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Decision Support

Range contracts: Risk sharing and beyond

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ABSTRACT

We introduce and study the *range* contract, which allows a buyer to procure from a supplier at a prescribed price any amount within a specified range. In return, the supplier is compensated up front for the width of the range with a *range fee*. This fee can be viewed as the buyer trading monetary value for reduced uncertainty. The range contract generalizes and unifies many common contracts, such as fixed-price, JIT, option, and quantity-flexibility contracts. The parameters that maximize the expected profit of the centralized supply chain are derived here and are shown to crucially depend on production flexibility. We also study here the buyer's expected profit-maximizing range endpoints as a function of the pricing parameters of the contract. Using the buyer's optimal range, we demonstrate how the supplier can set the contract's pricing parameters so as to maximize the supplier's expected profit for a uniform distribution of demand. We provide computational evidence, for uniformly distributed demand, that the range contract allows the optimal decentralized supply chain to attain significant reductions in standard deviation of profit in exchange for moderate reductions in expected value of profit. We further demonstrate computationally that both the buyer and supplier can benefit simultaneously, attaining higher risk-adjusted profits than the centralized supply chain.

1. Introduction

We introduce the *range* contract, which allows a buyer and supplier to share demand risk in a new way. In a range contract a range is available to the buyer who can order any quantity in the range, but pays in advance for the flexibility offered, as measured by the width of the range interval. The width of the range and the payment for it compensates the supplier for her flexibility. Many common contracts, such as fixed-price, just-in-time, option, quantity-flexibility as well as combinations of contracts (e.g., pairing of fixed-price and option contracts) can be cast as range contracts. However, the range contract has properties that are not apparent in the other contracts.

A unique characteristic of the range contract is that, despite risk-neutral firm decision making, risk reduction properties are achieved. We provide computational evidence, for uniformly distributed demand, that the range contract allows the optimal decentralized supply chain to attain significant reductions in standard deviation of profit in exchange for moderate reductions in expected value of profit. For example, a decentralized supply chain can attain 94.5 percent of the centralized supply chain's expected profit, yet only 80 percent of its standard deviation of profit. We utilize the notion of an *optimal risk-adjusted profit*, which is the maximized expected profit of a firm divided by its corresponding standard deviation. We demonstrate that the range contract makes it possible that both the supplier and buyer have higher optimal risk-adjusted profits than the centralized supply chain. Therefore, the range contract allows a "win-win" situation where both firms benefit from decentralization. Since the centralized supply chain can always mimic a decentralized supply chain, a managerial implication of this computational evidence is that the range contract can be used by those centralized supply chains where the reduction of risk is a priority.

The form of the range contract proposed here is motivated by a prevalent high-tech market environment characterized by inflexible production and short-lifecycle products. Due to the short lifecycles, demand learning is difficult, resulting in poor quality forecasts with substantial variability. Inflexible production diminishes a manufacturer's (buyer's) ability to respond to demand surprises, resulting in lost sales and loss of any first mover advantage.

Range contracts are especially relevant to the semiconductor industry, where capacity is expensive and excess capacity is a luxury. The range contract is a generalization of an option contract, and option contracts have been applied successfully in the semiconductor industry. For example, a recent Bloomberg Businessweek article, King (2012) reported that Intel has saved $125 million during 2008–2012 due to option contracts. As another example, according to executives at AMD's Memory Group, "supply agreements are important to chip makers because they guarantee that the billions of dollars invested

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in new production facilities will actually be used." (Associated Press 2001). Range contracts can be interpreted as the next generation of option contracts in this industry. Therefore, the motivation to apply range contracts is already present at supplier and buyer firms in high technology industries.

Related industries, where capacity is expensive and limited, can also benefit from the range contract, especially in the context of new products with volatile demand. For example, Apple experienced a shortage of screens for the iPod Touch shortly after launching the product in autumn 2007. In this case, the manufacturer did not anticipate the enthusiastic response to the product and did not contract for a sufficient quantity of touch-screens. To make matters worse, there were no alternative suppliers that had production capacity and could provide the additional units, regardless of the price. Consequently, Apple experienced substantial backlogs, likely loss of goodwill, and loss of sales (although made up since then). In this case, the manufacturer absorbed the total risk of the demand variability, with severe repercussions. In February 2010 it appeared that for its new iPad, Apple had contracted for all the available supplies of 9.7 inch screens, creating a shortage of such screens in the market for its competitors, as reported by another Bloomberg Businessweek article (Guglielmo & Hesseldahl, 2010).

The range contract studied here originated in the first author's consulting project for a large server manufacturer in Silicon Valley. That manufacturer (buyer) procured supplies from semiconductor manufacturers for products with short lifecycles and a high obsolescence rate. This manufacturer historically utilized fixed-price contracts, on a quarterly basis, which resulted in component shortages and lost sales. For products that turned out to be successful, these shortages resulted in a loss of momentum in the product introduction, resulting in a loss of any first-mover advantage. In many of these cases, contractual reservation of extra capacity compensating suppliers for their flexibility, would have resulted in the suppliers providing the additional components required to meet the extra demand.

