Quantity Discount Contract on the Supply Chain with Double Sided Moral Hazard: Model and Experiment

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\textbf{Abstract.} In the two stage supply chain with one manufacturer and one retailer, the double sided moral hazard is considered as the sales influenced by both the manufacturer’s and the retailer’s effort. In theory, the quantity discount contract can motive the manufacturer and the retailer to put the optimal effort, and make the supply chain get the most earning, which can be divided arbitrarily. In experiment, the effort of the retailer and order quantity are influenced by the ratio of the earning divided, but the effort of the manufacturer is not sufficient, hardly influenced by the ratio of the ratio divided. Unlike the theory, the quantity discount contract can not make the supply chain’s earning optimal. The analysis of the causes of the manufacturer’s insufficient investment in three aspects, risk attitude, characteristics of the input and the allocation of decision rights, is given to provide guidance for the practice of the supply chain with double moral hazard.

\textbf{Introduction}

How to realize the coordination and how to improve the efficiency of the supply chain has become a key factor for the 21st century’s enterprise to survive and develop. A vital problem for the supply chain coordination is asymmetric information. Choosing or designing suitable contracts can reveal the information and improve the whole supply chain’s earning, especially for the ex-ante information. So the supply chain moral hazard models have been the subject of intense theoretical study in recent years. But it is unknown that whether these models suit into the practice or not. So before we try to put them into practice, they should be tested by experiment (Katok and Wu, 2009). In this paper, the double sided moral hazard models in supply chain will be set up in order to give the optimal quantity discount contract. And the examination of real human behavior in a controlled laboratory environment and with monetary incentives is pursued.

This paper is structured as follows. In the next section we discuss some of the related literature, analytical, empirical, and experimental, to provide the necessary background for our study. In section 3, the mathematical model of the supply chain with double sided moral hazard is given. In section 4, we describe the details of the experimental design and the laboratory
protocol we used. We then present the details and the results of the retailer game and the manufacturer game (section 5). In section 6 we summarize our finding, point to limitations and directions for future research, and discuss managerial implications of our work.

**Literature Review**

Monahan (1984), Lee and Rosenblatt (1986) find out that the manufacturer can enhance its earning by using the quantity discount contracts. And Cachon (2003) reveals that, comparing to the wholesales contract, buyback contract, revenue sharing contract and quantity flexible contract, only the quantity discount contract can coordinate the supply chain with sales effort affects. So the quantity discount contract has been a major topic in the research of supply chain contracts. Sarmah et al. (2006) review the research of quantity discount contract. They classify these researches by the relationship of the manufacturer and the retailer. Kalkanci (2011) proves the applicability of quantity discount contract in the supply chain with asymmetric information.

For the supply chain experiment research, researchers place more emphasis on the features of the participant’s behavior, and then analyze the decision of the supply chain parties. Schweitzer and Cachon (2000) conduct an important experimental test of the newsvendor problem model. In their study, they analyzed 15 decision periods of ordering for each subject with known uniform distribution. They show that participants systematically deviate from the optimal order and that when marginal profit is larger (smaller) than the cost, participants tend to order less (more) than the optimal order. Keser and Paleologo (2004) find out that the coordination efficiency of the supply chain is as model predicted but profits are more equitably allocated among manufacturers and retailers. Benzion et al. (2008) investigates repetitive purchase decisions of perishable items in the face of uncertain demand, and shows that the order converges to a value between the mean demand and the quantity for maximizing the expected profit. Ho et al. (2010) experimentally test reference dependence into the newsvendor framework by assuming that there are psychological costs of leftovers and stockouts, and suggest that the behavioral theory captures actual orders and profits better. Katok and Wu (2007) investigate the performance of three commonly-studied supply chain contracting mechanisms: the wholesale price, the buyback, and the revenue-sharing contracts, and then compare the three mechanisms in a laboratory setting. They find that although the buyback and the revenue-sharing contracts improve supply chain efficiency relative to the wholesale price contract, the improvement is smaller than the theory predicts.

The asymmetric information has not been considered in the supply chain experimental research. Kalkanci et al. (2011) study a two-tier supply chain to characterize the impact of asymmetric information on performance and to compare theoretical predictions to actual behavior in human subject experiments.

