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LEADERSHIP SELECTION IN AN UNLIMITED THREE-ECHELON SUPPLY CHAIN

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Abstract. Supply chain (SC) management aims to increase the overall profit through improvement of various activities and components. Many contradictions between parts and different levels of a SC have been identified in order to achieve overall objectives. Such shortfalls may result in decreased strength and competitiveness of the SC. This paper considers the main conflicts related to inventory, pricing and marketing costs in an unlimited three-echelon supply chain. Aimed at avoiding a profit decrease, the research focuses on finding an equilibrium between inventory, pricing and marketing cost of an unlimited three-echelon SC. On each level, the best leadership option with the greatest payoff is sought for between K retailer, M manufacturer and S supplier. According to Stackelberg non-cooperative game theory, each SC level can become a decision-making leader depending on the available negotiating power. Consequently, three leadership types are modelled on each level and the total SC profit is calculated and compared to ascertain the best option. The authors of the article found that transfer of leadership from a retailer to supplier results in reduction of the total profit. In addition, the research focused on the main effects of parameters used in leadership models. Finally, validation of the proposed model was examined by simulation and Arena software, which indicated that models based on a game theory were performed accurately.

Keywords: supply chain, non-cooperative game, Stackelberg game, design of experiment, simulation models.

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JEL Classification: C44, C61, C63, C68, C72, C90, M11, L11.

1. Introduction

A management construct cannot be effectively used by practitioners and researchers if no uniform definition exists. Such is the case with the term "supply chain management", which has numerous definitions and little consensus on what it means (Mentzer *et al*. 2001). Supply chain paradigms of today have predominated over the field of business (Mentzer 2001). During the late 1950s, Forrester and his colleagues at the Massachusetts Institute of Technology developed a number of underlying ideas and theories (Blanchard 2010). The Council of Supply Chain Management Professionals (CSCMP) defines supply chain management (SCM) as the planning and management of all activities involved in sourcing and procurement, conversion and all logistics management activities (Stank *et al.* 2005). Many researchers believe that in the last decades, competition between companies has turn into competition between their supply chains (Jespersen, Larsen 2005).

Considering the role and importance of SCM, this concept is faced with many challenges and problems. Although no comprehensive model of SC issues exists, a literature review indicates that researchers are mostly interested in relevant information systems, marketing, financial management, logistical and organisational matters (Wang *et al*. 2007).

SCM is mostly focused on improving operations and increasing profits; thus, conflicting goals and objectives of two or more SC levels may result in problems for all levels and impact on the total profit. Numerous conflicting objectives of different components and levels may results in decreased strength and competitiveness of the entire supply chain. This paper considers the main conflicts related to inventory, pricing and marketing costs in an unlimited three-echelon SC. The game theory considers goals of all levels and players, which makes it a suitable and reliable tool for solving conflicting situations. On each level, the best leadership option with the greatest payoff is sought for between K retailer, M manufacturer and S supplier. According to Stackelberg non-cooperative game theory, each SC level can become a decision-making leader depending on the available negotiating power. Consequently, three leadership types are modelled on each level and the total SC profit is calculated and compared to ascertain the best option. Different models of leadership based on non-cooperative Stackelberg game theory are proposed to find the best option considering unlimited SC with three levels and three decision variables, namely inventory, marketing cost and pricing. The research considers shortages and incremental behaviour of a manufacturer as well as undertakes sensitivity analysis by design of experiment and validation of proposed models by simulation, which are its key contributions.

The paper is structured as follows: first, literature review is offered on SC coordination using game theory; next, assumption, steps and methodology pertaining to developed models are presented; then, variables and parameters are described. Three different leadership methods and three mathematical model based on non-cooperative game theory are then presented considering three types of negotiating power. The best leadership option is found simulating numerical examples with the help of design of experiment (DOE).

2. Literature review

As per definition, supply chain consists of all parties directly or indirectly involved in fulfilling a customer need (Chopra, Meindel 2007). This process involves all activities required to turn raw materials into a final product that is delivered to a customer (Gumus, Guneri 2007). Such activities and functions include new product development, marketing efforts, various other operations, distribution, financial and also customer services. A typical supply chain involves a variety of stages such as customers, retailers, wholesalers, distributors, manufacturers and raw material suppliers (Chopra, Meindel 2007).

The main game theory concept was devised by mathematical researchers from Argentina and Japan in 1940s. It was first used to prove theories with the help of mathematics and calculus. Later, it was applied in economics, industry and other practical sciences (Rasmusen, Blackwell 2005). In 1950, John Nash presented equilibrium for cooperative situations (Nash 1950a). He also developed a model for bargaining problems (Nash 1950b); and a year later, he presented an equilibrium point for non-cooperative situations (Nash 1951). This research is primarily concerned with the use of game theory in general and non-cooperative Stackelberg games in particular in supply chain management. Review of similar researches suggests that:

