Omega 41 (2013) 809–819

Contents lists available at SciVerse ScienceDirect

Omega

journal homepage: www.elsevier.com/locate/omega

Mixed contracts for the newsvendor problem with real options and discrete demand ☆

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ARTICLE INFO

Article history:
Received 7 July 2011
Accepted 29 October 2012
Processed by B. Lev
Available online 20 November 2012

Keywords:
Newsvendor model
Real options
Discrete demand
Mixed contract

ABSTRACT

In this paper we consider the newsvendor model with real options under discrete demand. We consider a mixed contract where the retailer can order a combination of q units subject to the conditions in a classical newsvendor contract and Q real options on the same items. We provide a closed form solution to this mixed contract when the demand is discrete and study some of its properties. In particular we demonstrate that a mixed contract may be superior to a real option contract when a manufacturer has a bound on how much variance she is willing to accept.

1. Introduction

It is important for a firm to establish effective supply contracts with their suppliers/buyers to enhance their performance in the supply chain. In capital-intensive industries improvements in the coordination of supply and demand may carry large economic benefits Kleindorfer & Wu [17]. Recently supply chain researchers have studied the performance of mixing two or more contracts, as the wholesale contract, the real option contracts and the usage of the spot market to improve the performance of one or more parties in the supply chain. The focus has been mainly on how the buyers can establish effective supply contracts with their suppliers to achieve benefits as increased flexibility, reduce cost and adequate supply.

The bulk of the literature on the newsvendor problem focuses on cases where demand has a continuous, very often normal, distribution. The standard argument invokes the central limit theorem, in which case total demand from a pool of many buyers with iid demands must be approximately normal. On closer inspection this argument is not in any way as good as it might first appear. Of course there are cases where the argument is valid, but often it is not.

Consider a small town where the local newspaper has subscribers and occasional buyers. The occasional buyers buy the newspaper if and only if the local football team wins. The resulting demand is hence a two point distribution. The setting is of course extremely simplified, but stresses a point of interest; when randomness in demand is driven by events, there is no reason to expect that demand has normal distribution. At best the distribution is normal conditional on events, and randomness due to events may lead to distributions that are very far from normal.

In this paper we advocate discrete models. Distribution of demand is usually unknown, and is revealed from (discrete) observations. A short time distribution may exist, but usually no limit exists in the long run. Hence it may well happen that we simply have not enough time to infer the full shape of the distribution. Our observations constitute a well defined discrete distribution, however, and if we try to fit this to our favorite class of continuous distributions information is in most cases lost, not gained. We believe that most people use continuous models because they do not know how to handle the discrete case, and the purpose of this paper is facilitate handling of the discrete case.

In this paper we study the mix of a wholesale and a real option contract, and compare the performance of the mixed contract both with the single wholesale contract and with the real option contract. We model the negotiation process as a Stackelberg game, where the supplier is the leader and determines the wholesale price, and the option- and exercise price for the real option contract. See Chen et al. [8,9] for recent contributions to Stackelberg issues in the newsvendor model. Initially we assume that the agents are risk-neutral in the sense that they only care about expected profits. When two contracts have the same expected profit, however, the contract offering the lowest variance will be preferred.

The game is divided into two separate stages. At the first stage the supplier (leader) offers a wholesale contract, and chooses the wholesale price to maximize her expected profit. The buyer (follower) chooses the order quantity that maximizes his expected profit. We assume that both parties have full information on the demand distribution. The resulting contract is pareto optimal, and we will refer to this contract as the original contract.

At the second stage of the game the supplier is faced with the original contract, and wants to design a mixed contract to further

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☆The research leading to these results has received funding from NFR project 196433.

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http://dx.doi.org/10.1016/j.omega.2012.10.011

advance profits. A new contract is feasible only if both parties have at least as much expected profit as in the original contract. The supplier hence search a feasible mixed contract to optimize profits.

If the supplier is risk-neutral, she can always extract all extra expected profit using a pure real option contract. A mixed contract cannot advance expected profits further since there is nothing more to take. If the supplier is risk-averse in the sense that she has a bound on how much variance she can tolerate, however, we show that expected profits can be enhanced considerably more by mixed contracts than by pure real option contracts. The explanation for this is quite simple. In the mixed contract the supplier has zero variance from the wholesale part of the contract, and as a consequence of this the variance of her profit falls much more rapidly (in comparison with the pure real option case) when the usage of the wholesale contract increases.

The paper is organized as follows: In Section 2 we give a literature review to explain how our theory fits in the existing literature in the field. In Section 3 we review the basic properties of the newsvendor and real option contracts. The main result is Proposition 3.1 which offers a closed form solution for the mixed contract in the discrete case. In Section 4 we examine some numerical examples to illustrate the some of the properties of the mixed contracts. In Section 5 we study the performance of mixed contracts for a risk-averse supplier. In particular we demonstrate that a mixed contract is superior to a real option contracts in enhancing profits for the supplier. Finally in Section 6 we offer some concluding remarks.

