{D}{Q_m}\right) - (D \times P_s) - (D.V \times C_V) - (Cm * D)\,;$$

$Subject\ to$:

$$D = K.p_r^{-\alpha}.C_m^{\beta}.V^{\gamma}; \tag{11}$$

$\alpha > 1$	$0 < \gamma < 1;$	$1 < V < 5$
$\alpha - \beta > 1$	$\beta - \gamma > 0.05;$	$P_m > P_s;$
$0 < \beta < 1;$	$\alpha - \gamma > 1.05;$	

Table 8. Supplier member model



Supplier's Payoff Function: Supplier's profit= ((supplier's price)*(manufacturer's demand))-(inventory costs)-(setup costs)-(extraction costs)
Constraint: Balance between extracted and offered products

$$max\,profit\;S = (p_S \times D) - \left(j \times C_e \times \frac{q_m}{2}\right) - \left(C_{sS} \times \frac{D}{q_m}\right) - (D \times C_e)\,;$$

$Subject\ to$:

$$D = K.p_r^{-\alpha}.C_m^{\beta}.V^{\gamma}; \tag{12}$$

$\alpha > 1;$	$0 < \gamma < 1;$	$1 < V < 5;$
$\alpha - \beta > 1$	$\beta - \gamma > 0.05;$	$D > 0;$
$0 < \beta < 1;$	$\alpha - \gamma > 1.05;$	$P_S > 0;$

Table 9. Follower-leader models

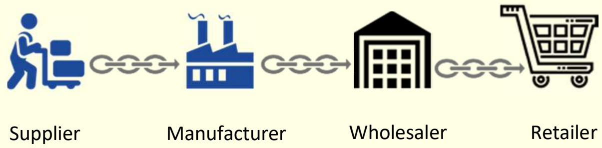
Condition	Profit Model	
Retailers Leadership	$max\,profit\ R = (p_r \times D) - \left(j.P_w \times \frac{Q_r}{2}\right) - \left(C_{sr} \times \frac{D}{Q_r}\right) - (D \times P_w)\,;$ $s.t.$ $Cm^* = \frac{-C_{sm}.\beta - P_m.Q_m.\beta + C_V.Q_m.V.\beta + P_s.Q_m.\beta}{Q_m(1+\beta)}$ $V^* = \frac{-C_{sm}.\gamma + C_m.Q_m.\gamma - P_m.Q_m.\gamma + P_s.Q_m.\gamma}{C_v(1+\gamma)}$ $b_m^* = \frac{\lambda.P_s.Q_m.j}{C_{bm} + P_s.j}$ $\frac{P_r^\alpha\left(\frac{C_e.Qm.j}{2} + \frac{C_e.C_m^\beta.K.V^\gamma}{P_r^\alpha} + \frac{C_m^\beta.C_s.K.V^\gamma}{P_r^\alpha.Qm}\right)}{C_m^\beta.K.V^\gamma} - P_s^* \leq 0$ $Q_m^* = \frac{\sqrt{P_r^\alpha.P_s.j\,(b_m^2.C_{bm}.P_r^\alpha + b_m^2.P_r^\alpha.P_s.j + 2.C_m^\beta.C_{sm}.K.\lambda.V^\gamma)}}{\lambda.P_r^\alpha.P_s.j}$ $b_w^* = \frac{P_m.Q_m.j}{C_{bw} + P_m.j}$ $Q_w^* = \frac{\sqrt{P_r^\alpha.P_m.j\,(b_w^2.C_{bw}.P_r^\alpha + b_w^2.P_r^\alpha.P_m.j + 2.C_m^\beta.C_{sw}.K.V^\gamma)}}{P_r^\alpha.P_m.j}$ $D = K.p_r^{-\alpha}.C_m^\beta.V^\gamma;$ $\alpha > 1;$ $0 < \gamma < 1;$ $1 < V < 5;$ $\alpha - \beta > 1;$ $\beta - \gamma > 0.05;$ $P_r > P_w;$ $0 < \beta < 1;$ $\alpha - \gamma > 1.05;$ $P_w > P_m.$	(13)
Wholesaler's Leadership	$max\,profit\ W = (p_w \times D) - \left(j \times P_m \times \frac{(Q_w - b_w)^2}{2Q_w}\right) - \left(C_{sw} \times \frac{D}{Q_w}\right) - \left(C_{bw} \times \frac{b_w^2}{2Q_w}\right) - (D \times P_m)\,;$ $s.t.$ $P_r^* = -\frac{C_{sr}\alpha + P_w * Q_r\alpha}{Q_r(1-\alpha)}$ $Q_r^* = \frac{\sqrt{(C_m^\beta.C_{sr}.K.V^\gamma)}}{P_r^\alpha.P_w.j}$ $Cm^* = \frac{-C_{sm}.\beta - P_m.Q_m.\beta + C_V.Q_m.V.\beta + P_s.Q_m.\beta}{Q_m(1+\beta)}$ $V^* = \frac{-C_{sm}.\gamma + C_m.Q_m.\gamma - P_m.Q_m.\gamma + P_s.Q_m.\gamma}{C_v(1+\gamma)}$ $b_m^* = \frac{\lambda.P_s.Q_m.j}{C_{bm} + P_s.j}$ $\frac{P_r^\alpha\left(\frac{C_e.Qm.j}{2} + \frac{C_e.C_m^\beta.K.V^\gamma}{P_r^\alpha} + \frac{C_m^\beta.C_s.K.V^\gamma}{P_r^\alpha.Qm}\right)}{C_m^\beta.K.V^\gamma} - P_s^* \leq 0$ $Q_m^* = \frac{\sqrt{P_r^\alpha.P_s.j\,(b_m^2.C_{bm}.P_r^\alpha + b_m^2.P_r^\alpha.P_s.j + 2.C_m^\beta.C_{sm}.K.\lambda.V^\gamma)}}{\lambda.P_r^\alpha.P_s.j}$ $D = K.p_r^{-\alpha}.C_m^\beta.V^\gamma;$ $\alpha > 1;$ $0 < \gamma < 1;$ $1 < V < 5;$ $\alpha - \beta > 1;$ $\beta - \gamma > 0.05;$ $P_w > P_m;$ $0 < \beta < 1;$ $\alpha - \gamma > 1.05;$ $P_r > P_w.$	(14)

