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Signaling Product Quality Information in Supply Chains via Corporate Social Responsibility Choices

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Abstract: This study focuses on how an upstream supplier signals the private information of its product quality with corporate social responsibility (CSR) choices to a downstream retailer and uninformed consumers in the final market. We build a signaling model to: capture the strategic interactions among the supplier, the retailer, and the final consumers in the supply chain; characterize completely the set of all separating perfect Bayesian equilibriums (PBEs); and finally, select a unique equilibrium that satisfies the intuitive criterion for exploring some comparative statics. The equilibrium results show that under some technical conditions: (1) a set of moderate levels of CSR conduct signal the upstream supplier's high quality in the sense of separating PBEs; (2) the unique separating PBE satisfying the intuitive criterion is the one with the lowest CSR level that separates a high-quality supplier from a low-quality supplier; (3) the lowest CSR level decreases in the proportion of informed consumers and the low-quality supplier's marginal CSR cost, but is independent of the high-quality supplier's marginal CSR cost; (4) the profits of the high-quality supplier increase in proportion to the number of informed consumers and the low-quality supplier's marginal cost CSR, but decrease in proportion to the high-quality supplier's marginal CSR cost. Managerial insights are also discussed.

Keywords: corporate social responsibility; product quality; signaling game; supply chain

1. Introduction

Corporate social responsibility (CSR) consists of economic, legal, and ethical responsibilities, as well as voluntary or philanthropic responsibilities, which are guided by an organization's discretion, as opposed to legal or more explicit requirements [1–3]. Under the current global business environment, CSR is now a determining factor of success that firms cannot ignore [4]. For instance, many leading brands such as Nike, GAP, Adidas, and McDonalds have been compelled to incorporate social responsibility into their supply chains [5]. A famous global corporation located in Amsterdam city of Netherlands, Klynveld Peat Marwick Goerdeler (KPMG), issues a survey of corporate responsibility reporting in 2015. It shows that 80% of the world's 250 largest companies have issued CSR reports in 2008, and that percentage has increased to over 90% in 2015 [6].

Traditionally, CSR activities are thought of as firms' responses to the requirement of sustainability pillared by the so-called "triple bottom line": firms must reconcile environmental, social equity, and economic demands for their stakeholders [1,3]. However, Baron's [7] strategic CSR view argues that firms conduct socially and environmentally responsible activities as a strategic instrument for the purpose of profitability maximization via influencing stakeholders' expectations on working conditions, environment protections, poverty alleviation, human health, and so on.

As important stakeholders, consumers usually care about the quality of a firm's products. In the setting of a supply chain, since consumers' expectations of quality induce the final market demand, the retailer who resells the supplier's products naturally cares about such quality. If the retailer and the consumers cannot access the information on the true state, conducting costly CSR activities may be a feasible tool for the supplier who produces high-quality products, in order to distinguish itself from a low-quality supplier. Accordingly, the retailer and the consumers form an expectation that the product is of high quality once a high enough level of CSR is observed (otherwise, the product quality is thought of as low). Thus, CSR can be used by a high-quality supplier as a strategic instrument to signal the high quality of its products to the retailer and the consumers.

In fact, CSR empirically increases consumer trust in the company and its products, and that trust is translated into a consumer's intention to purchase [8–11]. Fabrizio [12] claims that voluntary CSR disclosure can be interpreted as a signal of product quality that reflects a firm's confidence in its products. Furthermore, it is empirically observed that firms selling experience goods and credence goods are more likely to be socially responsible than firms selling search goods [13]. These empirical findings are consistent with our intuition that CSR can be strategically used as a signaling instrument. This intuition has been adopted in a single firm setting by some theoretical work. For example, the quality-signaling role of CSR is explored for a firm that privately provides public goods [14]. However, to the best of our knowledge, in the supply chain management literature, this signaling role of CSR is rarely revealed, even if there is a large body of authors who incorporated CSR into studies on supply chain operations (for more details, see the literature review section).

We apply signaling theory, which characterizes how an informed player credibly conveys the information in question to some uninformed player(s), by providing an observable but costly signal [15], in order to explore the quality-signaling role of CSR activities in a supply chain setting. We thus need to answer the following key questions: (1) is there any level of CSR conduct that an upstream firm can choose to reveal its true level of product quality to its downstream retailer and final consumers? (2) If there is, what is the profitability implication(s) for supply chain members?

To address these questions, we consider a two-echelon supply chain, where an upstream supplier (she) sells a product to a downstream retailer (he), and the retailer resells the product to the final consumers. The supplier has private information on her product quality, while the retailer and some of the consumers are uncertain about the true quality level (other consumers are completely informed). Further, the supplier signals the product quality by choosing costly CSR actions to a downstream retailer and uninformed consumers. We show that a set of CSR levels exists by which the supplier conveys the true product quality information to the retailer and uninformed consumers in the sense of separating perfect Bayesian equilibriums (PBEs). Then, we use the standard intuitive criterion, and select a unique one with the lowest CSR level that a high-quality supplier chooses to separate from a low-quality supplier. Based on this unique equilibrium, we finally reveal the impacts of the proportion of informed consumers and the supplier's marginal CSR cost on the lowest CSR level, respectively.

The main contributions of the paper are twofold. First, this paper introduces a CSR-signaling model to a supply chain management model with private product quality information, and identifies a new quality-signaling motivation of an upstream firm's CSR conduct. As shown in the literature review (Section 2), this research, on one hand, extends a single-firm quality-signaling model to a supply chain setting, and helps to link the literature on CSR operations and the literature on information sharing in the field of supply chain management. On the other hand, this research also complements the (downstream demand) information-sharing literature by demonstrating how an upstream firm signals its product quality information with CSR actions to a downstream firm (and uninformed consumers). Second, we reveal the lowest CSR level (satisfying the intuition criterion) that can truthfully convey the private quality information. This implies that a minimal level of CSR is necessary for an upstream high-quality firm to distinguish itself from a low-quality one. In addition, we also explore the effects of the extent of final-market information asymmetry and the marginal CSR cost on the lowest level of CSR, and an upstream firm's profitability, respectively.

The remainder of the paper is structured as follows. A supply chain operation model with private quality information is presented in Section 2. The information-symmetric version is solved as a benchmark in Section 3. The set of separating equilibriums of the information-asymmetric version are characterized, followed by an equilibrium selection in Section 4. In Section 5, comparative static analysis based on the selected unique separating equilibrium is provided; A numerical demonstration is given in Section 6. Finally, a discussion and concluding remarks are reported in Sections 7 and 8, respectively.

2. Literature Review

This work is mainly related to two groups of literature.

The first group of work incorporates CSR conduct into the classical framework of supply chain management, and examines its impacts on supply chain operations, with profitability implications from either a theoretical or an empirical perspective.

From the theoretical perspective, authors mainly express concerns about the following three aspects. The first line of authors focus on how the focal firm in a supply chain develops CSR approaches, procedures [16–20], and frameworks [21–23] to effectively manage other members' CSR conducts in order to meet the targeted economic, social, and environmental requirements for a sustainable supply chain.

The second line of research stems from Baron's stakeholder views of CSR [24], which state that each supply chain member should be responsible for the other members' actions. Thus, this group focuses on how to allocate CSR within supply chains to achieve a win–win outcome in terms of social and economic performance. Amaeshi et al. [5] claim that due to moral duties and the power of economic influence, the more powerful member in a firm–supplier relationship should bear the responsibility of reducing the irresponsible operations of the less powerful member. Furthermore, in a two-echelon supply chain setting, based on an interpretation of one member's responsibility as the corresponding right that the holder can use to manage the other member's operations, Ni et al. [25] show that the optimal allocation scheme is to assign the supplier as the responsibility holder, with appropriate restrictions on the corresponding rights.

