

Product Quality Information Disclosure in a Two-Stage Supply Chain Considering Informed Consumers

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Abstract: The main question of this paper is to investigate how an upstream supplier shares his private information about product quality in a two-stage supply chain considering informed consumers. In order to capture the strategic role of CSR behaviors in product information signaling, this paper constructs a signaling model and totally characterize all the separating equilibriums. The results reveal motivation for quality-disclosing of CSR strategy under the condition of informed consumers. Managerial insights are also discussed.

1. Introduction

It is well known that information asymmetry is one of the main factors that lead to the low efficient operations in supply chains. For example, the bullwhip effect results in an inefficient stock allocation in supply chains. However, the development of information technology (such as EDI system) makes (demand) information sharing possible. As demand information sharing, a large group of authors show the significance of information sharing and analyze the incentives/motivations for the members of supply chain to share demand information^[1]. The general conclusion is that sharing downstream demand information improves supply chains' operational efficiency. This line of research implicitly assumes that the sharing is direct in the sense that downstream supply chain members report truly what they know about the demand-related information through some information systems. However, it is costly to build and operates a reliable and efficient information system.

When direct information sharing is limited, it is natural to find some indirect way. The literature^[2, 3] studied whether and how an upstream firm strategically but indirectly leak demand information between competitive downstream retailers through signaling models. Clearly, demand mainly depends on product quality which is usually known by an upstream firm but is uncertain for downstream retailers and final consumers. Then the demand information asymmetry may root in different expectations of downstream retailers and final consumers on product quality. If they have an identical expectation, the information asymmetry would be reduced.

We thus believe that in supply chain operations, an upstream firm can take some observable and costly actions (as signals) to make its downstream retailer and final consumers have the same expectation for the quality of their products and rule out the downstream demand information

asymmetry. It is admitted in economics literature that a firm can signal its product quality level via several ways of “wasteful spending” such as advertising, price and warranty. However, another common observation is that more and more firms engage in CSR operations. For example, according to Time magazine (2015), the Starbucks Corporation poured \$2.5 billion for launching the “University plan” to support employees for higher education without any requirement of the staff’s backing to work after graduation.

Voluntary disclosures of CSR commitments can be seen as a signal of a company's commitment to quality, we hypothesize that the CSR behavior of upstream enterprises is a tool to indicate the quality of their products and eliminate the information asymmetry between downstream retailers and final consumers. This raises the following key questions on supply chain operations. (1) Is there a level of CSR chosen by upstream companies to reveal its product quality? (2) If there is, how to affect the profitability of supply chain members? We use a signaling model in a two-stage supply chain to examine these issues.

To tackle these issues, we develop a two-stage supply chain framework and refer to the literature on signal games, in which upstream suppliers(she) sell products to downstream retailers(he) by a wholesale price contract, and retailer resell products to end consumers. Supplier knows the true quality level (correspondingly, high-quality or low-quality) of her products but retailer and some consumers do not (other consumers are fully informed). Further, suppliers transmit the quality of products to retailers and unwitting consumers by selecting costly CSR actions. With the notion of perfect Bayesian equilibrium, we demonstrate that in the context of segregated equilibrium, there exists a set of CSR levels in which the supplier can effectively transmit the real product quality information to both the retailer and unwitting consumers. In the presence of multiple equilibriums, selecting a unique minimum level of CSR to separate high-quality supplier from low-quality supplier requires the application of standard intuitive guidelines. Based on this unique equilibrium, we show that a higher proportion of informed consumers leads to decrease in the lowest CSR level (and thus the amount of “wasteful spending”) decrease and then increased profitability for supplier. This result implies that a reduction of final-market information asymmetry benefits the supplier with private quality information since it decreases the spending in CSR signals. Finally, we reveal that the marginal cost of CSR for high-quality (low-quality) supplier decreases (increases) the high-quality supplier’s profit, but does not have any impact on the profit of low-quality supplier. Thus, a high-quality supplier with a higher efficiency of CSR conducts (relative to a low-quality supplier) separates from a low-quality supplier with a higher level of profitability.

It is worth pointing out that the topic of CSR in supply chain has garnered significant attention in academic literature. The topics include management procedures to ensure compliance CSR requirements^[4], allocating CSR in supply chains^[5], empirically exploring the correlation between CSR conducts and supply chain operational performance^[6] and the factors/conditions for CSR management^[7], and mathematically analyzing the interplay between CSR conducts and product transactions^[8], and coordinating CSR conducts and product transaction^[9]. These studies incorporate CSR conducts into the classical framework of supply chain operations and mainly examine their strategic interactions and the corresponding performance implications with useful managerial insights in different settings of complete information. However, the above authors seldom put their focused on the function of CSR conducts in signaling product quality information in a supply chain context.

