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Decision Support

Quality investment and price decision in a risk-averse supply chain

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ABSTRACT

In this paper, we investigate quality investment and price decision of a make-to-order (MTO) supply chain with uncertain demand in international trade. Due to volatility of orders from buyers, the supplier and the manufacturer in the supply chain are subject to financial risk. In contrast to the general assumption that players in a supply chain are risk neutral in quality investment and price decision, we consider the risk-averse behavior of the players in three different supply chain strategies: Vertical Integration (VI), Manufacturer's Stackelberg (MS) and Supplier's Stackelberg (SS). The study shows that both supply chain strategy and risk-averse behavior have significant impacts on quality investment and pricing. Compared to a risk-neutral supply chain, a risk-averse supply chain has lower, same and higher quality of products in VI, MS and SS, respectively. Also, we derive the conditions under which the supply chain strategy is implemented in a decentralized setting. A numerical study is used to illustrate some related issues.

1. Introduction

In recent years, rapid increase of China's share in global trade has been a significant feature of international trade. In the backdrop of globalization of trade, benefiting from its low labor cost, China has become one of the world's primary manufacturing centers. A typical trade scenario is that supplier-manufacturer supply chains in China produce goods according to orders placed by buyers from around the world.

Compared with make to stock, make to order might be a pattern with lower cost but higher variability (Grosfeld-Nir et al., 2000; Rajagopalan, 2002; Gunasekaran and Ngai, 2009). Based on China's Customs Express data, due to the changes in economic and business conditions, orders from buyers are seen to be fluctuant. In particular, many small-and-medium-sized manufacturers catering to overseas buyers have closed down due to a reduction in orders following the global financial crisis in 2008.

Supply chain quality is a key component in achieving a competitive advantage, and quality management practices are significantly correlated with players' strategies which influence tangible business results, and customer satisfaction levels (Lin et al., 2005). Although higher quality can be a reason for higher price, it can also cause higher costs. At the same time, quality and price influence demand and profits (Banker et al., 1998; Baiman et al., 2000). As a consequence, quality investment and price decision are important for players in a supply chain.

Enlightened by the procurement process of Wal-Mart, we investigate quality investment and price decision of a make-to-order (MTO) supply chain where quality of products is mainly decided by that of raw materials or spare parts provided by the supplier. The examples include automobile, electronic appliances assembly industries and food processing industries such as vegetables, fruits, milk and meat. During the course of procurement, the manager from Wal-Mart checks samples of products provided by the manufacturer. If the product is acceptable, considering market demand, the manager places an order on the basis of quality and price of products (Wal-mart, 2009). Usually, the order is stochastic because of volatility of market demand. Then, the manufacturer organizes production along with its suppliers with respect to the order.

As raw materials are usually processed into products not by a single firm but by firms throughout a supply chain, the quality of a manufacturer's products depends not only on its own process quality but also on the quality of its suppliers (Robinson and Malhotra, 2005; Hwang et al., 2006; Foster, 2008; Hsieh and Liu, 2010). For simplicity of analysis, we consider the case that quality of products is decided by the raw materials provided by the supplier in this study.

The quality problem has received intensive attention. Forker (1997) linked quality management with process optimization to address both effectiveness and efficiency concerns. The study suggested that system performance was affected by transaction-specific investments in coordination. Reyniers and Tapiero (1995) modeled the effect of price rebates and after-sales warranty costs on the choice of quality by a supplier, inspection policy of a manufacturer, and the resulting end product quality. They explored

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both non-cooperative and cooperative settings in quality management. Xu (2009) studied a joint pricing and product quality decision problem in a distribution channel, in which a manufacturer sells a product through a retailer. The manufacturer determines both wholesale price and quality of the product, while the retailer determines the retail price. The investigation showed that marginal revenue function is closely related to the distribution channel structure.

The paper closest to ours is Zhu et al. (2007), which considered a buyer who designed a product and owned the brand, and yet outsourced production to a supplier. Both the buyer and the supplier incurred quality-related costs. They explored the roles of different parties in a supply chain in quality improvement, and showed that the buyer's involvement could have a significant impact on profits of both parties and of the supply chain as a whole. Different from the supplier–buyer chain in Zhu et al. (2007), we investigate an MTO supplier-manufacturer chain which provides products for a buyer with uncertain demand. Instead of the design accomplished by the buyer in Zhu et al. (2007), we consider the case of both design and conformance quality characteristics decided by the supplier in the MTO supply chain in this study. Volatility of orders from the buyer leads to the financial risk of the players. Zhu et al. (2007) did not consider volatility of orders or risk-averse behavior of the players in the supply chain.

