Research on Product Quality Information Transmission in Supply Chain with Social Responsibility

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Abstract-This paper constructs a supply chain decision model involving manufacturers, retailers and consumers. Manufacturers have private information about product quality, which is expressed by corporate social responsibility (CSR) behavior. This paper discusses the feasibility of indirectly transmitting upstream quality signal mechanism through CSR behavior by manufacturers on the basis of retailers' CSR awareness, describes the separation equilibrium, and further analyzes the differences in strategy and performance of supply chain members under different circumstances. The results show that manufacturers can transmit their own quality information through a certain level of CSR behavior. Retailers' strategies under symmetric information and asymmetric information are exactly the same, and they don't have the motivation to raise their awareness of social responsibility. However, H-type manufacturers will implement higher corporate social responsibility behaviors under asymmetric information, so profits will be lost.

Keywords-supply chain; corporate social responsibility; product quality; signal game

1 INTRODUCTION

Information asymmetry is a common problem in the supply chain. In real life, information asymmetry leads to the imbalance of internal configuration in the supply chain, which in turn leads to the vicious development of the whole supply chain. Therefore, strengthening information sharing among supply chain enterprises is the key in the field of operation and supply chain management [1]. At present, the literature on supply chain information sharing mainly focuses on the demand information sharing of enterprises downstream of the supply chain [2]. On one hand, these studies confirm that vertical information sharing can improve the efficiency of supply chain; on the other hand, they also reveal that direct information sharing has the disadvantages of high system maintenance cost and distorted factual motivation. This causes us to think about the indirect information sharing mechanism.

The signal game model in information economics provides a feasible analysis framework for the indirect information sharing mechanism. At present, massive literature study the indirect sharing of demand information in supply chain [3,4]. However, with the improvement of people's living standards, consumers begin to attach importance to product quality. Therefore, product quality information is another important information that supply chain enterprises and

consumers need to pay attention to [5,6]. Under the background of supply chain, it is rare to study how upstream enterprises indirectly transmit quality signals to downstream enterprises and consumers. By analyzing the decision behavior of supply chain, we can find that it is a feasible idea for upstream enterprises to provide an external behavior that can be observed by downstream enterprises and consumers. Many economic documents have discussed the quality signal tools such as advertisement, product distribution channels, product warranty period and brand reputation [7,8]. By analyzing the above signals, it is found that enterprises show their true types through some kind of "wasteful" expenditure [9]. From this perspective, CSR can play the role of quality signal, and some scholars have proved that CSR behavior is related to product quality [10,11]. In recent years, the occurrence of various default events has not only brought adverse effects to enterprises, but also brought adverse effects to the whole supply chain. And CSR can enhance the value of enterprises [12], so it is of great practical significance to discuss the internal decision-making of CSR as a quality signal from the perspective of supply chain. At present, the research focuses on CSR from two perspectives. The first one is that CSR is the degree of concern of enterprises to stakeholders, and it will not affect the operating costs and market demand of enterprises. CSR is characterized as an exogenous variable. The other depicts social responsibility as an investment behavior of supply chain enterprises, and CSR as an endogenous variable. This paper considers both types of CSR, and studies the conditions for manufacturers to implement CSR strategies to realize the quality information transmission function of supply chain enterprises based on retailers' CSR awareness.

To sum up, this paper constructs a two-stage supply chain including manufacturers, retailers and consumers. Combined with the intuitive inference of signaling theory about CSR and the characteristics of retailers' awareness of CSR, this paper analyzes the conditions for CSR strategy to realize the function of quality information transmission in supply chain, and further analyzes the differences of strategies and performance of supply chain members in different situations.

