A quantitative examination of competition, coopetition and cooperation in supply chains

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Traditionally, the members of a supply chain compete to reduce their individual costs. However, as collaborative supply chain approach is urged within industries to reduce the overall costs, either full cooperation or partial coopetition is considered by the members. In cooperative approach, members benefit from lower overall costs and lower cost variations. But individually, some seem better off in a competitive approach in a single period considering their local costs. Coopetition, or partial cooperation, may be suggested as a compromise to lower overall supply chain costs, while members choose alliances towards lower average costs and cost variations.

A multi-stage, multi-member, multi-product and single period supply chain model is considered with deterministic demand, capacity and cost. Product prices are assumed to be constant. The objective is to minimize total production and distribution costs of the overall chain. Four distinct cases are considered, modeled, simulated and compared. These cases are complete competition, integrated cooperation, two-stage supply chain partition, and partial coopetition. Quantitative conclusions from the cost performance ratios are drawn using the simulation results.

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Introduction

Supply chain management (SCM) or similar terms, such as supply pipeline management, network sourcing and value chain management have become subjects of increasing interest to academics, consultants and business managers in the recent years (Hines, 1995). Most firms have focused their attention on the effectiveness and efficiency of outsourcing their business functions. As a new way of doing business, a growing number of firms have begun to realize the strategic importance of planning, controlling, and designing a supply chain as a whole (Min & Zhou, 2002).

SCM is considered as the most popular operations strategy for improving organizational competitiveness in the twenty-first century (Gunasekaran, Kee-hung & Cheng, 2008). Many organizations are attempting to gain a competitive advantage by integrating their suppliers more thoroughly into key supply chain processes. This calls for greater strategic and operational cooperation between the buyer and supplier firms, often involving some degree of collaborative planning (Petersen, Ragatz & Monczka, 2005). There is a recognition that competition is shifting from a "firm versus firm perspective" to a "supply chain versus supply chain perspective" (Whipple & Frankel, 2006). In response to this shift, firms seeking competitive advantage are participating in cooperative supply chain arrangements, such as strategic alliances or joint ventures, which combine their individual strengths and unique resources. Coordinated buyer-supplier sourcing relationships are a primary focus of alliance improvement efforts (Whipple & Frankel, 2006).

Advances in information technology are making it possible for firms to share planning information more quickly and easily. Petersen *et al.* (2005) surveyed purchasing executives whose firms are involved in collaborative planning with the suppliers. They examined several factors that support effective planning and the impact that effective collaborative planning has on SCM performance for the buying firm. The results show that effective collaborative planning is dependent on the level of trust and the quality of information shared between firms (Petersen *et al.,* 2005). The perspective of emerging IT-enabled organizational capabilities suggests that firms that develop IT infrastructure for SCM integration and leverage it to create a higher-order supply chain collaboration capability, generate significant and sustainable performance gains (Rai, Patnayakuni & Patnayakuni, 2006).

In this paper, alternative manners of competition, coopetition, and cooperation in supply chains are investigated quantitatively. In full competition, competitive supply chain members behave locally to minimize their respective costs. On the contrary, in the cooperation case, all of the supply chain members behave as a whole to optimize the overall SCM cost. Furthermore, in the analysis here, two in-between cases are considered as coopetition. First, in the partial cooperation case, some members in the same stage form groups, while members within each group behave cooperatively to minimize the cost associated with their group. Obviously, each group competes with other groups. The second coopetition case is two-partition arrangement in which the supply chain is divided into two sections.

Initially, the basic concepts and literature of SCM under competition, coopetition and cooperation approaches are reviewed. Basic models for various degree of cooperation in the supply SCM are formulated and developed. After analyzing sample numeric cases using sinulation, sample results are presented before quantitative conclusions are presented in the paper.

Changing perspective

The competitive perspective has dominated, for a long time, several fields of management research, from strategic management (Porter, 1985; Barney, 1991) to organizational economics (Williamson, 1975; 1985) to marketing management (Borden, 1964). This approach assumes the firms' interdependence, both horizontal and vertical. The metaphor of the firm as an "island in a sea of market relations" (Richardson, 1993) captures fully the distinctive feature of this standpoint. With reference to horizontal interdependence, the competitive perspective emphasizes the search for above normal profit realized either when a firm gains an advantageous position in an industry (Porter, 1985) or when it mobilizes and deploys resources and distinctive competences (Wernerfelt, 1984, Prahalad & Hamel, 1990) enabling it to offer superior products in relation to its competitors.

