

INFORMATION FORECAST IN A SUPPLY CHAIN WITH ELECTRONIC MARKET

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Abstract: This paper considers a supply chain consists with a risk-neutral supplier and a risk-averse manufacturer in the presence of electronic market. We study how superior demand-forecast information for the manufacturer affects the supplier's profit and strategy. Our study shows that if the profit margin is large for the manufacturer, the supplier will set a higher the wholesale price to a better-forecast manufacturer. We also find that if the correlation coefficient is zero, the forecast accuracy does not affect the supplier's profit. At last, we numerically study how the forecast accuracy affects the supplier's profit.

1 INTRODUCTION

Information technology has stimulated many business model innovations. Among them, the B2B electronic market is shown to be particularly powerful and enduring (Grey 2003). Thousands of B2B online exchanges have been opened on the Internet since the end of last century (e.g. e-Steel.com, ChemConnect; Turban et al. 2002). The kind of electronic market is widely used in the transactions of a variety of standardized commodities, such as commodity metal, chemical products, semiconductors, plastics, electrical power (Wu et al. 2002), and serves as a spot market providing the supply chain members new avenue to readjust their inventories.

Forecast accuracies on future demand and price obviously and directly influence the firms' planning processes and the supply chains decision making. Accurate forecasting can contribute to better inventory management and better price structuring. With the popularity of electronic markets, the manufacturer no only has to pay attention to the end customer demand uncertainty, but also has to concern the price volatility of the intermediate good.

Many papers study the direct effect of supply chain information sharing. This line of research includes Bourland et al. (1996), Chen (1998),

Gavirneni et al. (1999), Lee et al. (2000) and Cachon and Fisher (2000). However, these studies on supply chain information forecast have mainly considered the forecast on the demand uncertainty, and thus they do not analyze the effect of the spot price volatility.

In this paper, we will construct a supply chain in which one supplier contracts an intermediate good to one manufacturer, who uses the good to produce a product selling in the customer market. The supplier and the manufacturer negotiate a supply contract which specifies a transfer payment between them before the spot trading. After a period, the supplier and the manufacturer can trade the intermediate good in the electronic market. To deal with market uncertainties (including demand uncertainty and spot price volatility), the manufacturer (and the supplier) may invest in relevant software to create more accurate forecasts. This paper applies game theory to investigate the pricing strategies in the presence of electronic market. We investigate how the manufacturer's forecast accuracies on the demand affect the supplier's strategies and performance.

The rest of this paper is organized as follows. In section 2, we develop a mathematical model. In section 3, we analyze the effect of the manufacturer's forecast accuracy on the demand uncertainty, and provide some numerical examples

in section 4. Finally we offer some concluding remarks.

2 THE MODEL

Consider a decentralized supply chain consists of a risk-neutral supplier and a risk-averse manufacturer with a fully-liquid electronic market. The supplier sells an intermediate good via forward contract to the manufacturer, who use the good as one to one input to a product selling in the customer market with revenue p . The customer market faces a stochastic demand d . The supplier decides her wholesale price w to the manufacturer for the targeted period. In response to the offer, the manufacturer must decide the contracted quantity q . The contracted quantity is shipped to the manufacturer at the beginning of the period, and the supplier will sell her remaining production quantity (not ordered by the manufacturer) in the spot market with a stochastic spot price s . Besides contract procurement, the manufacturer can also purchase from the spot market during the targeted period. At the same time, he can sell his excessive inventory in the spot market. We assume that once the targeted period starts, the manufacturer cannot reorder from the supplier for this period. The interactions between the supplier and manufacturer form a Stackelberg game, in which the supplier is the leader and the manufacturer is the follower.

The customer demand d and the spot price s are typically positively correlated (Litzenberger and Rabinowitz. 1995, Seifert et al. 2004). That means that if the customer demand is high, the spot price usually goes up, and vice versa. For model tractability, we assume that d and s follow a bivariate normal distribution with a correlation coefficient $\rho \geq 0$, i.e. $(d,s) \sim BN[\mu_d, \mu_s, \sigma_d^2, \sigma_s^2, \rho]$.

Normal distribution assumption is commonly used in the literature, e.g., Seifert et al. (2004) and Van Mieghem (2007). To deal with a possible negative value, we further assume that the standard deviations of the normal random variables are relatively small compared to their means. In reality, the spot price and demand fluctuations in one period usually do not exceed a certain level.

Let π_s and π_m be the supplier's and the manufacturer's profits, respectively. Following to Seifert et al. (2004)'s model, the manufacturer's profit function is

$$\pi_m = pd - wq - s(d - q)^+ + s(q - d)^+$$

The supplier's profit includes the profits from the forward contract and the online spot market. We have

$$\pi_s = wq + s(Q - q),$$

where Q represents the supplier's capacity. More general model should include the production cost, which will not influence our analysis.

