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Contract designing for a supply chain with uncertain information based on confidence level

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ABSTRACT

We consider a contract-design problem for two competing heterogeneous suppliers working with a common retailer. The retailer's type – low-volume or high-volume – is unknown to the suppliers. One supplier has a high variable cost and a low fixed cost, whereas the other has a low variable cost and a high fixed cost, and their variable costs are uncertain. They sell the same products to the retailer, and each supplier offers the retailer a menu of contracts. The retailer chooses the contract that maximizes her alternative profit based on her confidence level instead of her expected profit. In this setting, we find that the retailer's optimal order quantity is determined by the inverse distribution of the external demand and the confidence level. Furthermore, higher confidence levels correlate with lower order quantities. We also show that the equilibrium contract menus depend on the magnitudes of the confidence level and the high fixed cost. Importantly, if the confidence level of the supply chain tends to be 0 or 1, the supplier with the low fixed cost possesses a competitive advantage over the other supplier. In some cases, the supplier with the low fixed cost may choose not to serve the high-volume retailer to avoid excessive information rent.

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1. Introduction

Contract-design theory has been successfully and widely applied in various types of supply chains in which information asymmetry exists related to, for example, production costs or external demands, which are uncertain and unobservable to one supply chain entity. The existing literature depicts the information asymmetry in supply chain problems using random variables. For example, Babich et al. [1] and Li et al. [2] assume the external demand is stochastic with the corresponding distribution. However, in some supply chain problems, no observed data regarding the information asymmetry, such as the demand for a new product, which cannot be exactly predicted in advance, may exist. Indeed, people can only give their subjective assumptions regarding this type of information. Thus, probability theory is no longer applicable for characterizing this type of information asymmetry. In addition, almost all work on contract-design problems considers the participant's goal to be the conventional expected utility maximization. However, Ellsberg [3] shows that this expectation cannot always be regarded as the individuals' decision rule. Motivated by these reasons, this paper investigates how the information asymmetry can

be characterized by uncertainty theory, which is an essential tool to handle subjective assumptions about unknown information in supply chain problems, and presents another alternative decision rule based on confidence level. The confidence level is the degree of belief in a successful result and can be represented as a percentage. This value reflects the individual's attitude to risk during a decision-making process: Higher confidence levels indicate that the successful result is more believable and, thus, that the individual is more risk-averse. Conversely, smaller confidence levels imply that the individual is more risk-loving and able to bear more potential risk. Specifically, when the confidence level is 1, the individual is completely risk-averse, whereas when the confidence level is 0, the individual is completely risk-loving. Thus, to depict the two participants' risks in supply chain problems, we maximize their profits based on their confidence level instead of their expected profits and build the corresponding model from the perspective of chance. The following questions are posed: How can we obtain the analytical solutions of the model? How does the confidence level affect the two participants' decisions? Where is the equilibrium between information symmetry and asymmetry?

To address these questions, we study a contract-design model for a supply chain with uncertain information based on confidence level, in which the two heterogeneous suppliers compete to sell the same products through a common retailer. One supplier has a high variable cost and a low fixed cost, whereas the other has a

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low variable cost and a high fixed cost. Each supplier designs a contract menu that is offered to the retailer. The retailer, who possesses private information regarding the external demand, which is uncertain, chooses just one of the contracts. The retailer can be either high-volume or low-volume. To induce the revelation of truthful information, the suppliers offer incentive contracts to overcome the hidden action and hidden information problem. First, we present a contract-design problem for a supply chain with full information (i.e., the suppliers know the retailer's type) using confidence level as the benchmark and obtain the optimal profit distribution decision and the "thresholds" distinguishing which supplier the retailer will choose. Then, we discuss the scenario with incomplete information (i.e., the suppliers do not know the retailer's type) based on confidence level, in which the suppliers offer new optimal incentive contracts with the aim of being chosen by the retailer. Finally, we investigate how the full and incomplete information equilibria results are affected by the confidence level and the high fixed cost. Moreover, we compare the differences in the suppliers' contract-design decisions and the retailer's choices under the full and incomplete information conditions.

