A Model on Information Sharing by Social Responsibility in Supply Chain

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Abstract: This paper constructs a two-level supply chain decision model involving one manufacturer, one retailer and consumers. The manufacturer owns private information about product quality, and signals it by corporate social responsibility (CSR) behavior. The retailer undertakes CSR with the manufacturer. In order to investigate the role of CSR on signaling quality, and the influence of the retailer's CSR-sharing behavior, this paper builds an information sharing model. The results show that under certain conditions, the retailer's CSR-sharing behavior does not have the impact on the manufacturer signals its quality information, and the manufacturer's CSR level helps to promote the retailer's investment in CSR. The results provide manufactures' managers with an implication on choosing an indirect way to share quality information, and disclosing quality information as much as possible.

Keywords: asymmetric information; corporate social responsibility; separation equilibrium

1 INTRODUCTION

With the development of supply chain management and the maturity of information technology (such as EDI and POS), information sharing plays an increasingly important role in supply chain, and the value of information sharing in supply chain has been recognized in previous studies [1-3]. The fact that supply chain enterprises have the motivation to share information has also become a consensus [4,5]. The current researches on supply chain information sharing have made great progress, which can be summarized as the horizontal competition [6,7], the prior incentive of vertical transmission [8,9], and the post-horizontal competition of demand information sharing [10], etc. But these studies mainly focus on the relation between information sharing and incentives, which belongs to direct information sharing. Moreover, it is assumed that the sharing cost is not included and there is no fake information among enterprises. However, it is difficult to satisfy the conditions of reality. It is necessary to investigate indirect information sharing.

According to the view of Information Economics, players with private information can transmit private information to others via observable behavior. Some economic literature revealed advertising, price, and quality assurance can achieve signal transmission under appropriate conditions. However, because CSR can effectively improve products demand

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when consumers have CSR-preference, Li believes that CSR is different from other medias, and establishes a game model using CSR as signal transmission medium [11], and obtained the separating equilibrium. But this model, in which only the upstream performs responsibility, does not investigate the situation of both upstream and downstream performing responsibility.

The simultaneous implementation of CSR by the upstream and the downstream was discussed only in studies of information symmetry supply chain represented by Ni [12], who systematically studied the optimal strategy of two players under three cases (only the upstream performing responsibility, only the downstream performing responsibility, both the upstream and the downstream performing responsibility). Therefore, in order to fill the gap of the study of the upstream and the downstream performing CSR in the information asymmetry supply chain, this paper follows Li's view on CSR signals quality and makes an in-depth modeling research on the third case of Ni's study. The modeling results mainly answer the following questions: how the manufacturer indirectly shares the quality information by its social responsibility strategy? How retailer's CSR-sharing behavior affects the manufacturer's social responsibility strategy?

2 MODEL DESCRIPTION

We construct a two-level supply chain consist of a manufacturer M, a retailer R and consumer. Due to product quality differences, manufacturers are divided into high quality (H-type) manufacturer and low quality (L-type) manufacturer. The type of quality is manufacturer's personal information, and manufacturers' type can be observed by the retailer and consumers via its CSR level y_M. According to the y_M, retailer and consumers correct the prior probability $\mu_0 = P(M = H)$ to the posterior belief $\mu = P(M = H|y_M)$. Assuming that the retailer's and H-type, L-type manufacturers' CSR cost respectively $C_R = \frac{1}{2}k_R{y_R}^2$, $C_{M-i} = \frac{1}{2}k_{M-i}{y_{M-i}}^2$, $i = H, L$, and $k_{M-L} > k_{M-H} > 1$. The utility brought to consumers by the products of H-type and L-type manufacturers is v_H and v_L respectively, $v_H \geq v_L$, and consumers according to the posterior belief $\mu(=\mu(y_M))$ formed the products expected utility, is $V = \mu v_H + (1-\mu)v_L$. Assuming that consumers in the market all have CSR preferences θ. When the manufacturer's and the retailer's CSR level are y_M and y_R respectively, the consumer's reserve utility for products is v, which is uniformly distributed on $[\theta y, V + \theta y]$, where $y = y_M + y_R$. Supposing that the two types of manufacturers' products marginal production are c_H and c_L respectively, and $c_H > c_L$. Without loss of generality, the cost of sales is 0.

