Supply Chain Coordination under Return Policy with Asymmetric Information about Cost of Reverse Logistics Operations

Ting Long Zhang
Institute of Economics and Management/Anhui Normal University, WuHu, China
satzl@mail.ustc.edu.cn

Abstract—In this paper, we study return policy and supply chain coordination in a channel of one supplier and one retailer. The paper assumes that unsold merchandise should be refunded to the supplier by the retailer. The retailer knows the cost of reverse logistics operations but the supplier has to estimate it. The contract menu under asymmetric reverse logistics cost information between supply chain members was designed and discussed. The goal of the supplier’s contract is to coordinate the channel and then get more profit. The problem is analyzed as a Stackelberg game in which the supplier declares a contract menu with return price and wholesale price to the retailer and requires the retailer report the cost of reverse logistics. Then the retailer reports the cost and gets the corresponding contract. The optimal solutions of the contract menu are derived, and numerical examples are presented to illustrate the properties of the contract menu.

Index Terms—supply chain; return policy; reverse logistics; asymmetric information

I. INTRODUCTION

Because of the existence of multiple decision makers in supply chain, the decisions that are locally optimal can be globally inefficient. It is well documented in marketing and economics literature that uncoordinated decisions lead to “double marginalization”, which is one of the causes of channel inefficiency [1],[2]. Coordination among suppliers and retailers is a very important strategic issue in supply chain management. Coordination between independent firms in a supply chain relationship has gained much attention recently and many studies have been presented. In order to provide compatible incentives to improve the supply chain performance and achieve the win-win solution, some types of supply chain contracts have been discussed. For instance, see return policies [3], revenue sharing[4], quantity discount [5], quantity flexibility [6], sales rebate[7]. See[8]for excellent reviews. The goal of these contracts is to coordinate supply chain, which means that the total profit of the decentralized supply chain will be equal to that achieved under a centralized system.

In this paper, the focus is on combined contract of wholesale price and return policy. Wholesale price is a fundamental decision for supply chain coordination in distribution channel. The “Quantity discount” is a popular method used to stimulate the retailer to order [9], [10] shows that in complex supply chain linear quantity discount alone cannot coordinate supply chain.

The return policy is also called as buyback policy for many cases and in many researches. This is understandable since almost all return policies incur buyback price. That is why vast researches pay more attention to buyback price. [3]demonstrates that a policy to offer full credit to the buyer for a partial return of goods may achieve channel coordination and the supplier can get any percentage of channel profit by setting proper wholesale price and buyback price. There are many restrictions about setting. For example, when the retail price which affects is endogenous, the buyback contract no longer coordinates the supply chain [8]. For more complex setting, the other contract will with buyback to improve the performance[7],[10].

Though both buyback policy and return policy decide buyback price, there are remarkable difference between them. That is, return policy incurs reverse logistics, but buyback policy may not incur reverse logistics. Most studies about buyback policy or return policy do not consider reverse logistics. Recently, more attention is devoted to the logistics of return policies. [11] shows that the development of e-commerce in electronic market increases the value of surplus products. [12] reviews return contract and illustrates the decision of contract when consider cost of the return good. [13] investigates a supply chain consider the forward logistics and reverse logistics simultaneously.

Most studies to date on return policy have assumed that the salvage value is same for all member of supply chain. But for some products, such as electronic products and books, the excess products should be reprocessed or delivered to another substitute channel if resend them to the supplier. Therefore, the value of excess goods may be higher for the supplier than for the retailer. This is a foundation assumption for return policy. On the other hand, the paper investigating buyback contract considers the logistics is rare. Furthermore, the majority of supply chain coordination researches assume a symmetric information situation. Because of the variety and complexity of logistics activities, the accurate cost accounting is troublesome. It is difficult to estimate the expenses of the returned purchase when the return
activities are managed by the retailer. This paper considers an asymmetric information about the cost of returned goods.

The paper proceeds as follows. The next section presents the assumptions and notations. In Section 3, the integrated model is discussed firstly. In Section 4, the return policy under symmetric information situation is investigated. Section 5 focuses on the return policy for an asymmetric information relationship. Section 6 gives the numerical analysis. Section 7 summarizes the findings.

