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Supply chain coordination under discrete information asymmetries and quantity discounts ☆

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ABSTRACT

We consider a two node supply chain with a rational manufacturer–retailer pair, in which the retailer has private information that affects the nodes' reservation levels. Quantity discounts offered by the manufacturer is the mechanism we propose in order to achieve reduced costs for both supply chain nodes. We derive analytical expressions of the quantity discounts that minimize the manufacturer's costs, while enabling the establishment of the business. Furthermore, we show that perfect coordination is possible even under asymmetric information. Sensitivity analysis and numerical examples offer evidence of the robustness of the results and of the potential of the approach for applications to real-life business ventures.

1. Introduction

A large body of literature addresses the way in which supply chain nodes (often referred to as players) interact in order to reduce both their own costs and the overall supply chain cost, in terms of inventories, ordering, transportation, etc. [26]. Supply chains involve players acting as suppliers or manufacturers, and buyers or retailers, who communicate via orders and deliveries [21]. The different preferences of the players in regard to the level of orders placed, may lead to an increase in the overall inventory-related cost of the supply chain [27]. Buyers opt for small orders, in contrast to suppliers who favor large shipments; the latter results in an increase of the annual inventory holding cost but a simultaneous decrease of the annual ordering cost for the buyers and of the annual set-up cost for the suppliers occurs [30]. If the nodes could coordinate their actions, it is evident that they could reduce the global supply chain costs [35,42,24]. The importance of reducing overall costs instead of just tackling individual node costs is also underlined both by private companies and academic researchers [7].

In a typical game-theoretic view of the relationship between suppliers and buyers, each player acts in order to maximize its own profits (rational player) without taking into account the global optimal and without entering a coalition [20]. Thus, decentralized solutions (i.e. solutions in which each player is a decision maker) are promoted; among them, the most preferable ones are those in which the payoffs of the players are aligned with system-wide objectives [9]. Coordination is considered to be perfect when the total cost in the decentralized system is equal to that in the centralized one, i.e. a system in which there is a single decision maker [38]. There exist multiple papers addressing supply chain coordination, a comprehensive review of which is provided by Cachon [5]. It is important to note that perfect coordination is an ideal scenario but requires either a single decision maker or a single owner of all nodes, a fact that is extremely restrictive for practical applications.

The supplier may seek chain coordination if in this case he achieves higher individual gains. Therefore, he offers an incentive to the retailer to influence the quantity the latter orders. Such an incentive is a quantity discount; i.e. reduced per unit product price when larger orders are placed. A survey of quantity discount schemes has been performed by Benton and Park [3]. We adopt quantity discounts as the means for node coordination, since they are widely used in practice [29,37,36], can be easily implemented, and require no additional information or physical flow between the two players beyond the initial transaction [4], in contrast to other coordination mechanisms (e.g. returns policies, back-up agreements, and quantity flexibility). Many firms, such as H. J. Heinz Company, use quantity discounts in order to reduce their own costs [1]. Economies of scale are achieved through quantity discounts, yielding higher profits for several or even all the players, while allowing each of them to make its own decisions [34,40,43].

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Weng [39] studied in detail the use of quantity discounts in two-node supply chains and showed that a simple linear policy is not sufficient to maximize joint profits. A crucial assumption in Weng's work is that the two players have complete information (knowledge) about the attributes (e.g. demand, costs) of the chain. This assumption is particularly restrictive in practice where individual players tend to keep private their cost structures or demand data. Cachon and Fisher [6] studied the role of private information for each node in a producer–buyer supply chain and addressed the way this information affects the nodes' strategies concerning orders and the effect of information sharing on the total supply chain cost. Corbett et al. [14] examined how the supplier's decisions can be affected by the retailer's private information, allowing the supplier to refuse to work with some retailers. Fiala [18] underlined the value of information exchange in the supply chain and the importance of the honest exchange of information among the supply chain participants for coordination. Ha and Tong [23] studied information sharing in a model with two competitive supply chains, each consisting of one manufacturer and one retailer. Finally, Ozer and Raz [33] examined how asymmetry of information affects the whole chain in a more complex model with one manufacturer and two competitive suppliers.

In our model, we study a two-node supply chain through which a single product is manufactured and forwarded to the market. We assume that both the retail price and the demand are constant and exogenously defined, a common assumption in the literature [11]. Our goal is to examine node coordination and the resulting players' benefits, in terms of operational costs. The retailer has an ordering and a holding cost and needs to decide on the order quantity (lot size) to place to the supplier, satisfying demand and minimizing his own cost. The supplier produces under a lot for lot policy, i.e. quantities equal to the retailer's orders. There exists a set-up cost for the supplier; thus he prefers large order quantities from the retailer. To force the retailer's orders to a higher level and achieve larger profits, the supplier uses quantity discounts.