The consequence of players' decision in the supply chain is as follows: the first stage: natural select manufacturer type; the second stage: manufacturer decides CSR level y_M. The third stage: the retailer formed a posterior Bayesian quality belief $\mu = P(M = H|y_M)$ based on the observed manufacturer CSR level y_M, and determine optimal CSR level y_R; The fourth stage: the manufacturer decides the wholesale price of the product. The fifth stage: the retailer decides the retail price p and the order quantity q. Finally, consumers decide whether to buy products according to their reserve utility v and the retail price p. Specific decision-making behaviors are as following:

2.1 Demand.

Whether consumers buy a product depends on its reserve utility v and the retail price p. For a retail price p, the consumer surplus $E = v - p$. Therefore, when the $\mu = 1$ (i.e., $V = v_H$), the demand is $q = q(\mu) = 1 + \frac{\theta(y_M + y_R) - p}{v_H}$; when the $\mu = 0$ (i.e., $V = v_L$), the demand is $q = q(\mu) = 1 + \frac{\theta(y_M + y_R) - p}{v_L}$.

2.2 Retailer decision-making.

Firstly, gave the wholesale price w_i, manufacturer's CSR level y_{M-i}, retailer's CSR level y_{R-i} and the profits function, decide the optimal retail price $p = p(w_i, \mu)$ to maximize the retailer's profit. The decision objective is

$$\max_{p_i} \pi_{R-i}(p_i, y_{R-i}) = \left(p_i(w_i, \mu) - w_i\right) q(y) - \frac{1}{2} k_R {y_{R-i}}^2, i = H, L \quad (1)$$

Then, under the posterior belief $\mu = \mu(y_M)$ modified by the manufacturer's CSR level and its profit function $max\ \pi_{R-i}(p_i, y_{R-i})$, decide the optimal CSR level y_R to maximize the profit.

2.3 Manufacturer decision-making.

First, given the retailer's optimal retail price p_i, decide the optimal wholesale price $w = w(\mu)$ to maximize the manufacturer's profit. The decision objective is

$$\max_{w_i} \pi_{M-i}(w_i, y_{M-i}, y_{R-i}) = (w_i - c_i) q(y_{R-i}, y_{M-i}) - \frac{1}{2} k_{M-i} {y_{M-i}}^2, i = H, L \quad (2)$$

Then, given the optimal wholesale price $w_i = w_i(\mu)$, retailer's optimal CSR strategy y_R and sales price p, according to the posterior belief of CSR response function $\mu = \mu(y_M)$ and the decision objective $\max \pi_{M-i}(w_i(\mu), y_{M-i}, y_{R-i})$, decide the optimal CSR level y_{M-i} to maximize the profit. Next, use Perfect Bayesian Equilibrium to solve the quality signal game model.

3 MODELLING AND ANALYSIS

3.1 Information symmetry situation

In order to compare with the strategies of the manufacturer and the retailer in the situation of information asymmetry. We studied the situation of information symmetry as a benchmark.