While seeking profit maximization, the manufacturer also needs to limit their risk exposures. In this paper, we explicitly incorporate the player's risk tolerances in the decision model. Let k measures his risk attitudes, and assume $k > 0$. Let $U_m = E[\pi_m] - kVar[\pi_m]$ be the manufacturer's utility. This mean-variance utility function has been widely used to characterize decision makers' risk-averse behaviors since the seminal work of Markowitz (1959), and has been widely adopted in recent operations management studies, e.g., Van Mieghem (2007).

Lemma 1 (Seifert et al. 2004).

If $(d, s) \sim BN[\mu_d, \mu_s, \sigma_d^2, \sigma_s^2, \rho]$, then

$$q^* = \mu_d + \frac{\mu_s - w}{2k\sigma_s^2} - \frac{\rho\sigma_d}{\sigma_s}(p - \mu_s)$$

Before the targeted period, the manufacturer observes a customer demand forecast $F = d + \varepsilon$, where $\varepsilon \sim N(0, \sigma_1)$. We assume that the forecast errors ε is independent of d and s . Since this paper mainly analyze the effect of forecast accuracy, we assume that the distributions of underlying customer demand d and the spot price s are fixed and only the level of noise in the manufacturer's forecast varies.

We denote $a \triangleq \sigma_1^2 / (\sigma_d^2 + \sigma_1^2)$ as the demand forecast accuracy of the manufacturer. The larger the value of a , the less accurate the manufacturer's forecast. In the limiting case where $a = 1$, the forecast contains no valuable information about demand and the posterior distribution is identical to the prior. In the opposite limiting case where $a = 0$, the forecast perfectly reveals the exact demand. For simplicity, we only focus our discussion to $a \in (0, 1)$.

To simply the following analysis, we denote $\bar{a} \triangleq 1 - a$, and define the demand conversion factor and price conversion factor as $\beta \triangleq \rho\sigma_s / \sigma_d$ and $\lambda \triangleq \rho\sigma_d / \sigma_s$, respectively. Then,

we have the following lemma.

Lemma 2. The posterior demand and spot price distributions under the forecast F still follow bivariate normal distributed, i.e.,

$$(d|F, s|F) \sim$$

$$BN[a\mu_d + \bar{a}F, \mu_s + \beta\bar{a}(F - \mu_d), a\sigma_d^2, (1 - \bar{a}\rho^2)\sigma_s^2, \rho_1].$$

where $\rho_1 = \rho\sqrt{a/(1 - \bar{a}\rho^2)}$.

Notice that the manufacturer's information acquisition upon the demand will also be used to update his conditional belief about the spot price. The posterior expectation on the spot price is linear function of the conditional variable F . The more accurate forecast on the demand uncertainty (smaller a), the larger the weight of $(F - \mu_d)$ in determining the posterior expectation of the spot price. And this effect is achieved through the conversion factor β . The posterior deviation of the spot price will become less if the manufacturer improves his forecast accuracy. We also find that $\rho_1 \leq \rho$ and increases in a .

3 MODEL ANALYSIS

In this section, we first present the manufacturer's best response to the supplier's decision. We then investigate the supplier's decision to derive the Stackelberg equilibrium. At last, we present some properties to describe the supplier's strategy and profit.

We denote $\gamma \triangleq p - \mu_s$ as the expected profit margin for the manufacturer, and assume $\gamma > 0$ since the price of the customer production should be more than the expected spot price of the intermediate good. Then, we obtain the manufacturer's best response function as follow.

Proposition 1. If the manufacturer only forecasts the demand, the optimal contract quantity for the manufacturer is

$$q^* = a\mu_d + \bar{a}F + \frac{\mu_s + \beta\bar{a}(F - \mu_d) - w}{2k\sigma_s^2(1 - \bar{a}\rho^2)} - \frac{a\lambda[\gamma - \beta\bar{a}(F - \mu_d)]}{1 - \bar{a}\rho^2}.$$

Anticipating the manufacturer's responses, the supplier chooses the wholesale price strategically to optimize her profit.

Proposition 2. If the manufacturer only forecasts on the demand, the equilibrium wholesale price are given by

$$w^* = \mu_s + k\sigma_s^2 [(1 - \bar{a}\rho^2)\mu_d - a\gamma\lambda]$$

Proposition 3. If the manufacturer only makes forecast on the demand and $\gamma > \beta\mu_d$, the wholesale price w^* always decreases in forecast accuracy a . Otherwise, w^* increases in a .

As the manufacturer's forecast accuracy improves (a decreases), it is optimal for the supplier to charge a higher wholesale price. This result is intuitive because when the manufacturer is very confident about his forecast, he will order a quantity that is close to his forecast regardless of the wholesale price.