II. ASSUMPTIONS AND NOTATIONS

The demand $D$ is a random within $[0,b]$. We denote by $f, F, \mu$ the density function, distribution function of $D$, respectively. Let $E(y) = \int_{-\infty}^{\infty} y f(x)dx$. The retail price $p$ and the supplier cost $c$ are exogenous variable and the wholesale price of the supplier $w$ is endogenous variable. The salvage values of the supplier and the retailer are different and denoted by $v_m$ and $v_r$, respectively. In this paper, we assume the retailer takes back work and pays the logistic cost, denoted by $l$. If $v_r \geq v_m - l$, from the supply chain point of view, returning goods is unreasonable. This paper assumes $v_r < v_m - l$ and considers an asymmetric information about the cost of reverse logistics. We assume the real value of $l$ is the retailer’s private knowledge and we call this retailer $l$-type retailer for convenience in presentation. The supplier does not make sure the type of the retailer, but he deems the value of $l$ is either $\hat{l}$ with probability of $\rho$ or $\tilde{l}$ with probability of $1-\rho$. The buyback contract is a practical method for the supplier to share risks and losses of the retailer. We denote $r$ as the buyback price, which is the decision variable of the supplier as well as $w$. In asymmetric information situation, the supplier should offer retailers a menu of returns policies trading off $\hat{l}$-type retailer with $\tilde{l}$-type retailer. The one goal of the supplier’s contract is to coordinate the supply chain and the other is to maximize the supplier profit.

Let $l$-type retailer’s ordering size is $Q(l)$, the expected surplus and sale are $O(l)$ and $S(l)$. Simply calculating gives

$$O(l) = \int_{-\infty}^{Q(l)} F(x)dx, \quad S(l) = Q(l) - O(l)$$

(1)

The total expected profit of the channel is

$$\Pi_{\text{tot}}(l) = (p - c)Q(l) - (p - v_m + l)O(l)$$

(2)

The profit of $l$-type retailer is

$$\Pi_l(l) = (p - w)Q(l) - (p - r + l)O(l)$$

(3)

The profit of the supplier is

$$\Pi_m(l) = (w - c)Q(l) - (r - v_m)O(l)$$

(4)

III. THE INTEGRATED MODEL

The goal of this paper is to develop a return policy to coordinate the supply chain. The coordination of supply chain means the decision in decentralized enable the channel to obtain the same profits as a vertically integrated firm’s. In order to give a benchmark for follows discussion, in this section, we first focus on an integrated structure in which both the supplier and the retailer agree to take decisions to maximize the total channel profits (joint profit maximization).

We denote the optimal order size and the maximum expected profit of the channel by $Q^*(l)$, $\Pi^*_{\text{tot}}(l)$. Using Leibniz’s rule to obtain the first and second derivatives shows that $\Pi^*_{\text{tot}}(l)$ is concave. The sufficient optimality condition is the well-known formula:

$$F(Q^*(l)) = (p - c)/(p + l - v_m).$$

(5)

Using the relationship

$$\int_{-\infty}^{Q(l)} xf(x)dx = \mu - \int_{-\infty}^{\infty} xf(x)dx$$

and substituting from (5) into (2) and simplifying gives the optimal expected profit:

$$\Pi^*_{\text{tot}}(l) = (p + l - v_m)E(Q^*(l))$$

(6)

Proposition 1. $Q^*(l)$ and $\Pi^*_{\text{tot}}(l)$ decrease as $l$ increases

Proof. From (5), we have $\partial Q^*(l)/\partial l < 0$. Taking the first-order derivative of $\Pi^*_{\text{tot}}(l)$, one has

$$\partial \Pi^*_{\text{tot}}(l)/\partial l = E(Q^*(l)) - Q^*(l)F(Q^*(l)) < 0.$$  

The higher $l$ means the higher the cost, thus this conclusion is intuitive.