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

Proposition 1: In the situation of information symmetry, the equilibrium strategies and profits of H-type and L-type manufacturers and retailers are as follows:

The manufacturer's CSR strategy and wholesale price:

$$y_{M-H}^{*}=\frac{16k_R^2v_H\theta(v_H-c_H)}{k_{M-H}(8k_Rv_H-\theta^2)^2-16k_R^2\theta^2v_H}$$

$$y_{M-L}^{*}=\frac{16k_R^2v_L\theta(v_L-c_L)}{k_{M-L}(8k_Rv_L-\theta^2)^2-16k_R^2\theta^2v_L}$$

$$w_H^{*}=\frac{4k_{M-H}k_Rv_H^2(8k_Rv_H-\theta^2)+c_Hk_{M-H}(\theta^4+32k_R^2v_H^2-12k_R\theta^2v_H)-16k_R^2\theta^2v_Hc_H}{k_{M-H}(8k_Rv_H-\theta^2)^2-16k_R^2\theta^2v_H}$$

$$w_L^{*}=\frac{4k_{M-L}k_Rv_L^2(8k_Rv_L-\theta^2)+c_Lk_{M-L}(\theta^4+32k_R^2v_L^2-12k_R\theta^2v_L)-16k_R^2\theta^2v_Lc_L}{k_{M-L}(8k_Rv_L-\theta^2)^2-16k_R^2\theta^2v_L}$$

The retailer's CSR strategy and retail price:

$$y_{R-H}^{*}=\frac{k_{M-H}\theta(v_H-c_H)(8k_Rv_H-\theta^2)}{k_{M-H}(8k_Rv_H-\theta^2)^2-16k_R^2\theta^2v_H}$$

$$y_{R-L}^{*}=\frac{k_{M-L}\theta(v_L-c_L)(8k_Rv_L-\theta^2)}{k_{M-L}(8k_Rv_L-\theta^2)^2-16k_R^2\theta^2v_L}$$

$$p_H^{*}=\frac{6k_{M-H}k_Rv_H^2(8k_Rv_H-\theta^2)+c_Hk_{M-H}(\theta^4+16k_R^2v_H^2-10k_R\theta^2v_H)-16k_R^2\theta^2v_Hc_H}{k_{M-H}(8k_Rv_H-\theta^2)^2-16k_R^2\theta^2v_H}$$

$$p_L^{*}=\frac{6k_{M-L}k_Rv_L^2(8k_Rv_L-\theta^2)+c_Lk_{M-L}(\theta^4+16k_R^2v_L^2-10k_R\theta^2v_L)-16k_R^2\theta^2v_Lc_L}{k_{M-L}(8k_Rv_L-\theta^2)^2-16k_R^2\theta^2v_L}$$

The manufacturer's and the retailer's profits:

$$\pi_{M-H}^{*}=\frac{8k_{M-H}k_R^2(v_H-c_H)^2v_H}{k_{M-H}(8k_Rv_H-\theta^2)^2-16k_R^2\theta^2v_H}$$

$$\pi_{M-L}^{*}=\frac{8k_{M-L}k_R^2(v_L-c_L)^2v_L}{k_{M-L}(8k_Rv_L-\theta^2)^2-16k_R^2\theta^2v_L}$$

$$\pi_{R-H}^{*}=\frac{k_{M-H}^2k_R(v_H-c_H)^2(8k_Rv_H-\theta^2)^3}{2[k_{M-H}(8k_Rv_H-\theta^2)^2-16k_R^2\theta^2v_H]^2}$$

$$\pi_{R-L}^{*}=\frac{k_{M-L}^2k_R(v_L-c_L)^2(8k_Rv_L-\theta^2)^3}{2[k_{M-L}(8k_Rv_L-\theta^2)^2-16k_R^2\theta^2v_L]^2}$$