The third stream in recent years tries to develop mechanisms or contracts to coordinate both CSR activities and the classical transactions of intermediate goods. A new revenue-sharing contract embedding corporate social responsibility is presented for coordinating a two-tier supply chain consisting of a manufacturer and a retailer [26]. Panda [27] develops a two-echelon supply chain, where either the manufacturer or the retailer conducts CSR and shows that a quantity discount contract can coordinate the supply chain. With an interpretation of CSR as a manufacturer's care about consumer surplus, Panda et al. propose a contract-bargaining process and show that it can resolve channel conflicts for a manufacturer–distributor–retailer supply chain [4]. Modak et al. [28] demonstrate that a dual-channel supply chain can be coordinated through all unit quantity discount contracts with proper franchise fees.

From an empirical perspective, researchers focus mainly on two concerns: the relationship between CSR performance and economic performance, and the practices of sustainable supply chain operations in different industrial contexts. For the first concern, Carter and Jennings [29] find a positive relationship between the buyer's CSR purchases and the supplier's economic performance with a sample collected through e-mail surveys. Golicic and Smith's [30] meta-analysis reveals that the link between environmental supply chain practices and market-based, operational-based, and accounting-based forms of firm performance is both positive and significant. With a French sample, Crifo and Forget [31] point out that how CSR affects economic performance depends on different CSR quality–quantity combinations. Based on the CSR reports of 100 Chinese national state-owned enterprises (CNSOEs), Zhu et al. [32] use the stakeholder theory to develop measurements of nine dimensions, and find that four dimensions of CSR practices can improve financial performance.

With examples of United States (US) corporations, Ullmann [33] finds no clear relationships among social disclosure, social performance, and economic performance.

As for the second concern, Fleury and Davies [34] examine how the social and environmental sustainability performance of products influences the sustainability agenda of the mining and metals sector. Silvestre [35] reports on the implementation and management of supply chain sustainability in developing and emerging economies. Chkanikova [36] investigates how food retailers manage their relationships with suppliers in order to influence the environmental and social performance of procured goods and improve the availability of sustainable product supply.

The second group focuses on information sharing in supply chains. In this aspect, there is a large body of literature on direct information sharing, in the sense that a member who has some private information directly reports to other members via some information systems, such as the electronic data interchange systems. This literature characterizes the value of information sharing, and explores the conditions of information sharing in a yes-or-no manner [37–41]. Recently, scholars have started to study indirect information sharing, where private information cannot be directly exchanged or conveyed by some other strategic instruments. For example, Anand and Goyal [42] use signaling models to study how an upstream firm strategically leaked final-market demand information via the order quantity of a downstream retailer to another competitive retailers. Based on the framework of [42], Kong et al. [43] show that a revenue-sharing contract can align the supplier's and two downstream competitive retailers' incentives to prevent such information leakage.

The above literature review clearly demonstrates that on the one hand, authors extend the classical models of supply chain operations to embrace CSR under the assumption of complete information, and then provide fruitful managerial insights on CSR operations. On the other hand, the information-sharing literature points out that if there is information asymmetry, information sharing is potentially valuable, and can be realized via direct information interchange systems or indirect strategic interactions. However, these two groups of authors conduct their research independently. The former takes the complete information assumption, and thus cannot determine whether CSR activities can be strategically conducted by supply chain members to realize indirect information sharing. The latter recognizes information asymmetry, and figures out a set of instruments to resolve it, but those instruments almost have nothing to do with CSR.

Given that CSR is able to influence stakeholders' expectations, and the formation of such expectations depends heavily on information, the present paper, in a setting of two-echelon supply chain operations, develops a signaling model where costly CSR activities are viewed as signals about product quality, and identifies conditions under which CSR activities accurately signal the supplier's private quality information to its retailer and final consumers. Thus, it on the one hand explores an information-sharing motivation of supply chain members to conduct CSR activities on top of the literature on CSR operations in supply chains, and on the other hand, complements the (indirect) information-sharing literature by adding a CSR instrument to signal upstream product quality information to uninformed downstream members.

3. The Model

We consider a two-echelon supply chain consisting of an upstream supplier (she) and a downstream retailer (he). The supplier and the retailer serve a final market with a percent, λ ($0 < \lambda < 1$), of informed consumers and a percent, $1 - \lambda$, of uninformed consumers. The supplier makes a product and knows the quality level (S) is high (H) or low (L). We accordingly call the supplier a high-quality or a low-quality supplier. The retailer and uninformed consumers do not know the true quality level, but they have prior beliefs, where $\mu_0 = \Pr(S = H)$ and $1 - \mu_0 = \Pr(S = L)$. However, the supplier can signal quality information via her observable CSR conduct to the retailer and uninformed consumers. Observing a CSR level t ($t \geq 0$), the retailer and uninformed consumers form a posterior belief, where $\mu = \Pr(S = H|t)$ and $1 - \mu = \Pr(S = L|t)$. The supplier and the retailer transact via a wholesale price contract.

Assume that a high-quality product has v_H quality units (for example, a certain number of hours of durability), while a high-quality product has v_L quality units. Consumers are heterogeneous in terms of their willingness to pay for a quality unit. Denote this willingness to pay by δ and assume that δ is uniformly distributed on the interval $[0, 1]$. In addition, we assume that each consumer purchases at most one unit of the product. Given the posterior belief $\mu = \Pr(S = H/t)$ and $1 - \mu = \Pr(S = L/t)$, consumers' expected quality unit is $v(\mu) = \mu v_H + (1 - \mu)v_L$. Thus, if a consumer δ buys at retail price p and consumes a product, her/his expected surplus is $E_\delta = \delta v(\mu) - p$. This implies that all consumers with δ 's satisfying $\delta v(\mu) - p \geq 0$, and induces that the demand function is

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

More specifically, when the product is of high quality, informed consumers' ($\mu = 1$) demand is $q_1 = \lambda(1 - p/v_H)$, and the uninformed consumers' ($\mu = \Pr(S = H|t)$) demand is $q_2 = (1 - \lambda)(1 - p/v(\mu))$. Then, the aggregate demand is

$$q_H(\mu, p) = \lambda \left(1 - \frac{p}{v_H}\right) + (1 - \lambda) \left(1 - \frac{p}{v(\mu)}\right)$$

Similarly, when the product is of low quality, the aggregate demand is

$$q_L(\mu, p) = \lambda \left(1 - \frac{p}{v_L}\right) + (1 - \lambda) \left(1 - \frac{p}{v(\mu)}\right)$$

Further, we assume that the constant marginal manufacturing cost of the product is independent of the quality level, i.e., $c_H = c_L = c_s$ and the retailer's constant marginal retailing cost, c_r . In reality, these two costs may be different. However, it can be easily verified that an alternative assumption of different manufacturing costs does not have any qualitative impact on the main results in Sections 5 and 6. However, the constant marginal cost, a_H , of the CSR conduct of a high-quality supplier may be different from that of a low-quality supplier (a_L).

The decision sequence is as follows. In stage one, the supplier chooses a CSR level t and a wholesale price w to maximize her expected profit:

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

In stage two, observing t and w chosen by the supplier, the retailer forms a posterior belief $\mu = \Pr(S = H/t)$, and decides a retail price p to maximize his expected profit:

$$p(w, \mu) = \operatorname{argmax}_p (p - w - c_r)[\mu q_H(\mu, p) + (1 - \mu)q_L(\mu, p)].$$

In stage three, all consumers decide whether to buy according to the posterior belief $\mu = \Pr(S = H/t)$ and the retail price p .

For this asymmetric information game, we will use the concept of perfect Bayesian equilibrium (PBE) to solve it in Section 4.