1. Some scientists have focused on the use of Nash equilibrium point in supply chain coordination by the use of profit sharing contract (Feng *et al*. 2007; Jiazhen, Qin 2008; Feng 2008; Ying *et al*. 2007; Jaber *et al*. 2006; Bai, Wang 2008; Xu, Zhong 2011; Liu, Zhang 2006; Wang *et al*. 2009).
2. Others used Nash and Stackelberg games and compared their results in supply chain coordination and cooperation problems (Leng, Parlar 2010; Arda, Hennet 2005).
3. Many focused on the use of other kinds of coordinating contracts such as buyback, rebate, cost sharing, profit sharing discount models, option contracts and benefit sharing in multi-echelon SC problems (Cachon, Lariviere 2005; Yali, Zhanguo 2010; Chen, Zhang 2008; Cao *et al*. 2007; Cachon, Lariviere 1999; Zhang, Huang 2010; Cachon, Lariviere 2001; Leng, Parlar 2009; Xiao, Qi 2008; Chen, Xiao 2009; Xiao *et al*. 2007; Stein, Ginevicius 2010a; Stein 2010).
4. Some used Shapley value equilibrium and Eliasberg model for coordination and cooperation problems in SC (Bahinipati *et al*. 2009; Zhao *et al*. 2010; Leng, Zhu 2009).
5. Finally, some papers focus on other optimisation tools such as queuing theory, Markov chain, backward induction, stochastic programming and genetic algorithm for solving coordination and cooperation problems in a supply chain, mostly in incomplete information games situations (Cachon, Kok 2010; Hennet, Arda 2008; Stein, Ginevicius 2010b; Zhen *et al*. 2006; Kaviani *et al*. 2011; Gupta, Weerawat 2006).

3. Research methodology and assumptions

Main steps used for the selection of leadership in an unlimited three-echelon supply chain are presented in Figure 1.

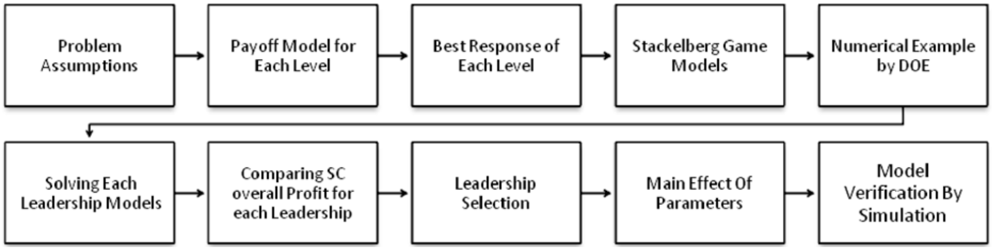


Fig. 1. Research methodology

3.1. Assumptions

1. Supply chain consists of K retailer, M manufacturer and S supplier (Jaafarnejad *et al*. 2012)

$$\begin{Bmatrix} s_1 \\ s_2 \\ . \\ . \\ . \\ s_M \end{Bmatrix} \Leftrightarrow \begin{Bmatrix} n_1 \\ n_2 \\ . \\ . \\ . \\ n_N \end{Bmatrix} \Leftrightarrow \begin{Bmatrix} r_1 \\ r_2 \\ . \\ . \\ . \\ r_K \end{Bmatrix} \leftrightarrow Customer.$$

2. The product demand function depends on a price and marketing costs. This function is non-linear $D_n = k \cdot P_{r_n}{}^{-\alpha} \cdot C_{M_n}{}^{\beta}$, thus standard deterministic inventory models are used. Alpha considers negative price behaviour in the model devised by the article authors (Abad 1994; Lee 1993; Lee *et al*. 1996; Kim, Lee 1998; Jung, Cerry 2001; Jung, Cerry 2005; Esmaeili 2008; Jaafarnejad *et al*. 2012).
3. In case of a manufacturer, shortages and stockout are allowed; consequently, shortage costs are considered during the stockout period. The total relative cost for the manufacturer when producing incrementally, are calculated as provided below (Oganezov 2006; Wang, Tang 2009; Chakrabortty *et al*. 2010; Chang 2008; Pentico *et al*. 2009; Jaafarnejad *et al*. 2012):

$$[C_{h_n} \times \frac{(\lambda_n.Q_{r_n} - B_n)^2}{2.\lambda_n.Q_{r_n}}] + [\frac{C_{B_n}.B_n^2}{2.\lambda_n.Q_{r_n}}]. \quad (1)$$

In terms of this research, pricing, inventory and marketing costs are the decision variables.

4. Production unit cost is a nonlinear function $C_{P_n} = u \cdot D_n^{-\gamma}$ which is related to the demand and decreases with growing demand (Bazaraa *et al*. 1993).
5. Each manufacturer sells a specific product to a specific retailer. However, suppliers sell their raw materials to any manufacturer as needed.
6. Irrespective of the level of the supply chain, to which it belongs, each player has a reasonable behaviour and opts for higher profit and lower cost.
7. As every player can act as a leader based on dominance and negotiating power, three types of leadership are considered.

3.2. Notations

Table 1 provides variables and parameters used for models that are designed in following section.

Table 1. Variable and parameters

Description	Note	Description	Note
Ordering cost from s to *n*	$C_{O_{sn}}$	Retailer's margin	G_r
Production function parameters	u, γ	Selling price from r to a customer	P_{r_n}
Manufacturer holding cost	C_{h_n}	Selling price from n to r	P_n
Manufacturer stockout	B_n	Product demand	D_n
Manufacturer's stockout cost	C_{B_n}	Marketing cost for product n	C_{M_n}
Manufacturer's margin	G_n	Price and marketing and demand coefficient	k, a, β
Manufacturer's total revenue	TR_n	Retailer's setup cost	$C_{s_{rn}}$
Manufacturer's total cost	TC_n	Manufacturer's production quantity	Q_{r_n}
Manufacturer's production capacity	PC_n	Holding Cost coefficient for a retailer	$k_n^{'}$
Supplier's margin	G_S	Retailer's total revenue	TR_r
Supplier's total revenue	TR_S	Retailer's total cost	TC_r
Supplier's total cost	G_S	Retailer's total payoff	Z_r
Supplier's unit cost for each unit of raw materials	G_S	Raw material coefficient in product *n*	k_{s_n}
Holding coefficient cost for a supplier	k_{S_s}	Raw material price from s to *n*	C_{P_s}
Supplier's ordering cost	C_{S_o}	Manufacturer's variable cost for each product	C_{S_n}

