

OPTIMAL COOPERATION MODES AND INFORMATION STRATEGIES UNDER ASYMMETRIC SUSTAINABLE INVESTMENT EFFICIENCY

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Abstract. Currently, sustainability is of widespread concern among consumers and branders, compelling an increasing number of suppliers to invest in sustainable practices. This paper establishes a supply chain model comprising a supplier with private investment efficiency and a brander. By employing signaling and reverse selection theories, the equilibrium strategies of the supplier and the brander are explored. Additionally, the impact of investment efficiency and the probability of H-type on the brander's information strategy and optimal cooperation mode are analyzed. Our analyses reveal that concealing private information may not be beneficial to the supplier under the quotation mode. Moreover, when the probability of H-type is low, the supplier prefers to signal its exact type to the brander. Under the bidding mode, the brander may benefit more from not obtaining the exact supplier type. When the efficiency difference is higher and the probability of H-type is smaller, the brander indicates a preference for the quotation mode and is more willing to await a signal from the supplier. Furthermore, different information structures yield different optimal cooperation modes for the brander.

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1. INTRODUCTION

Today, with the “green wave” sweeping across the globe, the focus on sustainability extends to consumer choices and manufacturing practices [3, 22]. Increasingly, consumers prioritize sustainability when deciding which products and brands to support [8, 15]. A survey conducted by R.I.S.E during COP 26 revealed that 89.1% of respondents expressed their willingness to purchase sustainable products, with 50.3% of respondents having purchased green and sustainable products. In response to growing consumers' awareness of sustainable consumption, many branders have implemented sustainable manufacturing practices, offering a wider range of sustainable products to consumers. Notable examples include automobile brand makers (*e.g.*, Volvo and Mercedes), electronic product makers (*e.g.*, Apple, Dell, and Toshiba), and fast fashion clothing branders (*e.g.*, C&A and Zara). To meet branders' sustainability requirements, an increasing number of upstream suppliers are investing in equipment renewal and improvements to produce environmentally friendly materials while reducing production costs [28]. For instance, an Apple supplier reported the successful provision of recycled rare earth to Apple since 2019, which was achieved through an early transformation of technical equipment, thereby avoiding environmental pollution and reducing costs. Similarly, XTY, a supplier to global fashion brands such as

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UNIQLO, H&M, and Zara, has introduced advanced European equipment to develop zero dye stock solution coloring technology. This innovation reduces water consumption by 72% and carbon emissions by 26% compared with traditional dyed fabrics. Undoubtedly, investments and production transformations toward sustainability not only consolidate the relationship between suppliers and branders but also generate considerable benefits.

In academic circles, the topic of sustainability has been extensively discussed [1, 5, 25]. However, this literature assumes that the sustainable investment cost or investment efficiency is publicly known. In practice, information asymmetry exists, where suppliers hold private information about their sustainable investment cost or efficiency, making it difficult for branders to observe [11]. This information asymmetry creates a situation where suppliers with low efficiency may have an incentive to mimic suppliers with high efficiency to maximize their profits. Anticipating this behavior, branders cannot accurately determine the supplier's exact type based only on wholesale prices, leading them to make decisions based on prior beliefs. This situation not only affects the high-efficiency supplier but also results in purchasing costs for the brander. Thus, branders should design an appropriate cooperation mode that encourages suppliers to disclose their actual investment information, thereby effectively reducing purchasing costs.

Based on the aforementioned statement, this study proposes two cooperation modes: first, to reduce losses, the supplier actively sends a signal to the brander through strategic wholesale prices, referred to as the quotation mode. Second, to effectively reduce purchasing costs, the brander can actively screen the supplier's sustainable investment efficiency through different contracts, denoted as the bidding mode. In practice, Lenovo purchases carbon fiber notebook shells from PTS firm using the quotation mode, where PTS firm provides investment information as a signal. Additionally, UNIQLO actively screens the sustainability information of XTY company through different contracts. However, a tradeoff exists for the brander, who lacks information advantage, as they must decide whether to wait for the supplier to provide information or actively screen it.