Lippman and McCardle (1997) studied competition between two or more firms in a one-period setting, where a consumer may switch among firms to find available inventory. Parlar (1988) and Li (1992) also studied the role of inventory in the competition among retailers. In a multi-echelon model with multiple retailers, Muckstadt and Thomas (1980) and Hausman and Erkip (1994), investigated a centralized control system that allowed each firm to optimize its own costs and still choose an outcome desirable to the central planner. Parker and Kapuscinski (2003), for instance, considered a two-stage serial supply chain with capacity limits, where each installation is operated by managers attempting to minimize their own costs. They examined the effect of capacity utilization on the system sub-optimality, and observe a degree of robustness.

An alternative perspective, partly spread out as a reaction to the competitive approach initially from Japanese JIT purchasing (Sepehri, 1986), emphasizes the development of collaborative advantage. Firstly upsurged in the marketing management field with reference to vertical interdependence (Håkansson & Ostberg, 1975), this perspective has quickly developed - in the eighties and nineties - in other more familiar research fields, ranging from strategic management (Contractor & Lorange, 1988; Hamel, Doz & Prahalad, 1989; Dyer & Singh, 1998) to organizational economics (Griesinger, 1990; Hill, 1990), and covering a wide array of strategic interfirm arrangements.

With the spread of the cooperative perspective, the view of the business world changed thoroughly giving rise to a network of strategic interdependence among firms pursuing convergent interests and deriving mutual benefits (Contractor & Lorange, 1988). Cachon and Zipkin (1999) investigated competitive and cooperative inventory policies in a two-stage supply chain to show competition reduces efficiency, while the value of cooperation is context specific. In some settings, competition increases total cost by only a fraction of a percent, whereas in others the cost increase is enormous.

Hoyt and Huq (2000) have discussed buyer-supplier relationships from the perspective of the emerging collaborative relationships. Ballou, Gilbert and Mukherjee (2000) discuss supply chain management challenges arising from the shift from competition to cooperation. By helping firms to enhance their strategic flexibility and learning capability (Volberda, 1996), inter-firm relationships are considered a strategic asset and a source of competitive leadership in the current fast-moving competitive environments (Teece, Pisano & Shuen, 1997). The economic interest to keep on with the current relationship and to enter new relationships in the future makes reputational concerns to emerge (Hill, 1990) and keep the partners aligned to the norms of trustworthy behavior (Brusco, 1996; Griesinger, 1990).

Some scholars have claimed that, in highly innovative cooperative contexts, the capability to detect opportunistic behavior is low (Hennart, 1988) and, as a consequence, the reputational incentives are weak (Hill, 1990). Other studies have stressed that, with the development of trust in a cooperative context, the control processes carried out by the partners are sensibly weakened and this may result in an incentive, to one or more partners, to behave opportunistically (Grandori & Neri, 1999).

Some of the motives that explain competitive pressures, emerging within a cooperative structure, can be summarized as follows. Typically they involve mixed motives in which the partners have private and common interests (Gulati, Nohria & Zaheer, 2000). Some empirical contribution in the field of inter-firm learning has highlighted that, when mutual dependence is not balanced, the more dependent partner is subject to the risk of holding up from his counterparts. This type of competitive pressure results from a coupling an asymmetric learning pace among partners (Hamel, 1991) and a low relative scope of the alliance (Khanna, 1998; Khanna, Gulati & Nohria, 1998).

In management literature, the hybrid behavior comprising competition and cooperation has been named coopetition. A number of authors (Brandenburger & Nalebuff, 1996 ; Lado, Boyd & Hanlon, 1997; Gnyawali & Madhavan, 2001) have emphasized the increasing importance of coopetition for today's interfirm dynamics. The coopetitive perspective stresses that the supreme interests of a partner are not necessarily aligned with the supreme interest of the other partner(s). This partial or incomplete interest congruence requires to explicitly take into consideration the fairness problem within the cooperative game structure (Grandori & Neri, 1999) which has been instead, implicitly or explicitly, taken for granted in the cooperative perspective. Socially mandated behaviors compel retail competitors to be sensitive to stable, sustainable collective welfare (Varman & Costa, 2009).

Bengtsson and Kock (2000) argued that the most complex, but also the most advantageous relationship between competitors, is "coopetition" where two competitors both compete and cooperate with each other. In Hirschman's (1970) terms, coopetition is communication-based, which insists on effective and timely transfer of information on process techniques among the participants in a supply chain, as opposed to market-based relationships, which discourages communication between purchasers and suppliers or various supplier for a purchaser.