2 MODEL DESCRIPTION

This section considers a two-stage supply chain consisting of a manufacturer M, a retailer R and consumers. Among them, the retailer R has a certain sense of social responsibility. He thinks that he should be responsible to stakeholders, so he not only pursues economic interest, but also consciously pays attention to the interests of consumers; the products produced by manufacturers are divided into two types: high quality (H) and low quality (L). Assuming that quality is the manufacturers' private information, retailers and consumers do not know the true quality type of manufacturers, but manufacturers can send quality signals to retailers and consumers through their observable CSR actions y to improve their quality beliefs. That is to say, retailers and consumers modify the prior probability $\mu_0 = P_r(M = H)$ to the posterior belief $\mu = P_r(M = H \mid y)$ according to observed y.

For the convenience of analysis, this article proposes the following hypotheses:

(1) Standardize the market capacity to 1. In addition, consumers' heterogeneous utility perception δ of the expected quality level of products is evenly distributed at [0, 1].

(2) The marginal CSR costs of two types are denoted as a_H and a_L, $a_L > a_H$. And the utility provided by H-type and L-type products to consumers is v_H and v_L respectively. However, the marginal production cost of products is c_m, $v_H > v_L > c_m$. Let the retailer's marginal cost of sales be c_r, which is smaller than the product utility.

Each actor in the supply chain has the following decision order:

Firstly, manufacturers choose whether to share private quality information, and determine CSR level y and wholesale price ω. When y = 0, it means no sharing.

Secondly, retailers form the posterior belief μ after observing y, thus forming market demand expectation to decide their order quantity q;

Finally, consumers decide whether to buy or not according to Bayesian quality belief μ and retail price p.

Furthermore, the decision-making behavior of each actor is as follows:

(1) Market demand: The expected utility of products formed by consumers δ according to the posterior belief μ modified by CSR level y is $v = \mu v_H + (1 - \mu)v_L$. For a given retail price p, the remaining consumption expectation is $E_\delta = \delta v - p$. Therefore, the market demand implied by the purchase condition $E_\delta > 0$ is $q = 1 - P/v$.

On the basis of vertical transmission of quality information in supply chain enterprises, this paper considers the realistic problem that retailers have different degrees of social responsibility consciousness. Therefore, this variable is introduced into the model. The awareness of corporate social responsibility is expressed through the consumer surplus of corporate stakeholders [13]. Consumer's surplus is the difference between the highest price that consumers are willing to pay for a product and the actual market price paid for the product, which is expressed as follows:

$$w = \int_{Pmin}^{pmax} qdp = \int_{v(1-q)}^{v} \left(1 - P/v\right)dp = \frac{(v - p)^2}{2v}$$

Retailer: Under the given wholesale price ω and the same posterior belief μ as consumers, which is corrected by CSR level y, the retail price P is determined to maximize profits. The expression is:

$$\max(\omega, \ \mu) = (p - \omega - c_r)\left(1 - P/v\right) + \frac{s(v - p)^2}{2v}$$

Manufacturer: According to the retailer's strategy p = p (ω, μ) and the reaction function μ = μ (y) of posterior belief to CSR level y, the manufacturer determines CSR level to realize quality information sharing, that is, he chooses CSR level y (y=0 or y>0) and wholesale price ω to realize profit maximization, and his goal can be described as follows:

$$\max\pi = \ (\omega \ (\mu) \ -c_m) \ (1 - \frac{p(\omega(\mu), \mu)}{v(\mu)}) - ay$$

3 Model solving

3.1 Information symmetry situation

When information is symmetrical, retailers and consumers make decisions based on accurate product quality information.

Proposition 1: When the information is symmetrical, different types of manufacturers can be directly observed, and the equilibrium strategy and profit are expressed as:

(1) Manufacturer's CSR is $y_L^* = y_H^* = 0$, and the wholesale price is:

$$\omega_H^* = \frac{v_H + c_m - c_r}{2}, \omega_L^* = \frac{v_L + c_m - c_r}{2}$$