Table 9 (continued). Follower-leader models

Condition	Profit Model	
Manufacturer's Leadership	$max\ profit\ M = (p_m \times D) - \left(\frac{C_{bm}.b_m^2}{2\lambda_m Q_{rm}}\right) - \left(j.P_s \times \frac{(\lambda_m Q_{rm} - b_m)^2}{2\lambda_m Q_{rm}}\right) - \left(C_{sm} \times \frac{D}{Q_m}\right) - (D \times P_s) - (D.V \times C_V) - (Cm * D);$ $s.t.$ $P_r^* = -\frac{C_{sr}\alpha + P_w * Q_r\alpha}{Q_r(1-\alpha)}$ $Q_r^* = \frac{\sqrt{(C_m^\beta.C_{sr}.K.V^\gamma)}}{P_r^\alpha.P_w.j}$ $\frac{P_r^\alpha\left(\frac{C_e.Qm.j}{2} + \frac{C_e.C_m^\beta.K.V^\gamma}{P_r^\alpha} + \frac{C_m^\beta.C_s.K.V^\gamma}{P_r^\alpha.Qm}\right)}{C_m^\beta.K.V^\gamma} - P_s^* \le 0$ $b_w^* = \frac{P_m.Q_m.j}{C_{bw} + P_m.j}$ $Q_w^* = \frac{\sqrt{P_r^\alpha.P_m.j\ (b_w^2.C_{bw}.P_r^\alpha + b_w^2.P_r^\alpha.P_m.j + 2.C_m^\beta.C_{sw}.K.V^\gamma)}}{P_r^\alpha.P_m.j}$ $D = K.p_r^{-\alpha}.C_m^\beta.V^\gamma;$ $\alpha > 1;$ $0 < \gamma < 1;$ $1 < V < 5;$ $\alpha - \beta > 1;$ $\beta - \gamma > 0.05;$ $P_w > P_m;$ $0 < \beta < 1;$ $\alpha - \gamma > 1.05;$ $P_r > P_w.$	(15)
Supplier's Leadership	$max\ profit\ S = (p_S \times D) - \left(j \times C_e \times \frac{q_m}{2}\right) - \left(C_{sS} \times \frac{D}{q_m}\right) - (D \times C_e);$ $Subject\ to:$ $b_w^* = \frac{P_m.Q_m.j}{C_{bw} + P_m.j}$ $Q_w^* = \frac{\sqrt{P_r^\alpha.P_m.j\ (b_w^2.C_{bw}.P_r^\alpha + b_w^2.P_r^\alpha.P_m.j + 2.C_m^\beta.C_{sw}.K.V^\gamma)}}{P_r^\alpha.P_m.j}$ $P_r^* = -\frac{C_{sr}\alpha + P_w * Q_r\alpha}{Q_r(1-\alpha)}$ $Q_r^* = \frac{\sqrt{(C_m^\beta.C_{sr}.K.V^\gamma)}}{P_r^\alpha.P_w.j}$ $Cm^* = \frac{-C_{sm}.\beta - P_m.Q_m.\beta + C_V.Q_m.V.\beta + P_s.Q_m.\beta}{Q_m(1+\beta)}$ $V^* = \frac{-C_{sm}.\gamma + C_m.Q_m.\gamma - P_m.Q_m.\gamma + P_s.Q_m.\gamma}{C_v(1+\gamma)}$ $b_m^* = \frac{\lambda.P_s.Q_m.j}{C_{bm} + P_s.j}$ $Q_m^* = \frac{\sqrt{P_r^\alpha.P_s.j\ (b_m^2.C_{bm}.P_r^\alpha + b_m^2.P_r^\alpha.P_s.j + 2.C_m^\beta.C_{sm}.K.\lambda.V^\gamma)}}{\lambda.P_r^\alpha.P_s.j}$ $D = K.p_r^{-\alpha}.C_m^\beta.V^\gamma;$ $\alpha > 1;$ $0 < \gamma < 1;$ $1 < V < 5;$ $P_w > P_m;$ $\alpha - \beta > 1;$ $\beta - \gamma > 0.05;$ $D > 0;$ $P_r > P_w;$ $0 < \beta < 1;$ $\alpha - \gamma > 1.05;$ $P_S > 0;$ $P_m > P_S.$	(16)