Problem formulation

A supply chain may be formulated as a flow network (Fayazbakhsh, Sepehri & Razzazi, 2009). A flow network, is a directed graph in which each node can produce, consume or pass a flow. Each directed arc is a one-way conduit for the flow with a defined capacity. Examples of the flow networks include electrical, urban transportation, telecommunication, railroad and oil product pipeline networks. Nodes are conjunction points of flow paths and can only pass the flow, except for two special nodes. A source node has only outgoing arc(s) and produces the flow, while a sink node has only incoming arc(s) and consumes the flow. Several studies (Ahuja, Magnanti & Orlin, 1993; Goldberg, Tardos & Tarjan, 1990) provide comprehensive surveys of algorithms for solving network-flow problems.
A flow network $G=(V,E)$ is a directed graph in which V is a set of nodes or vertices, and E has as elements subsets of V connected by arcs. Each arc $(u,v)\in E$ has a nonnegative capacity $c(u,v)\geq 0$. If $(u,v)\notin E$, it is assumed that $c(u,v)=0$. In a flow network, two nodes are distinguished as source node s and sink node t. It is assumed that every arc lies on some path from the source to the sink. A flow is a real-valued function $f:V\times V\rightarrow \mathbf{R}$ that satisfies the following properties:

(a Capacity constraint: for all $u,v\in V$, require $f(u,v)\leq c(u,v)$.

(b) Skew symmetry: for all $u,v\in V$, require $f(u,v)=-f(v,u)$.

(c) Flow conservation: for all $u\in V-\{s,t\}$, require $\sum_{v\in V} f(u,v)=0$.

$f(u,v)$, which can be positive, zero or negative, is the flow from node u to node v. A flow network may have several sources and sinks, rather than just one of each. In this case, the source and sink nodes should be replaced with a set of source nodes and a set of sink nodes, respectively.

Consider a network $G=(V,E)$ that satisfies three properties of a flow network discussed in the previous section. Each node represents a member of the supply chain and each directed arc represents a potential relationship between two members. In this model, sources and sinks of the flow network are equivalent to suppliers and retailers of the supply chain, respectively. Every directed arc (u,v) shows the possibility of providing basic components, raw materials or finished products from a member u to a member v. Arc capacities are given as capacities for supply, production, transportation or delivery (depending on the nature of a relationship) from an organization to another for a planning period. Moreover, a cost factor is assigned to each arc representing the costs of supply, production, transportation or delivery for each unit of a product. These costs are assigned to the first member in a relationship (i.e. organization u).

Consider k types of products which are produced from p different basic components or raw materials. Set $A_i=\{a_{i1},a_{i2},...,a_{ip}\}$ is the set of initial components (or raw materials) to compose one unit of a product type i $(i=1,2,...,k)$. Thus, a_{ij} is the quantity (or amount) of component type j necessary to produce one unit of product type i $(j=1,2,...,p)$. For example, if $A_4=\{0,2,1\}$ then every unit of forth type of products contains two units of component type 2 and one unit of component type 3. It is obvious that component type 1 is not needed to produce this type of product. Sset, Mset, Dset and Rset represent sets of suppliers, manufacturers, distributors and retailers, respectively:

$$\text{Sset}=\{sp_s, \forall s=1,2,...,S\},$$
$$\text{Mset}=\{manu_m, \forall m=1,2,...,M\},$$
$$\text{Dset}=\{dist_d, \forall d=1,2,...,D\},$$
$$\text{Rset}=\{ret_r, \forall r=1,2,...,R\}.$$

The original flow network is decomposed into two parts: network (I) which includes manufacturers, distributors and retailers. Network (II) which covers suppliers and manufacturers. Considering the practical nature of the problem, first the demand side from manufacturers to retailers is considered, and then the supply side from suppliers to manufacturer is evaluated. V_1 is a set of vertices or nodes of network (I) and V_2 is set of vertices or nodes of network (II). It is obvious that $V_1\bigcap V_2=\text{Mset}$.
In network (I) products flow, while in network (II) components (or raw materials) flow. Model (I) is the model for network (I) and model (II) is the model for network (II). They are specified in Figure 1 and Figure 2, respectively. In model (I), manufacturers and retailers are considered as

sources and sinks of products, respectively. Model (I) is a linear programming model. It takes as input the product demands from the retailers as well as the capacities and costs for the relevant arcs. d_{ir} is the quantity of demand for the product type i from the retailer r (where $r = 1, 2, ..., R$ and $i = 1, 2, ..., k$). For each arc (u, v) capacity and cost are also provided. $c_i(u, v)$ is the capacity of arc (u, v) for flow of product i and $o_i(u, v)$ is cost of flow of each unit of product i within arc (u, v).