Proof: when the manufacturer is H-type, consumer belief $\mu=1,\ q=1+\frac{\theta(y_M+y_R)-p}{v_H}$. Using backward induction and First Order Optimality Condition (FOC), solving the manufacturer and retailer's decision-making functions. Obtained $p_H^{*}=\frac{v_H+w_H+\theta(y_{M-H}+y_{R-H})}{2}$, $w_H^{*}=\frac{c_H+v_H+\theta(y_{M-H}+y_{R-H})}{2}$, $y_{R-H}^{*}=\frac{\theta^2y_{M-H}+\theta(v_H-c_H)}{8k_Rv_H-\theta^2}$, $y_{M-H}^{*}=\frac{16k_R^2v_H\theta(v_H-c_H)}{k_{M-H}(8k_Rv_H-\theta^2)^2-16k_R^2\theta^2v_H}$. Then, substituting y_{M-H}^{*} into y_{R-H}^{*} yields the retailer optimal CSR level $y_{R-H}^{*}=\frac{k_{M-H}\theta(v_H-c_H)(8k_Rv_H-\theta^2)}{k_{M-H}(8k_Rv_H-\theta^2)^2-16k_R^2\theta^2v_H}$, substituting y_{M-H}^{*}, y_{R-H}^{*} into w_H^{*} yields the optimal wholesale price $w_H^{*}=\frac{4k_{M-H}k_Rv_H^2(8k_Rv_H-\theta^2)+c_Hk_{M-H}(\theta^4+32k_R^2v_H^2-12k_R\theta^2v_H)-16k_R^2\theta^2v_Hc_H}{k_{M-H}(8k_Rv_H-\theta^2)^2-16k_R^2\theta^2v_H}$, substituting y_{M-H}^{*}, y_{R-H}^{*}, w_H^{*} into p_H^{*} yields the optimal retail price $p_H^{*}=\frac{6k_{M-H}k_Rv_H^2(8k_Rv_H-\theta^2)+c_Hk_{M-H}(\theta^4+16k_R^2v_H^2-10k_R\theta^2v_H)-16k_R^2\theta^2v_Hc_H}{k_{M-H}(8k_Rv_H-\theta^2)^2-16k_R^2\theta^2v_H}$, and the optimal order quantity $q_H^{*}=\frac{2k_{M-H}k_R(v_H-c_H)(8k_Rv_H-\theta^2)}{k_{M-H}(8k_Rv_H-\theta^2)^2-16k_R^2\theta^2v_H}$. Finally, substituting the optimal retail price p_H^{*}, the optimal

wholesale price w_H^* and the optimal CSR level y_{R-H}^* into the retailer's and manufacturer's profit functions respectively. Obtained the retailer's maximum profit $\pi_{R-H}^* = \frac{k_{M-H}^2 k_R (v_H - c_H)^2 (8k_R v_H - \theta^2)^3}{2[k_{M-H}(8k_R v_H - \theta^2)^2 - 16k_R^2 \theta^2 v_H]^2}$ and manufacturer's maximum profit $\pi_{M-H}^* = \frac{8k_{M-H} k_R^2 (v_H - c_H)^2 v_H}{k_{M-H}(8k_R v_H - \theta^2)^2 - 16k_R^2 \theta^2 v_H}$. The L-type manufacturer's optimal decision and maximum profit can be proved in the same way.

Proposition 1 shows that when the information is symmetrical, the H-type manufacturer's and the L-type manufacturer's optimal strategy expression have the same structure except the expected utility v_i and the cost coefficient $k_{M-i},\ i = H, L$.

Comparing the manufacturer's profits 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. Similarly, it easy to find that $\pi_{R-H}^* \geq \pi_{R-L}^*$. Further, the manufacturer's and the retailer's profits increases as the consumers' CSR-preference increases, which means they have the motivation to perform CSR as much as possible.

3.2 Information asymmetry situation

In this case, the manufacturer's product quality-information is asymmetrical. Consumers and the retailer can only revise the manufacturer's quality-information through the manufacturer's CSR behavior. Therefore, different types of manufacturers have the motivation to disclose or hide the information about their types (product quality). Using Perfect Bayesian Equilibrium (PBE) to solve the problem. Predictably, when the separation equilibrium exists, the strategies of all players revealed how the manufacturer makes decisions can transmit private information successfully in the supply chain of the retailer invests social responsibility.