Table 10. Possible coalitions strategies

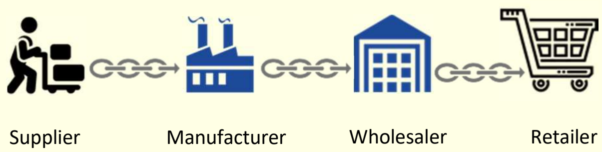
Coalition strategy: The supplier with the manufacturer and the wholesaler with the retailer (SM-WR)



$$V^* = \frac{-(Cssm.k.\gamma + Cesm.k.\gamma + Cm.k.\gamma.Qsm.\gamma - k.Psm.Qsm.\gamma)}{Cvsm.Qsm + Cvsm.k.Qsm.\gamma}$$
$$Cm^* = \frac{-(Cssm.\beta + Cesm.Qsm.\beta - Psm.Qsm.\beta + Cvsm.Qsm.V.\beta)}{Qsm + Qsm.\beta}$$
$$Pwr^* = \frac{-(Cswr.\alpha + Psm.Qwr.\alpha)}{Qwr + Qwr.\alpha}$$
$$Qwr^* = \frac{\sqrt{2.(Cm.\beta.Cswr.K.V^{k.\gamma})}}{j.Psm.Pwr^{\alpha}}$$
$$Qsm^* = \frac{\sqrt{2.(Cm.\beta.Cssm.K.V^{k.\gamma})}}{j.Cesm.Pwr^{\alpha}}$$
$$Pwr > Psm$$
$$D = K.p_r^{-\alpha}.C_m^{\beta}.V^{\gamma * k}; \tag{18}$$

$\alpha > 1;$	$0 < \gamma < 1;$	$1 < V < 5;$	$P_S > 0;$
$\alpha - \beta > 1;$	$\beta - \gamma > 0.05;$	$1.2 < k < 1.5;$	
$0 < \beta < 1;$	$\alpha - \gamma > 1.05;$	$D > 0;$	

Coalition strategy: The manufacturer with the wholesaler and other members act independently (MW)