2. Model Description

Taking into account the two-stage supply chain with an upstream supplier (she) and a downstream retailer (he). There is a percent λ ($0 < \lambda < 1$) of informed consumers and a percent,

$1-\lambda$, of uninformed consumers in the end market. The supplier manufactures the products and knows whether the quality of the product is high(H) or low(L). Therefore, we divide our supplier into high-quality supplier and low-quality suppliers. Though retailer and unwitting customers do not know the real level of quality, they have a prior belief $\mu_0 = \Pr(S = H)$ and $1-\mu_0 = \Pr(S = L)$. However, the supplier can transmit quality information to the retailer and unwitting customers by observing CSR behavior. By observing CSR level $t(t \geq 0)$, the retailer and unwitting customers form a posterior belief $\mu = \Pr(S = H | t)$ and $1-\mu = \Pr(S = L | t)$. The retailer and supplier use a wholesale price contract to transact.

Suppose there is a high-quality product with v_H quality units (for example, durability for a certain period of time) while a low-quality product has v_L quality units. Customers differ in their willingness to pay of a quality unit. Suppose the willingness to pay is δ (δ is uniformly distributed on the interval $[0, 1]$). In addition, we assume that each customer buys no more than one product. Given the posterior belief $\mu = \Pr(S = H | t)$ and $1-\mu = \Pr(S = L | t)$, the expected quality unit of consumer is $v(\mu) = \mu v_H + (1-\mu)v_L$. Thus if customer δ buys a product at retail price p , the total value of each consumer expectations is: $E_\delta = \delta v(\mu) - p$. It means that all customers with δ 's pleased $\delta v(\mu) - p \geq 0$ and that the demand function can be induced:

$$q(\mu) = 1 - \frac{p}{v(\mu)}$$

What's more, when the quality is high, the need of informed consumers ($\mu = 1$) and uninformed consumers ($\mu = \Pr(S = H | t)$) are $q_1 = \lambda(1 - p/v_H)$ and $q_2 = (1-\lambda)(1 - p/v(\mu))$, respectively.

The order of decision is as follows. In stage 1, suppliers expect the most profit when they choose a wholesale price w and a CSR level t :

$$\max_{t,w} (w - c_s) q_i(\mu, p) - a_i t \quad (i = H, L).$$

Secondly, the retailer observes the t and w of the supplier's choice, forming a posterior belief $\mu = \Pr(S = H | t)$ that determines a retail price p that is expected maximize profit:

$$p(w, \mu) = \arg \max_p (p - w - c_r) [\mu q_H(\mu, p) + (1-\mu) q_L(\mu, p)]$$

In the end, customer's decision based on the retail price p and posterior belief $\mu = \Pr(S = H | t)$.

3. Separating equilibriums of signaling model

Based on posterior beliefs that conforms to Bayesian rule (when applicable), the receiver rational decisions coincides with the sender's rational decision. Therefore, we divide the derivation of the separate PEBs into two steps.

In order to make the equilibrium more significant, we assume that the posterior beliefs of retailers and all uninformed consumers do not decrease at the level of CSR: for any $t \geq t'$, $\mu(t) \geq \mu(t')$. This assumption describes the straightforward that a supplier's commitment to a higher level of CSR increases the likelihood of their product being of high quality. It suggests a positive correlation between a firm's CSR efforts and the quality of its products. We give the necessary condition for the separating equilibrium as follows.

Lemma 1: it is assumed that a posterior beliefs is not decreasing, if in a separating PBE, $t_L^{s*} = 0$ and t_H^{s*} are chosen by the low-quality and the high-quality supplier, to prevents the

low-quality supplier from pretending to be the high-quality supplier, must satisfy $t_H^{s*} > 0$, $t_H^{s*} \geq t_1$, where t_1 is given by

$$t_1 = \frac{1}{a_L} ((v_1 - c_s - c_r)^2 / (8v_1) - (v_L - c_s - c_r)^2 / (8v_L)).$$

Lemma 1 gives another necessary condition for the CSR strategy of high-quality supplier in separating equilibrium. Note that $t_H^{s*} \geq t_1 > 0$, which means in order to avoid the low-quality's adverse selection, the high-quality supplier has to deviate from the CSR strategy in the symmetric case to implement a higher CSR level. Obviously, the distortion of CSR strategy will inevitably lead to a loss of profits for the high-quality supplier, which can be interpreted as the cost for separating from the low-quality. However, if the deviation costs so much that the high-quality supplier gains less in deviation than in adverse selection ($\mu=0$), the high-quality supplier will not meet the sequential and rational conditions, which means the separate equilibrium does not exist yet. Accordingly, in order to further characterize the CSR strategy of high-quality supplier in the separating equilibrium, we next derive another necessary condition from the sequential rational conditions for the high-quality supplier.

