Interfaces with Other Disciplines

First- and second-price sealed-bid auctions applied to push and pull supply contracts

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ABSTRACT

We investigate a newsvendor-type retailer sourcing problem under demand uncertainty who has the option to source from multiple suppliers. The suppliers' manufacturing costs are private information. A widely used mechanism to find the least costly supplier under asymmetric information is to use a sealed-bid reverse auction. We compare the combinations of different simple auction formats (first- and second-price) and risk sharing supply contracts (push and pull) under full contract compliance, both for risk-neutral and risk-averse retailer and suppliers. We show the superiority of a first-price push auction for a risk-neutral retailer. However, only the pull contracts lead to supply chain coordination. If the retailer is sufficiently risk-averse, the pull is preferred over the push contract. If suppliers are risk-averse, the first-price push auction remains the choice for the retailer. Numerical examples illustrate the allocation of benefits between the retailer and the (winning) supplier for different number of bidders, demand uncertainty, cost uncertainty, and degree of risk-aversion.

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1. Introduction

Over the past decades there has been a trend towards outsourcing the production of goods and services. For example, manufacturers in the automotive industry spent an average of 65% of their costs on goods and services from external suppliers. In order to minimize procurement costs, many companies purchase via reverse auctions and use online bidding systems. The Volkswagen Group, for instance, has a purchase volume of over 75.4 billion Euro and has been using electronic reverse auctions as one standard tool in global procurement since 2003 (Sanz, Semmler, & Walther, 2007). Due to the high amount of transaction volumes traded through reverse auctions, their design is critical and poses important challenges. In comparison to traditional purchasing methods, reverse auctions allow for high cost savings when used correctly (Tunca & Wu, 2009).

Current business practice shows that fixed quantity procurement auctions are predominately used, even though they are not always optimal, especially under demand uncertainty. There exist many practical auction examples where demand can be adjusted after the price has been determined (Li & Scheller-Wolf, 2011; McAdams, 2007) and flexible auctions receive increasing attention. For example, taking the newsvendor as the simplest single-product

problem under demand uncertainty, the optimal order quantity for a retailer (buyer) depends on the purchasing price and it is not appropriate for treating these procurement problems as simple single-unit auctions. It has already been shown that abandoning fixed quantity auctions and allowing the possibility of adjusting quantities after procurement prices are known results in lower purchasing prices (Hansen, 1988) and enables higher profits for the purchasing company (McAdams, 2007). However, allowing to adjust quantities after observing prices makes the computation of optimal bidding strategies more complex.

Although there are many possibilities for allocating demand risk within a supply chain, the two extremes of push and pull contracts are simple and easy to implement. Because their only parameter is the wholesale price, they find higher acceptance in practice than complex multi-attribute auctions (Elmaghraby, 2007; Li & Scheller-Wolf, 2011). Under a push contract, the retailer has to decide about the purchasing quantity before demand is known and the manufacturer produces the order quantity. The retailer bears all the risk of ordering too many or too few. Under a pull contract, the retailer postpones the order until demand is known. In this case, the supplier bears all the demand risk and must produce or build capacity when demand is still uncertain (e.g. Cachon, 2004). If the retailer or the suppliers are risk-averse, there is an additional benefit from using push or pull contracts as an effective instrument to shift demand risk within the supply chain.

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We analyze and compare simple auction and contract formats in a newsvendor sourcing problem under information asymmetry about the suppliers' manufacturing cost and flexible order quantities. We therefore evaluate the allocation of profits from the retailer's, the suppliers', and the entire supply chain's perspective. The options considered for auction design are the two most prominent first- and second-price auctions. For contract design, we limit the choice to simple pure push and pull contracts. We extend the work of Li and Scheller-Wolf (2011) by (1) additionally including first-price auctions, (2) enforcing supply contract compliance by introducing a common outside procurement option, and (3) risk-averse decision makers either on the supply or retail side. We show the dominance of first-price auctions and clear preferences of a push contract under risk-neutrality and full contract compliance. Furthermore, the numerical results show the impact of competition (number of bidders), cost and demand uncertainty, and the degree of risk-aversion on supply chain efficiency and profit allocation in the supply chain through the investigated auction and contract formats. The contribution to the literature is therefore the application of known formats and results from auction theory to the supply contracting problems and enabling the comparison of different format-contract setups under risk-neutral and risk-averse decision making.

The remainder of this paper is organized as follows: We review the relevant literature in Section 2. Section 3 describes and analyzes the model in detail. The influence of risk aversion is discussed in Section 4. Section 5 presents an example with closed form solutions, followed by numerical studies in Section 6. Section 7 contains concluding remarks and suggestions for future research.