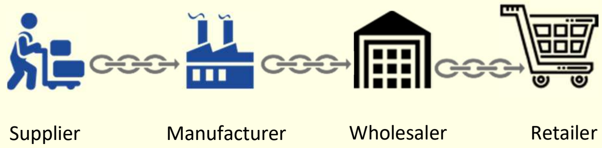


$$V^* = \frac{-(Csmw.k.\gamma + Cm.Qmw.k.\gamma - Pmw.Qmw.k.\gamma + k.Ps.Qmw.\gamma)}{Cvmw.Qmw + Cvmw.k.Qmw.\gamma}$$
$$Cm^* = \frac{-(Csmw.\beta - Pmw.Qmw.\beta + Ps.Qmw.\beta + Cvmw.Qmw.V.\beta)}{Qmw + Qmw.\beta}$$
$$Qmw^* = \frac{\sqrt{2.(Cm.\beta.Csmw.K.V^{k.\gamma})}}{j.Ps.Pr^{\alpha}}$$
$$P_r^* = -\frac{C_{sr}\alpha + P_{mw} * Q_r\alpha}{Q_r(1-\alpha)}$$
$$Q_r^* = \frac{\sqrt{(C_m^{\beta}.C_{sr}.K.V^{\gamma})}}{P_r^{\alpha}.P_{mw}.j}$$
$$\frac{P_r^{\alpha}\left(\frac{C_e.Qmw.j}{2} + \frac{C_e.C_m^{\beta}.K.V^{\gamma}}{P_r^{\alpha}} + \frac{C_m^{\beta}.C_s.K.V^{\gamma}}{P_r^{\alpha}.Qmw}\right)}{C_m^{\beta}.K.V^{\gamma}} - P_s^* \leq 0$$
$$Pr > Pmw > Ps$$
$$D = K.p_r^{-\alpha}.C_m^{\beta}.V^{\gamma * k}; \tag{19}$$

$\alpha > 1$	$0 < \gamma < 1;$	$1 < V < 5$	$P_S > 0;$
$\alpha - \beta > 1$	$\beta - \gamma > 0.05;$	$1.2 < k < 1.5$	
$0 < \beta < 1;$	$\alpha - \gamma > 1.05;$	$D > 0;$	

Table 10 (continued). Possible coalitions analysis

Coalition strategy: The supplier with the manufacturer and other members act independently (SM)



$$b_w^* = \frac{P_{sm}.Q_m.j}{C_{bw} + P_{sm}.j}$$

$$Q_w^* = \frac{\sqrt{P_r^\alpha.P_{sm}.j\ (b_w^2.C_{bw}.P_r^\alpha + b_w^2.P_r^\alpha.P_{sm}.j + 2.C_m^\beta.C_{sw}.K.V^\gamma)}}{P_r^\alpha.P_{sm}.j}$$

$$P_r^* = -\frac{C_{sr}\alpha + P_w * Q_r\alpha}{Q_r(1-\alpha)}$$

$$Q_r^* = \frac{\sqrt{(C_m^\beta.C_{sr}.K.V^\gamma)}}{P_r^\alpha.P_w.j}$$

$$Qsm^* = \frac{\sqrt{2.(Cm.\beta.Cssm.K.V^{k.\gamma})}}{j.Cesm.Pr^\alpha}$$

$$V^* = \frac{-(Cssm.k.\gamma + Cesm.k.\gamma + Cm.k.\gamma.Qsm.\gamma - k.Psm.Qsm.\gamma)}{Cvsm.Qsm + Cvsm.k.Qsm.\gamma} \quad (20)$$

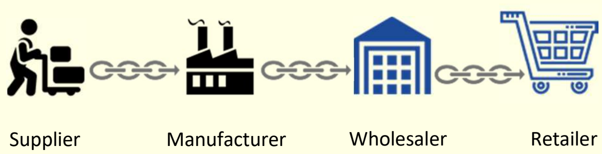
$$Cm^* = \frac{-(Cssm.\beta + Cesm.Qsm.\beta - Psm.Qsm.\beta + Cvsm.Qsm.V.\beta)}{Qsm + Qsm.\beta}$$

$Pr > Pm > Psm$

$D = K.p_r^{-\alpha}.C_m^\beta.V^{\gamma*k};$

$\alpha > 1;$	$0 < \gamma < 1;$	$1 < V < 5;$	$P_S > 0;$
$\alpha - \beta > 1;$	$\beta - \gamma > 0.05;$	$1.2 < k < 1.5;$	
$0 < \beta < 1;$	$\alpha - \gamma > 1.05;$	$D > 0.$	