Although some studies have addressed the issue of cooperation modes, there is still a lack of comprehensive investigation into the cooperation modes between branders and suppliers from the perspective of asymmetric investment efficiency. This study aims to fill this gap by examining the effect of investment efficiency on cooperation modes and market strategies. The specific research questions addressed in this study are as follows:

- (i) Under the quotation mode, how do different information structures affect the market strategies of the supplier and the brander? How does the supplier signal sustainable investment information to the brander?
- (ii) Under the bidding mode, what strategy does the brander employ to screen information? What factors determine the brander's screening strategy?
- (iii) In the presence of information asymmetry, how does the brander select the cooperation mode that maximizes profits?

To address the aforementioned problems, we propose a sustainable supply chain mode consisting of a brander and a supplier, where the supplier's sustainable investment results in cost reduction and increased demand. The paper emphasizes the presence of information asymmetry between the supply chain members. Specifically, it assumes that, given the same investment cost, the supplier's investment efficiency in sustainability can be either low type (L-type) or high type (H-type), which is private information known only to the supplier. The brander is aware of the probability of the supplier being of the H-type. Under the quotation mode, the present study examines both separating and pooling equilibria. Three contracts are considered under the bidding mode: separating, pooling, and closing. By utilizing signaling and reverse selection theories, this study aims to explore the information strategies and optimal cooperation modes for the supplier and the brander in the presence of asymmetric investment efficiency. The main conclusions are as follows:

- (i) Counterintuitively, the supplier does not always prefer to signal his type to the brander under the quotation mode. In the separating equilibrium, when the probability of the supplier being of the H-type is small, the H-type supplier may be regarded as an L-type supplier. Therefore, actively signaling his type to the brander would reduce losses for the supplier. In the pooling equilibrium, a larger probability of the supplier being of the H-type indicates decreased losses for the H-type supplier. Therefore, the supplier may choose not to signal their investment efficiency to the brander.

- (ii) For the brander, relinquishing the acquisition of the supplier's exact type can yield higher profits under the bidding mode. Intuitively, one might believe that obtaining the supplier's exact type through the separating strategy is more advantageous for the brander, as the pooling strategy limits flexibility in resource allocation. Compared with the pooling strategy, the separating strategy is dominant only when the efficiency difference is small. When the efficiency difference is small and the probability of the supplier being of the H-type is higher, the separating strategy necessitates higher information rent payment for the brander to screen the supplier's type. Conversely, the pooling strategy exhibits more favorable outcomes.
- (iii) We find that the optimal cooperation mode differs across different information structures. In case of information symmetry, the brander finds the quotation mode optimal due to the higher cost of the bidding mode. However, under information asymmetry, one might intuitively judge that the brander prefers the quotation mode due to the higher information rent under the bidding mode. The optimal cooperation mode depends on the interaction between the efficiency difference and the probability of the supplier being of the H-type. Specifically, when the probability of the supplier being of the H-type is lower and the efficiency difference is higher, the brander prefers the quotation mode and waits for the supplier to disclose his type. Conversely, when the probability of the supplier being of the H-type is higher and the efficiency difference is smaller, the brander prefers to actively screen the supplier's type through the bidding mode.

The rest of this paper is organized as follows. Section 2 presents a review of literature. Section 3 presents the model and notations. Section 4 analyzes the benchmark case under information symmetry. Under information asymmetry, the supplier's and the brander's strategies under two cooperation modes are presented in Sections 5 and 6, respectively. In Section 7, the brander's preference for cooperation modes is analyzed. Finally, Section 8 presents the conclusions and future research directions.

2. LITERATURE REVIEW

This study contributes to three streams of literature: sustainability operations, signaling games, and information screening. We discuss the literature for each stream in the following sections.

First, this study adds to the research on sustainability operations [19]. For instance, Ding *et al.* [6] analyzed optimal pricing strategies for corporations considering environmental regulations. Li *et al.* [17] examined the relation between the green level of a product and the performance of a decentralized green product supply chain. In the context of a maritime supply chain, Lai *et al.* [11] analyzed the effects of risk-averse behavior and information sharing on sustainability investment. Sarkar *et al.* [22] investigated the joint impacts of quality decision and carbon emissions on sustainable supply chains. In the realm of circular economy, Tian *et al.* [25] explored the joint recovery of products produced by different manufacturers or sold in different markets. Pal and Sarkar [21] focused on the level of green innovation in a dual-channel green supply chain with recycling. Dey *et al.* [5] explored the role of green technology and automated inspection in carbon emissions and waste reduction. Additionally, in a closed-loop supply chain, Taleizadeh *et al.* [24] investigated cost-sharing contracts under returning and remanufacturing policies. Zhao *et al.* [28] observed that introducing the wholesale price and quality cost-sharing contracts can coordinate closed-loop supply chains with remanufactured products. Savaskan *et al.* [23] and Zheng *et al.* [29] discussed product recycling channels and recycling alliance modes. Yet, theoretical studies contributing to our understanding on the interaction between a supplier and a brander under asymmetric sustainable investment efficiency information are lacking. The present study aims to fill this gap in literature.