Our results demonstrate that the equilibrium contract menus depend on the magnitudes of the high fixed cost and confidence level. When the confidence level of the supply chain is equal to 0 or 1, i.e., the supply chain is completely risk-loving or completely risk-averse, the supplier with the low fixed cost acts as a monopolist. Moreover, if the confidence level of the supply chain tends to be 0 or 1, the supplier with the low fixed cost has a competitive advantage over the supplier with the high fixed cost. Conversely, if the confidence level of the supply chain is moderate (e.g., tends to 0.5), the two suppliers have individual advantages. In these cases, when the confidence level of the supply chain is given, the equilibrium contract menus depend on the magnitude of the high fixed cost. Additionally, the supplier with the low fixed cost has a competitive advantage over the supplier with the high fixed cost when the high fixed cost increases. In other words, the supplier with the low fixed cost will be more readily selected by the retailer when the high fixed cost increases. In contrast, the supplier with the high fixed cost will more likely be selected by the retailer when his fixed cost is smaller. By comparing the full and incomplete information equilibria, we find that the supplier with the high variable cost will be chosen by the retailer in some cases but must pay information rent to the retailer under the incomplete information scenario. However, in some other cases, the supplier with the small fixed cost may choose not to serve a high-volume retailer to avoid excessive information rent. Furthermore, we note that the optimal order quantity of the retailer is determined by the inverse distribution of the external demand and the confidence level: the higher the confidence level is, the lower the order quantity is.

The rest of the paper is organized as follows. In Section 2, we review the literature relevant to our study. In Section 3, we recall some fundamental concepts and formulas regarding uncertainty theory. In Section 4, we describe and build the model. In Section 5, we give the full information equilibrium and perform a numerical analysis. In Section 6, we give the incomplete information equilibrium and compare the full information and incomplete information equilibria for using consistent retailer confidence levels. In Section 7, we conduct some extensions. In Section 8, we conclude the paper.

2. Literature review

This paper draws on two streams of literature: the literature on contract-design problems with uncertain information and market competition and that based on uncertainty theory.

The relevant literature addressing contract design for a supply chain investigates explicit modeling under information asymmetry and can be divided into two lines of research: one focusing on information asymmetry in production cost (Corbett et al. [4] and Ha [5]) and the other focusing on information asymmetry in market demand (Cachon et al. [6], Ozer et al. [7], and Gan et al. [8]). Within each line, either the informed member discloses the private information in a credible way or the uninformed member provides incentive contracts to induce the revelation of true information (Fudenberg et al. [9] and Chen [10]). However, all of these works apply probability theory to handle uncertain information, and most focus on a setting involving one supplier and one retailer without market competition. In our article, we use uncertainty theory to investigate a supply chain problem with two competing heterogeneous suppliers working with a common retailer.

Our study is also related to the literature on the competition between retailers or suppliers, in which many scholars have researched the competition model for commodity procurement. For example, Wu et al. [11] study a procurement problem with option contracts in a setting consisting of one buyer and n competitive sellers. Martinez et al. [12] build a multi-attribute competitive model for electricity procurement. Fu et al. [13] provide a portfolio method to process the procurement contracts between a buyer and n competing sellers. Giri et al. [14] consider a two-echelon supply chain that consists of one manufacturer and two competing retailers with advertising cost-dependent demand. The manufacturer operates as the Stackelberg leader, determining the wholesale price for each retailer. The two retailers then compete with each other in advertising and have different sales costs. Glock et al. [15] study a single-vendor-multi-retailer supply chain and consider the case in which the vendor merges with one of its retailers. After the merger, the vendor supplies products to the market through both a direct (integrated) sales channel and the remaining retailers. However, all of these researchers assume that the sellers and the buyer possess symmetric information about the market, and typically, the contract parameters are given. In this paper, we focus on the competition between two suppliers under information asymmetric regarding the external demand and employ a screening model to examine the contracting problem for a wholesale price contract.

Several papers have addressed uncertain information and market competition simultaneously in contract-design problems. Some of the similarities and differences between the literature and our paper are given below.

Ozer et al. [16] examine a supply chain with two suppliers competing over a contract to supply components to a manufacturer. One of the suppliers is a large company for whom the manufacturer's business constitutes a small part of his total business. The other supplier is a small company for whom the manufacturer's business constitutes a large portion of his total business. They analyze the problem from the perspective of the large supplier, whose objective is to win the contract with the manufacturer instead of his small supplier rival. The authors find that the buyer benefits when the small supplier's variable cost is known, whereas the large supplier benefits when the small supplier keeps its production cost private. In their paper, Ozer et al. [16] suppose that the large supplier has incomplete information on the small supplier's production cost. In contrast, we suppose that both suppliers have incomplete information on the retailer's type, and we find that full information always benefits the suppliers. Conversely, incomplete information is good for the retailer in most cases and for the suppliers in some cases. Furthermore, Ozer et al. [16] show that the buyer always chooses to contract with the large supplier because the large supplier is supposed to have a cost advantage over the small supplier. However, we provide a fixed cost for the large supplier, ensuring that neither supplier has a cost advantage for either retailer type. We find that

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