Coalition strategy: The wholesaler with the retailer and other members act independently (WR)



$$Pwr^* = \frac{-(Cswr.\alpha + Pm.Qwr.\alpha)}{Qwr + Qwr.\alpha}$$

$$Qwr^* = \frac{\sqrt{2.(Cm.\beta.Cswr.K.V^{k.\gamma})}}{j.Pm.Pwr^\alpha}$$

$$Cm^* = \frac{-C_{sm}.\beta - P_m.Q_m.\beta + C_V.Q_m.V.\beta + P_s.Q_m.\beta}{Q_m(1+\beta)}$$

$$V^* = \frac{-C_{sm}.\gamma + C_m.Q_m.\gamma - P_m.Q_m.\gamma + P_s.Q_m.\gamma}{C_v(1+\gamma)}$$

$$Q_m^* = \frac{\sqrt{P_r^\alpha.P_s.j\ (b_m^2.C_{bm}.P_r^\alpha + b_m^2.P_r^\alpha.P_s.j + 2.C_m^\beta.C_{sm}.K.\lambda.V^\gamma)}}{\lambda.P_r^\alpha.P_s.j} \quad (21)$$

$$\frac{P_r^\alpha\left(\frac{C_e.Qm.j}{2} + \frac{C_e.C_m^\beta.K.V^\gamma}{P_r^\alpha} + \frac{C_m^\beta.C_s.K.V^\gamma}{P_r^\alpha.Qm}\right)}{C_m^\beta.K.V^\gamma} - P_s^* \le 0$$

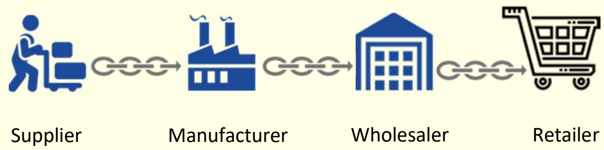
$Pwr > Pm > Ps$

$D = K.p_r^{-\alpha}.C_m^\beta.V^{\gamma*k};$

$\alpha > 1;$	$0 < \gamma < 1;$	$1 < V < 5;$	$P_S > 0;$
$\alpha - \beta > 1;$	$\beta - \gamma > 0.05;$	$1.2 < k < 1.5;$	
$0 < \beta < 1;$	$\alpha - \gamma > 1.05;$	$\alpha - \gamma > 1.05.$	

Table 10 (continued). Possible coalitions analysis

Coalition strategy: The supplier with the manufacturer and the wholesaler (SMW)



$$\frac{P_r^{\alpha}\left(C_{cosmw} + \frac{C_e.Q_r.j}{2} + \frac{C_e.C_m^{\beta}.K.V^{k.\gamma}}{P_r^{\alpha}} + \frac{C_m.C_m^{\beta}.K.V^{k.\gamma}}{P_r^{\alpha}} + \frac{C_{Vsmw}.C_m^{\beta}.K.V.V^{k.\gamma}}{P_r^{\alpha}} + \frac{C_{ssmw}.C_m^{\beta}.K.V^{k.\gamma}}{P_r^{\alpha}.Q_r}\right)}{C_m^{\beta}.K.V^{k.\gamma}} - P_{smw} \leq 0$$

$$P_r^* = -\frac{C_{sr}\alpha + P_w * Q_r\alpha}{Q_r(1-\alpha)}$$

$$Q_r^* = \frac{\sqrt{(C_m^{\beta}.C_{sr}.K.V^{\gamma})}}{P_r^{\alpha}.P_w.j}$$

$$Cm^* = \frac{-(C_{ssmw}.\beta + C_e.Q_r.\beta + C_{vsmw}.Q_r.V.\beta}{Q_r + Q_r.\beta}$$

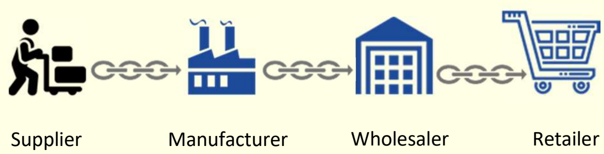
$$V^* = \frac{-(C_{ssmw}.k.\gamma + C_e.K.Q_r.\gamma + C_m.k,Q_r.\gamma - k.P_{smw}.Q_r.\gamma)}{C_{vsmw}.Q_r + C_{vsmw}.k.Q_r.\gamma}$$

$$Pr > Psmw$$

$$D = K.p_r^{-\alpha}.C_m^{\beta}.V^{\gamma * k}; \tag{22}$$

$\alpha > 1;$	$0 < \gamma < 1;$	$1 < V < 5;$
$\alpha - \beta > 1;$	$\beta - \gamma > 0.05;$	$1.2 < k < 1.5;$
$0 < \beta < 1;$	$\alpha - \gamma > 1.05;$	$D > 0.$

