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Asymmetric supply chain models implementable with a mechanism design

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ABSTRACT

Many game–theoretical models have been proposed in the area of supply chain management over the last few decades and they have played an essential role in finding the optimal strategies that should be adopted by the participants in a supply chain system. Most research in the area however, is restricted to cases where both buyer and seller possess symmetric information on each other's operations, where demands are deterministic and shortages are not allowed. In reality however, the participants would possess information related to their operations which are not common knowledge, where demands are function of the players' decision variables and shortages will occur due to irregular production capacity and unanticipated demand. In this paper, we present several seller-buyer supply chain models with asymmetric information structure and the additional feature of shortage as a decision variable controlled by the seller. We also investigate two mechanism design contracts provided by the seller to the buyer as an incentive to improve the profit of both parties.

1. Introduction and literature review

There has been much research done in supply chain systems during the last few decades and at its broadest level, the research involves designing strategies based on concepts such as seller-buyer coordination, information sharing and business process management [1]. In general, researchers in this area aim to find optimal strategies involving decision variables such as selling price, order quantity and marketing expenditure so that efficient outcomes will be achieved by the participants of the supply chain. In recent years, a number of mechanisms to achieve these favorable outcomes have been discussed in the literature, such as quantity discount, credit option, return policies, quantity flexibility and commitment of purchase quantity [2–6]. Among the many models proposed, a model where demand is price sensitive has been proposed by Abad [7], who also provided a procedure for finding the optimal policy for both seller and buyer under a cooperative game structure. Similarly, Freeland [8], Lee and Kim [9], Kim and Lee [10] and Sadjadi et al. [11] proposed models which assumed that demand is influenced by marketing expenditure and price.

In these works however, the interaction between seller and buyer were ignored, especially when it comes to the advantage that accrues to the player who takes the initiative and makes the first move. This was later rectified in Esmaeili et al. [12] where the interaction between seller and buyer was modeled as non-cooperative Stackelberg games [13]. In these games, the buyer and seller takes turn being the *leader* and *follower*, with the former taking the initiative by making the

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first move, and the latter then reacts by playing the best strategy consistent with all the available information. Recently, Guo and Ma [14] considered a closed-loop supply chain problem of retailer collecting and selling. The authors approached the problem based on Stackelberg game model and a centralized control decision-making model, and provide a comparison of price decisions that arise from these models. Zhang and Liu [15] studied the coordination mechanism in a three–level green supply chain under a non-cooperative game scenario. Several Stackelberg games were investigated and various coordination mechanism proposed in this paper.

All the aforementioned papers assumed that information available to the players of the supply chain game are *symmetric*, i.e., they are common knowledge to both seller and buyer. This assumption is often contravened in practice, where information concerning certain elements of the model are only known to one player and not revealed to the other player. For example, the buyer often holds information about the market demand privately, and the seller may not reveal his cost structure to the buyer. There have been many papers which investigated supply chain under an *asymmetric* information structure. To name a few, Lau and Lau [16], and Lau et al. [17] investigated supply chain model as a non-cooperative game with symmetric and asymmetric information pattern where demand is a function of price and not known to both seller and buyer. Corbett and deGroote [18] suggested offering a discount as an inducement to reveal information and Chu and Lee [19] suggested paying a cost to extract information. All of these models assumed that certain information concerning the model parameters are unknown to one of the players while the other is fully aware of their values. By contrast, Esmaeili and Zeephongsekul [20] formulated several seller-buyer supply chain models as a non-cooperative asymmetric game where the seller is ignorant of the demand and the buyer is not aware of the seller's setup and production cost. Recently, Ha et al. [21] studied an information sharing problem in a manufacturer-retailer supply chain, where the retailer possesses private information about the demand and the manufacturer offers a payment as an incentive strategy to extract demand information from the retailer. The authors considered two cases of games, ie., retail quantity competition in Cournot game, and retail price competition in Bertrand game. Both games have been solved through the application of backward induction techniques.

In recent years, *mechanism design* in supply chain has captured some researchers' interest. Mechanism designs are contracts designed by individuals or organizations in order to help achieve certain objectives. Its formal treatment began with Hurwicz [22] and it provides players in asymmetric games with the means of obtaining information through implementing incentive schemes inducing other players to reveal their private information. Lim [23] studied a contract design problem in a quality control situation where the quality of a product is unknown and provided an incentive scheme which involve price rebate and product warranty to obtain information on the quality of the product. Corbett [24] investigated several contracts concerning cycle stock, safety stock and consignment stock under asymmetric information structure. Two mechanism designs were studied, depending upon when the supplier has private information about setup cost and when the supplier is unable to observe the buyer's backorder cost. Wang et al. [25] extended the model proposed by Cachon and Zipkin [26] from single supplier/single retailer situation to a single supplier/multiple retailers scenario. They studied the local inventory policy and echelon inventory policy separately, and provided a contract based on each inventory policy in order to achieve an optimal cooperative solution. However, the information in their model is assumed to be symmetric. Özer and Wei [27] studied an information sharing problem between a supplier and a manufacturer, where the manufacturer holds private information about the forecast of demand, and this information are unknown to the supplier. The authors developed two contracts to assure credible forecast information sharing. One contract depends on a monetary commitment, and the other bases on a quantity commitment. Burnetas et al. [28] investigated several quantity discount schedules in single-period supply contracts with asymmetric demand information and found that the supplier can earn larger profits with an all-unit discount than with an incremental discount schemes. Taylor and Xiao [29] considered demand-forecast information problem in supply chain involving a manufacturer and a newsvendor retailer, where the retailer possesses superior information concerning the demand forecasting. Two contracts have been proposed and studied in this paper, one is the wholesale price contract, and the other is the procurement contract or a quantity discount contract. The impact of retailer's forecasting accuracy to manufacturer's expected profit was investigated in that paper.

It can be seen from the above articles that mechanism design can be used as an incentive device for extracting a variety of information such as quality control employed, cost structure, demand information and inventory planning in order to achieve the best outcomes for chain members.

Demand information is also critical for a supply chain to achieve an efficient outcome. Huge cost in inventory and stockout can occur due to uncertain demand or inaccurate demand forecast. A potential saving by sharing information among supply chain members has been well documented, ranging from $14 billion for the food service industry [30] to $30 billion for the grocery industry [31]. An inaccurate reported demand can inflict huge cost on suppliers, for example, Solectron, a major electronics supplier, had $4.7 billion in excess inventory due to inflated demand forecasts reported by its customers [32]. Shortage is another issue that managers should be concerned since it causes lost sale opportunities and leads to dissatisfied consumers. For example, Sport Obermeyer, a major supplier of fashion skiwear, experienced high costs in the form of missed sale opportunities due to stockout [33]. One way to reduce costs and enhance the efficiency of the supply chain is to obtain credible information that best match the market demand and reflect supply chain members' characteristics. All this can be achieved through the design of incentive contracts.

In this paper we will investigate several seller-buyer supply chain models based on a model proposed in Zhang et al. [34] but with an asymmetric information pattern. Information are asymmetric for both seller and buyer in the sense that demand is only known to the buyer through price and marketing elasticity, the setup and production cost are known only

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