For the convenience in presentation is follows subsections, let

$$O'(l) = \int_{-\infty}^{Q^*(l)} F(x)dx.$$  

(7)

IV. THE RETURN POLICY UNDER SYMMETRIC INFORMATION SITUATION

For the sake of comparing, before investigate the asymmetric information situation, now we discuss the problem of channel coordination by return policy with common knowledge about $l$. When the supplier know the retailer’s cost $l$, the supplier first declares the wholesale price $w$ and buyback price $r$. The retailer, as the follower sets the decision of ordering size $Q(l)$. It is straightforward to find that only if $r > v_m + l$, then the retailer sends back the excess goods.

Using the same method gives

$$F(Q^*(l)) = (p - w)/(p + l - r).$$

(8)

l-type retailer’s expected profit, denoted by $\Pi'_l(l)$, is

$$\Pi'_l(l) = (p + l - r)E(Q^*(l))$$

(9)

From (5) and (8), we get the observation as in Proposition 2.

Proposition 2. If $w, r$ satisfy

$$w = \beta c + (1 - \beta) p_r, \quad r = (1 - \beta)(p + l) + \beta v_m$$

where $l/(l + c - v_m) \leq \beta \leq 1,$

(10)

the combined contract of wholesale price and buyback policy can coordinate the supply chain and has the follows properties:
For $I$-type retailer, if she reports honestly, i.e. $l_f = \tilde{l}$, then her profit, denoted by $\Pi^w_\omega(\tilde{\beta}, \tilde{l})$, is
$$\Pi^w_\omega(\tilde{\beta}, \tilde{l}) = \tilde{\beta}\Pi^w_{\omega, \omega}(\tilde{l}),$$
if she reports dishonestly, i.e. $l_f = \tilde{l}$, then her profit, denoted by $\Pi^w_\omega(\tilde{\beta}, \tilde{l})$, is
$$\Pi^w_\omega(\tilde{\beta}, \tilde{l}) = \tilde{\beta}\Pi^w_{\omega, \omega}(\tilde{l}) + \Delta\text{O}'(\tilde{l}).$$

The incentive compatibility constraint is
$$\Pi^w_{\omega, \omega}(\tilde{l}) - \Pi^w_{\omega, \omega}(\tilde{l}) > 0, \Pi^w(\tilde{\beta}, \tilde{l}) - \Pi^w_{\omega, \omega}(\tilde{l}) > 0.$$  (14)

Let
$$\alpha(\tilde{l}, \tilde{u}) = \Pi^w_{\omega, \omega}(\tilde{l}), b(\tilde{l}, \tilde{u}) = \frac{\Delta\text{O}(\tilde{u})}{\Pi^w_{\omega, \omega}(\tilde{l})}, e(\tilde{l}, \tilde{u}) = \frac{\Delta\text{O}(\tilde{l})}{\Pi^w_{\omega, \omega}(\tilde{l})}.$$  (15)

The condition of (16) is same as
$$\tilde{\beta}a(\tilde{l}, \tilde{u}) + b(\tilde{l}, \tilde{u}) > \tilde{\beta}a(\tilde{l}, \tilde{u}) + c(\tilde{l}, \tilde{u}).$$  (16)

We assume that the reserved profit of the retailer is the profit which she can get in decentralized setting without the supplier’s buyback policy. In this model, the supplier set the optimal wholesale price which maximizes his profit. We denote the retailer profit by $\Pi^w_\omega$. Hence, the participate constraint is
$$\Pi^w_{\omega, \omega}(\tilde{l}) \geq \Pi^w_\omega, \Pi^w_{\omega, \omega}(\tilde{l}) \geq \Pi^w_\omega.$$  (19)

From (11) and (19), let
$$\beta^0 = \max\left\{\frac{\Pi^w_\omega}{\Pi^w_{\omega, \omega}(\tilde{l})}, \frac{l + c - v_m}{l + c - v_m}\right\},$$
$$\tilde{\beta}_0 = \max\left\{\frac{\Pi^w_\omega}{\Pi^w_{\omega, \omega}(\tilde{l})}, \frac{\tilde{l}}{\tilde{l} + c - v_m}\right\}.$$  (20)