These properties are constant for each planning period. $c_i(u, v)$ is interpreted as maximum feasible capacity of organization u for providing (i.e. manufacturing or distributing) product i and delivering it to organization v with cost $o_i(u, v)$. Value of the flow of each product through each arc is determined by solving the model (I). $f_i(u, v)$ is the value of flow of product type i in arc (u, v).

The competitive case

The first case investigates a supply chain composed of selfish members behaving in a locally optimum or a purely competitive fashion. Competitive members place orders based on their locally optimum utility rather than complying with the globally optimum solution. Thus, each competitive member seeks to find available sources with the lowest cost until its demand is fulfilled.

Using the concept of flow networks above, assume v is a destination member which wants to receive flow (product, component or raw materials) from a source node t where an arc (t, v) exists in the corresponding graph. Consider S as an array of information about all potential sources for v to fulfill its demand, such that S_t (t^{th} element of the array) is an ordered pair $(o(t, v), c(t, v))$. From previous sections, $o(t, v)$ indicates cost of flow in the arc (t, v), and $c(t, v)$ shows capacity of this arc. In-fact, the member v forms array S using the information received from its potential source nodes. The following pseudo-code describes the competitive behavior of the destination member v:

$$
\begin{aligned}
&\text{UnfulfilledDemand} = \text{Demand}\\
&\text{Sort array S ascendingly based on } o(t, v)\\
&\text{while (UnfulfilledDemand} > 0)\\
&f(t, v) = \min(\text{UnfulfilledDemand},\ c(t, v))\\
&\text{UnfulfilledDemand} = \text{UnfulfilledDemand} - f(t, v)\\
&t = t + 1 \quad \text{(i.e. going to the next potential source}\\
&\qquad\qquad \text{with the lowest cost)}
\end{aligned}
$$

Based on the pseudo-code, each member of supply chain which wants to source its demands simply searches for available sources with the lowest costs. We assume that members of each stage do their respective sourcing sequentially with a random order. For example, if there are three members R1, R2 and R3 in the retailer stage, a random sequence can imply that first R1 do its sourcing followed by R2, and finally R3 tries finding its sources based on what is available.

The coopetition (partial cooperation) case

In coopetition, or partial cooperation, groups are formed by the supply chain members. Foundation of such groups may be based on business alliances or temporary alignment of interests. Groups may be formed, in many ways and different sizes, horizontally, vertically or arbitrarily. For illustration, it is simply assumed that members of each group are from the same stage, i.e. all of them are either suppliers, manufacturers, distributors or retailers.

From the formulation point of view, each group may be shown by a new individual member whose capacity is the sum of its members' capacity parameters and its costs is determined from the cost parameters of its members. Figure 1 provides an example of a typical supply chain. The parentheses on the edges of the graph represent cost and capacity parameters respectively. The numbers before the slash sign indicate cost parameters for different components or products and the numbers after the slash sign indicate capacity parameters, respectively. There are three different products manufactured from four different types of components in Figure 1 example.

Now some members in a same stage form a group, as in Figure 2. M3={M1, M2}, D6={D2, D3}, D7={D4, D5}, R7={R1, R2, R3}, and R8={R5, R6} are the newly formed groups. The new representative graph for the supply chain shows the aggregates in-flows and out-flow of members.