(2) Retailer's retail price is:

$$p_H^* = \frac{-3v_H + 2sv_H - c_m - c_r}{2(-2 + s)}$$

$$p_L^* = \frac{-3v_L + 2s v_L - c_m - c_r}{2(-2 + s)}$$

(3) Manufacturer's profit :

$$\pi_{M-H}^* = \frac{(v_H - c_m - c_r)^2}{4(2 - s) v_H}$$

$$\pi_{M-L}^* = \frac{(v_L - c_m - c_r)^2}{4(2 - s) v_L}$$

Retailer's profit:

$$\pi_{R-H}^* = \frac{(v_H - c_m - c_r)^2}{8(2 - s) v_H}$$

$$\pi_{R-L}^* = \frac{(v_L - c_m - c_r)^2}{8(2 - s) v_L}$$

When the manufacturer is H-type, the consumer belief $\mu = 1$, and the product utility is v_H. Given the wholesale price ω, the retailer chooses the optimal retail price p to maximize profits, and the decision objective is expressed as:

$$\max(\omega, \ \mu) = (p - \omega - c_r)\left(1 - \frac{P}{v_H}\right) + \frac{s(v_H - p)^2}{2v_H} \tag{1}$$

The retail price and order quantity obtained by first-order conditions are:

$$p = \frac{-v_H + sv_H - \omega - c_r}{-2 + s}$$

$$q = \frac{-v_H + \omega + c_r}{(-2 + s)v_H} \tag{2}$$

Given the CSR level y, H-type manufacturer chooses the best ω to maximize profits, and the decision objective is expressed as follows:

$$\max\pi = \left(\omega(\mu) - c_m\right)\left(1 - \frac{p(\omega(\mu), \mu)}{v_H(\mu)}\right) - a_H y \tag{3}$$

The wholesale price obtained by first-order conditions is:

$$\omega_H = {v_H + c_m - c_r}/{2} \tag{4}$$

Substituting formula (4) into formula (3), the profit of H-type manufacturer is:

$$\pi^*_{M-H} = {(v_H - c_m - c_r)^2}/{4(2-s)\,v_H} - a_H y_H$$

At last, the H-type manufacturer decides the CSR level y, and the decision target is maxπ.

Obviously, the best decision is $y^*_H = 0$, and the profit is π^*_{M-H}. Substituting formula (4) into formula (2) to obtain retail price P^*_H, substituting P^*_H into formula (1) to obtain the retailer's profit π^*_{R-H}. For L-type manufacturer, similar equilibrium results can be obtained.

Proposition 1 shows that when the information is symmetric, the manufacturer's optimal CSR level is zero. In other words, the manufacturer does not need to use CSR to send quality signals.

Comparing the manufacturer's earnings of the two quality types, it can be concluded that $\pi^*_{M-H} \geq \pi^*_{M-L}$. This means that high quality brings high profits to manufacturers. At the same time, by comparing the profits of retailers, it is found that when $\pi^*_{R-H} \geq \pi^*_{R-L}$. For convenience of explanation, if the function $\pi(v) = {(v - c_m - c_r)^2}/{4(2-s)v}$ is introduced, then $\pi^*_{M-H} = \pi(v_H)$, $\pi^*_{M-L} = \pi(v_L)$. And it is easy to prove that π (v) strictly increases with respect to v $\in (0, +\infty)$.

3.2 Separation equilibrium

In this case, due to the asymmetry of product quality type information of two manufacturers, consumers can only revise their quality belief according to manufacturers' CSR level, and then affect the product supply. Based on the consumers' reaction, different types of manufacturers have the motivation to transmit or hide their own types. This is a dynamic game problem under incomplete information, which will be solved by refined Bayesian equilibrium. The following describes the separation equilibrium of the model under asymmetric information.

Firstly, the necessary conditions for the existence of separation equilibrium are discussed. Lemma 1: The existence conditions of separation equilibrium （y^{S*}_L, y^{S*}_H） are (1) $y^{S*}_L = 0$, (2) when y = 0, μ (y) = 0; When y$\geq y^{S*}_H$, μ (y) = 1.

