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Contracting with asymmetric demand information in supply chains

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ABSTRACT

We solve a buyback contract design problem for a supplier who is working with a retailer who possesses private information about the demand distribution. We model the retailer's private information as a space of either discrete or continuous demand states so that only the retailer knows its demand state and the demand for the product is stochastically increasing in the state. We focus on contracts that are viable in practice, where the buyback price being strictly less than the wholesale price, which is itself strictly less than the retail price. We derive the optimal (for the supplier) buyback contract that allows for arbitrary allocation of profits to the retailer (subject to the retailer's reservation profit requirements) and show that in the limit this contract leads to the first-best solution with the supplier keeping the entire channel's profit (after the retailer's reservation profit).

1. Introduction

Consider a powerful supplier selling to a newsvendor retailer who needs to achieve a minimum expected profit for himself. When there is no information asymmetry, the supplier can use one of several simple contracts (see Cachon, 2003 for a review) to extract for herself all the first-best channel profit, leaving the retailer nothing but his reservation profit. What if the retailer holds private information, for example, about the distribution of market demand? Then, simple contracts will not provide the supplier with the highest profit, in particular, they are unlikely to maximize supply chain profit and even if they do, they allow the retailer to earn more than his reservation value at the expense of the supplier.

In particular, consider the well-known buy-back contract, with a wholesale price w and an inventory buyback price b. Pasternack (1985) shows that the supplier can offer an infinite variety of such contracts to coordinate the supply chain, as long as they satisfy a coordinating condition (using our notation this condition is $\frac{w-b}{r-b}=\frac{c}{r}$, where c is the unit cost and r is the unit revenue). Of course, the supplier's objective is not channel coordination. However, each of those different contracts represents a different division of the total maximized supply chain profit between the supplier and the retailer. If the distribution of the retailer's demand is known to the supplier, by adjusting contract terms (w,b) so that the coordinating condition is satisfied, the supplier can make sure that the retailer receives only the reservation profit and keep the rest for herself. The key observation here is that even though the coordinating condition is distribution-free, the allocation of the profits requires that the supplier knows the retailer's demand distribution.

With asymmetric information about demand distribution, the supplier does not knows how much the retailer is profiting above the reservation or even whether the retailer's report about the demand distribution is accurate. Thus, even though the supply chain appears to be coordinated, the allocation of profit is a challenge. The general approach for contracting under asymmetric information is mechanism-design or principal-agent theory and for the supplier to offer a menu of contracts. In general, contracts in that menu do not satisfy the coordinating condition above, the channel does not achieve its maximum profit, and the retailer can earn a positive profit above his minimum requirement.

In this paper, we derive the menu of optimal (for the supplier) buyback contracts, comprising a wholesale price w, a buyback b and a lump-sum transfer T. These contracts satisfy arbitrary retailer's reservation profit requirements. In general our contracts do not satisfy Pasternack's coordinating condition. However, being optimal for the supplier, they do generate higher supplier's profits than the tradition optimal buyback contract would (or even a traditional buyback contract enhanced with an additional transfer payment term T). Furthermore, we show how in the limit (as w and b approach r) the menu of optimal contracts we derived allows the supplier to (almost) coordinate the channel and extract all the channel profit, leaving the retailer nothing but his minimum

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required profit. We explain this by showing that in the limit (which is of course not practical) the supplier essentially buys the retailer's business. Our contribution is to offer the contract menu which is optimal for the supplier, regardless how far away from the limit the practical business considerations allow her to be.

We model the retailer's private information as a space of either discrete or continuous demand states so that only the retailer knows its demand state and the demand for the product is stochastically increasing in the state. We focus on contracts that are viable in practice, so that the buyback price is strictly less than the wholesale price, which is itself strictly less than the retail price. We allow arbitrary reservation profits for the retailer.

A fundamental problem of the supplier designing contracts when the retailer has private information has recently attracted attention among researchers. For example, Arya and Mittendorf (2004) consider a supplier–retailer channel where the retailer holds private information about the value that final customers put on the product. In this setting, they consider a supplier who uses a return policy added to a quantity and transfer price contract to elicit retailer's information. While the resulting contract can improve supplier's profitability, it cannot eliminate the information rent the supplier has to pay, nor can it achieve the first-best solution for the channel.