Coalition strategy: The manufacturer with the wholesaler and the retailer (MWR)



$$P_{mwr}^* = -\frac{C_{smwr}.\alpha + C_m.Q_{rmwr}.\alpha + P_s.Q_{rmwr}.\alpha + C_{vmwr}.Q_{rmwr}.V.\alpha}{Q_{rmwr} - Q_{mwr}\alpha}$$

$$C_m^* = -\frac{C_{smwr}.\beta + P_{mwr}.Q_{rmwr}.\beta + P_s.Q_{rmwr}.\beta + C_{vmwr}.Q_{rmwr}.V.\beta}{Q_{rmwr} + Q_{mwr}\beta}$$

$$V^* = -\frac{C_{smwr}.k.\gamma + C_m.k.\gamma.Q_{rmwr} + P_s.Q_{rmwr}.k.\gamma - P_{mwr}.Q_{rmwr}.k.\gamma}{C_{vmwr}.Q_{rmwr} + C_{vmwr}.k.Q_{mwr}\gamma}$$

$$\frac{P_r^{\alpha}\left(\frac{C_e.Qmw.j}{2} + \frac{C_e.C_m^{\beta}.K.V^{\gamma}}{P_r^{\alpha}} + \frac{C_m^{\beta}.C_s.K.V^{\gamma}}{P_r^{\alpha}.Qmw}\right)}{C_m^{\beta}.K.V^{\gamma}} - P_s^* \leq 0 \tag{23}$$

$$Pmwr > Ps; \quad D = K.p_{mwr}^{-\alpha}.C_m^{\beta}.V^{\gamma * k};$$

$\alpha > 1;$	$0 < \gamma < 1;$	$1 < V < 5$	$P_S > 0;$
$\alpha - \beta > 1$	$\beta - \gamma > 0.05;$	$1.2 < k < 1.5$	
$0 < \beta < 1;$	$\alpha - \gamma > 1.05;$	$D > 0.$	

Table 11. Decentralized supply chain formulation

Decentralized supply chain

$$
\begin{aligned}
&b_w^* = \frac{P_m . Q_m . j}{C_{bw} + P_m . j} \\
&Q_w^* = \frac{\sqrt{P_r^\alpha . P_m . j\,(b_w^2 . C_{bw} . P_r^\alpha + b_w^2 . P_r^\alpha . P_m . j + 2 . C_m^\beta . C_{sw} . K . V^\gamma)}}{P_r^\alpha . P_m . j} \\
&P_r^* = -\frac{C_{sr}\alpha + P_w * Q_r\alpha}{Q_r(1-\alpha)} \\
&Q_r^* = \frac{\sqrt{(C_m^\beta . C_{sr} . K . V^\gamma)}}{P_r^\alpha . P_w . j} \\
&Cm^* = \frac{-C_{sm} . \beta - P_m . Q_m . \beta + C_V . Q_m . V . \beta + P_s . Q_m . \beta}{Q_m(1+\beta)} \\
&V^* = \frac{-C_{sm} . \gamma + C_m . Q_m . \gamma - P_m . Q_m . \gamma + P_s . Q_m . \gamma}{C_v(1+\gamma)} \\
&b_m^* = \frac{\lambda . P_s . Q_m . j}{C_{bm} + P_s . j} \\
&Q_m^* = \frac{\sqrt{P_r^\alpha . P_s . j\,(b_m^2 . C_{bm} . P_r^\alpha + b_m^2 . P_r^\alpha . P_s . j + 2 . C_m^\beta . C_{sm} . K . \lambda . V^\gamma)}}{\lambda . P_r^\alpha . P_s . j} \\
&\frac{P_r^\alpha\left(\frac{C_e . Qm . j}{2} + \frac{C_e . C_m^\beta . K . V^\gamma}{P_r^\alpha} + \frac{C_m^\beta . C_s . K . V^\gamma}{P_r^\alpha . Qm}\right)}{C_m^\beta . K . V^\gamma} - P_s^* \leq 0 \\
&D = K . p_r^{-\alpha} . C_m^\beta . V^\gamma;
\end{aligned}
\tag{24}
$$

$\alpha > 1$;	$0 < \gamma < 1$;	$1 < V < 5$;	$P_w > P_m$;
$\alpha - \beta > 1$	$\beta - \gamma > 0.05$;	$D > 0$;	$P_r > P_w$;
$0 < \beta < 1$;	$\alpha - \gamma > 1.05$;	$P_S > 0$;	$P_m > P_S$.