It is proved that if there is separation equilibrium （y^{S*}_L, y^{S*}_H）, given that L-type manufacturer implements CSR of y^{S*}_L, the afterthought of the consumer is corrected to μ (y) = 0, thus the product utility is v＝v_L. At this time, the optimal CSR level of L-type manufacturer is y^{S*}_L＝0, that is, CSR will not be implemented, and conclusion (1) holds. According to the equilibrium of root separation, μ（y^{S*}_L）＝0, μ（y^{S*}_H ）＝1, combined with the monotony of posterior belief, it is easy to prove that the conclusion (2) holds. Lemma 1 is proved.

Then, this section discusses the sufficient conditions for the existence of separation equilibrium, and gives a specific description of separation equilibrium.

Proposition 2: The following strategy combinations and posterior beliefs constitute the

separation equilibrium:

(1) Manufacturer's CSR level is $y_L^{S*}=0$, $y_H^{S*} \in [\pi(v_H) - \pi(v_L)/_{a_L}, \quad \pi(v_H) - \pi(v_L)/_{a_H}]$. Wholesale price: $\omega_H^{S*} = v_H + c_m - c_r/_2, \omega_L^{S*} = v_L + c_m - c_r/_2$

(2) Retailer's retail price:

$$p_H^{S*} = \frac{-3v_H + 2sv_H - c_m - c_r}{2(-2+s)}$$

$$p_L^{S*} = \frac{-3v_L + 2sv_L - c_m - c_r}{2(-2+s)}$$

(3) The posterior belief is that if $y \geq y_H^{S*}$, $\mu = 1$; if $y < y_H^{S*}$, $\mu = 0$. Manufacturer's profit is

$$\pi_{M-H}^{S*} = \pi(v_H) - a_H y_H^{S*}, \pi_{M-L}^{S*} = \pi(v_L).$$

The profit of the retailer is $\pi_{R-H}^{S*} = \pi(v_H)/_2, \pi_{R-L}^{S*} = \pi(v_L)/_2$.

Proof: Let y_H^{S*} be a CSR level of real separation of H-type manufacturer. On one hand, given the posterior belief (3), there is $\mu = 0$ on the path $y < y_H^{S*}$. Therefore, both manufacturers get the maximum profit on this path at $y = 0$: $\pi_{M-H}(0) = \pi_{M-L}(0) = \pi(v_L)$, On the path $y \geq y_H^{S*}$, there is $\mu = 1$, which shows that both manufacturers get the maximum profit on this path at $y = y_H^{S*}$. For H-type manufacturer, when $\pi_{M-H}(y_H^{S*}) \geq \pi_{M-H}(0)$, there is $y \in D_H = [0, y_1] = [0, \pi(v_H) - \pi(v_L)/_{a_H}]$. The optimal strategy of H-type manufacture is $y = y_H^{S*}$. Secondly, for L-type manufacturer, when $\pi_{S-L}(y_H^{S*}) \leq \pi_{S-L}(0)$, it is equivalent to $y \in D_L = [y_2, +\infty] = [\pi(v_H) - \pi(v_L)/_{a_L}, +\infty]$. Due to $a_L > a_H$ and $y_2 < y_1$, when $y \in D_H = [0, y_1]$, the optimal CSR level of H-type manufacturer is $y = y_H^{S*}$, and that of L-type manufacturer is $y = 0$. It is easy to know the wholesale price, retail price and profit of each member. On the other hand, given the strategies (1) and (2) of the manufacturer and retailer, the posterior belief as shown in (3) satisfies the necessary conditions of proposition 1. Therefore, the posterior belief can be obtained.

Proposition 1 depicts the separation equilibrium of CSR signaling game model. When implementing CSR, the key to whether upstream enterprises can share private quality information through CSR action is the existence of separation equilibrium in the model. Only when the CSR level implemented by upstream enterprises is moderate, the product quality information can be effectively shared only within the appropriate level range. Therefore, consumers and retailers can accurately infer the manufacturer's quality type through CSR level, which proves theoretically that CSR as a quality signal means is feasible for manufacturers to indirectly share private quality information in the supply chain.