Proposition 2: When $y_2 \leq y_4$, the separation equilibrium of strategies and posterior belief is shown as follows:

The manufacturer's CSR and wholesale pricing strategy:

$$y_{M-L}^{S*} = \frac{16k_R^2 v_L \theta (v_L - c_L)}{k_{M-L}(8k_R v_L - \theta^2)^2 - 16k_R^2 \theta^2 v_L}$$

$$y_{M-H}^{S*} \in \left[max\left\{y_{M-H}^*,\ y_2\right\}, y_4\right]$$

$$w_{M-L}^{S*} = \frac{4k_{M-L}k_R v_L^2 (8k_R v_L - \theta^2) + c_L k_{M-L}(\theta^4 + 32k_R^2 v_L^2 - 12k_R \theta^2 v_L) - 16k_R^2 \theta^2 v_L c_L}{k_{M-L}(8k_R v_L - \theta^2)^2 - 16k_R^2 \theta^2 v_L}$$

$$w_{M-H}^{S*} = \frac{c_H(4k_R v_H - \theta^2) + 4k_R v_H (v_H + \theta y_{M-H}^{S*})}{8k_R v_H - \theta^2}$$

The retailer's CSR and sale price strategy:

$$y_{R-L}^{S*} = \frac{k_{M-L}\theta (v_L - c_L)(8k_R v_L - \theta^2)}{k_{M-L}(8k_R v_L - \theta^2)^2 - 16k_R^2 \theta^2 v_L}$$

$$y_{R-H}^{S*} = \frac{\theta^2 y_{M-H}^{S*} + \theta (v_H - c_H)}{8k_R v_H - \theta^2}$$

$$p_L^{S*} = \frac{6k_{M-L}k_R v_L^2 (8k_R v_L - \theta^2) + c_L k_{M-L}(\theta^4 + 16k_R^2 v_L^2 - 10k_R \theta^2 v_L) - 16k_R^2 \theta^2 v_L c_L}{k_{M-L}(8k_R v_L - \theta^2)^2 - 16k_R^2 \theta^2 v_L}$$

$$p_H^{S*} = \frac{c_H(2k_R v_H - \theta^2) + 6k_R v_H (v_H + \theta y_{M-H}^{S*})}{8k_R v_H - \theta^2}$$

The manufacturer's and the retailer's profits:

$$\pi_{M-L}^{S*} = \frac{8k_{M-L}k_R^2(v_L - c_L)^2 v_L}{k_{M-L}(8k_R v_L - \theta^2)^2 - 16k_R^2\theta^2 v_L}$$

$$\pi_{M-H}^{S*} = \frac{8{k_R}^2 v_H (v_H + \theta y_{M-H}^{S*} - c_H)^2}{(8k_R v_H - \theta^2)^2} - \frac{1}{2}k_{M-H}{y_{M-H}^{S*}}^2$$

$$\pi_{R-L}^{S*} = \frac{k_{M-L}^2 k_R (v_L - c_L)^2 (8k_R v_L - \theta^2)^3}{2[k_{M-L}(8k_R v_L - \theta^2)^2 - 16k_R^2\theta^2 v_L]^2}$$

$$\pi_{R-H}^{S*} = \frac{k_R (v_H + \theta y_{M-H}^{S*} - c_H)^2}{2(8k_R v_H - \theta^2)}$$

Posterior belief:

When $y \geq y_{M-H}^{S*}$, consumer faith $\mu = 1$, when $0 < y < y_{M-H}^{S*}$, consumer faith $\mu = 0$.