2. Literature review

Qin, Wang, Vakharia, Chen, and Seref (2011) provide a review of the newsvendor problem, including the issue of risk-aversion. Cachon (2003) provides a survey of supply contracts and coordination. Lariviere and Porteus (2001) analyze wholesale price contracts in the context of the newsvendor problem with a manufacturer selling to a retailer that faces uncertain demand. They show how market size and demand variability influence the optimal wholesale price set by the manufacturer. Cachon and Lariviere (2001) address the problem of information asymmetry about demand forecasts and study contracts that allow for sharing demand forecast credibly. Cachon (2004) compares push and pull contracts and proposes an advance-purchase discount where the risk of demand is shared by shifting the excess inventory risk from the supplier to the manufacturer. Contrary to the push and pull contracts, this advance-purchase discount allows to coordinate the supply chain and achieves an efficient production quantity. Comparing push and pull, Cachon shows that the pull contract leads to a higher efficiency than the push contract. Perakis and Roels (2007) compare push and pull contracts and characterize efficiency depending on various supply chain configurations such as different numbers of stages in the supply chain and the number of competing suppliers or competing retailers. They show that under a push contract more competition always leads to higher efficiency. However, in a pull contract more competition can also decrease supply chain efficiency.

While in simple single-unit auctions the format does not matter, a sealed-bid first-price auction leads to different profits in multi-unit auctions in comparison with a second-price auction or an open English auction. The retailer therefore has to choose the auction format wisely. Elmaghraby (2000), Elmaghraby (2007) and Pinker, Seidmann, and Vakrat (2003) provide comprehensive surveys about sourcing, online auctions and internet enabled marketplaces.

Dasgupta and Spulber (1990) study different procurement auctions for companies facing downward sloping demand curves. Chen (2007) enhances this model and derives general conditions for a firm's optimal auction mechanism that selects a supplier and determines the procurement quantity and corresponding payments. He proposes an auction where the retailer determines the optimal quantity-payment schedule. In order to be able to set up this optimal schedule, the retailer needs specific information concerning the cost distribution of the suppliers. As opposed to Chen (2007), we consider price-only auctions where the retailer does not need any specific information about the suppliers' cost distribution to select the optimal contract. Duenyas, Hu, and Beil (2013) provide an extension of Chen (2007) by studying a more simple auction. They show its optimality for ex-ante asymmetric suppliers and a class of non-linear production costs. Li and Scheller-Wolf (2011) compare different auction designs for a buyer facing uncertain demand using an open descending price-only auction format (English auction). Using an open auction format and letting the supplier determine the service level of supply, they show that intense competition in pull contracts can lead to lower retailer profits. To address this, they propose an enhanced pull contract that enables a certain service level and establish how characteristics of demand and supply influence the retailer's preferences between a push and an (enhanced) pull mechanism. The authors show that the retailer prefers a push mechanism if supplier competition is high and a pull mechanism if demand uncertainty or the supplier cost level is relatively high. In contrast to Li and Scheller-Wolf (2011), we consider sealed-bid auctions and thus are able to implement a first-price auction that leads to lower purchasing prices in push contracts than in an open auction format. By enforcing contract compliance using an outside option, rather than choosing a service level in pull contracts, we can establish that more competition between suppliers always leads to higher expected retailer profits.

Hansen (1988) considers the impact of endogenous quantities in procurement auctions under deterministic, price-sensitive demand. He shows that the auctioneer always prefers a first-price to a second-price auction and that the first-price dominates the second-price auction from the perspective of the total surplus of the considered economy as well. Milgrom (1989) also discusses this model and shows the same results by using the envelope theorem. Spulber (1995) and Lofaro (2002) analyze a similar framework for Bertrand competition where the rivals costs are unknown. Further, Ausubel and Cramton (2002) show how inefficiency occurs under multi-unit forward auctions if large bidders have an influence on the price under a uniform price auction. They show that efficiency and revenue rankings of the uniform-price and pay-as-bid auctions are inherently ambiguous. In some situations, the pay-as-bid auction leads to an efficient outcome while the uniform-price auction does not and vice versa.

For a risk-averse newsvendor, Cachon (2003) provides an overview of the literature. Eeckhoudt, Gollier, and Schlesinger (1995) determine comparative-static effects for changes in price and cost parameters. They further study the effect of an increase of the newsvendor's riskiness or the addition of background risks. Agrawal and Seshadri (2000) study the role of intermediaries offering the possibility of emergency orders and buy-back options in supply chains with risk-averse retailers and Gan, Sethi, and Yan (2004) study the coordination of supply chains with risk-averse agents. Keren and Pliskin (2006) set a benchmark by deriving a closed form solution of the risk-averse newsvendor for a special case of uniform demand. Wang, Webster, and Suresh (2009) provide insights on how selling prices influence the risk-averse newsvendor and thus investigate some limitations of the expected utility theory.

We follow the common modeling philosophy in supply chain management to analyze a stand-alone newsvendor. This restrictive