3.3 comparative analysis

After confirming CSR behavior as a feasible means of quality information sharing, the following conclusions can be drawn by comparing the strategies and performance of members in the two situations.

Proposition 3: Retailers' strategies in the two situations are exactly the same, but H-type manufacturer will implement higher CSR behaviors in asymmetric situations, and thus lose

profits.

Proof: According to Propositions 1 and 2, it is easy to get $\pi_{R-i}^* = \pi_{R-i}^{S*}$, $p_i^* = p_i^{S*}$, $q_i^* = q_i^{S*}$ (i=H,L), $y^{S*} > y^* = 0$, $\pi_{M-H}^* - \pi_{M-H}^{S*} = \frac{aH}{aL} * (\pi_M^*(v_H) - \pi_M^*(v_L))$.

Proposition 3 shows that under incomplete information, the H-type manufacturer's CSR behavior is "distorted" upwards and therefore suffers loss of profits. It can also be explained that the H-type manufacturer proves the signal cost of its type by implementing CSR. The stronger the awareness of CSR of retailers, the higher the information cost of H-type manufacturers to realize quality information sharing through CSR.

Proposition 4: Retailers' awareness of social responsibility is inversely proportional to their economic profits, but directly proportional to the profits of the corresponding H-type and L-type manufacturers. The stronger the awareness of CSR of retailers, the greater the welfare of consumers.

Proof: $\dfrac{\partial \pi_{R-H}^{S\text{纯}}}{\partial s} = \dfrac{s(v_H - c_m - c_r)^2}{4(-2+s)^3 v_L} < 0$、 $\dfrac{\partial \pi_{R-L}^{S\text{纯}}}{\partial s} = \dfrac{s(v_L - c_m - c_r)^2}{4(-2+s)^3 v_L} < 0$、

$\dfrac{\partial w}{\partial s} = -\dfrac{(-v + c_m + c_r)^2}{4(-2+s)^3 v} > 0$、 $\dfrac{\partial \pi_{M-L}^{S*}}{\partial s} = \dfrac{(c_m + c_r - v_L)^2}{4(2-s)^2 v_L} > 0$、

$\dfrac{\partial \pi_{M-H}^{S*}}{\partial s} = \dfrac{a_L(c_m + c_r - v_H)^2 v_L + a_H(v_H - v_L)(c_m^2 + 2c_m c_r + c_r^2 - v_H v_L)}{4(-2+s)^2 a_L v_H v_L} > 0$

The proposition shows that whether the manufacturer type is high or low, its corresponding retailer's economic profit is inversely proportional to corporate social responsibility awareness. Therefore, retailers don't have the motivation to raise their awareness of social responsibility. At the same time, it is found that the stronger the awareness of corporate social responsibility of retailers, the greater the surplus of consumers and the greater the profits of manufacturers. When retailers fulfill their social responsibility, their economic interests will give in to the social interests and manufacturers' profits in the supply chain, which is the fundamental reason why many enterprises lack the awareness of social responsibility in reality.

4 CONCLUDING REMARKS

This paper constructs a two-level supply chain game model including manufacturers, retailers and consumers, studies the conditions for realizing the quality information transmission function of supply chain enterprises by CSR strategy, and further analyzes how to transmit their private quality information to the downstream under the real background that retailers have different degrees of social responsibility consciousness.

The research results show that in asymmetric situations, manufacturers can transmit their own quality information through a certain level of CSR behavior, but profits will be lost, and the lost part can be understood as the certification costs of H-type manufacturers in order to indicate their own types. No matter the type of manufacturer is high or low, its corresponding retailers don't have the motivation to raise the awareness of social responsibility, which is the fundamental reason why many enterprises lack the awareness of social responsibility in reality. These results provide economic and theoretical references for the information sharing

strategies of competitive enterprises in supply chain, and enrich the indirect sharing methods of product quality information. It is pointed out that the research channel in this paper is single, and the quality information transmission of mixed channel market conditions can be studied in the future.

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