Therefore, the constraint condition of (11) and (19) can be simplified as
$$\beta \geq \beta^0, \tilde{\beta} \geq \tilde{\beta}_0.$$  (21)

Let
$$\beta = \alpha(\tilde{l}, \tilde{u})\beta^0 + c(\tilde{l}, \tilde{u}), \tilde{\beta} = \alpha(\tilde{l}, \tilde{u})\tilde{\beta}_0 + b(\tilde{l}, \tilde{u}).$$  (22)

After making clear the conditions which ensures the retailer report honestly and achieves the coordination of the supply chain, we now discuss the supplier’s decisions of $\beta, \tilde{\beta}$ which optimizes the supplier’s profit. The problem of the supplier is
$$\max\Pi^w_{\omega, \omega}(\tilde{l}) - (1 - \rho)\Pi^w_{\omega, \omega}(\tilde{l})$$
s.t. (19) and (21)

Lemma. If $0 \leq \tilde{\beta}_0 \leq 1$ and $\tilde{l} \geq 1$, then
$$\Pi^w_{\omega, \omega}(\tilde{l}) + \Delta\text{O}'(\tilde{l}) \leq \Pi^w_{\omega, \omega}(\tilde{l})$$
if $\tilde{\beta} \leq 1$.

Proof. Given $\tilde{l}$, the derivative of $\Pi^w_{\omega, \omega}(\tilde{l}) + \Delta\text{O}'(\tilde{l})$ with respect to $\tilde{l}$ is
$$\frac{\partial\Pi^w_{\omega, \omega}(\tilde{l}) + \Delta\text{O}'(\tilde{l})}{\partial\tilde{l}} = E(Q'(\tilde{l})) - Q'(\tilde{l})F(Q'(\tilde{l})) - [E(Q'(\tilde{l})) - Q'(\tilde{l})F(Q'(\tilde{l}))].$$

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and the derivative of $E(Q'(l)) - Q'(l)F(Q'(l))$ with respect to $l$ is
\[
\frac{dE(Q'(l))}{dl} - \frac{dQ'(l)F(Q'(l))}{dl} = -F(Q'(l)) < 0.
\]
Thus, $E[\Pi^*_{m,r}(l)] + \Delta Q'(l)/\Pi^*_{m,r}(l) \leq 0$, which means $E[\Pi^*_{m,r}(l)] + \Delta Q(l)/\Pi^*_{m,r}(l) \leq 0$. Because
\[
\beta_l \leq a(l,\tilde{l}) + b(l,\tilde{l}) < [\Pi^*_{m,r}(l)] + \Delta Q'(l)/\Pi^*_{m,r}(l),
\]
so $\beta_l \leq 1$.

Eq.(23) shows that the supplier’s problem is a Liner Program (LP) and all value coefficient are negative. If the restricts of $\beta \geq 0$ is omitted, the feasible region for $\beta$, $\bar{\beta}$ is illustrated as in Fig.1. Due to the properties of LP, the nearest point to origin of coordinates is the solution of (23).

Proposition 3. The solution of the supplier’s problem, denoted by $\hat{\beta}$, $\bar{\beta}$, is

(i) if $\beta_0 \leq \beta_l$, then $\hat{\beta} = \beta_0$ and $\bar{\beta} = \beta_0$ (as in Fig.1),
(ii) if $\beta_l < \beta_0 < \beta_l$, then $\hat{\beta} = \beta_0$ and $\bar{\beta} = \beta_0$ (as in Fig.2),
(iii) if $\beta_0 < \beta_l < a(l,\tilde{l}) + b(l,\tilde{l})$, then $\hat{\beta} = \beta_0$ and $\bar{\beta} = \beta_0$ (as in Fig.3),
(iv) if $\beta_0 > a(l,\tilde{l}) + b(l,\tilde{l})$, then (23) has no feasible solution.

