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Seller–buyer models of supply chain management with an asymmetric information structure

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ABSTRACT

A seller–buyer supply chain represents a network consisting of a seller who wholesales a product to a buyer, who in turn retails it to the consumer. Most seller–buyer supply chains are modeled by non-cooperative and cooperative games under a deterministic and symmetric information pattern. Under a symmetric information pattern, the seller and buyer have complete information on each other's operations. However, in a supply chain, the buyer and seller, being independent entities, have private information about various aspects of their businesses which are not common knowledge. In this paper, several seller–buyer supply chain models are proposed under an asymmetric information pattern. The proposed models rely on the fact that the seller's setup/purchase costs are unknown to the buyer and the buyer withholds certain information related to market demand. The relationships between seller and buyer are modeled by non-cooperative *Stackelberg* games where buyer and seller take turn as leader and follower. In addition, a semi-cooperative model, where sharing marketing expenditure is used as an incentive strategy to reveal information, is proposed. Finally, numerical examples presented in this paper, including sensitivity analysis of some key parameters, seek to compare results between the different models considered.

1. Introduction and literature review

A seller–buyer supply chain model symbolizes a manufacturer who wholesales a product to a retailer, who then retails the product to the consumer (Yang and Zhou, 2006; Chen et al., 2006; Dai et al., 2005). In the literature, the terms vendor, supplier, and manufacturer have been used interchangeably to represent the seller. Likewise, the word retailer has been used to represent the buyer. In this paper, we will simply use the nomenclature buyer and seller. Recent literature on the seller–buyer supply chain have addressed the problem of determining the optimal order quantity (lot size) and production cycles between the two members of a seller–buyer supply chain. The main objectives of all these studies are to maximize savings and enhance profit for the whole supply chain while fixing demand rate (Sucky, 2005; Chan and Kingsman, 2007; van den Heuvel et al., 2007; Dai and Qi, 2007).

Moreover, various types of coordination mechanisms have been discussed in the literature on supply chain such as quantity discount, credit option, return policies, quantity flexibility and commitment of purchase quantity (Sarmah et al., 2006; Weng, 1995; Chiang et al., 1994; Corbett and de Groote, 2000; Viswanathan and Wang, 2003; Abad and Jaggi, 2003). Also, the effort expended in marketing a product is also an important coordination mechanism tool that can occur in a seller–buyer supply chain. For example, Huang and Li (2001) and Li et al. (2002), Yue et al. (2006a, b) and Esmaeili et al. (2009) have investigated manufacturer–retailer coordination in cooperative advertising in supply chain problem.

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All of these papers assume that the seller and the buyer have complete information on each others operations. However, in many situations, some information is only privy to one party and the other party makes decisions with limited available information. Unfortunately, research which consider supply-chain problem as an interactive mechanism with asymmetric information is uncommon and the majority of this research is concentrated on uncertain market demand. For instance, Reyes (2005) examines the two-echelon newsboy problem where demand is uncertain. Chu and Lee (2006) investigate a two-member supply chain where the retailer is better informed about the demand than the vendor, and has to consider the factors that will influence how much information is to be revealed. Yue et al. (2006a,b) investigate two separate firms that produce two complementary goods as a mixed bundle and present a profit maximization model to obtain optimal strategies for the firm making decision under uncertain market demand. Finally, Lau and Lau (2005) and Lau et al. (2007) model a manufacturer and retailer in a supply chain as a non-cooperative game with symmetric and asymmetric information where the market demand is unknown to both manufacturer and retailer and is a function of price only. Moreover, to avoid the confounding effect of logistic cost, they assume that lot size is equal to demand. In our model, demand is a function of both price and marketing; also, we do not assume that lot size is the same as demand.

In addition, under asymmetric information, several works have addressed some incentive strategies to share or reveal information, such as offering a price discount (Corbett and de Groote, 2000), paying the cost of revealing information (Chu and Lee, 2006) and bargaining which involves side payments to reveal cost structure (Sucky, 2006). A significant shortcoming of all these models is that first, they assume the information is unknown only for one of the parties and second, they assume that lot size is equal to demand to minimize model complexity. To the best of our knowledge, this paper provides the first model where asymmetric information is assumed for *both* buyer and seller.

In Esmaeili et al. (2009), several supply chain models are introduced which are modeled by non-cooperative and cooperative games under a symmetric information scenario. The paper assumes that the seller and buyer have complete information on each others cost structure and market demand. In reality, however, the buyer is better informed about demand and the seller's costs is known only to herself, and there is no reason for them to reveal this information to each other. In this paper, we assume that the demand function is known only to the buyer and also that the buyer is unaware of the seller's setup cost and purchasing cost, both of which are known to the seller. Thus, the paper deals with the situation where information is asymmetric. In the non-cooperative game model, the relationships between seller and buyer is modeled from two different perspectives: the *Seller-Stackelberg* and *Buyer-Stackelberg* scenarios. In the first scenario, the seller dominates the buyer by making the first move, whereas in the second scenario, this power has shifted from the seller to the buyer. We also propose a semi-cooperative model where sharing of marketing expenditure is used as an incentive strategy to reveal information between the seller and buyer. Note that in this paper, the seller produces a product and wholesales it to the buyer, who then retails it to the consumer. The seller's production rate is linearly related with the market demand rate and demand is sensitive to both selling price and marketing expenditure.

The remainder of this paper is organized as follows. The notation and assumptions underlying our models are given in Section 2. This section also briefly summarizes the buyer and seller's model and some basic concepts of a game with incomplete information relevant to this work. In Section 3, the non-cooperative, seller–buyer supply chain model is discussed under an asymmetric information pattern and, in Section 4, this is extended to Stackelberg games. In Section 5, based on the premise that uncertainty in demand would have a more serious impact on the seller's profit than the buyer, we obtain results where sharing of marketing cost is used as an incentive by the seller on the buyer to reveal information on demand. Section 6 presents some computational results, including a number of numerical examples and their sensitivity analysis. Finally, the paper concludes in Section 7 with some suggestions for future work in this area.

2. Notation and problem formulation

This section introduces the notation and formulation used in our supply chain problem. All decision variables, input parameters, assumptions and details of our models will be stated here.

2.1. Decision variables

$\mathscr{Y}$	the price charged by the seller to the buyer (\$/unit)
Q	lot size determined by the seller (units)
P	selling price charged by the buyer to the customer (\$/unit)
M	marketing expenditure incurred by the buyer (\$/unit)
t	the fraction of total marketing expenditure cost paid by seller

2.2. Input parameters

k	scaling constant for demand function ($k>0$)
u_0	scaling constant for production function ($u_0 \geq 1$)
i	percent inventory holding cost (%/unit/unit time)
α	price elasticity of demand function ($\alpha>1$)
β	marketing expenditure elasticity of demand ($0<\beta<1, \beta+1<\alpha$)
A_b	buyer's ordering cost (\$/order)
A_s	seller's setup cost (\$/setup)
C_s	seller's production cost including purchasing cost (\$/unit)
L	the ratio of marketing expenditure elasticity to price elasticity ($L=\beta/\alpha$)
R	seller's production rate (/unit time)
$D(P,M)$	market demand rate (/unit time); as in Lee and Kim (1993), we will assume

$$D(P,M) = kP^{-\alpha}M^{\beta}. \tag{1}$$

2.3. Assumptions

The proposed models in this paper are based on the following assumptions:

1. Planning horizon is infinite.
2. Market demand, defined by (1), is only known to the buyer through α and β. However, there are empirical