Table 12. Significant parameter values for the full factorial experimental design

α	β	γ	K	α	β	γ	K	α	β	γ	K
1.45	0.15	0.03	3500	1.3	0.2	0.02	3000	1.3	0.2	0.02	4000
1.6	0.1	0.02	3000	1.3	0.2	0.04	4000	1.6	0.2	0.04	3000
1.6	0.2	0.04	4000	1.3	0.1	0.02	3000	1.3	0.2	0.04	3000
1.6	0.1	0.04	4000	1.6	0.2	0.02	3000	1.6	0.1	0.02	4000
1.3	0.1	0.02	4000	1.6	0.2	0.02	4000	1.3	0.1	0.04	4000
1.3	0.1	0.04	3000	1.6	0.1	0.04	3000	-	-	-	-

Table 13. Non-significant parameter values for the full factorial experimental design

Parameter	Value
Csr	2
Csw	4
Cbw	1.5
Cbm	1
Csm	20
C_e	5
C_{Vsm}	2
C_{Ssmw}	25
C_{Smwr}	1.8
C_{COmwr}	11
C_{COsm}	10
C_{Swr}	5
C_{COwr}	7
C_{Smw}	22
C_{Vmw}	2.5
C_{COmw}	8
C_{Vsmw}	1.5
C_{COsmw}	12
C_{Vmhr}	2.2
C_{Ss}	15

Table 14. Leader-follower equilibrium results

Experiment	α	β	γ	K	Retailer's Leadership	Supply chain overall profit for each leadership scenario		
						Wholesaler's leadership	Manufacturer's leadership	Supplier's leadership
1	1.45	0.15	0.03	3500	259.5107614	170.237	298.7409	181.8891699
2	1.6	0.1	0.02	3000	67.4399587	38.07248	113.9521	34.91742797
3	1.6	0.2	0.04	4000	129.3593672	97.59624	183.1419	110.1501007
4	1.6	0.1	0.04	4000	101.8827711	73.07542	163.2261	80.37270516
5	1.3	0.1	0.02	4000	692.8702664	426.3499	672.1883	440.6121292
6	1.3	0.1	0.04	3000	501.4665204	354.7039	529.0644	368.5989024
7	1.3	0.2	0.02	3000	614.904258	452.8248	615.7326	908.7963114
8	1.3	0.2	0.04	4000	847.0354848	645.4392	852.3403	676.6799383
9	1.3	0.1	0.02	3000	500.6665204	315.4587	493.6802	333.2038882
10	1.6	0.2	0.02	3000	104.7464533	54.9522	129.3954	63.90485396
11	1.6	0.2	0.02	4000	129.3593672	76.9435	182.4701	88.38589512
12	1.6	0.1	0.04	3000	63.6399587	51.62965	114.6323	60.11456777
13	1.3	0.2	0.02	4000	1047.035485	610.938	831.3391	644.9536921
14	1.6	0.2	0.04	3000	83.24645326	69.67672	130.1345	81.44937656
15	1.3	0.2	0.04	3000	614.904258	477.5933	633.2663	504.7668129
16	1.6	0.1	0.02	4000	101.8827711	831.3748	161.6643	60.95052583
17	1.3	0.1	0.04	4000	645.7245091	480.1292	673.192	501.5615263

Table 15. Pairwise comparisons for the optimal leadership

	R	W	M	S	Total
R	*	0	0	1	**1**
W	0	*	-1	0	**-1**
M	0	1	*	1	**2**
S	-1	0	-1	*	**-1**

Optimal Leadership (→ M)