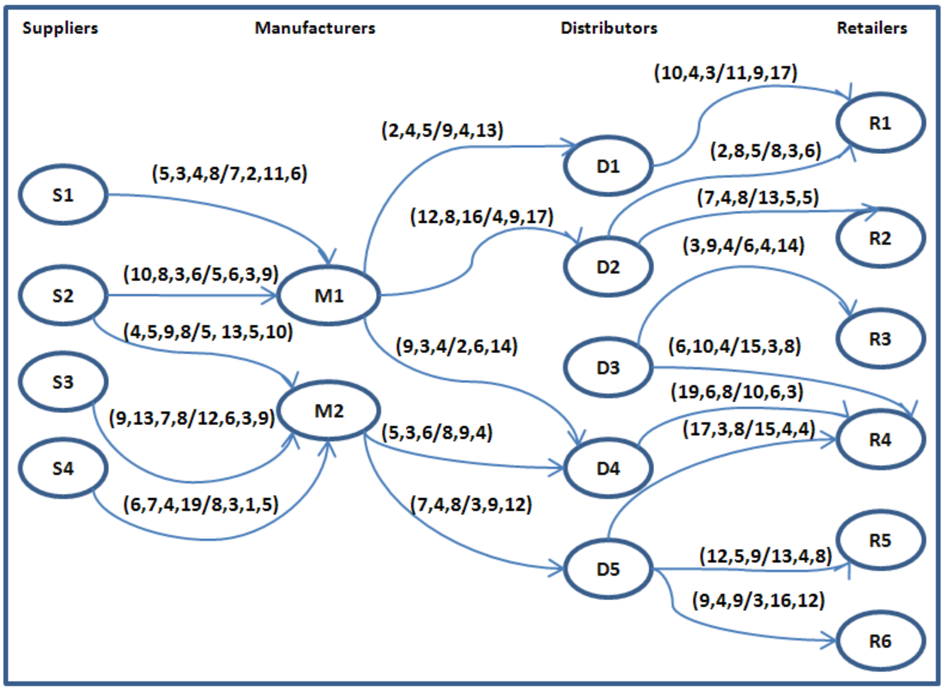

Figure 1: A typical supply chain

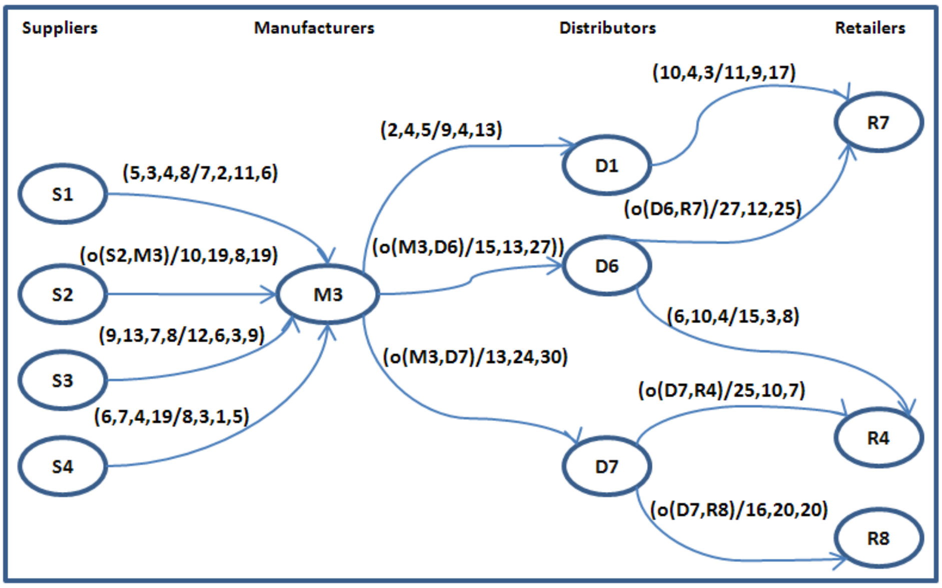

Figure 2: The supply chain after the formation of the groups

After the formation of the groups, members of each group behave as one. As depicted in the Figure 2, some edges specify $o(u,v)$ function before the slash signs. When two or more members in the same stage form a group, the group is capable of providing components or products based on its members' costs and capacities. For example, when the newly formed distributor D7, which includes D4 and D5 distributors, provides the retailer R4 with product 1 with $o_1(D7,R4)$ and $c_1(D7,R4)$ cost and capacity parameters, specified as follows:

$$o_1(D7,R4)=\begin{cases}17, & \text{Order Quantity} \leq 15 \\ 19, & 16 \leq \text{Order Quantity} \leq 25\end{cases}$$

In other words, R4 can place orders with unit cost of 17 as long as its demand is less or equal to 10 units of product type 1. However, for order quantities greater than 10 and less or equal to 25, the unit price is 19, using the aggregated capacities and costs of distributors D4 and D5 that now are operating as the new D7 distributor. This concept may be generalized for groups consisting of more than two members. If a group is comprised of 4 members, for instance, a four criteria function can describe its parameters. Each group is then considered as a competitive member of a supply chain behaving in a competitive (selfish) manner. The algorithmic mechanism of the supply chain may be formulated exactly as previously described in the competitive case.

The coopetition (two-partition) case

In a two-partition case, the supply chain is divided into two groups. The first group is composed of the retailers and the distributors, and the manufacturers, while the second group covers the manufacturers and the suppliers. After the first group optimizes its target (products), the second group will optimize its target (components) using the first group's solution. This case is further described in Fayazbakhsh *et al.* (2009).