4. Modelling process

Based on the research methodology and using assumptions and notations described in previous sections of the article, the primary model for each player is identified. A retailer (*r*) confronts holding and setup costs as well purchasing cost from manufacturer. In addition, to participate in a supply chain, a retailer should have a positive sales margin. Finally a retailer's income involves the revenue achieved by selling goods to the final customer. Considering the above, retailer's payoff function and its constraints are presented in (2) (Jaafarnejad *et al*. 2012).

$$Max\ Z_r = (k.P_{r_n}^{-\alpha}.C_{M_n}^{\beta}[P_{r_n} - P_n - C_{M_n} - C_{S_{rn}}.Q_{r_n}^{-1}]) - \frac{1}{2} \times Q_{r_n} \times k_n^{'} \times P_n ,$$

$$s.t:$$

$$P_{r_n} - P_n \geq 0\,,$$
$$D_n = k \cdot P_{r_n}{}^{-\alpha} \cdot C_{M_n}{}^{\beta} \geq 0\,,$$
$$D_n \leq PC_n\,, \tag{2}$$
$$k > 0,\ \alpha > 1,\ 0 < \beta < 1,\ \alpha - \beta > 1\,.$$

Manufacturer's (n) confront holding, setup, ordering and stockout as well as purchasing and production costs. On the other hand, a manufacturer receives revenues from selling the final product to a retailer in large amounts. The production is incremental; in addition, unit production costs are related to products sold to a retailer. In 2012, Jaafarnejad *et al.* proposed a manufacturer's model, which does not include unit production costs while computing gross revenues in an objective function; consequently, the model became unbounded in many situations. Consequently, the authors of the article considered this problem and revised the manufacturer's model. It was noticed that manufacturer and retailer leadership model has to be revised due accordingly. Considering the aforementioned, manufacturer's payoff function and its constraints are shown in (3).

$$Max\ Z_n = [(P_n - \sum_{s=1}^{M}(k_{s_n} \cdot C_{p_s}) - u \cdot D_n^{-\gamma}) \times D_n] - [(\sum_{s=1}^{m}(C_{O_{sn}}) + C_{S_n}) \times \frac{D_n}{Q_{r_n}}] - [C_{h_n} \times \frac{(\lambda_n \cdot Q_{r_n} - B_n)^2}{2 \cdot \lambda_n \cdot Q_{r_n}}] - [\frac{C_{B_n} \cdot B_n^2}{2 \cdot \lambda_n \cdot Q_{r_n}}]\,,$$

$$s.t.:$$

$$P_n - [\sum_{s=1}^{m}(C_{P_s} \cdot k_{s_n}) + u.D_n^{-\gamma}] \geq 0\,,$$
$$CP_n \geq D_n\,, \tag{3}$$
$$D_n = k \cdot P_{r_n}^{-\alpha} \cdot C_{M_n}^{\beta}\,,$$
$$k > 0,\ u > 0,\ \alpha > 1,\ 0 < \beta < 1,\ 0 < \gamma < 1,\ \alpha - \beta > 1\,.$$

Suppliers confront costs related to holding, setup, ordering as well as purchasing or acquiring raw materials. In contrast, every supplier gains revenues by selling raw materials to manufacturers depending on their usage for production. Considering the aforementioned, a supplier's payoff function and constraints are depicted in (4) (Jaafarnejad *et al*. 2012).

$$Max\ Z_S = [(C_{P_S} - C_{S_o}) \times \sum_{n=1}^{N} k_{s_n} \cdot D_n] - [\sum_{n=1}^{N} \frac{D_n}{Q_{r_n}} \times C_{S_s}] - [\sum_{n=1}^{N} k_{S_s} \cdot C_{S_o} \cdot k_{S_n} \cdot \frac{Q_{r_n}}{2}]\,,$$

$$s.t.:$$

$$C_{P_S} - C_{S_o} \geq 0\,, \tag{4}$$
$$D_n = k \cdot P_{r_n}^{-\alpha} \cdot C_{M_n}^{\beta}\,,$$
$$k > 0,\ u > 0,\ \alpha > 1,\ 0 < \beta < 1,\ 0 < \gamma < 1,\ \alpha - \beta > 1\,.$$

Table 2. Best responses

Best response	Decision variables	No.	Note	Player
$P^*_{r_n} = \frac{\alpha \cdot (P_n + C_{S_{rn}} \cdot Q^{-1}_{r_n})}{\alpha - \beta - 1}$ (5) $C^*_{M_n} = \frac{\beta \cdot (P_n + C_{S_{rn}} \cdot Q^{-1}_{r_n})}{\alpha - \beta - 1}$ (6)	C_{M_n}, P_{r_n}	$r \in \{1,2,...,K\}$	R	Retailers
$P^*_n = \varphi' \times ([\sum_{s=1}^{M}(k_{s_n} \cdot C_{p_s}) + u.D_n^{-\gamma}] + [\frac{(\sum_{s=1}^{m}(C_{O_{sn}}) + C_{S_n})}{Q_{r_n}}] + [C_{h_n} \times \frac{(\lambda_n \cdot Q_{r_n} - B_n)^2}{2.\lambda_n.Q_{r_n}.D_n}] + [\frac{C_{B_n} \cdot B_n^2}{2.\lambda_n.Q_{r_n}.D_n}])$ (7) $Q^*_{r_n} = \sqrt{\frac{2 \cdot (\sum_{s=1}^{m}(C_{O_{sn}}) + C_{S_n}) \cdot D_n}{E_n.\lambda_n.C_{B_n}}}$ (8) $B^*_n = \sqrt{\frac{2 \cdot (\sum_{s=1}^{m}(C_{O_{sn}}) + C_{S_n}) \cdot D_n.E_n.\lambda_n}{C_{B_n}}}$ (9)	Q_{r_n}, P_n, B_n	$n \in \{1,2,...,N\}$	N	Manufacturers
$C^*_{P_S} = \varphi \cdot [C_{S_o} + \frac{(\sum_{n=1}^{N}\frac{D_n}{Q_{r_n}} \times C_{S_s}) + (\sum_{n=1}^{N} k_{S_s} \cdot C_{S_o} \cdot k_{S_n} \cdot \frac{Q_{r_n}}{2})}{\sum_{n=1}^{N} k_{s_n} \cdot D_n}]$ (10)	C_{P_S}	$s \in \{1,2,...,M\}$	S	Suppliers