The expected profit of the supplier is

$$E[\pi_s] = \mu_s Q + \frac{k\sigma_s^2 [(1 - \bar{a}\rho^2)\mu_d - a\gamma\lambda]}{2(1 - \bar{a}\rho^2)} - \rho\bar{a} \left[\sigma_d \sigma_s \left(1 + \frac{a\rho^2}{(1 - \bar{a}\rho^2)} \right) + \frac{\rho}{2k(1 - \bar{a}\rho^2)} \right].$$

Proposition 4. If $\rho = 0$, the manufacturer's forecast accuracy does not affect the supplier's profit.

4 NUMERICAL ILLUSTRATION

We use the following data: $\mu_s = 10, \mu_d = 100, \sigma_s = 2, \sigma_d = 20, \rho = 0.2, k = 0.01, Q = 150$

As the increase of a , the expected profit of the supplier will decrease for all value of σ_d as shown in Figure1. We also find that the larger value σ_d , the expected profit decreases more sharply.

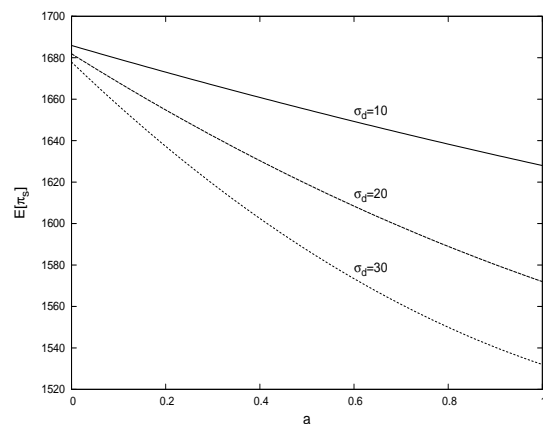


Figure 1: Effect on the Forecast Accuracy.

5 CONCLUSIONS

This paper investigates how superior demand-forecast information for the manufacturer affects the supplier's profit and strategy in the presence of electronic market. Our study reveals some important managerial insights. First of all, our study shows that if the profit margin is large for the manufacturer, the supplier will set a higher the wholesale price to a better-forecast manufacturer. We also find that if the correlation coefficient is zero, the forecast accuracy does not affect the supplier's profit. At last, we numerically study how the forecast accuracy affects the supplier's profit.

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REFERENCES

- Chen, F., 2003. Information sharing and supply chain coordination. S. Graves and T. De Kok, eds. *Handbooks in Operations Research and Management Science: Supply Chain Management*. North Holland, Amsterdam.
- Grey W., T. Olavson and D. Shi, 2005. The role of e-marketplaces in relationship-based supply chain: A survey. *IBM System Journal* 44, 109-123.
- Hausman, W. H., 1969. Sequential decision problems: a model to exploit existing forecasters. *Management Science*, 16(2), 93-111.
- Lee, H., V. K. So, C. Tang, 2000. The value of information sharing in a two-level supply chain. *Management Science*, 46(5), 626-643.
- Litzenberger, R. H., N. Rabinowitz, 1995. Backwardation in oil futures markets: theory and empirical evidence. *Journal of Finance*, 50(5), 1517-1545.
- Markowitz, H., 1959. *Portfolio Selection*. Wiley, New York.
- Raju, J., A. Roy, 2000. Market information and firm performance. *Management Science*, 46(8), 1075-1084.
- Seifert, R. W., U. W. Thonemann, W. H. Hausman, 2004. Optimal procurement strategies for online spot markets. *European Journal of Operational Research*, 152(3), 781-799.
- Tunca, T., S. A. Zenios, 2006. Supply auctions and relational contracts for procurement. *Manufacturing Service Oper. Management* 8(1), 43-67.
- Wang, S. Y., Y. S. Xia, 2002. *Portfolio Selection and Asset Pricing*. Springer-Verlag, Berlin.
- Wei Xing, S. Y. Wang, G. Z. Feng, 2008. Game Analysis on Supply Chain with B2B Electronic Marketplace. *System Engineering Theory and Practice* (in Chinese) 28(7): 56-60.
- Van Mieghem, J. A., 2007. Risk mitigation in newsvendor networks: resource diversification, flexibility, sharing, and hedging. *Management Science* 53(8), 1269-1288.
- Wu, D. J., Kleindorfer, P. R., Zhang, J. E., 2002. Optimal bidding and contracting strategies for capital-intensive goods. *European Journal of Operational Research* 137(3), 657-676.
- Zhu K., 2004. Information Transparency of Business-to-Business Electronic Markets: A game-theoretic analysis. *Management Science* 50 (5), 670-685.