A linear programming model is used to formulate the case. The objective function z_1 is total operational costs of the supply chain in the Partition (I) section, and is to be minimized. Six categories of linear constraints are considered in this model. The first three categories of constraints are capacity constraints, flow symmetry and flow conservation properties, respectively. The fourth category of constraints assures that demand from retailers is satisfied. The fifth category of constraints guarantees that manufacturers produce enough products. Finally, the sixth group of constraints is non-negativity constraints on values of outflows. Solving model (I) provides values for flows $f_i(u,v)$ so that network (I) satisfies customer demand with minimum possible cost. Figure 3 shows model (I), and Figure 4 specifies model (II) which should be solved after model (I) to provide components to manufacturers.

$$\min z_1 = \sum_{u,v\in V_1} \sum_{i=1}^{k} o_i(u,v) f_i(u,v)$$

subject to

$$f_i(u,v) \le c_i(u,v) \text{ for each } i=1,2,\ ,k \text{ and for each } u,v \in V_1,$$

$$f_i(u,v) = -f_i(v,u) \text{ for each } i=1,2,\ ,k \text{ and for each } u,v \in V_1,$$

$$\sum_{v\in V_1} f_i(u,v) = 0 \text{ for each } i=1,2,\ ,k \text{ and for each } u \in (V_1 - (Mset \cup Rset)),$$

$$\sum_{u\in V_1} f_i(u,ret_r) = d_{ir} \text{ for each } i=1,2,\ ,k \text{ and for each } r=1,2,\ ,R,$$

$$\sum_{m=1}^{M} \sum_{v\in V_1} f_i(manu_m,v) = \sum_{r=1}^{R} d_{ir} \text{ for each } i=1,2,\ ,k,$$

$$f_i(u,v) \ge 0 \text{ for each } i=1,2,\ ,k \text{ and for each } u,v \in V_1$$

Figure 3: Model (I): The retailers, the distributors, and the manufacturers

In model (II), $c_j(u,v)$ is the capacity of arc (u,v) for flow of basic component (or raw material) type j and $o_j(u,v)$ is cost of flow of component type j through arc (u,v) $(j=1,2,...,p)$. $c_j(u,v)$ may be interpreted as a maximum feasible capacity of supplier u for providing component j and delivering it to manufacturer v incurring cost $o_j(u,v)$. Note that $f_i(manu_m,v)$ values have been determined in model (I) and are subsequently inputs of model (II) along with $c_j(u,v)$ and $o_j(u,v)$. Model (II) determines optimal flow of different components in network (II) (i.e. $f_i(u,v)$ values). Objective function z_2 is total operational costs of the supply chain in network (II) section to be minimized.

The four groups of linear constraints in model (II) are as follows: The first group of constraints are equivalent to capacity constraint of flow networks. The second group of constraints guarantees satisfying demand from the manufacturers for basic components to produce sufficient products. The third group of constraints assures that the suppliers provide enough basic components to the manufacturers. Lastly, the fourth group of constraints are non-negativity constraints on values of out flows. Solving model (II) provides values for the flows $f_j(u,v)$ so that network (I) satisfies customer demand with minimum possible cost.

$$\min z_2 = \sum_{u,v\in V_2} \sum_{j=1}^{p} o_j(u,v)\, f_j(u,v)$$

subject to

$$f_j(u,v) \le c_j(u,v) \quad \textit{for each } j=1,2,...,p \textit{ and for each } u,v \in V_2,$$

$$\sum_{u\in V_2} f_j(u,manu_m) = \sum_{i=1}^{k}(a_{ij} \sum_{v\in V_1} f_i(manu_m,v)) \quad \textit{for each } j=1,2,...,p \textit{ and for each } m=1,2,...,M,$$

$$\sum_{s=1}^{S} \sum_{v\in V_2} f_j(sp_s,v) = \sum_{m=1}^{M}\sum_{i=1}^{k}(a_{ij} \sum_{v\in V_1} f_i(manu_m,v)) \quad \textit{for each } j=1,2,...,p,$$

$$f_j(u,v) \ge 0 \quad \textit{for each } j=1,2,...,p \textit{ and for each } u,v \in V_2.$$

Figure 4: Model (II): The manufacturers and the suppliers

A supply chain is composed of network (I) and network (II). Therefore operational costs of the supply chain are the sum of the costs of these two networks, and the optimal cost for the supply chain equals $z_1 + z_2$. Since both model (I) and model (II) are linear programming models, existing polynomial-time algorithms such as Karmarkar's algorithm (Winston, 2002) may be used to solve them. By solving the models and informing the supply chain members of the related flow values, the members are able to make decisions and place orders which results in optimal situation for the whole supply chain.