4. Benchmark Model: Symmetric Information Case

In this section, we solve the model in a symmetric information case as a benchmark. When the supplier is of high quality, all of the consumers and the retailer know that the true quality level is high. Therefore, we thus have $\mu_0 = \mu = 1$ and $v = v_H$, and the total demand is

$$q_H(1, p) = 1 - \frac{p}{v_H} \quad (1)$$

The retailer's profit can be written as

$$\pi_{R-H}(p) = (p - w - c_r)\left(1 - \frac{p}{v_H}\right) \quad (2)$$

The retailer chooses a retail price to maximize his profit. From the first-order condition (the second-order condition is clearly satisfied), the retail price and the order quantity can be solved as

$$p^* = (v_H + w + c_r)/2, q^* = (v_H - w - c_r)/(2v_H) \quad (3)$$

Given the retailer's responses in Equation (3), the high-quality supplier's profit can be written as

$$\pi_{S-H}(w, t) = (w - c_s)(v_H - w - c_r)/(2v_H) - a_H t \quad (4)$$

Then, the supplier chooses a CSR level t and a wholesale price w to maximize her profit. The first-order condition (the second-order condition is clearly satisfied) immediately implies

$$w_H^* = (v_H + c_s - c_r)/2, t_H^* = 0 \quad (5)$$

Plugging w_H^* into Equation (3), we calculate the equilibrium retail price as $p_H^* = (3v_H + c_s + c_r)/4$ and the equilibrium order quantity as $q_H^* = (v_H - c_s - c_r)/(4v_H)$. The retailer's equilibrium profits can be obtained by substituting w_H^* and p_H^* into Equation (2), and the high-quality supplier's profits can be calculated by plugging w_H^* and t_H^* into Equation (4).

When the supplier is of low quality, all of the equilibrium variables can be derived in the same way. We summarize the equilibrium in Proposition 1.

Proposition 1. *In the symmetric information case, the equilibrium is characterized as*

- (i) *The supplier's CSR levels are $t_H^* = t_L^* = 0$ and the wholesale price are $w_H^* = (v_H + c_s - c_r)/2$ and $w_L^* = (v_L + c_s - c_r)/2$;*
- (ii) *The retail prices are $p_H^* = (3v_H + c_s + c_r)/4$ and $p_L^* = (3v_L + c_s + c_r)/4$, the order quantity are $q_H^* = (v_H - c_s - c_r)/(4v_H)$ and $q_L^* = (v_L - c_s - c_r)/(4v_L)$;*
- (iii) *The supplier's profits are $\pi_{S-H}^* = (v_H - c_s - c_r)^2/(8v_H)$ and $\pi_{S-L}^* = (v_L - c_s - c_r)^2/(8v_L)$, while the retailer's profits are $\pi_{R-H}^* = (v_H - c_s - c_r)^2/(16v_H)$ and $\pi_{R-L}^* = (v_L - c_s - c_r)^2/(16v_L)$.*

Proposition 1 (i) demonstrates that in the symmetric information case, the supplier does not have any motivation to conduct any CSR, no matter whether the upstream supplier is of high quality or low quality. From Proposition 1 (iii), a direct comparison reveals $q_H^* \geq q_L^*$ and $\pi_{S-H}^* \geq \pi_{S-L}^*$. Thus, if the quality information was asymmetric, and uninformed consumers' posterior beliefs were positively correlated with CSR levels, the low-quality supplier would have an incentive to imitate the high-quality supplier by choosing some positive level of CSR. Meanwhile, to separate from the low-quality supplier, the high-quality supplier would choose a much higher CSR level, which would nevertheless be bounded from above, since CSR is costly. This point will be explored in the following section.

5. Model Analysis: Asymmetric Information Case

In the asymmetric information case, we employ the concept of perfect Bayesian equilibrium to the model. It is well known that for a signaling model, there usually exist both pooling and separating equilibria [15]. However, since any pooling equilibrium does not convey any private information of the sender, we focus on only the set of separating equilibria to investigate the role of the supplier's CSR conduct in signaling her private quality information. Moreover, since there usually are multiple separating equilibria, we use the classic intuition criterion [44] to select a unique one for exploring the comparative statics with regard to a set of exogenous parameters in Section 5.

5.1. Separating Equilibriums

A separating equilibrium of a signaling game requires that the receiver makes her/his rational decisions based on posterior beliefs that are consistent with—in the sense of satisfying the Bayesian rule (when applicable)—the sender's rational decisions. We thus divide the derivation of the set of separating PBEs into two steps. First, we figure out the necessary conditions on the posterior beliefs, and the supplier's CSR choices that prevent both the high-quality and the low-quality supplier from imitating each other (Lemmas 1 to 3). Second, we characterize the set of separating PBEs in Proposition 2 by showing that these necessary conditions are also sufficient, with an additional restriction of the relative marginal CSR cost between the two types of suppliers.

To make the equilibrium more meaningful, we assume that the retailer's and all uninformed consumers' posterior beliefs are non-decreasing in the CSR level: for any $t \geq t'$, $\mu(t) \geq \mu(t')$. This assumption captures the intuition that the higher level of CSR the supplier chooses, the more likely her product is of high quality.

Lemma 1. *Under the assumption of non-decreasing posterior beliefs, if t_L^{s*} and t_H^{s*} chosen by the low-quality and the high-quality supplier are in a separating PBE, then it must be that*

- (i) $t_L^{s*} = 0$ and $t_H^{s*} > 0$;
- (ii) $\mu(t_L^{s*}) = 0$ and $\mu(t) = 1$ for all $t \geq t_H^{s*}$.

Proof. By the definition of a separating PBE, $t_L^{s*} \neq t_H^{s*}$. If $t_L^{s*} > t_H^{s*}$, the assumption of non-decreasing posterior beliefs implies that $\mu(t_H^{s*}) = 0$ and $\mu(t_L^{s*}) = 1$. That is, observing t_L^{s*} and t_H^{s*} , the retailer and all uninformed consumers infer that the supplier's product is of high and low quality, respectively. This contradicts the definition of a separating PBE. Thus, it must hold that $t_L^{s*} < t_H^{s*}$. By the assumption of non-decreasing posterior beliefs, $\mu(t_L^{s*}) = 0$ and $\mu(t_H^{s*}) = 1$. Given $\mu(t_L^{s*}) = 0$, one can check that the low-quality supplier's expected profit strictly decreases in t . Thus, a rational low-quality supplier must choose $t_L^{s*} = 0$ in equilibrium. This further implies $t_H^{s*} > t_L^{s*} = 0$. Finally, the assumption of non-decreasing posterior beliefs requires that $\mu(t) = 1$ for all $t \geq t_H^{s*}$. \square

Lemma 1 reveals that the low-quality supplier has no motivation to conduct any CSR in a separating PBE, while it is necessary for the high-quality supplier to choose a positive level of CSR to separate from the low-quality supplier. However, Lemma 1 does not characterize the lowest CSR level that the high-quality supplier would choose to prevent the low-quality supplier from imitating. This lowest CSR level will immediately be solved in Lemma 2. For convenience, we introduce a notation $v_1 = (\lambda/v_L + (1 - \lambda)/v_H)^{-1}$.

Lemma 2. *Under the assumption of non-decreasing posterior beliefs, and with posterior beliefs given in Lemma 1, if $t_L^{s*} = 0$, and the t_H^{s*} chosen respectively by the low-quality and the high-quality supplier are in a separating PBE, then any $t_H^{s*} > 0$, which prevents the low-quality supplier from pretending to be the high-quality supplier, must satisfy $t_H^{s*} \geq t_1$, where t_1 is given by*

$$t_1 = \frac{1}{a_L} \left(\frac{(v_1 - c_s - c_r)^2}{8v_1} - \frac{(v_L - c_s - c_r)^2}{8v_L} \right) \quad (6)$$

Proof. For convenience, we denote $\pi_{S-i}(t, w; \mu(t))$ as the i -type ($i = H, L$) supplier's profit for any given wholesale price w , CSR level t , and posterior belief μ , and denote $\pi_{R-i}(p; \mu(t))$ as the retailer's profit for any given retail price p and posterior belief μ faced with an i -type supplier.