Lemma 2 In order to avoid adverse selection of the high-quality supplier, the separate equilibrium (t_L^{s*}, t_H^{s*}) must satisfy $t_H^{s*} \leq t_2$, in which t_2 is given as the equation (13).

Proof. It can be derived from the equations (10), (11) and (12) that

$$(v_2 - c_s - c_r)^2 / (8v_2) \leq (v_H - c_s - c_r)^2 / (8v_H) - a_H t.$$

Solving the above inequality we get

$$t \leq t_2 = \frac{1}{a_H} ((v_H - c_s - c_r)^2 / (8v_H) - (v_2 - c_s - c_r)^2 / (8v_2)).$$

Therefore, the high-quality supplier must enforce CSR of a level $t_H^{s*} \leq t_2$ in separating equilibrium to avoid its adverse selection.

Remark. Lemma 2 points out another necessary condition for separating equilibrium that, it is only when the CSR level of the high-quality supplier varies in a limited region that the high-quality supplier can separate from the low-quality. Combining Lemma 2 and Lemma 3 we find that when and only when $t_2 \geq t_1$, the region $[t_1, +\infty)$ in Lemma 2 and the region $[0, t_2]$ in Lemma 3 can intersect, which means the sequential and rational conditions hold for the suppliers of two type. To be convenient, we introduce a function $\pi(v) = (v - c_s - c_r)^2 / (8v)$, then we have

$$t_1 = (\pi(v_1) - \pi(v_L)) / a_L, t_2 = (\pi(v_H) - \pi(v_2)) / a_H,$$

And the condition $t_2 \geq t_1$ equals to $\theta = \frac{a_L}{a_H} \geq \frac{\pi(v_1) - \pi(v_L)}{\pi(v_H) - \pi(v_2)}$, in which the parameter θ

represents the difference between marginal CSR cost of two type suppliers. We sum up the conclusions of Lemma 1, Lemma 2 and Lemma 3 to give the sufficient condition for the separating equilibrium as follows.

Proposition 1 When $\theta = \frac{a_L}{a_H} \geq \frac{\pi(v_1) - \pi(v_L)}{\pi(v_H) - \pi(v_2)}$, there exist a set of separating equilibriums with the

following characteristics:

(1) The CSR level of supplier is $t_H^{s*} \in D = [t_1, t_2]$, $t_L^{s*} = 0$, the wholesale price is given by (1) in Proposition 1;

(2) The retail price is given by (2) in Proposition 1;

(3) The uninformed customers and retailer form a belief of

$$\mu = \begin{cases} 1, & t \geq t_H^{s*} \\ 0, & t < t_H^{s*} \end{cases}$$

(4) The profit of supplier is $\pi_{S-H}^{s*} = \pi(v_H) - a_H t_H^{s*}$, $\pi_{S-L}^{s*} = \pi(v_L)$ and the profit of retailer is $\pi_{R-H}^* = \pi(v_H)/2$, $\pi_{R-L}^* = \pi(v_L)/2$.

Proof. Assume the CSR level of high-quality supplier in separating equilibrium is $t = t_H^{s*} \in D$. We prove in following steps: 1. Given the beliefs in (3) of Proposition 2, the tactics of the supplier and retailer are as (1) and (2) of Proposition 2 respectively; 2. Given the strategies of the supplier and retailer as (1) and (2) of Proposition 2 respectively, the beliefs are as (3) of Proposition 2.

On the one hand, given the beliefs in (3) of Proposition 2, the low-quality supplier will not diverge from the equilibrium path $t_L^{s*} = 0$ to emulate the high-quality's CSR level t_H^{s*} or a level $t > t_H^{s*}$ according to Lemma 2, therefore the optimal CSR level of low-quality supplier is $t_L^{s*} = 0$; besides, the high-quality supplier will not deviate from equilibrium path t_H^{s*} to select adversely $t_L^{s*} = 0$, therefore t_H^{s*} is optimal CSR level of the high-quality supplier.