2. Literature review

A mixed option and wholesale contract has previously been addressed also by other authors in different type of settings. Cheng et al. [7] considered a mixed wholesale and option contract for an exogenously given wholesale price. For the option contract to be effective, they suggest that the exercise price should be less than the wholesale price in the forward contract. Otherwise, they show that the supplier will take most of the profit improvement, leaving the buyer with little incentive to procure the options. To overcome this difficulty and achieve channel coordination, they propose a simple negotiation mechanism to share the profit improvement over the newsvendor model. Burnetas and Ritchken [4] consider a mixed wholesale and option contract when the retailers demand distribution is influenced by pricing decisions (the retailer has an uncertain downward sloping demand curve). They show that the introduction of option contracts into the wholesale contract causes the wholesale price to increase and the volatility of the retail price to decrease. Conditions are derived under which the supplier is always better off with a mixed contract. They further find that the retailer will benefit from a mixed contract only if the demand uncertainty is low.

Barnes-Schuster et al. [2] consider a two-periodic mixed forward- and option-contract where the supplier has flexibility in choosing between a normal and a more expensive expedite production. They illustrate how options provide flexibility for the buyer to respond to market changes in the second period, but note that options not always coordinate the channel and may alleviate the individual rationality constraint. Barnes-Schuster et al. [2] show that contracts, as the backup agreements analyzed by Eppen and Iyer [11], the quantity flexibility contract analyzed by Tsay and Lovejoy [25], and the pay-to-delay capacity reservation contracts analyzed by Brown and Lee [3], are all special cases of their proposed model. A buyer–supplier relationship with two ordering opportunities is also discussed/considered in Zhou and Wang [28] and Weng [26].

In the recent year there has been a focus on papers that combine the traditional long-term contracts, with the option of using spot market to sell the participants excess inventory or to buy additional inventory depending on the need. A literature survey that presents and discusses the literature that considers integrating long-term contract as forward and options with short-term spot contracts in capital-intensive industries is given by Kleindorfer and Wu [17]. They illustrate the reviewed work with examples of goods and services currently being traded in both short-run and long-term contract markets and discuss the challenges of implementation. They conclude the survey by addressing unexplored research questions in the literature. A more recent survey that focuses on supply chain operation in the presence of a spot market, by Hakssz and Seshadri [14], also reviews and discusses papers that consider the optimal mix of long-term contracts and the usage of the spot market. They mention Akella et al. [1] and Seifert et al. [22] that mainly address the procurement problem for the buyer, and Wu et al. [27] and Golovachkina and Bradley [13] that also consider the buyer–supplier coordination. More specific, Wu et al. [27] and Golovachkina and Bradley [13] consider a real option capacity reservation contract where both parties have access to the spot market and the supplier has limited capacity while the spot market has unlimited supply. Golovachkina and Bradley [13] focus on how access to the spot market affect buyer–seller coordination, while Wu et al. [27] study how to find the optimal balance between selling capacity using a forward contract and reserving capacity to sell in the spot market for a single supplier and multiple buyer supply chain. Both papers conclude that the optimal strategy for the supplier is to "set the exercise price sufficiently low to guarantee that the buyer will exercise the options and set the reservation price to achieve the trade-off between immediate and future revenues", Golovachkina and Bradley [13].

A buyer of commodity products has typically many different suppliers to procure from. By selecting the right mix of contracts from the long-term market (wholesale and option) and the short term (spot) market the buyer may increase the flexibility and enhance the profit. Martinez-de-Albeniz and Simchi-Levi [19] address the multi-periodic supplier selection problem for a buyer with access to forward contracts, real option contracts, and the spot market. They study how the buyer can find the portfolio of contracts that maximizes his expected profit, based on the flexibility-price trade-off of the potential contracts. This setting is particularly meaningful for commodity products where a large pool of suppliers is available. Through numerical examples, Martinez-de-Albeniz and Simchi-Levi [19] show that the "expected profitability of a portfolio contract dominates the long-term contract both in terms of the mean and the variance of profit", while the real "option contracts may attain less profit variability compared to the portfolio contracts". In order for the suppliers to get the buyers attention they have to compete on price and flexibility. In Martinez-de-Albeniz and Simchi-Levi [19] the suppliers' bids are exogenous, i.e., there is no competition among the suppliers. Martínez-de-Albéniz and Simchi-Levi [21] analyze the behavior of the suppliers when they compete on the attention from the buyer. They present the optimal conditions for suppliers' bids and provided necessary conditions for equilibrium bids in a one periodic model. They find that the equilibria in pure strategies give rise to what they call cluster competition. Hazra and Mahadevan [15] also address the supplier selection problem for a buyer with access to both the spot market and to long-term contracts through a supplier bidding process. They model the pricing behavior of the suppliers (offering capacity both through long-term contracts and at the spot market) and derive expressions for the optimal contract mix for the buyer.

Serel [23] discusses how to design a long-term multi-period capacity reservation contract between a buyer and a long-term supplier when the buyer also has access to a spot market. The long-term contract gives the buyer access to a given volume in