We first derive the low-quality supplier's profit when she imitates the high-quality supplier by choosing the CSR level $t_H^{s*} > 0$. Then, we have $\mu(t_H^{s*}) = 1$ by Lemma 1, and the demand is

$$q_L(1, p) = \lambda \left(1 - \frac{p}{v_L}\right) + (1 - \lambda) \left(1 - \frac{p}{v_H}\right) = 1 - \frac{p}{v_1}$$

For any given wholesale price w , the retailer decides the retail price p to maximize his profit as

$$\pi_{R-L}(p; 1) = (p - w - c_r) \left(1 - \frac{p}{v_1}\right)$$

From the first-order condition (the second-order condition is clearly satisfied), the retail price and the order quantity can be solved as

$$p^* = \frac{v_1 + w + c_r}{2}, q^* = \frac{v_1 - w - c_r}{2v_1} \quad (7)$$

Anticipating the retailer's responses in Equation (7), the low-quality supplier's profit is

$$\pi_{S-L}(t_H^s, w; 1) = \frac{(w - c_s)(v_1 - w - c_r)}{2v_1} - a_L t_H^s \quad (8)$$

The first-order condition with respect to the wholesale price (the second-order condition is clearly satisfied), the optimal wholesale price is derived as $w_L^\# = (v_1 + c_s - c_r)/2$.

Plugging $w_L^\#$ into Equation (8), the low-quality supplier's optimal profit when imitating can be rewritten as

$$\pi_{S-L}(t_H^s, w_L^\#; 1) = \frac{(v_1 - c_s - c_r)^2}{8v_1} - a_L t_H^s \quad (9)$$

Second, suppose that the low-quality supplier does not imitate the high-quality supplier. She chooses $t = t_L^s = 0$. Then, Lemma 1 implies $\mu(t_L^s) = 0$. Since the low-quality supplier reveals her true quality level, the optimal decisions and the resulting profit are the same as those obtained in the symmetric information case. From Proposition 1 (iii), we know the low-quality supplier's profit under no imitation is

$$\pi_{S-L}^\#(t_L^s, w^*; 0) = \pi_{S-L}^\# = \frac{(v_L - c_s - c_r)^2}{8v_L} \quad (10)$$

Therefore, to prevent the low-quality supplier from imitating, the high-quality supplier's choice of the CSR level, t_H^s must be such that the low-quality supplier's imitation is not profitable. We thus have

$$\pi_{S-L}(t_H^s, w_L^*; 1) \leq \pi_{S-L}^\#(t_L^s, w_L^*; 0)$$

With Equations (9) and (10), we have

$$\frac{(v_1 - c_s - c_r)^2}{8v_1} - a_L t_H^s \leq \frac{(v_L - c_s - c_r)^2}{8v_L}$$

which is equivalent to

$$t_H^s \geq t_1 = \frac{1}{a_L} \left(\frac{(v_1 - c_s - c_r)^2}{8v_1} - \frac{(v_L - c_s - c_r)^2}{8v_L} \right)$$

This completes the proof of Lemma 2. \square

Lemma 2 indicates that in order to prevent the low-quality supplier from imitation, a relatively high level of the high-quality supplier's CSR conduct is necessary ($t_H^s \geq t_1 > 0$). However, since CSR is costly, it is intuitive that if t_H^s is too high, the high-quality supplier may have some motivation to imitate the low-quality supplier via choosing $t_L^s = 0$. Lemma 3, below, is going to explore this point. We introduce a notation $v_2 = (\lambda/v_H + (1 - \lambda)/v_L)^{-1}$.

Lemma 3. Under the assumption of non-decreasing posterior beliefs, and with posterior beliefs given in Lemma 1, if $t_L^{s*} = 0$ and t_H^{s*} chosen by the low-quality and the high-quality supplier are in a separating PBE, then any $t_H^{s*} > 0$, which prevents the high-quality supplier from imitating the low-quality supplier, must satisfy $t_H^{s*} \leq t_2$, where t_2 is determined by:

$$t_2 = \frac{1}{a_H} \left(\frac{(v_H - c_s - c_r)^2}{8v_H} - \frac{(v_2 - c_s - c_r)^2}{8v_2} \right) \quad (11)$$

Proof. First, we calculate the high-quality supplier's profit when she imitates the low-quality supplier by choosing the CSR level $t_L^{s*} = 0$. By Lemma 1, the posterior belief is $\mu(t_L^{s*}) = 0$. This implies that the demand is

$$q_H(0, p) = \lambda \left(1 - \frac{p}{v_H} \right) + (1 - \lambda) \left(1 - \frac{p}{v_L} \right) = 1 - \frac{p}{v_2}$$

For any given wholesale price w , the retailer decides the retail price p to maximize his profit as

$$\pi_{R-H}(p; 0) = (p - w - c_r) \left(1 - \frac{p}{v_2} \right)$$

From the first-order condition, the retail price and the order quantity can be solved as

$$p^* = \frac{v_2 + w + c_r}{2}, q^* = \frac{v_2 - w - c_r}{2v_2} \quad (12)$$

Anticipating the retailer's responses in Equation (12), the low-quality supplier's profit is

$$\pi_{S-H}(0, w; 0) = \frac{(w - c_s)(v_2 - w - c_r)}{2v_2} \quad (13)$$

The first-order condition with respect to the wholesale price directly implies that the optimal wholesale price is $w_H^\# = (v_2 + c_s - c_r)/2$.

Plugging $w_H^\#$ into Equation (13), the high-quality supplier's optimal profit when imitating can be rewritten as

$$\pi_{S-H}^\#(0, w_H^\#; 0) = (v_2 - c_s - c_r)^2 / (8v_2) \quad (14)$$

Second, when the high-quality supplier chooses $t = t_H^{s*} > 0$, Lemma 1 implies $\mu(t_H^{s*}) = 1$. The demand is

$$q_H(1, p) = 1 - \frac{p}{v_H}$$

The retailer's profit can be written as

$$\pi_{R-H}(p) = (p - w - c_r) \left(1 - \frac{p}{v_H} \right)$$

From the first-order condition (the second-order condition is clearly satisfied), the retail price and the order quantity can be solved as

$$p^* = \frac{v_H + w + c_r}{2}, q^* = \frac{v_H - w - c_r}{2v_H} \quad (15)$$

Given the retailer's responses in Equation (15), the high-quality supplier's profit can be written as

$$\pi_{S-H}(t, w; 1) = \frac{(w - c_s)(v_H - w - c_r)}{2v_H} - a_H t \quad (16)$$

From the first-order condition with respect to the wholesale price (the second-order condition is clearly satisfied), the optimal wholesale price is derived as $w_H^* = (v_H + c_s - c_r)/2$.

By plugging $w_{H_2}^*$ into Equation (16), the high-quality supplier’s optimal profit is

$$\pi_{S-H}(t_H^{s*}, w_H^*; 1) = \frac{(v_H - c_s - c_r)^2}{8v_H} - a_H t_H^{s*} \tag{17}$$

Therefore, to rule out the high-quality supplier’s incentive to imitate, t_H^{s*} must be such that

$$\pi_{S-H}^\#(0, w_H^\#; 0) \leq \pi_{S-H}^*(t_H^{s*}, w_H^*; 1)$$

With Equations (14) and (17), we have

$$\begin{aligned} \left(\frac{v_2 - c_s - c_r}{8v_2}\right)^2 &\leq \left(\frac{v_H - c_s - c_r}{8v_H}\right)^2 - a_H t_H^{s*} \\ \Leftrightarrow t_H^{s*} \leq t_2 &= \frac{1}{a_H} \left(\frac{(v_H - c_s - c_r)^2}{8v_H} - \frac{(v_2 - c_s - c_r)^2}{8v_2} \right) \end{aligned}$$

Lemma 3 is thus proved. □

Lemma 3 shows that in order to prevent the high-quality supplier from imitating the low-quality supplier, the CSR level must be bounded above. By the definition of this upper bound t_2 , it is clear that for a separating PBE with any CSR level below, the high-quality supplier obtains a higher profit than the low-quality supplier. Together with Lemmas 1 and 2, it demonstrates that given the non-decreasing posterior beliefs in Lemma 1, the existence of a separating PBE is equivalent to the non-emptiness of the interval $D = [t_1, t_2]$. Proposition 2 below provides a condition for this non-emptiness, and shows that under this condition, the necessary conditions in Lemmas 1–3 are also sufficient.