Similar supply chains have been studied by Corbett and de Groote [12] who considered a continuously distributed holding cost for the retailer, and Ha [22] for the case of an expanded newsvendor model. Our framework differs from the aforementioned ones in two ways: (i) we consider reservation levels that depend upon the retailer's private knowledge, in contrast to previous works, where the reservation levels are exogenous; and (ii) we assume discrete asymmetric information, i.e. two possible values for the retailer's holding cost. In practice both our assumptions are more realistic: reservation levels depend upon business relationships that are indeed affected by information that partners keep for themselves. Furthermore, continuous asymmetries are not very realistic in applications compared to discrete asymmetries [28]. For example, a retailer importing goods from a manufacturer may store inventory at privately owned warehouses (low cost) or at the customs location (high cost) – the latter in case duty is paid only when the product is delivered to the end customer. This discrete treatment of the holding cost's values leads to a different solution approach compared to the one proposed by Corbett and de Groote [12], thus justifying our research endeavor.

Finally, it is worth noting that a discrete treatment of information asymmetry has been proposed by Xiao and Qi [41] and Cakanyildirim et al. [8]. The first study considered a supplier–manufacturer chain, in which the manufacturer has private information about production cost. The second study addressed a supply chain similar to our model, but employed a reverse information asymmetry, i.e. production costs at the supplier level take two potential values. In both cases, the authors derived closed form solutions of the underlying optimization problems and proved that even with asymmetry of information perfect coordination is feasible.

The contribution of our work lies in the analytical derivation of quantity discounts offered by a manufacturer to a retailer that enable the establishment of the business relationship and allow reduced operational costs for both players, without the existence of bilateral contracts and under discrete information asymmetry emanating from the retailers' storage options.

The remainder of the paper is organized as follows: Section 2 provides the mathematical model for a two-node supply chain and the game-theory perspective of the players' interaction via orders and discounts. Section 3 develops the analytical solution of the game, proving the joint EOQ result for the case of complete information and devising exact values for orders and discounts based on global optimization for the case of asymmetric information. Section 4 provides numerical results for sample data sets concerning inventory holding cost and set-up cost relationships, offering insights on the effect of the various parameters and providing sensitivity analysis for performance evaluation. Section 5 summarizes the conclusions of our work and puts forth pointers for future research.

2. Model description

Let us consider a two node supply chain, with S denoting the supplier (manufacturer) and R denoting the retailer (buyer), interacting via orders for a single product. The market demand D is constant, exogenously defined, and known to both parties. Shortages or backorders are not allowed. Both players are rational and risk neutral, so they choose their strategies in order to minimize their own expected cost function (non-cooperative game, [20]).

The retailer has an ordering and a holding cost denoted by K_R and H_R, respectively, and has to decide on the order quantity $Q>0$ he will place to the supplier, satisfying demand and minimizing his own cost. The retailer's cost is a function of his order quantity Q and can be expressed as $C_R(Q)=K_RD/Q+H_RQ/2$. There exists a set-up cost in the production phase, included in the supplier cost function and denoted by K_S. The supplier produces under a lot for lot policy, i.e. a quantity equal to the retailer's order Q. As a result, the supplier is not a decision maker and his cost is a function of the retailer's order quantity, expressed as $C_S(Q)=K_SD/Q$ and not influenced by any of his potential actions. It is obvious that if the supplier could decide about the order quantity he would favor huge quantities because in this way he would reduce his own total costs (the supplier's cost function is a decreasing function of the order quantity Q). Consequently, the total supply chain (or joint) cost can be expressed as $C_J(Q)$ and is equal to the sum of the retailer's and supplier's cost, i.e.:

$$C_J(Q)=C_S(Q)+C_R(Q)=(K_R+K_S)D/Q+H_RQ/2 \tag{2.1}$$

The retailer selects the order quantity to minimize his own cost function. The optimal value can be directly derived by taking the first order derivative of the cost function, setting it equal to zero and solving with respect to Q, giving $Q_R^*=\sqrt{2K_RD/H_R}$. This results in the following costs:

Retailer's cost: $C_R(Q_R^*)=K_RD/Q_R^*+H_RQ_R^*/2=\sqrt{2K_RDH_R}$.

Supplier's cost: $C_S(Q_R^*)=K_SD/Q_R^*=K_S\sqrt{DH_R/2K_R}$.

Joint cost: $C_J(Q_R^*)=C_S(Q_R^*)+C_R(Q_R^*)=(2K_R+K_S)\sqrt{DH_R/2K_R}$.

Note that, the optimal cost for the whole supply chain is the minimum of the function $C_J(Q)$. This is achieved when the order quantity is $Q_J^*=\sqrt{2(K_R+K_S)D/H_R}$ and we observe that $Q_J^*>Q_R^*$. For the overall supply chain costs the following inequality holds:

$$C_J(Q_J^*)<C_J(Q_R^*) \tag{2.2}$$

Thus, a higher than Q_R^* order quantity is preferable to reduce the total costs. However, this is reached at the expense of increased retailer's cost, rendering him negative to a potential cooperation. Therefore, to raise the retailer's order level (preferred case for the supplier) and achieve reduced costs, the supplier must offer him an incentive when selecting the order quantity. We allow the supplier to provide quantity discounts to the retailer, in order to affect the