On the other hand, suppose the strategy of the supplier and the retailer are (1) and (2) of Proposition 2 respectively, the beliefs as (3) of Proposition 2 satisfy the necessary condition in Lemma 1, which prove the proposition.

Remark. Proposition 1 characterizes the separating equilibrium of CSR signaling game, and reveals the mechanism for suppliers applying CSR to achieve quality information sharing. Since the implementation of a high CSR level helps to strengthen the consumers' quality beliefs, further to promote the demand curve upward, the low-quality supplier may be motivated to mimic the CSR strategies of high-quality supplier. However, considering the marginal cost of implementing CSR for a low-quality supplier is greater than that of a high-quality supplier ($\theta = \frac{a_L}{a_H} \geq \frac{\pi(v_1) - \pi(v_L)}{\pi(v_H) - \pi(v_2)}$), at

the level of CSR, the profit curve of low-quality supplier decreases faster than the high-quality supplier. Therefore, when the high-quality supplier implements a high enough level, the imitation will result in the low-quality supplier not being worth the cost, which avoids the adverse selection of the low-quality supplier. Because the different level of CSR in the separating equilibrium reveals the quality information of supplier, the supplier indirectly realizes the quality information sharing through CSR mechanism.

Proposition 1 points out that under the condition that suppliers choose to implement CSR, whether the supplier can share private quality information through CSR depends on the separating equilibrium in the signaling model. Downstream enterprises and consumers are able to gain sufficient information to identify quality type of supplier through separation equilibrium, which means that under certain conditions the upstream firm can realize to share indirectly the private quality information vertically in the supply chain via CSR mechanism. The mechanism functions on the base that the CSR level is neither too large nor too small, only in a moderate region.

Moreover, Proposition 1 implies that under the condition the supplier chooses to implement no CSR, in other words, the CSR level is zero, there exists no separating equilibrium for the reason that the CSR level $t_H^{s*} \in D = [t_1, t_2]$ is a necessary condition of separating equilibrium, which means

that the supplier cannot realize to share quality information in the supply chain.

Particularly, when the proportion of informed consumers λ tends to 1, which means that there exist no uninformed consumers in the market, the model will evolve into a complete information case. According to the formula (13) we know that the lower bound t_1 of the separating CSR region tends to 0, and the upper bound t_2 tends to 0 as well, and the condition $\theta = \frac{a_L}{a_H} \geq \frac{\pi(v_1) - \pi(v_L)}{\pi(v_H) - \pi(v_2)}$ in

Proposition 1 holds clearly. This means as a particular case of Proposition 3, in the symmetric model, high-quality supplier don't need to apply CSR mechanism to share quality information, at the time, the asymmetric conclusions in Proposition 3 will degenerate into the symmetric conclusions in Proposition 1. This further implies that the models under two different information structures are effectively unified, namely, quality information asymmetry and quality information asymmetry. Compared to the supply chain literature considering separately information symmetry case, or information asymmetry case, this paper introduces a factor of informed consumers to establish a general model under partial information asymmetry, which shows more advantages in completeness from a theoretical perspective.

4. Conclusion

A lot of literature has proven that the significance of information sharing in supply chain management, therefore it is important to investigate sharing mechanism for various information in the supply chain. We consider a supply chain including a retailer, a supplier and consumers. The supplier has private quality information. Before sales it is impossible for retailers and uninformed consumers to know the real product quality information, while informed consumers can foreknowledge the true quality. Under the partial quality information asymmetry, we build a signaling model of sharing upstream quality information by CSR mechanism. We describe completely the separating equilibriums in the model, and select a unique equilibrium by the Intuitive Criterion, in order to inspect the feasibility of CSR mechanism in sharing the quality information, and investigate the factors affecting CSR mechanism.

With the perfect Bayesian equilibriums, we identify conditions under which CSR mechanism can function effectively to signal indirectly quality information. The results demonstrate that under certain conditions, a higher the level of corporate social responsibility, the higher the quality level in the sense of a separate equilibrium. These results reveal the motivation of quality sharing of CSR strategies in the supply chain. Besides we provide enlightenment for supply chain managers to choose how to sharing information. The conclusions provide insights for realistic management in supply chain. On the one hand, it provides theoretical basis for node enterprises to implement CSR behavior to achieve sharing quality information vertically in the supply chain, which implies the feasibility of CSR mechanism to share quality information; on the other hand, it provides theoretical guidance to adjust CSR behavior to share quality information based on the extent of information asymmetry.

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