Each player of a three-level supply chain acts in its best interest when playing a game. Considering reasonable behaviour of each player as well as Nash best response principle, the best decision for each player of a three-echelon SC is identified by derivation of the payoff function to decision variables. The first order condition of each payoff function is used for the best response and the second condition is used for concavity analysis. By calculating the determinant of Hessian matrix for each player depending on its decision variables, it can be concluded that all models are concave to their decision variables; thus, optimal solution for the proposed models are definable. Table 2 represents the best response for each player if Nash principle is used, by calculating the first order condition of each player's payoff function according to their decision variables.

Once modelling is completed and the best response for each player is found, it is time to finalise the research and produce the leadership model for coordination of a three-level supply chain by Stackelberg non-cooperative approach. As three levels are included in the SC game, three types of leadership are possible. Each level – a supplier, manufacturer and retailer – can act as a leader while the remaining two would play the role of a follower. In this research, based on a make of a system and type of a supply chain, three leadership followership systems were considered. The main objective is to maximise the total profit based on the best response of followers. Consequently, the sum of leader payoffs will be the objective function and the best response of followers will act as constraints. The aforementioned basic constraints are considered in other models as well. Figure 2 presents leadership types considered in this research.

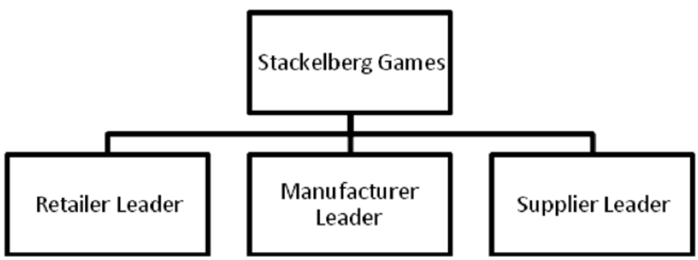
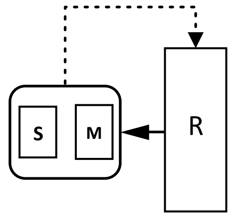


Fig. 2. Leadership types

4.1. Retailer leadership according to stackelberg model

The first model describes the situation with retailers as leaders and manufacturers and suppliers as followers. The objective function insist on maximising the retailer's profit, first four constraints explain the rational behaviour of followers and the remaining constraint describes the logic of the game, namely: demand should exist and the selling price established by each player for the next level should be greater than the purchasing price from previous level. Other relevant information is presented in Table 3.

Table 3. Retailer leadership situation

Inputs	Condition/Model	Outputs	Figure
$K_{s_n}, C_{o_{sn}}, C_{s_n}, C_{s_{r_n}}, C_{S_s}, CP_n$ $k, \alpha, \beta, \gamma, M, N, K, C_{B_n}$ $C_{h_n}, K_{s_s}, \varphi_s, \varphi'_n, k'_n, u$	Leader: Retailer Follower: Manufacturer & Supplier $TZ_r = \sum_{r=1}^{K} Z_r$ $S.T: C^*_{P_s}, Q^*_{r_n}, B^*_n, P^*_n$	$C^*_{M_n}, P^*_{r_n}$	

$$MaxTZ_r = \sum_{r=1}^{K}[(k \cdot P_{r_n}^{-\alpha} \cdot C_{M_n}^{\beta}[P_{r_n} - P_n - C_{M_n} - C_{S_m} \cdot Q_{r_n}^{-1}]) - \frac{1}{2} \times Q_{r_n} \times k'_n \times P_n]$$

s.t:

$$MaxTZ_r = \sum_{r=1}^{K}[(k \cdot P_{r_n}^{-\alpha} \cdot C_{M_n}^{\beta}[P_{r_n} - P_n - C_{M_n} - C_{S_m} \cdot Q_{r_n}^{-1}]) - \frac{1}{2} \times Q_{r_n} \times k'_n \times P_n]$$

$$P_n = \varphi'_n \times \left(\begin{array}{l} \left[\sum_{s=1}^{M}(k_{s_n} \cdot C_{p_s}) + u \cdot D_n^{-\gamma}\right] + \left[\frac{(\sum_{s=1}^{m}(C_{O_{sn}}) + C_{S_n})}{Q_{r_n}}\right] + \\ \left[C_{h_n} \times \frac{(\lambda_n \cdot Q_{r_n} - B_n)^2}{2 \cdot \lambda_n \cdot Q_{r_n} \cdot D_n}\right] + \left[\frac{C_{B_n} \cdot B_n^2}{2 \cdot \lambda_n Q_{r_n} \cdot D_n}\right] \end{array} \right); \quad \forall n \in N$$

$$Q_{r_n} = \sqrt{\frac{2.(\sum_{s=1}^{m}(C_{O_{sn}}) + C_{S_n}).D_n}{E_n.\lambda_n.C_{B_n}}}; \quad \forall n \in N$$

$$B_n = \sqrt{\frac{2 \cdot (\sum_{s=1}^{m}(C_{O_{sn}}) + C_{S_n}) \cdot D_n \cdot \lambda_n \cdot E_n}{C_{B_n}}}; \quad \forall n \in N$$