Before presenting Proposition 2, we introduce another notation $\pi(v) = (v - c_s - c_r)^2 / (8v)$.

Proposition 2. *When $a_L/a_H \geq (\pi(v_1) - \pi(v_L)) / (\pi(v_H) - \pi(v_2))$, there exists a set of separating equilibriums that are characterized by*

- (i) *The supplier’s CSR levels are $t_H^{s*} \in D = [t_1, t_2]$ and $t_L^{s*} = 0$. The corresponding wholesale prices are given by (i) in Proposition 1;*
- (ii) *The retail prices and order qualities are given by (ii) in Proposition 1;*
- (iii) *The retailer and uninformed consumers form a belief of*

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

- (iv) *The supplier’s profits are $\pi_{S-H}^{s*} = \pi(v_H) - a_H t_H^{s*}$ and $\pi_{S-L}^{s*} = \pi(v_L)$ with $\pi_{S-H}^{s*} \geq \pi_{S-L}^{s*}$, and the retailer’s profits are $\pi_{R-H}^* = \pi(v_H)/2$ and $\pi_{R-L}^* = \pi(v_L)/2$.*

Proof. The interval $D = [t_1, t_2]$ is non-empty, if and only if $t_2 \geq t_1$, which is equivalent to

$$\theta = \frac{a_L}{a_H} \geq \frac{\pi(v_1) - \pi(v_L)}{\pi(v_H) - \pi(v_2)}$$

According to the definition of a separating PBE, given the beliefs in Proposition 2 (iii), the proofs of Lemma 2 and 3 have shown that the retail prices given in Proposition 2 (ii) are optimal for the retailer. To complete the proof of Proposition 2, what remains is to show that with the retailer’s optimal choice in Proposition 2 (ii), $t_H^{s*} \in D = [t_1, t_2]$ and $t_L^{s*} = 0$ are respectively the high-quality supplier’s and the low-quality supplier’s optimal decisions, and these choices induce the beliefs in Proposition 2 (iii), according to the Bayesian rule.

We first show that given the belief in Proposition 2 (iii), $t = t_H^{s*}$ is the high-quality supplier's optimal choice. For any $t < t_H^{s*}$, the posterior belief is $\mu(t) = 0$. Given $\mu(t) = 0$, the high-quality supplier's profit is

$$\begin{aligned}\pi_{S-H}(t, w; 0) &\leq \pi_{S-H}(t, w_H^{\#}; 0) = (v_2 - c_s - c_r)^2 / (8v_2) - a_H t \\ &\leq (v_2 - c_s - c_r)^2 / (8v_2) = \pi_{S-H}(0, w_H^{\#}; 0) \leq \pi_{S-H}(t_H^{s*}, w_H^*; 1),\end{aligned}\quad (18)$$

where the last inequality is obtained by Lemma 3. This means that $t < t_H^{s*}$ is not optimal for the high-quality supplier. For any $t > t_H^{s*}$, according to Proposition 2 (iii), $\mu(t) = 1$. It follows that the high-quality supplier's profit is

$$\begin{aligned}\pi_{S-H}(t, w; 1) &\leq \pi_{S-H}(t, w_H^*; 1) = (v_H - c_s - c_r)^2 / (8v_H) - a_H t \\ &\leq (v_H - c_s - c_r)^2 / (8v_H) - a_H t_H^{s*} = \pi_{S-H}(t_H^{s*}, w_H^*; 1).\end{aligned}\quad (19)$$

Thus, $t > t_H^{s*}$ is not optimal for the high-quality supplier either. Therefore, $t = t_H^{s*}$ is the high-quality supplier's optimal choice.

Second, we verify that given the belief in Proposition 2 (iii), the low-quality supplier's optimal choice is $t = t_L^{s*} = 0$. For any $t > t_H^{s*}$, the posterior belief is $\mu(t) = 1$. Given $\mu(t) = 1$, the low-quality supplier's profit is

$$\begin{aligned}\pi_{S-L}(t, w; 1) &\leq \pi_{S-L}(t, w_L^{\#}; 1) = (v_1 - c_s - c_r)^2 / (8v_1) - a_L t \\ &\leq (v_1 - c_s - c_r)^2 / (8v_1) - a_L t_H^{s*} = \pi_{S-L}(t_H^{s*}, w_L^{\#}; 1) \leq \pi_{S-L}(0, w_L^*; 0),\end{aligned}\quad (20)$$

where the last inequality is achieved by Lemma 2. This means that $t > t_H^{s*}$ is not optimal for the low-quality supplier. For any $0 < t < t_H^{s*}$, according to Proposition 2 (iii), $\mu(t) = 1$. It follows that the low-quality supplier's profit is

$$\begin{aligned}\pi_{S-L}(t, w; 0) &\leq \pi_{S-L}(t, w_L^*; 0) = (v_L - c_s - c_r)^2 / (8v_L) - a_L t \\ &\leq (v_L - c_s - c_r)^2 / (8v_L) = \pi_{S-L}(0, w_L^*; 0).\end{aligned}\quad (21)$$

Thus, $t > t_H^{s*}$ is not optimal for the low-quality supplier either. Therefore, $t = t_L^{s*} = 0$ is the low-quality supplier's optimal choice.

Third, we show that given the high-quality supplier's and the low-quality supplier's optimal choices, the retailer and uninformed consumers form a posterior belief in Proposition 2 (iii). If the retailer and uninformed consumers observe a CSR level t_H^{s*} , they infer the supplier's quality level via the Bayesian rule. Given the pure strategies $\sigma(t_H^{s*} | S = H) = 1$, $\sigma(t_L^{s*} = 0 | S = H) = 0$, $\sigma(t_L^{s*} = 0 | S = L) = 1$, and $\sigma(t_H^{s*} | S = L) = 0$, the posterior belief on the CSR level t_H^{s*} can be derived by Bayesian rule as follows.

$$\begin{aligned}\mu(t_H^{s*}) &= P(S = H | t_H^{s*}) = \frac{\sigma(t_H^{s*} | S = H) \cdot \mu_0}{\sigma(t_H^{s*} | S = H) \cdot \mu_0 + \sigma(t_H^{s*} | S = L) \cdot (1 - \mu_0)} \\ &= \frac{\sigma(t_H^{s*} | S = H) \cdot \mu_0}{\sigma(t_H^{s*} | S = H) \cdot \mu_0} = 1, \\ \mu(t_L^{s*}) &= P(S = L | t_L^{s*}) = \frac{\sigma(t_L^{s*} | S = L) \cdot (1 - \mu_0)}{\sigma(t_L^{s*} | S = L) \cdot (1 - \mu_0) + \sigma(t_L^{s*} | S = H) \cdot \mu_0} = 1\end{aligned}$$

Finally, Proposition 2 (iv) can be easily obtained via substituting the equilibrium CSR levels, the wholesale prices, the retail prices, and the order quantities into the profit functions for the high-quality supplier, the low-quality supplier, and the retailer. The proof of Proposition 2 is thus completed. \square

Proposition 2 characterizes the set of the separating PBEs in which the upstream supplier signals her private quality information via CSR conduct to the downstream retailer and uninformed consumers. The reasoning is as follows. Due to the asymmetric information, the low-quality supplier has an incentive to imitate the high-quality supplier by choose a CSR level $t_H^{s*} > 0$, since the higher t_H^{s*} induces the retailer and uninformed consumers to believe that the product is of high quality, and thus results a higher demand. On the other hand, CSR is costly. Thus, if the low-quality supplier's marginal CSR cost is relatively high compared to the high-quality supplier's marginal CSR cost ($a_L/a_H \geq (\pi(v_1) - \pi(v_L))/(\pi(v_H) - \pi(v_2))$), it tends to make the low-quality supplier's imitation unprofitable. As for the high-quality supplier, given that the comparison of the relative marginal CSR cost rules out the low-quality supplier's incentive to imitate, the benefit of the high demand induced by t_H^{s*} dominates the cost of t_H^{s*} , and thus stimulates the high-quality supplier to separate from the low-quality supplier.