**Basic Model**

In the simplest supply chain contracting setting analyzed theoretically, and the one we investigate here, the retailer faces the newsvendor problem, and orders from a manufacturer. The retailer sells the product at a $p$ price. Both the manufacturer’s effort $e_s$ and the retailer’s effort $e_r$ will affect the sales quantity. It will cost the manufacturer $h(e_s) = k_s e_s^2 / 2$ for the
effort $e_s$, and the retailer $g(e_r) = \frac{e_r^2}{2}$ for the effort $e_r$. Both the manufacturer and the retailer’s effort can be seen as the sales’ effort. The whole sales promotion effect is influenced together by the manufacturer’s effort and the retailer’s effort, which we can see as $e = \lambda_s e_s + \lambda_r e_r$. The market demand follows uniform distribution on $[0, e]$, with distribution function $F(x/e) = x/e$ and density function $f(x/e) = 1/e$. $S(q, x)$ is the expected sales with the manufacturer’s order $q$, and the market demand $x$, so

$$S(q, x) = E \min(q, x) = q - \int_0^q F(x/e_s, e_r)dx.$$ 

According to Cachon (2003), the transfer price between the manufacturer and the retailer is defined as,

$$w(q) = \rho \frac{pS(q, x)}{q} + (1 - \rho) \frac{h(e_s)}{q} - \rho \frac{g(e_r)}{q} \quad (1)$$

The whole supply chain’s profit can be divided into two parts in the distribution ratio $\rho$, of that is the manufacturer’s earning, and $(1 - \rho)$ of that is the retailer’s earning. It is easy to find that, the manufacturer’s effort, the retailer’s effort and the order quantity can get the coordination level. That is to say, the supply chain under double sided moral hazard can be coordinated by the quantity discount contract, whatever the distribution ratio $\rho$ is.

**Experimental Design**

For examining the supply chain under double sided moral hazard can be coordinated, this experiment is taken under different distribution ratio. These parameters are supposed as $p = 40, \lambda_s = 6, \lambda_r = 4, k_s = 150, k_r = 120$. According to equation (1), the transfer price is given under different distribution ratio, as Table 1.

<table>
<thead>
<tr>
<th>Distribution ratio</th>
<th>Transfer price</th>
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<tbody>
<tr>
<td>$\rho = 0.5$</td>
<td>$w = (20 \min(q, x) + 37.5 e_s^2 - 30 e_r^2) / q$</td>
</tr>
<tr>
<td>$\rho = 0.8$</td>
<td>$w = (32 \min(q, x) + 15 e_s^2 - 48 e_r^2) / q$</td>
</tr>
<tr>
<td>$\rho = 0.2$</td>
<td>$w = (8 \min(q, x) + 60 e_s^2 - 12 e_r^2) / q$</td>
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According to the different transfer price, the experiment would be divided into three parts. During the experiment, all the basic information of supply chain including the transfer price is known by the participants. And the participants who play as the manufacturer make the decision of the effort $e_s$, and who play as the retailer decide the effort $e_r$ and order quantity $q$. Table 2 lists the different decision parameters for the participants and their value range. The market demand is produced randomly by computer according to the assumption, after the decisions. Each participant gets some reward on average of 60RMB, on the basis of its earning in the experiment. Most of the participators in economic experiment are students (Katok et al.,...
2008; Moritz et al., 2013; Bolton et al., 2012). There are 20 participators in the experiment, including 10 senior and 10 junior students, 12 female and 8 male. They are in three different majors, management science, industrial engineering, and engineering management.

<table>
<thead>
<tr>
<th>Characters</th>
<th>Decision</th>
<th>Value range</th>
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<tbody>
<tr>
<td>Manufacturer</td>
<td>$e_s$</td>
<td>[0,1]</td>
</tr>
<tr>
<td>Retailer</td>
<td>$e_r$</td>
<td>[0,1]</td>
</tr>
<tr>
<td></td>
<td>$q$</td>
<td>[0,10]</td>
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Results Analysis

The data from the experiment has passed the consistency analysis. And the data is analyzed by the view of manufacturer, retailer and the whole supply chain.

The Manufacturer’s Effort

Fig.1 shows the retailer’s effort and how it changes under different distribution ratio.