1.1. Comparison to contracts in related literature

There have been many extensions of the basic price-only contract, which include: multiple selling seasons (Anupindi & Bassok, 1998), effort-dependent demand (Corbett & DeCroix, 2001), demand updating (Cachon & Lariviere, 2005), and competing manufacturers (Cachon & Kok, 2010), to name just a few. What we are proposing is a different generalization of the price-only contract, in which the demand support is split between the buyer and supplier. The issue of the risk associated with price-only contracts has been noted and addressed in research on contracts. Tsay, Nahmias, and Agrawal (1999) and Cachon (2003) provide good reviews of the literature on supply chain coordination with contracts.

The paper most relevant to ours is Cachon and Lariviere (2001), which studies a similar contract, which consists of a combination of firm order commitments and options for subsequent orders. However, they consider an environment with capacitated production with a single unit cost, whereas we allow cheap and expensive modes of production. Furthermore, the focus of Cachon and Lariviere (2001) is heavily on compliance, whereas we focus on quantifying the risk reduction properties of our contract (despite the firms taking a risk-neutral perspective). A study of option contracts in the semiconductor industry can be found in Brown and Lee (1997), and an analysis of a spot market's influence on option contracts can be found in Wu, Kleindorfer, and Zhang (2002). Recall that option contracts are a special case of range contracts (see Section 1.3).

Tsay (1999) studies a *quantity flexibility contract*, generalized by the range contract, where the buyer's final order quantity must be within a given percentage of an initial forecast. Bassok and Anupindi (1997) consider a different generalization of the quantity flexibility contract that specifies that cumulative orders placed over multiple periods by a buyer be at least as large as a given contracted quantity; in return for the commitment by the buyer, the supplier discounts the unit purchase price and this discount applies to all units purchased, with no upper bound on the order quantity. More complex variations on quantity flexibility contracts are considered by Tsay and Lovejoy (1999) and by Plambeck and Taylor (2007).

There are only a few other models that present some form of risk sharing. In addition to the basic quantity flexible contract, there are the *buy-back contract* and the *revenue-sharing contract*. In a buy-back contract, the supplier charges the buyer a fixed amount per unit purchased, but makes a (lower) per-unit payment to the buyer for each unit remaining at the end of the season; if the supplier's net salvage value is less than the buyer's net salvage value, the buyer salvages the units and the supplier credits the buyer for those units. See Pasternack (1985) and Cachon (2003) for further details. In a revenue-sharing contract, the supplier charges a fixed amount per unit purchased by the buyer, but the buyer gives the supplier a percentage of his revenue; see Cachon and Lariviere (2005) for further details. Cachon (2003) points out that, in their basic form, revenue-sharing contracts are essentially equivalent to buy-back contracts. In these contracts, the supplier ends up producing a *fixed* amount, and then *monetary* compensation substitutes for risk sharing. In contrast, under the generic *range contracts* proposed here, the supplier is required to face actual demand variability.

The range contract that we propose, like the quantity-flexibility contract, has the feature that the supplier is compensated for her increased exposure to demand risk. Tsay et al. (1999) point out that with (other types of) quantity flexible contracts, "this exercise of flexibility implies reconsideration of a prior decision, even the simplest model requires at least two decisions on the part of the buyer for each purchase: there is an initial inventory decision, and then revisions conditional on whatever new information about demand becomes available." In contrast, an additional novelty about the range contract is that it does not require a reconsideration of the decision—the buyer and supplier make a decision only *once*.

Other authors have considered contracts over multiple periods. Bassok and Anupindi (2008) study the problem of procurement using a flexible contract in a rolling horizon model. They formulate the problem and propose two heuristic policies, derive a lower bound, and demonstrate the performance of these heuristics numerically. Ross and Zhu (2008) study the procurement policy for a non-storable product (e.g. electricity) using a flexible contract in which the purchase quantity in each period must be within some predefined range. They formulate the objective value as the total of gains and losses between the contract price and the spot price. The structure of a swing contract's optimal value is then studied. A contract form between a buyer and a supplier with a total order quantity commitment over a multiple-period horizon is studied in Chen and Krass (2001). Under the contract the buyer agrees to procure a certain total quantity over the predetermined period of time. Extra quantity could be purchased at a different price. Dynamic considerations and inventory issues are beyond the scope of our paper and could form the basis of an extension study of the range contract.

1.2. The structure of the range contract

We model the demand D as a continuous random variable with distribution F, with mean and standard deviation equal to μ and σ, respectively. We assume that the support of the demand distribution is $[\ell, u]$, where $0 \leq \ell \leq u$. The interaction between the supplier and buyer follows a Stackelberg game, a common modeling technique in the contracting literature (see, for example, the large variety of contract analyses in the survey of Cachon, 2003). Indeed, most contracts, including fixed-price, buy-back, quantity-flexibility, quantity-discount, and sales-rebate, have the supplier proposing the contract's pricing parameters and the buyer choosing the order quantities.