If $\Pi^*_{m,r}(l) \geq l/(l + c - v_m)$, it is straightforward to get
\[
\beta_0 = \frac{\Pi^*_{m,r}(l)}{\Pi^*_{m,r}(l)} - \Delta Q(l)/\Pi^*_{m,r}(l)
\]

Proposition 4. If $\Pi^*_{m,r}(l) \geq l/(l + c - v_m)$, then $\beta_l \leq \beta$, and $\hat{\beta} = \beta, \bar{\beta} = \beta_0$.

I. NUMERICAL ANALYSIS

In this section, we assume $D$ is uniform distribution within $[0, b]$.

By simply operation, one gets
\[
a(l,\tilde{l}) = \frac{p + l - v_m}{p + l + \Delta l - l} \cdot b(l,\tilde{l}) = \frac{\Delta l}{p + l - v_m},
\]
\[
c(l,\tilde{l}) = \frac{p + l - v_m}{(p + l + \Delta l - l)}
\]

\[
\beta_l = \frac{p + l - v_m}{4(p - v_m)} \cdot \frac{l}{c + l - v_m}
\]

\[
\beta_0 = \frac{p + l + \Delta l - v_m}{4(p - v_m)} \cdot \frac{l + \Delta l}{c + l + \Delta l - v_m}
\]

The sensitivity analysis of $\hat{\beta}$, $\bar{\beta}$ are listed in Tables 1-3. Tables 1-3 show that $\hat{\beta}$, $\bar{\beta}$ increase as $\Delta l$ increase. The greater $\Delta l$ means more uncertainty of the supplier about the retailer’s type and it is disadvantageous for the supplier. Table 2 shows that $\hat{\beta}$, $\bar{\beta}$ decrease as $c$ increases. The higher cost make the supplier ask for the higher percentage to ensure enough profit. The
higher \( c \) and the higher \( \Delta \) should decrease the supplier’s profit. Table 4 shows that \( \beta^* \), \( \bar{\beta} \), increase as \( p \) increases, this is easy to understand because the higher retailer price leads to the higher reserved profit.

(i) \( c = 40, p = 80, v_r = 25, v_p = v_m - \Delta v, l = 2, \bar{l} = l + \Delta l \)

Table 1. \( \beta^* \times \bar{\beta} \) vary with \( \Delta v \) and \( \Delta l \)

<table>
<thead>
<tr>
<th>( \Delta l )</th>
<th>( \beta^* )</th>
<th>( \bar{\beta} )</th>
<th>( \beta^* )</th>
<th>( \bar{\beta} )</th>
<th>( \beta^* )</th>
<th>( \bar{\beta} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta l = 2 )</td>
<td>0.225</td>
<td>0.214</td>
<td>0.219</td>
<td>0.210</td>
<td>0.219</td>
<td>0.210</td>
</tr>
<tr>
<td>( \Delta l = 4 )</td>
<td>0.282</td>
<td>0.285</td>
<td>0.282</td>
<td>0.285</td>
<td>0.282</td>
<td>0.285</td>
</tr>
<tr>
<td>( \Delta l = 6 )</td>
<td>0.329</td>
<td>0.347</td>
<td>0.329</td>
<td>0.347</td>
<td>0.329</td>
<td>0.347</td>
</tr>
<tr>
<td>( \Delta l = 8 )</td>
<td>0.364</td>
<td>0.4</td>
<td>0.364</td>
<td>0.4</td>
<td>0.364</td>
<td>0.4</td>
</tr>
<tr>
<td>( \Delta l = 10 )</td>
<td>0.390</td>
<td>0.444</td>
<td>0.390</td>
<td>0.444</td>
<td>0.390</td>
<td>0.444</td>
</tr>
</tbody>
</table>

(ii) \( c = 40, 50, 60, p = 80, v_r = 25, v_p = 10, l = 2, \bar{l} = l + \Delta l \)

Table 2. \( \beta^* \times \bar{\beta} \) vary with \( c \) and \( \Delta l \)