$$C_{P_S} = \varphi_s \cdot \left[C_{S_o} + \frac{(\sum_{n=1}^{N}\frac{D_n}{Q_{r_n}} \times C_{S_s}) + (\sum_{n=1}^{N} k_{S_s} \cdot C_{S_o} \cdot k_{S_n} \cdot \frac{Q_{r_n}}{2})}{\sum_{n=1}^{N} k_{s_n} \cdot D_n} \right]; \quad \forall s \in M \qquad (11)$$

$$D_n = k \cdot P_{r_n}^{-\alpha} \cdot C_{M_n}^{\beta}; \; \forall n \in N$$

$$P_n - [\sum_{s=1}^{m}(C_{P_s}.k_{s_n}) + u.D_n^{-\gamma}] \geq 0$$

$$P_{r_n} - P_n \geq 0\ ;\quad \forall r \in K, \forall n \in N$$

$$D_n \geq 0\ ;\ \forall n \in N$$

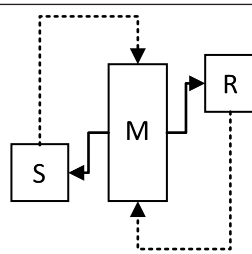
$$D_n \leq PC_n\ ;\ \forall n \in N$$

$$\lambda_n = 1 - \frac{D_n}{PC_n};\ \forall n \in N$$

4.2. Manufacturer leadership according to stackelberg model

The first model describes the situation where manufacturers act as leaders while retailers and suppliers are followers. The objective function insists on maximising the manufacturer's profit, first three constraints explain the rational behaviour of followers and the remaining constraint describes the logic of the game, namely: demand should exist and the selling price established by each player for the next level should be greater than the purchasing price from previous level. Other relevant information is presented in Table 4.

Table 4. Manufacturer leadership situation

Inputs	Condition/Model	Outputs	Figure
$K_{s_n}, C_{o_{sn}}, C_{S_{r_n}}, C_{S_s}, CP_n$ $k, \alpha, \beta, \gamma, M, N, K, C_{S_o}, C_{B_n}$ $C_{h_n}, K_{S_s}, \varphi_s, \varphi'_n, k'_n, K_{s_n}, u$	Leader: Retailer Follower: Manufacturer & Supplier $TZ_n = \sum_{n=1}^{N} Z_n$ $S.T: C^*_{P_s}, C^*_{M_n}, P^*_{r_n}$	$Q^*_{r_n}, B^*_n, P^*_n$	

$$Max\ \ TZ_n = \sum_{n=1}^{N}[[(P_n - \sum_{s=1}^{M}(k_{s_n}.C_{p_s}) - u.D_n^{-\gamma}) \times D_n] - [(\sum_{s=1}^{m}(C_{O_{sn}}) + C_{S_n}) \times \frac{D_n}{Q_{r_n}}] -$$

$$[C_{h_n} \times \frac{(\lambda_n.Q_{r_n} - B_n)^2}{2.\lambda_n.Q_{r_n}}] - [\frac{C_{B_n}.B_n^2}{2.\lambda_n.Q_{r_n}}]]$$

s.t:

$$C_{M_n} = \frac{\beta.(P_n + C_{S_{rn}}.Q_{r_n}^{-1})}{\alpha - \beta - 1}\ ;\ \forall n \in N$$

$$P_{r_n} = \frac{\alpha.(P_n + C_{S_{rn}}.Q_{r_n}^{-1})}{\alpha - \beta - 1}\ ;\quad \forall n \in N$$

$$C_{P_S} = \varphi_s \cdot [C_{S_o} + \frac{(\sum_{n=1}^{N} \frac{D_n}{Q_{r_n}} \times C_{S_s}) + (\sum_{n=1}^{N} k_{S_s} \cdot C_{S_o} \cdot k_{S_n} \cdot \frac{Q_{r_n}}{2})}{\sum_{n=1}^{N} k_{s_n} \cdot D_n}] \;;\; \forall s \in M \qquad (12)$$

$$P_n - [\sum_{s=1}^{m} (C_{P_s} \cdot k_{s_n}) + u \cdot D_n^{-\gamma}] \ge 0 \;;\; \forall n \in N$$

$$P_{r_n} - P_n \ge 0 \;;\; \forall n \in N$$

$$\lambda_n = 1 - \frac{D_n}{CP_n} \;;\quad \forall n \in N$$

$$D_n = k.P_{r_n}^{-\alpha}.C_{M_n}^{\beta} \;;\quad \forall n \in N$$

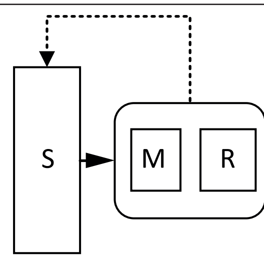
$$D_n \ge 0;\; \forall n \in N$$

$$CP_n \ge D_n \;;\quad \forall n \in N$$

4.3. Supplier leadership according to stackelberg model

The first model describes the situation where suppliers act as leaders while manufacturers and retailers are followers. The objective function insists on maximising the supplier's profit, first five constraints explain the rational behaviour of followers and the remaining constraint describe the logic of the game, namely: demand should exist and the selling price established by each player for the next level should be greater than the purchasing price from previous level. Other relevant information is presented in Table 5.