It may be necessary to include another group of constraints to ensure that some or all of the decision variables (i.e. $f_i(u,v)$ and $f_j(u,v)$) will take integer values. Such additional constraints may be necessary when a product or component is countable and may not be fractional. In this case, mixed-integer programming (Taha, 1996) methods are applicable.

The cooperation (integrated) case

In the integrated case, the supply chain members fully cooperate to optimize the supply chain-wide target, which is minimum cost when demand is fully satisfied at a fixed unit cost. With aforementioned parameters, the proposed model for the whole supply chain is as follows:

$$\min \ z = \left(\sum_{u,v \in V_1} \sum_{i=1}^{k} o_i(u,v) f_i(u,v) \right) + \left(\sum_{u,v \in V_2} \sum_{j=1}^{p} o_j(u,v) f_j(u,v) \right)$$

subject to

$$f_i(u,v) \le c_i(u,v) \qquad \forall \ i = 1,2,\ldots,k \ \text{ and } \ \forall \ u,v \in V_1 \ ;$$

$$f_i(u,v) = -f_i(v,u) \qquad \forall \ i = 1,2,\ldots,k \ \text{ and } \ \forall \ u,v \in V_1 \ ;$$

$$\sum_{v \in V_1} f_i(u,v) = 0 \qquad \forall \ i = 1,2,\ldots,k \ \text{ and } \ \forall \ u \in Dset;$$

$$\sum_{u \in V_1} f_i(u,ret_r) \ge d_{ir} \qquad \forall \ i = 1,2,\ldots,k \ \text{ and } \ \forall \ r = 1,2,\ldots,R;$$

$$f_j(u,v) \le c_j(u,v) \qquad \forall \ j = 1,2,\ldots,p \ \text{ and } \ \forall \ u,v \in V_2 \ ;$$

$$\sum_{u \in V_2} f_j(u,manu_m) \ge \sum_{i=1}^{k} (a_{ij} \sum_{v \in V_1} f_i(manu_m,v)) \ \forall \ j = 1,2,\ldots,p \ \text{ and } \ \forall \ m = 1,2,\ldots,M;$$

$$f_j(sp_s,manu_m) \ge 0 \qquad \forall \ s = 1,2,\ldots,S \ \text{ and } \ \forall \ m = 1,2,\ldots,M \ \text{ and } \ \forall \ j = 1,2,\ldots,p;$$

$$f_i(manu_m,dist_d) \ge 0 \qquad \forall \ m = 1,2,\ldots,M \ \text{ and } \ \forall \ d = 1,2,\ldots,D \ \text{ and } ; \forall \ i = 1,2,..\ k;$$

$$f_i(dist_d,ret_r) \ge 0 \qquad \forall \ d = 1,2,\ldots,D \ \text{ and } \ \forall \ r = 1,2,\ldots,R \ \text{ and } \ \forall \ i = 1,2, \ k;$$

The objective function here is the sum of production and distribution costs for the network. The constraints are similar to the previous section, and include capacity constraints, flow symmetry, demand satisfaction, and non-negativity of the flows. The model may be solved similarly as a flow model with a linear programming infrastructure.

Numerical analysis

To evaluate the various alternatives and the corresponding formulations, the case of competitive behavior is used as a comparison base. The objective is to determine the impact of different degrees of cooperativeness in a supply chain. Consider the following variables:

$TC1$: Total supply chain cost in the cooperative behavior case, (Section 7);

$TC2$: Total supply chain cost in the partial cooperation case, (Section 4);
$TC3$: Total supply chain cost in the two-partition case, (Section 6);

$TC4$: Total supply chain cost in the competitive case,(Section 4);

To evaluate effectiveness of different degrees of cooperation, the following 3 metrics are defined:

$$\text{Performance Ratio(Partial)} = \frac{TC2}{TC1}$$

$$\text{Performance Ratio(Two-Partition)} = \frac{TC3}{TC1}$$

$$\text{Performance Ratio(Integrated)} = \frac{TC4}{TC1}$$

The first objective is to determine how performance ratios are dependent on the variety of flows in the supply chain. $k+p$ is a metric to represent the variety of flows in a supply chain, where k types of commodities are produced from p different basic components or raw materials. A supply chain containing 70 suppliers, 10 manufacturers, 20 distributors and 50 retailers is simulated. Values for k and p are set randomly such that $k < p$ and their summation equals the intended value, during simulation. Figure 3 shows the simulation results from ILOG CPLEX 11.0 standard mathematical programming solver. The values of Performance Ratios for Two-Partition, Partial Cooperation, and Competitive cases are demonstrated by rhombi, squares, and triangles respectively.

