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Individually rational buyback contracts with inventory level dependent demand

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ABSTRACT

In this paper, we consider a supply chain coordination problem when demand faced by a retailer is influenced by the amount of inventory displayed on the retail shelf. We assume that shelf space inventory is used as one of the levers to stimulate demand. Our objective in this research is to design individually rational contracts that coordinate the supply chain when the retailer faces inventory-level-dependent demand. We consider a buyback contract where any leftover inventory at the retailer can be returned to the supplier at a pre-specified terms of the buyback contract. The existing buyback contracts in the supply chain coordination literature do not guarantee the satisfaction of individual rationality constraint. A continuum of buyback contracts coordinate the supply chain. The contracts may differ on the basis of division of profits resulting in contracts that may not be individually rational. This motivates us to use the Shapley value from the cooperative game theory which ensures fairness and individual rationality in the buyback contract. We also provide managerial insights into the design of the contracts and analyze the impact of shelf space inventory on the contract parameters.

1. Introduction

Contract theory provides important mechanisms that align the objectives of a firm with supply chain's objective. The past decade has motivated research on supply chain contracts in designing several contracts such as *revenue sharing* contracts (Giannoccaro and Pontrandolfo, 2004; Cachon and Lariviere, 2005), *quantity flexibility* contracts (Tsay and Lovejoy, 1999; Tsay, 1999; Lian and Deshmukh, 2009), *buyback contracts* (Pasternack, 1985; Padmanabhan and Png, 1995; Song et al., 2008; Shen and Willems, 2012). Jeuland and Shugan (1983) discuss the problem of coordinating supply chains through profit sharing. Tsay et al. (1999) and Cachon (2003) provide a comprehensive review on supply chain coordination with contracts.

A typical contract design problem in supply chain coordination literature considers a supplier selling to a retailer that faces newsvendor problem. Several variants and extensions of newsvendor framework have been analyzed. These are, among others, retail pricing decision in addition to the ordering quantity, competing retailers, two procurement opportunities, and additional effort by retailers to influence demand.

In this paper, we consider a supply chain coordination problem when demand faced by a retailer is influenced by the amount of inventory displayed on the retail shelf. This phenomenon is commonly observed in retail settings such as groceries, book stores, apparel, etc. Shelf space inventory is used as one of the levers to stimulate demand. The assumption in this action is that retailers can attract more sales volume of a product by increasing the shelf space allocation. This phenomenon is evident even in online retailing like amazon.com, eBay.com, etc. For each title, amazon.com displays the related titles to stimulate demand. Marketing literature has recognized this motivational effect of displayed inventory level on the demand (Corstjens and Doyle, 1981). For achieving supply chain coordination, traditionally, ordering policies are driven by the service level requirements within the newsvendor framework. The fact that the inventories can play a role in stimulating customer demand is relatively a new attraction for operations and supply chain coordination (Wang and Gerchak, 2001; Urban, 2005; Balakrishnan et al., 2008; Zhou et al., 2008; Stavrulaki, 2011).

In this research, we consider a supply chain comprising a single supplier and a single retailer. The retailer faces inventory-level-dependent-demand (ILDD). However, the exogenous uncertainty

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may still influence the demand. Hence, we model the demand faced by a retailer as a function of displayed inventory level and the exogenous uncertainty. First, by determining the performance of an integrated firm, we identify the set of optimal actions of the retailer and the supplier. Next, we provide arguments on lack of incentives for the firms to take optimal actions and the consequential inefficiencies in the supply chain.

Our objective in this research is to design *individually rational contracts* that coordinate the supply chain when the retailer faces inventory-level-dependent demand. We consider a buyback contract where any leftover inventory at the retailer can be returned to the supplier at some prespecified terms of the buyback contract. As elaborated later in the paper, in buyback contracts, the objective is to maximize the overall supply chain profits rather than emphasizing on the division of that profit. There may be combinations of wholesale and buyback prices that maximize the supply chain's profits; however, they may induce lower profits for a firm in the contract, compared to decentralized supply chain. The existing buyback contracts in the supply chain coordination literature do not guarantee the satisfaction of individual rationality constraint. A continuum of buyback contracts coordinate the supply chain. The contracts may differ on the basis of division of profits resulting in contracts that may not be individually rational (Cachon and Terwiesch, 2009; Lariviere, 1999). This motivates us to use the Shapley value from the cooperative game theory which ensures fairness and individual rationality in the buyback contract.