<table>
<thead>
<tr>
<th>( \Delta l )</th>
<th>( \beta^* )</th>
<th>( \bar{\beta} )</th>
<th>( \beta^* )</th>
<th>( \bar{\beta} )</th>
<th>( \beta^* )</th>
<th>( \bar{\beta} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta l = 2 )</td>
<td>0.219</td>
<td>0.210</td>
<td>0.219</td>
<td>0.210</td>
<td>0.219</td>
<td>0.210</td>
</tr>
<tr>
<td>( \Delta l = 4 )</td>
<td>0.283</td>
<td>0.285</td>
<td>0.281</td>
<td>0.217</td>
<td>0.218</td>
<td>0.217</td>
</tr>
<tr>
<td>( \Delta l = 6 )</td>
<td>0.329</td>
<td>0.347</td>
<td>0.233</td>
<td>0.242</td>
<td>0.217</td>
<td>0.225</td>
</tr>
<tr>
<td>( \Delta l = 8 )</td>
<td>0.364</td>
<td>0.4</td>
<td>0.264</td>
<td>0.285</td>
<td>0.217</td>
<td>0.232</td>
</tr>
<tr>
<td>( \Delta l = 10 )</td>
<td>0.390</td>
<td>0.444</td>
<td>0.288</td>
<td>0.324</td>
<td>0.229</td>
<td>0.255</td>
</tr>
<tr>
<td>( \Delta l = 12 )</td>
<td>0.410</td>
<td>0.482</td>
<td>0.308</td>
<td>0.358</td>
<td>0.247</td>
<td>0.285</td>
</tr>
</tbody>
</table>

(iii) \( c = 40, 50, 60, 70, 80, 90, 100, v_p = 25, \bar{v}_r = 10, l = 2, \bar{l} = l + \Delta l \)

Table 3. \( \beta^* \) \times \( \bar{\beta} \) vary with \( p \) and \( \Delta l \)

<table>
<thead>
<tr>
<th>( \Delta l )</th>
<th>( \beta^* )</th>
<th>( \bar{\beta} )</th>
<th>( \beta^* )</th>
<th>( \bar{\beta} )</th>
<th>( \beta^* )</th>
<th>( \bar{\beta} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta l = 2 )</td>
<td>0.221</td>
<td>0.210</td>
<td>0.225</td>
<td>0.214</td>
<td>0.226</td>
<td>0.215</td>
</tr>
<tr>
<td>( \Delta l = 4 )</td>
<td>0.281</td>
<td>0.285</td>
<td>0.281</td>
<td>0.285</td>
<td>0.282</td>
<td>0.285</td>
</tr>
<tr>
<td>( \Delta l = 6 )</td>
<td>0.325</td>
<td>0.347</td>
<td>0.329</td>
<td>0.347</td>
<td>0.331</td>
<td>0.347</td>
</tr>
<tr>
<td>( \Delta l = 8 )</td>
<td>0.357</td>
<td>0.4</td>
<td>0.364</td>
<td>0.4</td>
<td>0.369</td>
<td>0.4</td>
</tr>
<tr>
<td>( \Delta l = 10 )</td>
<td>0.380</td>
<td>0.444</td>
<td>0.390</td>
<td>0.444</td>
<td>0.398</td>
<td>0.444</td>
</tr>
</tbody>
</table>

II. Conclusions

This paper has formulated a supply chain coordination problem with asymmetric information between one supplier and one retailer for a single-period product. This paper assumes that the salvage value of unsold products is higher for the supplier than for the retailer. The supplier wants to coordinate by proper return contract. In this return policy we assume that the excess goods refunded by the retailer and the cost of reverse logistics is asymmetric information. This paper formulates a contract menu with return price and wholesale price. The observations are developed and show that this contract menu enables the retailer report the logistics cost honestly and can achieve the coordination. The solution of this contract menu is derived, and the numerical examples illustrate that the greater variation of the supplier’s estimation about the logistics cost is disadvantageous for the supplier. The greater variation will produce more harm to the supplier who has the higher cost.

There a number of possible extensions of our study that can constitute future research endeavors in this area. One immediate extension is to consider the cooperating reverse logistics between the channel members. Developing better contract menu to deal with the asymmetric information is another interesting theme.

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Ting Long Zhang, Ph.D., Associate Professor of Institute of Economics and Management, Anhui Normal University. Field of Research: Management Science, Supply Chain Management, Logistics.