Figure 1. Data of the effort of the manufacturer.
Opt=Optimal, Ave=Average

\[\phi = 0.5\] \hspace{1cm} \[\phi = 0.8\] \hspace{1cm} \[\phi = 0.2\]
Under different distribution ratio, whatever how much part of the whole supply chain profit the manufacturer can get, the manufacturer puts much less effort than the optimal level, from Fig.1. And from Fig.1 (a), (b) and (c), we can see that all the average of the manufacturer’s effort is almost equal, and much less than the optimal. So how much effort that the manufacturer put is not so much influenced by the distribution ratio and it is very hard to motivate the manufacturer to put more effort. The Proposition 1 is as following.

**Proposition 1.** In the experiment of supply chain with quantity discount contract, the manufacturer’s effort has a stability. It is almost equal under different distribution ratios, and much less than the optimal level.

**The Retailer’s Effort**

Fig.2 shows the retailer’s effort and how it changes under different distribution ratio.

![Figure 2](image)

Figure 2. Data of the effort of the retailer.

Opt=Optimal, Ave=Average

When the distribution ratio $\rho=0.5$ from Fig.2 (a), the average of the retailer’s effort is equal to the optimal one. But under both the other two situation $\rho=0.8$ and $\rho=0.2$ from Fig.2 (b) and Fig.2 (c), the average of retailer’s effort is not equal to the optimal level. When $\rho=0.8$ Fig.2 (b), the average is small than the optimal, which means the effort is not enough. When $\rho=0.2$ Fig.2 (c), the average is larger than the optimal, which means the effort is more than enough. Let us consider the part of the distribution which the retailer can earn, from Fig.2 (d), it is clearly to find out that the average of the retailer’s effort increases along with the part of the distribution which the retailer can earn. From Fig.1, we can get the Proposition 2.
Proposition 2. In the experiment of supply chain with quantity discount contract, the retailer’s effort increases along with the part of the whole supply chain which the retailer can earn. And when the distribution ratio is 0.5, the retailer put the optimal retailer.

The Retailer’s Order Quantity

Fig. 3 shows the retailer’s order quantity and how it changes under different distribution ratio.

From Figs. 3 (a), (b) and (c), we can see that, most of the order quantity in experiment is smaller than the optimal level. And the average order quantity in experiment can’t catch up the optimal level whatever the distribution ratio is, $\rho = 0.5, \rho = 0.8$ or $\rho = 0.2$. But if the retailer can get most of the supply chain’s profit, or when the retailer can earn four of fifth of the supply chain’s profit, that is when $\rho = 0.2$ Fig.3 (d), the retailer orders more but not as much as the optimal. So we can get Proposition 3.

Proposition 3. In the experiment of supply chain with quantity discount contract, the retailer’s order quantity is less. If the retailer can get most of the supply chain’s profit, the retailer will order more, but still not as much as the optimal.

It is easy to find out that the key factor to prevent the supply chain with double sided moral hazard to be coordinated by the quantity discount contract is the manufacturer’s effort. Risk attitude, characteristics of the input and the allocation of decision rights influence the results of the experiment, leads to less effort of the manufacturer. In supply chain practice, in order to
motivate the manufacturer to put more effort, we should not only consider the contracts, but also from these three aspects.

**Conclusion**

Double sided moral hazard models in supply chain have been set up in order to give the optimal quantity discount contract. And the examination of real human behavior in a controlled laboratory environment and with monetary incentives is pursued. In theory, the quantity discount contract can motive the manufacture and the retailer to put the optimal effort, and make the supply chain get the most earning, which can be divided arbitrarily. In experiment, the effort of the retailer and order quantity are infected by the ratio of the earning divided, but the effort of the manufacture is insufficient, hardly influenced by the ratio of the ratio divided. Unlike the theory, the retailer’s effort increases along with the part of the whole supply chain which the retailer can earn. And when the distribution ratio is 0.5, the retailer put the optimal effort. The retailer’s order quantity is less. If the retailer can get most of the supply chain’s profit, the retailer orders more but not as much as the optimal. Whatever how much part of the whole supply chain profit the manufacturer can get, the manufacturer puts much less effort than the optimal level. So the supply chain with double sided moral hazard can’t be coordination in experiment by the quantity discount contract. The analysis of the causes of the manufacture’s insufficient investment in three aspects, risk, characteristics of the input and the allocation of decision rights, is given to provide guidance for the practice of the supply chain with double moral hazard.

Although in this paper, we are primarily interested in the supply chain with risk neutral manufacturer and risk neutral retailer. The research could be extended to different risk attitude participants. Another possible extension of this study is to investigate the more efficiency contracts for supply chain with double sided moral hazard.

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