Table 5. Supplier leadership situation

Inputs	Condition/Model	Outputs	Figure
$K_{s_n}, C_{o_{sn}}, C_{s_n}, C_{S_s}, CP_n$ $k, \alpha, \beta, \gamma, M, N, K, u$ $C_{h_n}, K_{s_s}, \varphi'_n, k'_s, C_{B_n}, C_{s_o}$	Leader: Retailer Follower: Manufacturer & Supplier $TZ_s = \sum_{s=1}^{M} Z_s$ $S.T: Q^*_{r_n}, B^*_n, P^*_n, C^*_{M_n}, P^*_{r_n}$	$C^*_{P_s}$	

$$Max\ TZ_S = \sum_{s=1}^{M} [[(C_{P_S} - C_{S_o}) \times \sum_{n=1}^{N} k_{s_n}.D_n] - [\sum_{n=1}^{N} \frac{D_n}{Q_{r_n}} \times C_{S_s}] - [\sum_{n=1}^{N} k_{S_s} \cdot C_{S_o} \cdot k_{S_n} \cdot \frac{Q_{r_n}}{2}]]$$

s.t:

$$P_{r_n} = \frac{\alpha \cdot (P_n + C_{S_{rn}} \cdot Q_{r_n}^{-1})}{\alpha - \beta - 1};\; \forall n \in N$$

$$C_{M_n} = \frac{\beta \cdot (P_n + C_{S_{rn}} \cdot Q_{r_n}^{-1})}{\alpha - \beta - 1}\ ;\ \forall n \in N$$

$$Q_{r_n} = \sqrt{\frac{2 \cdot (\sum_{s=1}^{m} (C_{O_{sn}}) + C_{S_n}) \cdot D_n}{E_n \cdot \lambda_n \cdot C_{B_n}}};\quad \forall n \in N$$

$$B_n = \sqrt{\frac{2 \cdot (\sum_{s=1}^{m} (C_{O_{sn}}) + C_{S_n}) \cdot D_n \cdot \lambda_n \cdot E_n}{C_{B_n}}}\ ;\ \forall n \in N$$

$$P_n = \varphi_n{}' \times ([\sum_{s=1}^{M} (k_{s_n} \cdot C_{p_s}) + u \cdot D_n^{-\gamma}] + [\frac{(\sum_{s=1}^{m} (C_{O_{sn}}) + C_{S_n})}{Q_{r_n}}] +$$
$$[C_{h_n} \times \frac{(\lambda_n \cdot Q_{r_n} - B_n)^2}{2 \cdot \lambda_n \cdot Q_{r_n} \cdot D_n}] + [\frac{C_{B_n} \cdot B_n^2}{2 \cdot \lambda_n \cdot Q_{r_n} \cdot D_n}])\ ;\ \forall n \in N$$

$$D_n = k.P_{r_n}^{-\alpha}.C_{M_n}^{\beta}\ ;\ \forall n \in N$$

$$D_n \geq 0;\ \forall n \in N$$
$$\lambda_n = 1 - \frac{D_n}{PC_n};\ \forall n \in N$$

$$P_{r_n} - P_n \geq 0\ ;\ \forall n \in N$$
$$P_n - [\sum_{s=1}^{m} (C_{P_s} \cdot k_{s_n}) + u \cdot D_n^{-\gamma}] \geq 0\ ;\ \forall n \in N \qquad (13)$$

5. Numerical example

Considering the models mentioned above, for sensitivity analysis and leadership selection, a three-echelon supply chain including 2 suppliers, 2 manufacturers and 2 retailers was designed. Table 6 indicates the numerical values of parameters in a proposed supply chain.

Table 6. Initial data for the numerical example

Amount	Par	Amount	Par
2	M	2	R
4	$C_{S_r}(1)$	2	S
0.15	k_1'	5	$C_{S_r}(2)$
1.1	φ_1'	0.2	k_2'
3	$k_{sn}(11)$	1.15	φ_2'
3	$k_{sn}(21)$	4	$k_{sn}(12)$
6	$Co_{sn}(11)$	3	$k_{sn}(22)$
4	$Co_{sn}(21)$	5	$Co_{sn}(12)$
1	$C_B(1) = C_B(2)$	6	$Co_{sn}(22)$
25	$C_{S_S}(1)$	0.5	$C_{h_n}(1) = C_{h_n}(2)$
0.15	$k_{s_S}(1)$	24	$C_{S_S}(2)$
2	$C_{S_o}(1)$	0.2	$k_{s_S}(2)$
15	$PC(1) = PC(2)$	1.5	$C_{S_o}(2)$
8	$C_{S_n}(2)$	7	$C_{S_n}(1)$
1.1	φ_2	1.15	φ_1

To select the best type of leadership and analyse the sensitivity of the total profit, five constants were selected from demand and production nonlinear functions including $\alpha, \beta, \gamma, k, u$. The lower and upper bounds of these five elements are provided in Table 7.

Table 7. Key parameters for sensitivity analysis

Max	Min	
1.25	1.2	α
0.15	0.05	β
0.1	0.01	γ
4000	3000	k
4	2	u

Using design of experiment (DOE) and 2^{k-p} experiments as well as including one central point in each block, 17 different experiments were designed with the help of MINITAB 16.5 software. The experiments are presented in Table 8.

Table 8. Types of experiments

Design	γ	**U**	**K**	α	β
1	0.01	4	4000	1.2	0.15
2	0.1	2	3000	1.2	0.05
3	0.01	4	3000	1.2	0.05
4	0.1	4	3000	1.25	0.05
5	0.1	4	4000	1.25	0.15
6	0.1	4	3000	1.2	0.15
7	0.055	3	3500	1.225	0.1
8	0.01	4	3000	1.25	0.15
9	0.1	2	3000	1.25	0.15
10	0.01	2	3000	1.2	0.15
11	0.01	2	3000	1.25	0.05
12	0.1	4	4000	1.2	0.05
13	0.01	2	4000	1.2	0.05
14	0.1	2	4000	1.2	0.15
15	0.01	2	4000	1.25	0.15
16	0.01	4	4000	1.25	0.05
17	0.1	2	4000	1.25	0.05

The experiments listed in Table 7 were used in all three leadership models. The models were coded, debugged and solved using LINGO 11. The total profit in case of each different type of leadership was calculated. The results are presented in Table 9.