There is a broader supply chain literature studying contracting problems with asymmetric information under settings different from ours. These problems can in general be classified into two categories: screening problems where the uninformed party offers contracts to the informed to induce information revelation, and signaling problems in which the informed party offers contracts to the uninformed to signal the true information. Our work here belongs to the first category. Also, under this category, Corbett and deGroote (2000), Corbett (2001), Corbett and Tang (1999), and Ha (2001) consider supplier–retailer channels where one party holds private information about his costs (e.g., inventory ordering or holding costs). Yang et al. (2008, 2009) consider screening models where the asymmetric information is about supplier's risk. Yang et al. (2009) study how backup production options of the buyer and the supplier perform in the presence of such asymmetric information. Yang et al. (2008) consider the model with two suppliers and study another risk-management tool: diversification. For more on asymmetric information models about supply risk (see Aydin et al., 2009). Xu et al. (2010) consider model with asymmetric information about the backup supplier's cost and characterize optimal lead-time plus transfer payment contracts. Burnetas et al. (2007) study quantity discount contracts for a supplier to induce retailer's demand information, while Porteus and Whang (1999) consider minimum order quantity requirement contracts. None of these papers, however, identifies contract that allows a supplier or the uninformed party to extract the first-best channel profit. In contrast, Cakanyildirim et al. (2006) present conditions on reservation utilities of the suppliers that ensure coordination in the model with the asymmetric information about supplier costs. Lau and Lau (2001) propose models where the retailer has private information about the market and study them for uniform and normal demands. Chambers and Snir (2007) consider a supplier selling to a newsvendor retailer with private information about demand distribution. They show that with certain restriction on the demand distribution, the supplier can optimally offer a single wholesale price contract with a buy-back policy; such a contract coordinates the channel but does not allow the supplier to extract all the channel profit. Li et al. (2009) study a setting similar to the one in this paper but focus on valuation of forward and options contracts. Gan et al. (2010) also endow the retailer with better demand information and propose the optimal for the supplier menu of commitment-penalty contracts in drop-shipping supply chains. For the category of signaling problems, Cachon and Lariviere (2001), and Ozer and Wei (2006) study channels where an informed manufacturer (retailer) offers contracts to her supplier to secure production capacity. Liu and Ozer (2010) investigate whether price-only, quantity flexibility, and buyback contracts induce information sharing between the retailer and the supplier.

The main innovation of our work is to investigate contracts that combine wholesale pricing commitments, transfer payments, and return option features, simultaneously, in such a way so that the less informed party can extract information as efficiently as possible. We also examine the conditions that are necessary to extract this information at essentially zero cost. Most contracting relationships in supply chains have focused on two of these three features. And in the absence of information asymmetry this has proved fruitful. For example, two-part tariff contracts have a commitment price and a fixed transfer fee with no option features. Buyback contracts typically have fixed wholesale prices with put options allowing the retailer to return unsold goods, but there is no fixed transfer fee. Several other policies have been investigated that provide retailers with flexibility for managing demand using call options, for example, that allows the retailer to order more quantities at predetermined prices, after demand has materialized, but typically these policies have not involved transfer payments as well. Our policies involve all three components. Our results indicate that these types of contracting relationships should be found in supply chains where there are large asymmetries of information, uncertainty in demand, and where the less informed supplier has significant market power, and can offer menus of choices to retailers who possess superior information.

The paper proceeds as follows. In Section 2 we establish our basic model where there are two possible types of retailer and demonstrate how the information rent and loss in system efficiency can simultaneously be made arbitrarily small. The implications of this policy are explored. We demonstrate that the traditional buyback contracts are inferior and how in the limit our solution results in the coordinated supply chain. In Section 3, we consider a continuum of types of retailers, and show that the three parameter policies are still viable policies for the supplier to extract the full benefits of the supply chain and attain the first-best solution. Section 4 summarizes the findings and offers indications of the types of supply chains where these policies are most likely to be found useful.

2. A model with two demand states

Consider a supplier who produces a product at a constant unit cost of c dollars, and contracts with a retailer for selling the product to the market. The retailer, as a price-taker, sells the product at a constant price for r dollars per unit. As we discuss below, to focus on the essential model features, we assume that the salvage value and the shortage penalty are zero.

Market demand for the product is uncertain and, depending on the market condition, can occur in two states: a low state L and a high state H. In particular, in the low state of the market, demand follows a probability distribution of $F_L(x)$ for $x \geqslant 0$. Demand in high state is *stochastically higher* than that in the low state, such that $F_L(x) \geqslant F_H(x)$ for all $x \geqslant 0$. Let $f_i(x)$ denote the density function of $F_i(x)$, for $i = L, H$.

Being closer to the market and having direct contacts with consumers, the retailer has a better knowledge about the market condition than the supplier. Specifically, the retailer knows for sure which of the two demand states will occur, while the supplier has only a subjective assessment about the likelihood of the two states. Let p be the probability that the supplier believes that the demand is in low state, and let $(1 - p)$ be the probability that the demand is in the high state.