Our contribution in this research is to design individually rational buyback contracts that coordinate the supply chain when the retailer faces inventory-level-dependent demand. We also provide managerial insights into the design of the contract and the impact of shelf space inventory on the contract parameters.

In what follows, we first determine the performance of an integrated firm and contrast it with the performance of the decentralized decision making of supplier and the retailer. Section 3 describes the individually rational buyback contract when retailer faces inventory level dependent demand. We compute different combinations of wholesale and buyback prices that implement the Shapley value of the coordinated supply chain. The computational results to provide managerial insights are provided in Section 4. We conclude in Section 5.

2. Model

We consider a one period setting consisting of a supplier selling to a newsvendor retailer facing inventory-level-dependent-demand. The retail price of an item is fixed at P per unit. The retailer allocates Q units of shelf space to an item. The item is procured from the supplier at wholesale price w. The marginal cost of procurement incurred by the supplier is C per unit. Any unsold inventory is salvaged at S per unit. The shortages incur a cost of p per unit. The demand x has a probability density function $f_d(x)$. We assume that the retailer's demand function x has two components. The first component captures the impact of displayed inventory level (stimulation effect). The second component is the random uncertainty of demand due to exogenous factors. We consider that the stimulation effect of displayed inventory level on demand is $\alpha+\beta Q$; α, $\beta>0$. α is the realized demand even when there is no stimulation. β is the sensitivity parameter of demand stimulation. Urban (2005) provides detailed analysis of this demand function and other popular demand functions that retailers assume for modeling demand stimulation due to displayed inventory level. We further assume that the exogenous uncertainty ϵ follows a uniform distribution. The choice of uniform distribution is not restrictive. It is driven by the motivation to get insights into the structure of the problem using uniform distribution. Amit and Mehta (2010) model the stimulation of demand with a general demand distribution and obtain encouraging results. Applying the stochastic dominance concept, they assume that the probability of higher realized demand is more with higher stocking level. The distribution of realized demand with higher stocking level stochastically dominates the distribution of realized demand with lower stocking level. This assumption of stochastic dominance permits them to model the endogenous impact of stocking level on the general demand distribution. A summary of the notation used in the paper is provided in Table 1.

Table 1
Notation.

P	Marginal selling price
C	Marginal production cost ($P>C$)
w	Marginal wholesale price
S	Marginal salvage value ($S<P$)
p	Marginal penalty for shortage
x	Random demand
$f_d(x)$	Probability density function of demand
α	Intercept parameter of demand
β	Elasticity parameter of demand
ϵ	Random error variable
$f_\epsilon(.)$	Probability density function for ϵ
Q	Order quantity
$\Pi_c(Q)$	Expected profit of the centralized supply chain
$\Pi_r(Q)$	Expected profit of the retailer
$\Pi_m(Q)$	Expected profit of the supplier

We consider that the retailer shelf space is replenished via the $(Q-1,Q)$ policy, hence the stock level is always Q. The probability distribution of ϵ that follows uniform distribution is:

$$f_\epsilon(y)=\begin{cases}\frac{1}{b-a} & \text{for } a\le y\le b\\ 0 & \text{otherwise}\end{cases} \tag{1}$$

Since the demand function is $\alpha+\beta Q+\epsilon$, from Eq. (1), demand varies from $\alpha+\beta Q+a$ to $\alpha+\beta Q+b$. The probability distribution function for demand is

$$f_d(x)=\begin{cases}\frac{1}{b-a} & \text{for } \alpha+\beta Q+a\le x\le \alpha+\beta Q+b\\ 0 & \text{otherwise}\end{cases} \tag{2}$$

In a single period setting, the retailer's expected profit is given by

$$Profit=\begin{cases}xP-QC+(Q-x)S & \text{if } Q\ge x\\ QP-QC-(x-Q)p & \text{if } Q<x\end{cases}$$

$$E(\Pi)=\int xf_d(x)\,dx$$

We now present the analysis of an integrated firm in a centralized decision making framework.

2.1. Centralized decision

Consider a situation in which the supplier and the retailer are willing to form an integrated firm. It means manufacturing and selling of product is centralized. This is also called centralized decision environment. The expected profit of an integrated firm as function of stocking level Q is given by

$$\Pi_c(Q)=\frac{1}{b-a}\left\{\int_{d_1}^{Q}Px\,dx+\int_{Q}^{d_2}PQ\,dx-\int_{Q}^{d_2}p(x-Q)\,dx+\int_{d_1}^{Q}S(Q-x)\,dx\right\}-CQ \tag{3}$$