Table 9. The total profit of the supply chain by type of leadership

The total profit of the supply chain			
Supplier leadership	Manufacturer leadership	Retailer leadership	Design
2631	2686	3432	1
1328	1332	1838	2
1293	1331	1800	3
956	997	1370	4
1820	1866	2507	5
1866	1904	2554	6
1548	1577	2129	7
1314	1361	1852	8
1307	1362	1878	9
1888	1928	2568	10
994	1025	1395	11
1824	1854	2442	12
1853	1901	2470	13
2659	2686	3455	14
1851	1925	2529	15
1344	1399	1844	16
1395	1443	1890	17

Using the two paired test, results of all three types of leadership in a supply chain were compared. The results from MINITAB 16.5 software are provided below. The authors of the article concluded that retailer leadership ranked first and manufacturer and supplier leaderships ranked second and third, respectively. Consequently, it is proposed that if negotiating power increases by moving from the end of chain to the beginning, the total profit would decrease.

Paired T-Test and CI: ZSC(R); ZSC(N)

Paired T for ZSC(R) – ZSC(N)

	N	Mean	StDev	SE Mean
ZSC(R)	17	2233	599	145
ZSC(N)	17	1681	487	118
Difference	17	551.6	116.1	28.2

95% lower bound for mean difference: 502.5

T-Test of mean difference = 0 (vs > 0): T-Value = 19.59 P-Value = 0.000

Paired T-Test and CI: ZSC(R); ZSC(S)

Paired T for ZSC(R) – ZSC(S)

	N	Mean	StDev	SE Mean
ZSC(R)	17	2233	599	145
ZSC(S)	17	1639	485	118
Difference	17	593.1	118.2	28.7

95% lower bound for mean difference: 543.1

T-Test of mean difference = 0 (vs > 0): T-Value = 20.69 P-Value = 0.000

Paired T-Test and CI: ZSC(N); ZSC(S)

Paired T for ZSC(N) – ZSC(S)

	N	Mean	StDev	SE Mean
ZSC(N)	17	1681	487	118
ZSC(S)	17	1639	485	118
Difference	17	41.46	15.40	3.74

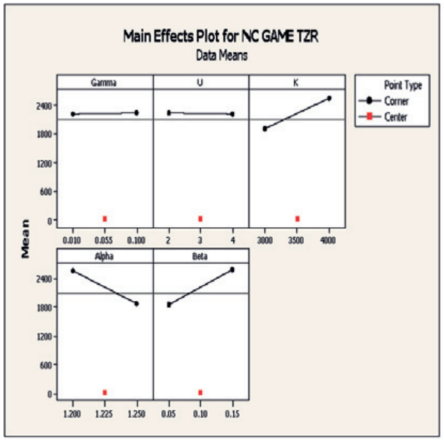
95% lower bound for mean difference: 34.94

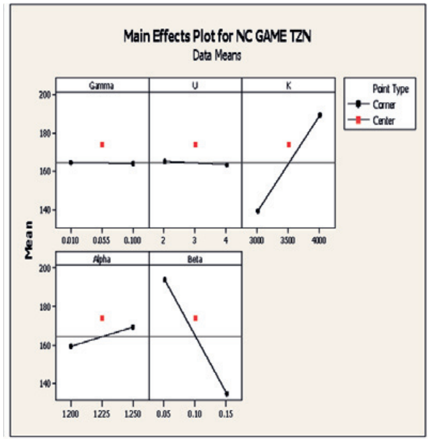
T-Test of mean difference = 0 (vs > 0): T-Value = 11.10 P-Value = 0.000

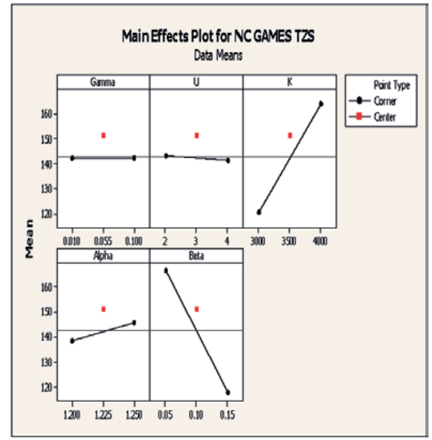
The main effects of each leadership game in terms of five critical elements were calculated using MINITAB 16.5 software. The results are provided in figures of Table 10. In all models, Gama and U have the least effect and K, Alpha and Beta have the greatest, which indicates that the sensitivity effect of a price and marketing changes on SC profit is greater than unit production costs. K has a direct effect on all three leadership models while Alpha has an inverse effect on the retailer leadership, and Beta has an inverse effect on the manufacturer and supplier models. Thus, it can be concluded that the increase in the selling prices would bring down the total profit; in addition, while the manufacturer and supplier act as leaders, increase in marketing cost would decrease the total profit as they would be making the first impact, which would require the retailer to invest more in marketing in order to gain a greater market share, based on demand equation.