Just like the definition of quality in Banker et al. (1998), we use the term "quality" to refer to both design and conformance quality characteristics of interest to the consumer when evaluating the product offered by the supply chain. Before and after orders are placed, quality of raw materials and price of the product are set by the supplier and the manufacturer, respectively, and production takes place.

Due to volatility of orders, the supplier and the manufacturer in the supply chain are subject to financial risk. In contrast to the general assumption that players in a supply chain are risk neutral in quality and price decisions, we consider risk tolerance of players. The supplier and the manufacturer determine respective quality and price of products. Thus, the question that may arise is what is the impact of players' risk tolerance level on quality, price, demand and profits? How to measure the utility of risk-averse players? Do supply chain strategies affect quality and price? Which supply chain strategy leads to the highest quality or price of products?

On the basis of the preference theory, we use a certainty equivalent to represent the utility of an individual. For different supply chain strategies, including Vertical Integration (VI), Manufacturer's Stackelberg (MS) and Supplier's Stackelberg (SS), we model utilities of players and analyze impacts of supply chain strategy and risk tolerance on quality investment and price decision. Moreover, we derive the conditions under which the supply chain strategy is implemented in a decentralized setting.

The remainder of this paper is organized as follows. The problem is described in the next section. On the basis of the preference theory, we obtain utilities of players and analyze quality investment and price decision in supply chain strategy VI in Section 3. In Section 4, we consider MS and SS supply chain strategies. A numerical study is used to illustrate some related issues with some discussion of the results in Section 5, followed by a conclusion and suggestions for possible future research in the last section.

2. Description of the problem

We consider quality investment and price decision of a supply chain which produces goods against specific orders placed by buyers from around the world. The orders are stochastic. Before orders are placed, quality of raw materials and prices of products are set by the supplier and the manufacturer, respectively. After orders are placed, the supply chain organizes production with respect to the orders. We consider quality and price decisions in different supply chain strategies: Vertical Integration (VI), Manufacturer's Stackelberg (MS) and Supplier's Stackelberg (SS). Below we present the assumptions on the problem.

Assumption 1. Buyers can recognize the quality of products provided by the supply chain. Different from common consumers, buyers usually have more professional expertise for procurement. Hence, they can know about the quality of products in detail.

Assumption 2. There is no moral hazard between the supplier and the manufacturer in an MTO supply chain. We use the term "quality" to refer to both design and conformance quality characteristics of interest to the consumer.

Notations used are presented in Table 1.

In this study, x_i and p_i are decision variables and other variables are exogenous variables, known to both players in the supply chain. In addition, we assume that $p_i > w + v_M$ and $w > v_S$. These inequalities ensure that each firm makes a positive profit.

Extending the demand function in Banker et al. (1998), we assume that the primary demand function for the products is decided by price p_i and quality x_i as follows:

$$D_i = a + \alpha x_i - \beta p_i, \tag{1}$$

where a is potential intrinsic demand, α is demand responsiveness to quality, and β is demand responsiveness to price. Furthermore, in order to capture the uncertainty in market demand resulting from changes in economic and business conditions, we assume that a is a random variable, as follows:

$$a = \bar{a} + \varepsilon. \tag{2}$$

Here $\bar{a}$ is the mean of the potential intrinsic demand and ε follows a normal distribution such that $E(\varepsilon) = 0, Var(\varepsilon) = \sigma^2$ (Yue and Liu, 2006; Tang, 2006). In an MTO scenario (Fig. 1), both the supplier and the manufacturer know the distribution of the demand and organize the production accordingly.

As the orders are stochastic, there is financial risk to players. Therefore, we should consider the risk attitude of the players towards quality investment and price decision. The preference theory provides the framework for incorporating the players' financial risk propensity into their decision process. The valuation measure we use is known in the preference theory as the certainty equivalent, which is defined as that certain value for an uncertain event which a player is just willing to accept (Raiffa, 1968; Holloway, 1979).

One form of the utility function dominant in both theoretical and applied work in areas of decision theory and finance is the exponential utility function. This is of the form $U(\prod) = -e^{-\prod/R}$, where R is the risk tolerance level, $\prod$ is profit, and e is the exponential constant. A value of $R < \infty$ implies risk-averse behavior. When R approaches ∞, risk-neutral behavior is implied

Table 1
Notations.

i	Supply chain strategy i, $i = VI, MS, SS$
x_i	Quality of raw materials
p_i	Price per unit of product
w	Wholesale price per unit of raw materials
v_M	Variable production cost per unit of the manufacturer
v_S	Variable production cost per unit of the supplier
c	Fixed cost related to quality
R_S	Risk tolerance level of the supplier
R_M	risk tolerance level of the manufacturer