Compared with Proposition 1, the wholesale price contract for both the high-quality supplier and the low-quality supplier in the asymmetric information case is the same as that in the information-symmetric case. However, Proposition 2 reveals that the information asymmetry requires the high-quality supplier's spending in conducting a positive level of CSR ($t_H^{s*} > 0$) to separate from the low-quality supplier. The costly CSR conduct indicates the information cost that the high-quality supplier has to incur so as to make the retailer and uninformed consumers believe that $t_H^{s*} > 0$ is not the low-quality supplier's optimal choice, but the high-quality supplier's.

Despite the information cost, Proposition 2 highlights that an upstream supplier with private quality information is able to use CSR conduct to truthfully signal her quality level to a downstream retailer and (uninformed) consumers (if any). This, in turn, reveals the quality-signaling motivation of an upstream supplier to conduct CSR activities. However, as indicated in Proposition 2, there exists many such levels of CSR conduct. The existence of multiple separating PBEs naturally raises an important question: which separating PBE is most likely to be observed? The question is usually answered by restricting the posterior beliefs to some more reasonable ones according to the classic intuitive criterion [44].

5.2. Equilibrium Selection with the Intuitive Criterion

To illustrate how the intuitive criterion requires more reasonable posterior beliefs, we take into account a separating PBE with a CSR level $t_H^{s*} \in (t_1, t_2)$ as an example. Consider a CSR level t_1 , which is on an off-equilibrium path. Proposition 2 (iii) shows that in the separating PBE with t_H^{s*} , the posterior belief is $\mu(t_1) = 0$. However, according to Lemma 2, the low-quality supplier does not have any incentive to deviate from $t_L^{s*} = 0$ to choose t_1 even if the posterior belief is $\mu(t_1) = 1$. On the other hand, because CSR is costly, the belief $\mu(t_1) = 1$ would induce the high-quality supplier to deviate from t_H^{s*} . This behavioral tendency indicates that a more reasonable posterior belief would be $\mu(t_1) = 1$ rather than $\mu(t_1) = 0$. The intuitive criterion is devoted to ruling out PBEs with such unreasonable posterior beliefs.

Suppose a signaling game involving two members, a supplier and a retailer, where the supplier owns the information quality privately and acts as a sender, and the retailer acts as a receiver. The supplier's type is $\theta \in \Theta = \{H, L\}$. Nature firstly chooses the supplier's type θ , the supplier observes her type, and chooses a CSR level t as a message. Observing the CSR level t , the retailer updates his prior beliefs $\mu(H) = \mu_0$ and $\mu(L) = 1 - \mu_0$, forms posterior beliefs $\mu = \mu(H|t)$ and $1 - \mu = \mu(L|t)$, and chooses an order quantity $q \in Q = [0, +\infty)$. Let $u_S(t, q, \theta)$ and $u_R(t, q, \theta)$ denote the supplier's profits and the retailer's profits for a given CSR level t and order quantity q faced with a θ -type supplier, respectively.

Definition 1. (the Intuitive Criterion): Let $(t^*, q^*; \mu)$ be a PBE of the signaling game, and denote $u_S^*(\theta)$ as the θ -type supplier's equilibrium profits. An off-equilibrium $t (\neq t^*)$ is equilibrium-dominated for the θ -type supplier if $u_S^*(\theta) > \max_{q \in Q} u_S(t, q, \theta)$. Furthermore, if t is equilibrium-dominated for the supplier

of some type θ , but not for the other type, and if the posterior probability distributed on θ -type satisfies that $\mu(\theta|t) \neq 0$, we say that the PBE $(t^*, q^*; \mu)$ does not satisfy the intuitive criterion. Otherwise, the intuitive criterion is satisfied.

We now report the unique selected PBE from the set of the separating PBEs given in Proposition 2 by the intuitive criterion.

Proposition 3. *In the set of the separating PBEs given in Proposition 2, the unique PBE satisfying the intuitive criterion is the one with the lowest CSR level*

$$t_H^{s*} = t_1 = (\pi(v_1) - \pi(v_L)) / a_L \quad (22)$$

Proof. The proof of Proposition 3 is divided into two steps. First, we prove that any separating PBE with $t_H^{s*} \in (t_1, t_2]$ does not satisfy the intuitive criterion. Considering the off-equilibrium t_1 , Lemma 2 implies that t_1 is equilibrium-dominated for the low-quality supplier. Moreover, since CSR is costly, then it follows from Equation (17) in the proof of Proposition 2 that the high-quality supplier's profits when choosing t_1 are larger than her equilibrium profits, and thus, t_1 is not equilibrium-dominated for the high-quality supplier. Therefore, the intuitive criterion requires $\mu(t_1) = 1$. However, the posterior belief given in Proposition 2 is $\mu(t_1) = 0$. This implies that any separating PBE with a CSR level $t_H^{s*} \in (t_1, t_2]$ does not satisfy the intuitive criterion.

Second, we prove that the separating PBE with $t_H^{s*} = t_1$ satisfies the intuitive criterion. Lemma 2 shows that any off-equilibrium $t_0 (t_0 > t_1)$ is equilibrium-dominated for the low-quality supplier. The proof in the first step above has demonstrated that t_0 is also equilibrium-dominated for the high-quality supplier. According to the definition, the posterior belief induced by t_0 is out of the scope of the restrictions specified by the intuitive criterion, implying that the intuitive criterion is satisfied. In addition, for any off-equilibrium $t_0 (0 < t_0 < t_1)$, it can be directly checked that if the posterior belief were $\mu(t_0) = 1$, the high-quality supplier could reap a higher profit by choosing t_0 over the equilibrium profits, and thus t_0 would not be equilibrium-dominated. Lemma 2 indicates that the low-quality supplier has an incentive to deviate from $t_L^{s*} = 0$ to choose t_0 if $\mu(t_0) = 1$, thus t_0 is not equilibrium-dominated for the low-quality supplier, either. Then, the posterior belief induced by t_0 is not applicable to the restrictions in the intuitive criterion. Therefore, the intuitive criterion is satisfied, too. The proof of Proposition 3 is thus completed. \square

Proposition 3 demonstrates that the PBEs in Proposition 2 with unreasonable beliefs on the off-equilibrium path are ruled out by the intuitive criterion, and the only PBE left is the one with the lowest CSR level. Furthermore, the costly CSR conduct implies that the lowest level of information cost is necessarily required for an upstream high-quality supplier to truthfully signal her level of product quality to the downstream retailer and uninformed consumers. Therefore, the unique PBE satisfying the intuitive criterion and representing the lowest information cost is the most likely to be observed among all the PBEs in Proposition 2. Finally, Proposition 3 shows that the high-quality supplier's lowest information cost depends on the low-quality supplier's marginal CSR cost and the proportion of uninformed consumers. To investigate the effect of the above parameters on the lowest CSR level and the supplier's profits, we provide comparative static analysis on the unique separating PBE, satisfying the intuitive criterion in the following section.

6. Comparative Static Analysis

We take into account the effect of the proportion of informed consumers λ , the low-type supplier's CSR marginal cost a_L , and the high-type supplier's CSR marginal cost a_H on the lowest CSR level $t_H^{s*} = t_1$ and the suppliers' equilibrium profits in the unique PBE satisfying the intuitive criterion. We have a proposition as follows.