Table 10. Sensitivity analysis

	Retailer leadership		Manufacturer leadership		Supplier leadership	







Term	Effect	Coefficient	Effect	Coefficient	Effect	Coefficient
Constant	2215	0	164.11	0	142.10	0
Gamma	5	3	–0.13	–0.07	–0.15	–0.08
U	–28	–14	–1.86	–0.93	–1.54	–0.77
K	659	329	50.06	25.03	43.48	21.74
Alpha	–665	–333	9.64	4.82	7.19	3.6
Beta	727	363	–59.53	–29.77	–49.16	–24.58

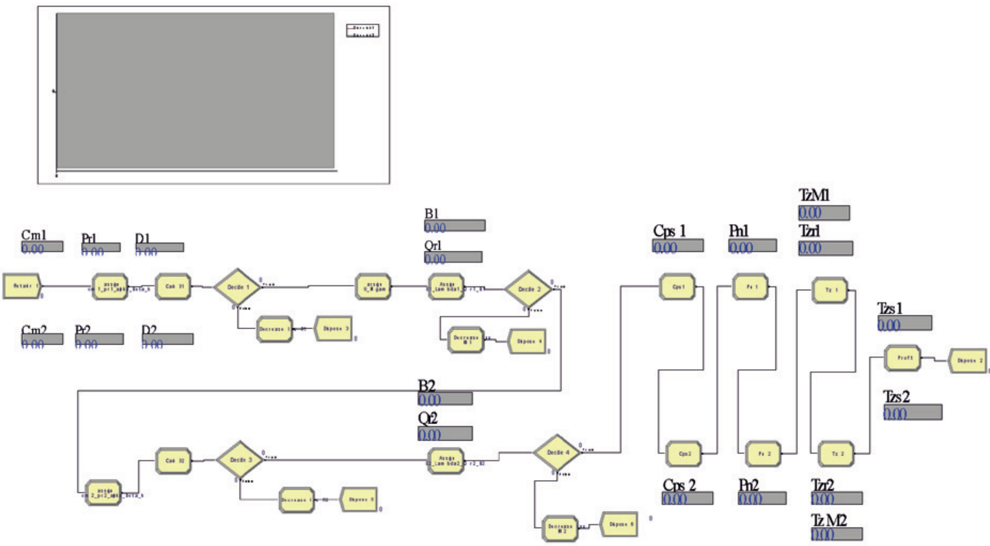


Fig. 3. Arena-based retailer leadership, a simulated model

Verification of different types of proposed leadership models based on non-cooperative game theory was delivered considering assumptions of models. For this purpose, a simulated supply chain was designed by Arena software, based on data from the aforementioned numerical example. The simulated model is demonstrated in Fig. 3. The simulated model is based on random marketing costs and a random retailer price, each retailer has a supply chain. By this randomisation, the demand of each product is computable and other decision variables are reached using the best response of each player calculated in the previous section, depending on Nash equilibrium definition.

The simulated model performed 100 runs for each type of experiment and the results are given in Table 11. As results suggest, the total profit of the supply chain in case of the proposed leadership model is similar to the total profit of SC based on Arena, where retailer is the leader. The SC total profit is always between the upper and lower bounds of the confidence interval.

Table 11. Model verification results in 17 experiments

Experiment	Retailer leadership model	Ave total profit of simulation	Half width	90% Confidence interval Min	90% Confidence interval Max
Design 1	3,432.21	3,302.76	153.22	3,149.54	3,455.98
Design 2	1,838.18	1,832.81	85.30	1,747.51	1,918.11
Design 3	1,800.10	1,810.25	83.98	1,726.27	1,894.23
Design 4	1,370.40	1,400.66	64.99	1,335.67	1,465.65
Design 5	2,506.56	2,457.33	114.00	2,343.33	2,571.33
Design 6	2,554.22	2,640.80	114.16	2,526.64	2,754.96

Continued Table 11

Experiment	Retailer leadership model	Ave total profit of simulation	Half width	90% Confidence interval Min	90% Confidence interval Max
Design 7	2,129.12	2,100.36	97.44	2,002.92	2,197.80
Design 8	1,851.76	1,820.40	84.45	1,735.95	1,904.85
Design 9	1,878.19	1,827.09	84.76	1,742.33	1,911.85
Design 10	2,568.25	2,461.21	114.18	2,347.03	2,575.39
Design 11	1,394.95	1,400.12	64.95	1,335.17	1,465.07
Design 12	2,442.21	2,431.24	112.79	2,318.45	2,544.03
Design 13	2,469.80	2,429.41	112.71	2,316.70	2,542.12
Design 14	3,455.26	3,307.45	153.44	3,154.01	3,460.89
Design 15	2,528.73	2,459.10	114.10	2,345.00	2,573.20
Design 16	1,844.17	1,879.58	87.21	1,792.37	1,966.79
Design 17	1,890.24	1,882.27	50.00	1,832.27	1,932.27

6. Conclusion

The research considered coordination in multi-echelon supply chains, in which non-co-operative game theory was used as a suitable tool for coordination of pricing, inventory and marketing expenditure policies in a three-level supply chain where the leadership changed depending on negotiating power. The situation and assumptions used in this paper will be valuable for future researches. In case of more levels, researchers are guided towards a comprehensive model, which would need to be coordinated in the future. In addition, as the competency of information and also complete information sharing in different levels seems to be impossible, using incomplete or imperfect game theory approaches such as signalling game or Nash Bayesian game would solve this problem and allow for more realistic options in the future. As interaction between layers in SC occurs continuously, repetitive games would adapt and fit real situations. This type of games considers time and patience of players within a modelling process.

The coordination mechanism used in this paper is based on leader follower Stackelberg game. It must be noted that other kinds and coordination options such as a profit sharing contract, revenue sharing contract, buyback contract and also option contract are all possible solutions for establishing coordination, Thus, the total profit and each stage profit would increase and bring more competitive advantages for the entire chain. The aforementioned contracts are all based on probabilistic demand function. Finally, Opt Quest application in Arena software is a suitable tool for estimating the best amounts of nonlinear model parameters. By identifying the optimal amount of the proposed models, optimal solution for unlimited three-echelon supply chain would be developed.

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