Proof: When a L-type manufacturer performing a higher CSR level than it should (adverse selection), the posterior belief $\mu = 1$. Firstly, according to the profits function

$$\max_{p_L'} \pi_{R-L}(\mu = 1)$$

$$= (p_L' - w_L')\left[1 + \frac{\theta(y_{M-L}' + y_{R-L}') - p_L'}{v_H}\right] - \frac{1}{2}k_R y_{R-L}'^2 \quad (3)$$

Using First Order Optimality Condition (FOC), yields the optimal retail price

$$p_L'^* = \frac{v_H + w_L' + \theta(y_{M-L}' + y_{R-L}')}{2} \quad (4)$$

And the demand is

$$q_L'^* = \frac{v_H - w_L' + \theta(y_{M-L}' + y_{R-L}')}{2v_H} \quad (5)$$

Secondly, the L-type manufacturer according to the optimal $p_L'^*$ and the profit function

$$\max_{w_L'} \pi_{M-L}(\mu = 1)$$

$$= (w_L' - c_L)\frac{v_H - w_L' + \theta(y_{M-L}' + y_{R-L}')}{2v_H} - \frac{1}{2}k_{M-L}{y_{M-L}'}^2 \quad (6)$$

Using First Order Optimality Condition (FOC), obtained the optimal wholesale price

$$w_L'^* = \frac{c_L + v_H + \theta(y_{M-L}' + y_{R-L}')}{2} \quad (7)$$

Then, the retailer according to the optimal retail price, the optimal wholesale price, and the profit function

$$\max_{y_{R-L}'} \pi_{R-L}(\mu = 1) =$$

$$\frac{(v_H - c_L)^2 + 2\theta(v_H - c_L)(y_{R-L}' + y_{M-L}') + \theta^2(y_{R-L}' + y_{M-L}')^2}{16v_H} - \frac{1}{2}k_R{y_{R-L}'}^2 \quad (8)$$

Using First Order Optimality Condition (FOC), obtained the optimal CSR level

$$y'^{*}_{R-L} = \frac{\theta^2 y'_{M-L} + \theta(v_H - c_L)}{8k_R v_H - \theta^2} \tag{9}$$

By substituting y'^{*}_{R-L} and w'^{*}_{L} into the manufacturer's profit function, the profit of L-type manufacturer is given by

$$\pi_{M-L}(\mu = 1) = \frac{8k_R^2 v_H (v_H + \theta y'_{M-L} - c_L)^2}{(8k_R v_H - \theta^2)^2} - \frac{1}{2} k_{M-L} {y'_{M-L}}^2 \tag{10}$$

Substituting y'^{*}_{R-L}, w'^{*}_{L}, q'^{*}_{L} and p'^{*}_{L} into retailer's profit function, the profit of the retailer is given by

$$\pi_{R-L}(\mu = 1) = \frac{k_R \left(v_H + \theta y'_{M-L} - c_L\right)^2}{2(8k_R v_H - \theta^2)} \tag{11}$$

To avoid L-type manufacturer adverse selection, and imitate H-type manufacturer. Condition $\pi^{*}_{M-L}(\mu = 1) \le \pi^{*}_{M-L}$ need to be fulfilled, namely

$$\frac{8k_R^2 v_H (v_H + \theta y'_{M-L} - c_L)^2}{(8k_R v_H - \theta^2)^2} - \frac{1}{2} k_{M-L} {y'_{M-L}}^2 \le \frac{8k_{M-L} k_R^2 (v_L - c_L)^2 v_L}{k_{M-L}(8k_R v_L - \theta^2)^2 - 16k_R^2 \theta^2 v_L} \tag{12}$$

In order to describe the separating equilibrium, supposing that y_1 and y_2 are the thresholds of the inequality. Predictably y_1 and y_2 are the functions of θ. Assuming that y_2 is the larger root. To realize separating equilibrium, the H-type manufacturer's CSR level needs to satisfy $y^{S*}_{M-H} \ge y_2$ or $y^{S*}_{M-H} \le y_1$. However, because of the posterior belief $\mu(y_M)$ nondecreasing character, $y^{S*}_{M-H} \ge y_2$ is the final result.