Proposition 4. *In the unique separating PBE satisfying the intuitive criterion,*

- (i) $t_H^{s*} = t_1$ decreases in the proportion of informed consumers λ and the low-quality supplier's CSR marginal cost a_L respectively, but it is independent of the high-quality supplier's CSR marginal cost a_H .
- (ii) the high-quality supplier's equilibrium profits increase in the proportion of informed consumers λ and the low-quality supplier's CSR marginal cost a_L respectively, but decrease in the high-quality supplier's CSR marginal cost a_H . The low-quality supplier's equilibrium profits are independent of λ , a_L , and a_H .

Proof. (i) Since $\pi(v) = (v - c_s - c_r)^2 / (8v)$ increases in v and $v_1 = v_1(\lambda) = (\frac{\lambda}{v_L} + \frac{1-\lambda}{v_H})^{-1}$ decreases in λ , it follows that $\pi(v_1)$ decreases in λ . Furthermore, the CSR level $t_H^{s*} = t_1$ decreases in λ according to Equation (22) in Proposition 3. It is clear that $t_H^{s*} = t_1$ decreases in a_L and is independent of a_H according to Equation (22).

(ii) Plugging Equation (22) into the high-quality supplier's profits in Proposition 2, we derive

$$\pi_{S-H}^{s*} = \pi(v_H) - \frac{a_H}{a_L} (\pi(v_1) - \pi(v_L)) \quad (23)$$

Since $\pi(v_1)$ decreases in λ , it follows that π_{S-H}^{s*} increases in λ . From Equation (23), it is obvious that π_{S-H}^{s*} increases in a_L and decreases in a_H . Compared with Proposition 1, the low-quality supplier's equilibrium profit in the asymmetric information case is the same as that in the symmetric information case. Proposition 1 (iii) shows that the low-quality supplier's equilibrium profit in the symmetric information case is independent of λ , a_L , and a_H , therefore, the low-quality supplier's equilibrium profit in the asymmetric information case is clearly independent of λ , a_L , and a_H . \square

Proposition 4 reveals the impacts of the proportion of informed consumers and the marginal CSR cost of the low-quality and the high-quality supplier on the lowest CSR level and the supplier's profit in equilibrium. First, when final-market information asymmetry decreases, the low-quality supplier benefits less via imitating the high-quality supplier, thus her incentive to imitate is weakened. In order to separate from the low-quality supplier, a lower CSR level is necessary for the high-quality supplier. Therefore, the informational cost decreases, and then, the high-quality supplier's equilibrium profits increase. Second, note that a higher level of the low-quality supplier's marginal CSR cost weakens the low-quality supplier's incentive to imitate. This directly implies a higher level of the high-quality supplier's equilibrium profits due to the saving of some informational cost. Third, as indicated in Lemma 2, the CSR level t_1 is the lowest to prevent the low-quality supplier from imitating the high-quality supplier. Together with the low-quality supplier's incentive to imitate being independent of any of the high-quality supplier's attributes, it is natural that t_1 and the high-quality supplier's equilibrium profits are independent of the high-quality supplier's marginal CSR cost. Finally, as for the low-quality supplier's profitability, since the low-quality supplier does not conduct any CSR in any separating PBE, and all of the consumers know that her product is of low quality, then her profitability is independent of the market parameter (λ) and CSR cost-related parameters (a_L and a_H).

The results in Proposition 4 are illustrated numerically in Figures 1–3, corresponding to the proportion of informed consumers (λ), the low-quality supplier's marginal CSR cost (a_L), and the high-quality supplier's marginal CSR cost (a_H).

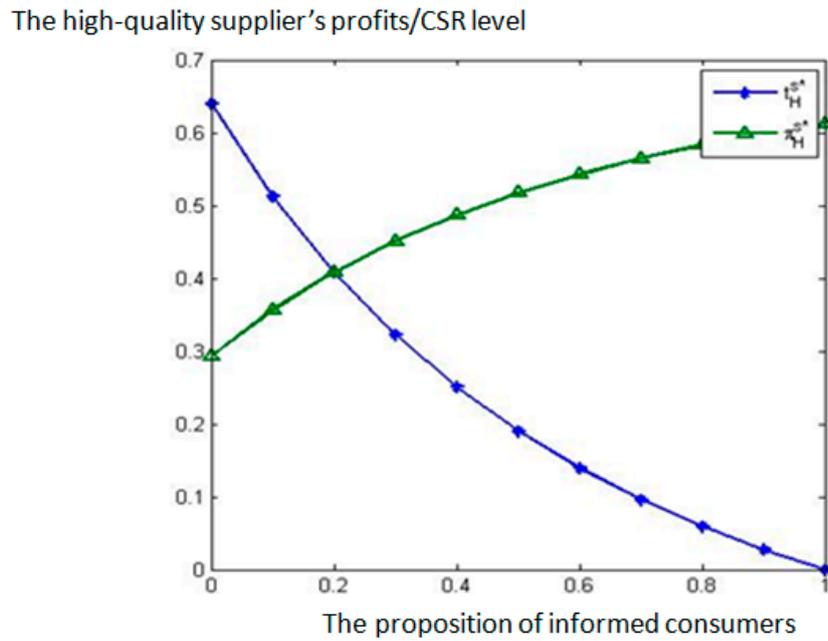


Figure 1. The effect of the proposition of informed consumers λ on the lowest corporate social responsibility (CSR) level and the high-quality supplier's profits. ($v_H = 10, v_L = 5, c_s = 2, c_r = 1, a_L = 0.8$ and $a_H = 0.5$).

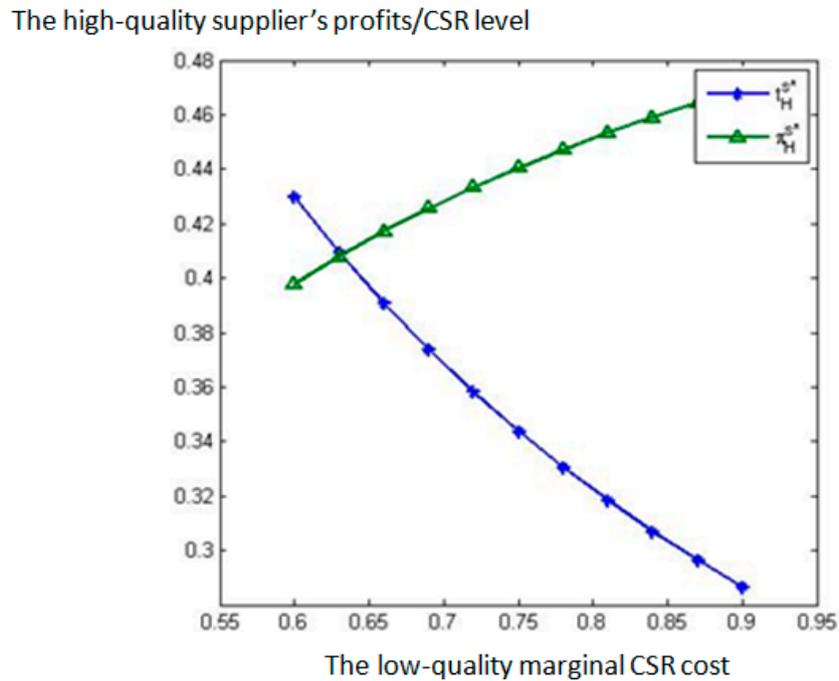


Figure 2. The effect of the low-quality marginal CSR cost a_L on the lowest CSR level and the high-quality supplier's profits. ($v_H = 10, v_L = 5, c_s = 2, c_r = 1, \lambda = 0.3$ and $a_H = 0.5$).