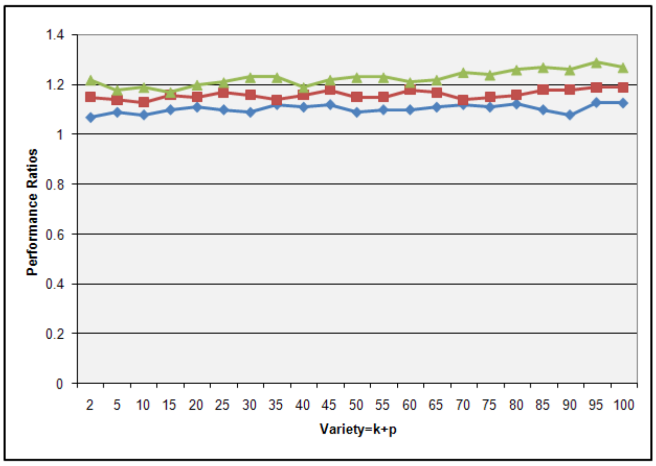

Figure 5: Performance ratio in different degrees of cooperation

In 400 repetition simulated cases, the integrated or cooperative case always provides the highest performance, and it is used as the comparison base. As the figure 5 demonstrates, the performance (rations of total costs) of the two-partition case is better (the lowest curve is competition and the middle curve is partial cooperation or coopetition) than the performance of the partial cooperation case. Finally, the competitive behavior imposes the highest cost to the supply chain.

Investigating the effects of four different cases on each single member of the supply chain may be also insightful. For this purpose, the average cost and range of costs for each member are compared, for various k and p values (number of products and component types, respectively) in one year when the computations are carried out on a monthly basis. Table 1 shows, partially, the average costs of two randomly selected members from each stage of the simulated supply chain. Table 2 indicates cost ranges (cost variation) for the same members in a one year period.

Table 1: Average costs for members of the supply chain

Member	Competition	Partial Cooperation	Two-Partition Case	Cooperation
Manufacturer(1)	746	732	735	720
Manufacturer(2)	391	380	367	367
Distributor(1)	423	420	433	458
Distributor(2)	538	511	508	496
Retailer(1)	1073	1025	1017	1006
Retailer(2)	832	825	807	802

Table 2: Cost variation (ranges) for members of the supply chain

Member	Competition	Partial Cooperation	Two-Partition Case	Cooperation
Manufacturer(1)	34	20	22	19
Manufacturer(2)	27	16	18	18
Distributor(1)	24	19	15	17
Distributor(2)	36	29	25	22
Retailer(1)	58	52	44	35
Retailer(2)	46	41	39	38

As an approximate pattern it can be concluded that higher degrees of cooperation provides the supply chain members with lower cost ranges or variations. From the two tables above, as it is expected, for some members such as Distributor(1) competition will be more beneficial in average. However, as other members suffer from higher costs in competition, the winning member with the lower cost (Distributor(1)) is faced with higher variation in cost over time.

Conclusion

This paper makes a quantitative examination of the conventional wisdom that cooperation in a supply chain is generally better, while only few individual members may gain benefits from selfish competitive behavior. Coopetition, or partial cooperation, is introduced and examined. Four distinct cases are defined, formulated and simulated, which are complete competition, partial and two-stage coopetition and integrated cooperation. Simulation is used to draw conclusions on the impact of behavior under various cases for individual members versus the overall supply chain, in a multi-stage, multi-member, and multi-product, single period setup where constant prices are justified.

In general, the trend in the supply chain management has been towards cooperation and alliances, although individual members may be tempted to act selfishly to lower their local costs. However, with suitable collaboration policies and long-term strategies, SCM members learn to comply with the best solution approach for the whole supply chain, as shown quantitatively in this paper. Alliances of members horizontally or vertically and parent divisions in large organizations are set to benefit in this way by developing and coordinating their members' supplies. Coopetition may be a compromise in large supply chains for partial and selective cooperation.

From the simulation results of large number of random cases under different cooperation policies, it is concluded that while, in general, individual members may benefit from competition, the other members will pay a higher amount. Thus, the overall supply chain, looking at the average members' results, benefits from higher cooperation. Examining partial cooperation, the quantitative analysis of two-partition coopetition and partial coopetition cases shows better performance over competitive supply chains from both average cost and cost variation. As the variety in a chain, which is the sum of number of products and components, go up, the performance of the model slightly increases.

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