When the H-type manufacturer makes adverse selection, the posterior belief $\mu = 0$. Again, using backward induction method and First Order Optimality Condition (FOC) to find the appropriate CSR level, so that avoid H-type manufacturer adverse selection. And the condition is $\pi_{M-H} \ge \pi^{*}_{M-H}(\mu = 0)$, more specifically

$$\frac{8k_R^2 v_H (v_H + \theta y_{M-H} - c_H)^2}{(8k_R v_H - \theta^2)^2} - \frac{1}{2} k_{M-H} {y_{M-H}}^2 \ge \frac{8k_{M-H} k_R^2 (c_H - v_L)^2 v_L}{k_{M-H}(8k_R v_L - \theta^2)^2 - 16k_R^2 \theta^2 v_L} \tag{13}$$

The same, supposing that y_3 and y_4 are the thresholds of the inequality, and assuming that y_4 is the larger root. Only when $y^{S*}_{M-H} \in [y_3, y_4]$ can be the H-type manufacturer's CSR strategy realizes type separation successfully. When the CSR cost coefficient k_{M-L} of L-type manufacturer is larger than that of H-type manufacturer k_{M-H}, that is, $y_2 \le y_4$, the separation equilibrium exists.

Assuming that $(y^{S*}_{M-L,}\ y^{S*}_{M-H})$ is a separation equilibrium. From the above solution, when the CSR level of H-type manufacturers is in the interval $(-\infty, y_1)$ and $(y_2, +\infty)$, the L-type manufacturers cannot imitate H-type manufacturers. According to the posterior belief, it has the nondecreasing character, the optimal strategy is $y^{S*}_{M-L} = y^{*}_{M-L}$. Moreover, when the H-type manufacturer's CSR level is in the interval $[y_3, y_4]$, it will not make adverse selection. Therefore, H-type manufacturer's separation equilibrium strategy is $y^{S*}_{M-H} \in [\, y_2, y_4]$. Furthermore, considering the character of posterior beliefs. The optimal CSR strategy of

H-type manufacturers is $y_{M-H}^{S*} \in [max\{y_{M-H}^{*},\ y_2\}, y_4]$. Finally, combining the nondecreasing character of the posterior belief, we can obtain the posterior belief in equilibrium.

Proposition 2 solves the problem of how H-type manufacturers and L-type manufacturers performing CSR to achieve quality type separation under the circumstance that retailers' CSR strategy can improve demand, and gives the optimal strategies of L-type manufacturers and H-type manufacturers. It reveals that in the situation of downstream sharing CSR for upstream, separation equilibrium is still existing. In the separation equilibrium, on the one hand, because consumers and retailers accurately obtain manufacturer quality-information in the equilibrium path, the posterior belief is modified. On the other hand, the influence of the posterior belief's monotonicity on H-type and L-type manufacturer's CSR strategy contributes to the existence of separation equilibrium.

3.3 Comparative analysis

In order to describe the changes brought by information asymmetry to the strategies of manufacturers and retailers. Comparing Propositions 1 and 2, the following conclusions are obtained.

Proposition 3: The L-type manufacturer's and its downstream retailer's strategies are exactly the same, but H-type manufacturers and their downstream retailers will perform higher CSR levels in asymmetric situations, and lose profits.

Proof: According to Proposition 1 and Proposition 2, it is easy to obtain $y_{R-L}^{S*} = y_{R-L}^{*}$, $y_{M-L}^{S*} = y_{M-L}^{*}$, $\pi_{R-L}^{S*} = \pi_{R-L}^{*}$, $\pi_{M-L}^{S*} = \pi_{M-L}^{*}$, and $y_{R-H}^{S*} - y_{R-H}^{*}$, $y_{M-H}^{S*} > y_{M-H}^{*}$, $\pi_{R-H}^{S*} < \pi_{R-H}^{*}$, $\pi_{M-H}^{S*} < \pi_{M-H}^{*}$.