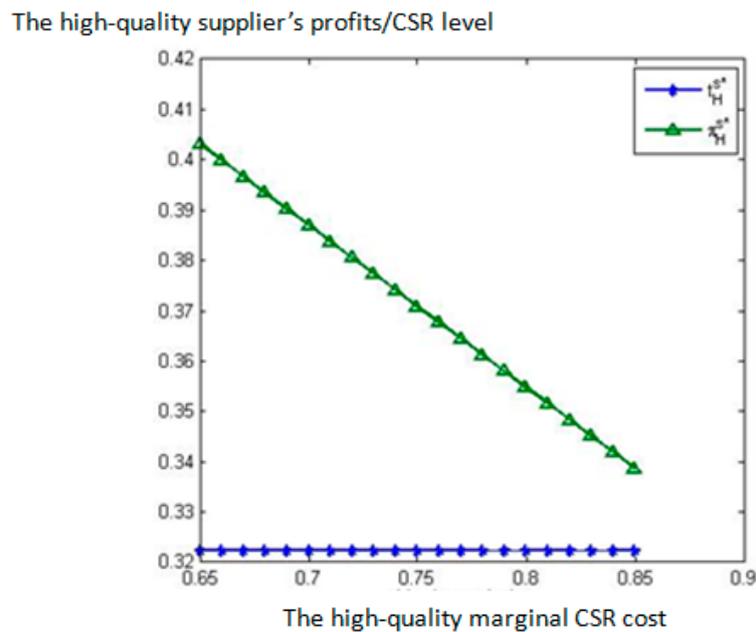


Figure 3. The effect of the high-quality marginal CSR cost a_H on the lowest CSR level and the high-quality supplier's profits. ($v_H = 10$, $v_L = 5$, $c_s = 2$, $c_r = 1$, $\lambda = 0.3$ and $a_L = 0.8$).

7. Discussion

Our findings in Proposition 3 demonstrate that CSR conduct can be used in a supply chain setting as an instrument for an upstream firm to signal its product quality information to a downstream firm and final consumers, and a moderate level of CSR conduct signals the upstream firm's high quality. These findings can be viewed as a theoretical support for the empirical judgment of Fabrizio [12] that voluntary CSR disclosure can be interpreted as a signal of product quality, and the empirical observation of [13] that firms selling experience goods and credence goods are more likely to be socially responsible than firms selling search goods. Moreover, we show in Proposition 2 that the high-quality supplier gets a higher profit than the low-quality supplier if the former conducts CSR activities to separate from the latter. These results are helpful to explain an empirically observed positive relationship between CSR performance and financial performance [30,31,45].

Theoretically, a firm can use CSR as a market signal to convey its ethical nature or build some reputation [12,46]. A recent paper [14] explores the role of CSR in signaling product quality in a setting of the private provision of public goods. The authors argue that competitive warm-glow firms can signal their quality levels by providing public goods (as a kind of CSR activity), and this quality-signaling motivation may offset the free-riding motivation. Consequently, public goods may be oversupplied. To avoid the inefficiency of this oversupply, governments should correspondingly tax CSR rather than subsidize it. We complement Tomer et al. [14] by showing that the quality-signaling role can work in non-competitive settings, where upstream quality-signaling firms in supply chains do not have any warm-glow preference, and they suffer from the negative externality of downstream retailers' marginalization.

The main managerial insight is that a private information possessor in a supply chain can use CSR activities as an alternative tool to communicate that information to the corresponding uninformed members and final consumers. More specifically, according to the signaling mechanism, a successful communication depends on the following aspects. First, the sender's CSR activities must be costly, in order to make the receiver believe that it is credible that some specific levels of CSR benefit the sender of some specific types, and make the sender of other types worse off. This is the basic mechanism that a sender's CSR activities influence the expectation formation of its (rational) receiver(s). Second, it is not necessary that CSR activities are relevant to the product attributes themselves, as long as their

costliness can prevent some specific types from mimicking the others. This leaves a large space for the sender to flexibly choose its signals among many kinds of CSR initiatives such as pollution reduction, charitable contributions, biodiversity protection, etc. Third, in spite of the flexibility of CSR signal choice, the receiver's attention and interpretation is the key to determine whether a choice of a CSR initiative as a signal is effective.

From a practical perspective, given that CSR is costly, the sender's flexibility of CSR signals and the receiver's attention and interpretation establish a strategic insight: it is better to choose a CSR initiative that has the lowest marginal cost and is known by a large population of receivers who tend to perceive it as a quality attribute. Starbucks' incentive to its suppliers' environmental protection may provide a good example of this insight [47]. On the one hand, environmental protection is one of the main concerns of consumers all over the world, and coffee beans grown in a better environment are more easily thought as of being more green (and thus possessing a higher level of quality). On the other hand, a better environment may decrease the suppliers' production costs, and thus help Starbucks to negotiate a lower purchase price to buy coffee beans from its suppliers. This may in turn offset some of Starbucks' cost to incentivize such environmental protection.

Finally, our findings, together with the implications of Tomer et al. [14] and the Starbucks case, furnish a quality-signaling response to the extant controversy of whether firms can coordinate the short-term economic goal with the long-term sustainability goal [48,49]. Take the environmental sustainability as an example. If high-quality firms (as senders) choose an environment-friendly CSR initiative as a quality signal, and the CSR initiative is "bundled" in their operational processes (to realize some kind of scale/scope economies), then they can achieve a win-win outcome. In the short run, they resolve the asymmetry of quality information, build a reputation of high quality, and then reap a high profit. In the long run, their environment-friendly CSR contributions enhance the environmental sustainability.

8. Concluding Remarks

In this work, we investigate how an upstream firm signals the product quality information via CSR choices in a supply chain consisting of an upstream supplier, a downstream retailer, and final consumers. The supplier privately owns information on the product quality, while the retailer and uninformed consumers are uncertain about the true quality level. The supplier tries to signal it through her CSR conduct to the retailer and uninformed consumers. These two supply chain members transact the product via a wholesale price contract. We build a signaling model to describe this decision-making setting, characterize the set of separating PBEs, select a unique PBE by the intuitive criterion, and provide a comparative static analysis on the unique PBE. Under the condition that the high-quality supplier's marginal CSR cost is relatively low to the low-quality supplier's marginal CSR cost, the main results are obtained as follows.

- (1) There are a set of moderate levels of CSR conduct that allow an upstream supplier can choose to truthfully report its product quality in the sense of a separating equilibrium. This implies a role of costly CSR in signaling the product quality information to a downstream retailer and uninformed consumers in the final market.
- (2) By ruling out the unreasonable posterior beliefs on off-equilibrium paths according to the classic intuitive criterion, we select a unique one with the lowest CSR from the set of PBEs as the most likely observation, because it is with reasonable beliefs and the lowest information cost that a high-quality supplier has to incur.
- (3) Based on the unique PBE satisfying the intuitive criterion, the high-quality supplier benefits from, in terms of profitability, a lower level of final-market information asymmetry, and/or a higher marginal CSR cost of the low-quality supplier, but becomes worse off as her marginal CSR cost increases. On the other hand, the low-quality supplier's profitability is independent of the final-market information asymmetry, and the marginal CSR costs of the high-quality and low-quality suppliers alike.

The current model assumes that final consumers do not derive any extra utility from the supplier's CSR activities. This implies that consumers are not socially responsible. In reality, there usually exist some socially responsible consumers [50,51]. Thus, it is worth extending our model to capture this consumer heterogeneity in terms of CSR preference. Second, for a multi-channel supply chain, it is intuitive that different quality expectations may lead to different behaviors of supply chain members in different channels. Then, in the case of quality information asymmetry, does a supplier have any motivation to use different signals to make her members in different channels form different quality expectations? What is the implication of channel choices, given that channel choices are an important research topic of supply chain management [52,53]? These questions need to be answered. Third, the one-retailer assumption in our model rules out the competition in the final market. We also expect future studies to explore the role of such downstream competition in the supplier's strategy to signal her product quality.

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