Table 16. Supply chain overall profit for various coalition strategies

Experiment	α	β	γ	K	Supply chain overall profit for each coalition strategy						
					KN	SM / WR Coalition	PW Coalition	SM Coalition	WR Coalition	SMW Coalition	MWR Coalition
1	1.60	0.10	0.04	3000	1.50	137.257	127.1011	68.72381	102.3045	143.8836	206.063
2	1.60	0.20	0.02	3000	1.50	136.8335	130.5426	92.00016	106.9119	139.221	202.8045
3	1.60	0.10	0.02	4000	1.50	142.549	132.5452	94.38225	75.85565	147.9804	211.0499
4	1.60	0.10	0.04	4000	1.20	176.2049	162.2207	99.79619	143.1724	183.9495	259.3932
5	1.30	0.20	0.04	4000	1.20	1038.975	1029.14	840.9236	1023.648	1035.463	1265.619
6	1.30	0.20	0.02	4000	1.50	1016.31	1005.115	875.2885	971.5757	1013.365	1297.454
7	1.30	0.10	0.04	3000	1.20	602.3675	584.6035	466.748	323.0361	609.4002	770.5999
8	1.30	0.10	0.04	4000	1.50	838.2504	812.648	636.2759	694.7607	850.091	1039.249
9	1.45	0.15	0.03	3500	1.35	353.2727	342.8358	256.5698	310.8916	365.9216	504.9088
10	1.60	0.20	0.02	4000	1.20	176.7428	167.3922	129.0932	148.078	179.6416	291.4275
11	1.30	0.20	0.02	3000	1.20	743.2701	737.2227	644.942	719.7512	739.2119	965.5652
12	1.30	0.10	0.02	4000	1.20	733.2037	710.5003	631.2219	671.0708	741.6758	994.8514
13	1.30	0.10	0.02	3000	1.50	562.0558	545.8857	466.65	498.109	568.1311	739.3294
14	1.60	0.20	0.04	4000	1.50	239.428	225.2562	133.3371	192.2558	246.3531	347.4534
15	1.30	0.20	0.04	3000	1.50	774.5658	769.5542	518.3622	761.2133	772.1282	991.9144
16	1.60	0.10	0.02	3000	1.20	89.32125	84.38354	57.70015	72.45511	92.15327	137.0166
17	1.60	0.20	0.04	3000	1.20	160.8267	152.401	91.71926	120.7882	164.7006	239.6044

Table 17. Pairwise comparison for the optimal coalition

	WR/M/S	SM/W/R	MWR/S	R/SMW	R/MW/S	WR/MS	Total
WR/M/S	*	1	-1	-1	-1	-1	**-3**
SM/W/R	-1	*	-1	-1	-1	-1	**-5**
MWR/S	1	1	*	1	1	1	**5**
R/SMW	1	1	-1	*	1	1	**3**
R/MW/S	1	1	-1	-1	*	-1	**-1**
WR/MS	1	1	-1	-1	1	*	**1**

Optimal Coalition (→ MWR/S)

Table 18. Decentralized supply chain findings

Experiment	α	β	γ	K	Overall Profit
1	1.45	0.15	0.03	3500	424.6305
2	1.6	0.1	0.02	3000	65.88128
3	1.6	0.2	0.04	4000	145.9916
4	1.6	0.1	0.04	4000	126.8784
5	1.3	0.1	0.02	4000	638.4466
6	1.3	0.1	0.04	3000	531.0285
7	1.3	0.2	0.02	3000	680.7907
8	1.3	0.2	0.04	4000	959.542
9	1.3	0.1	0.02	3000	473.2611
10	1.6	0.2	0.02	3000	79.27258
11	1.6	0.2	0.02	4000	112.056
12	1.6	0.1	0.04	3000	85.29944
13	1.3	0.2	0.02	4000	916.312
14	1.6	0.2	0.04	3000	121.2019
15	1.3	0.2	0.04	3000	712.4342
16	1.6	0.1	0.02	4000	92.14694
17	1.3	0.1	0.04	4000	675.6231

Table 19. Supply chain overall profit comparison for all optimal conditions

Experiment	Decentralized	Manufacturer Leadership	MWR Coalition
1	424.630537	298.7409291	206.062991
2	65.88128125	113.9520658	202.8045029
3	145.9915778	183.1419366	211.0499194
4	126.8784472	163.2261195	259.3931501
5	638.4466239	672.1882607	1265.618813
6	531.0284991	529.0643507	1297.454141
7	680.7906972	615.7326308	770.5999329
8	959.5420357	852.3403399	1039.248615
9	473.2610858	493.6802117	504.9087738
10	79.2725787	129.3954406	291.4275149
11	112.0559562	182.4701466	965.5652283
12	85.29943923	114.6322757	994.8513882
13	916.3120233	831.3391125	739.3294044
14	121.2018639	130.1344921	347.4533605
15	712.4342262	633.2662664	991.9143842
16	92.14694317	161.6642747	137.0166309
17	675.6230888	673.1919925	239.6043579