Proposition 3 shows the differences between strategies in the two situations. In the situation of information asymmetry, the H-type manufacturer's CSR level and its downstream retailer's CSR level tend to be distorted upward. This distortion of CSR level can be regarded as the cost of signal transmission.

It is worth noting that, according to $y_{R-H}^{*} = \frac{\theta^2 y_{M-H} + \theta(v_H - c_H)}{8k_R v_H - \theta^2}$ in Proposition 1 proof, the retailer's CSR level y_{R-H} increases as the manufacturer's CSR level y_{M-H} increases. Similarly, y_{R-L} increases as y_{M-L} increases. In equation (9), the retailer's CSR level $y_{R-L}^{\prime *}$ and $y_{R-H}^{\prime *}$ increases as the manufacturer's CSR level $y_{M-L}^{\prime}$ and $y_{M-H}^{\prime}$ increases. Which means that in information symmetry and information asymmetry two cases, the manufacturer's CSR level helps to promote the retailer's investment in CSR, and have no relation to upstream manufacturer's quality type. Thus, the upward distortion of H-type manufacturer's downstream retailer's CSR level can be seen as affected by the manufacturer's CSR behavior.

4 CONCLUSION

This paper constructs a two-level supply chain consisting of one manufacturer and one retailer, and investigates how the manufacturer indirectly shares the quality information by its social responsibility strategy and how the retailer's CSR-sharing behavior affects the manufacturer's

social responsibility strategy.

The result shows that a moderate CSR level signals a high quality level in the sense of a separate equilibrium (Proposition 2), and the manufacturer's CSR level to signal product quality helps to promote the retailer's investment in CSR. The results provide supply chain managers with an implication on choosing an indirect way to share quality information, and disclosing quality information as much as possible. And extend the study of corporate social responsibility-sharing in supply chains under information asymmetry condition.

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REFERENCES

[1] Shang, W., Ha, A. Y., & Tong, S. (2016) Information sharing in a supply chain with a common retailer. Management Science, 62(1): 245-263.

[2] Yu, M., & Cao, E. (2020) Information sharing format and carbon emission abatement in a supply chain with competition. International Journal of Production Research, 58(22): 6775-6790.

[3] Kadiyala, B., Özer, Ö., & Bensoussan, A. (2020) A Mechanism Design Approach to Vendor Managed Inventory. Management Science, 66(6): 2628-2652.

[4] Cui, R., Allon, G., Bassamboo, A., & Van Mieghem, J. A. (2015) Information sharing in supply chains: An empirical and theoretical valuation. Management Science, 61(11): 2803-2824.

[5] Teunter, R. H., Babai, M. Z., Bokhorst, J. A., & Syntetos, A. A. (2018) Revisiting the value of information sharing in two-stage supply chains. European Journal of Operational Research, 270(3): 1044-1052.

[6] Li, L. (2002) Information sharing in a supply chain with horizontal competition. Management Science, 48(9): 1196-1212.

[7] Ha, A. Y., Tong S. (2008) Contracting and information sharing under supply chain competition. Management Science, 54(4): 701-715.

[8] Li, T., Zhang, H. (2015) Information sharing in a supply chain with a make-to-stock manufacturer. Omega, 50(1): 115-125.

[9] De Giovanni, P. (2021) A dynamic supply chain game with vertical coordination and horizontal competition. International Transactions in Operational Research. (28)6: 3117-3146.

[10] Kembro, J., Näslund, D., & Olhager, J. (2017) Information sharing across multiple supply chain tiers: A Delphi study on antecedents. International Journal of Production Economics, 193, 77-86.

[11] Li, Y., Ni, D., Xiao, Z., & Tang, X. (2017) Signaling product quality information in supply chains via corporate social responsibility choices. Sustainability, 9(11), 2113.

[12] Ni, D., Li, K. W., & Tang, X. (2010) Social responsibility allocation in two-echelon supply chains: Insights from wholesale price contracts. European Journal of Operational Research, 207(3), 1269-1279.