This study also enriches the literature on information asymmetry, particularly in the domains of signaling and information screening. One strand of this literature explores incentive mechanisms in the presence of information asymmetry and investigates the selection of screening contracts that encourage the agent to truthfully disclose information. For instance, Xiao and Yang [26] developed a model of information revelation between a manufacturer and a retailer and studied how the manufacturer can screen the retailer's risk sensitivity information through a wholesale price-quantity contract. Löffler *et al.* [18] examined the effect of information asymmetry on a firm's supplier switching process. Bakshi *et al.* [2] proposed a menu of after-sale service contracts to elicit

product reliability information. Under demand information asymmetry, Li *et al.* [13] demonstrated how a supplier with encroachment motivation can screen market demand information by offering contracts to the retailer. Zhou *et al.* [30] investigated a screening mode involving a dominant manufacturer and a downstream retailer under information asymmetry. They found that in the presence of demand uncertainty, the manufacturer can achieve greater profits without paying information rent. In contrast to the existing literature, Xu *et al.* [27] discussed how the private cost information of an urgent supplier affects the performance of overseas suppliers and manufacturers under different contract mechanisms. Additionally, Li *et al.* [16] proposed two regimes to reduce disruption risk under screening menu contracts. Ni *et al.* [20] demonstrated that longer contracts can foster innovation but may result in higher wholesale prices for manufacturers with high innovation efficiency. Unlike this stream of literature, the present study focuses on information screening contracts under asymmetric sustainable investment efficiency, thereby expanding the application scope of information screening.

Existing literature, as discussed above, has primarily focused on situations where the uninformed party motivates the informed party to reveal private information through screening mechanisms. However, our research relates to the broader field of signaling games in operations management. In this field, Cachon and Lariviere [4] analyzed how a downstream manufacturer, who possesses private information, signals it to an upstream supplier. Li *et al.* [14] further presented a setting involving supplier encroachment and found that when the retailer strategically distorts the order quantity downwards, the double marginalization effect is amplified. Jiang *et al.* [10] analyzed three information sharing formats (no sharing, voluntary sharing, and mandatory sharing), where the supplier signals the market size to the retailer by distorting the wholesale price. Hu and Qi [9] investigated how a powerful original equipment manufacturer procures multiple inputs for assembly from suppliers with private costs. Li and Zhou [12] considered the signaling game concerning capacity reservation between an integrated device manufacturer and a foundry. In dual-channel distribution, Gao *et al.* [7] examined the manufacturer's signaling strategy under asymmetric sales efficiency and demonstrated that upstream private information can improve channel efficiency and consumer surplus. Accordingly, it is evident that most extant studies have employed either the screening mode or the signaling mode to investigate asymmetric information settings. By contrast, our study not only focuses on the screening model but also incorporates the signaling game. This study conducts a cross-comparison between the two modes to demonstrate how the brander's preference in the cooperation mechanism is affected by asymmetric sustainable investment efficiency under different exogenous conditions.

Unlike the aforementioned studies, our work presents a quotation mode with signaling game and a bidding mode with information screening in cases where the brander faces an informational disadvantage in sustainable investment efficiency. We examine equilibrium strategies under different cooperation modes and analyze when the brander should screen information or wait for information. Furthermore, we explore how the probability of the supplier being of the H-type and the efficiency difference in sustainable investment affect the brander's cooperation mode with the supplier. For comparison, Table 1 summarizes the main differences to better illustrate the contributions of the present study.

3. MODEL AND NOTATIONS

We consider a sustainable supply chain comprising a supplier and a brander. The supplier makes considerable investments in sustainability-related capital during the initial stage to improve production technology, reform the production process, and renew raw materials. These enhancements result in lower production costs and higher demand in later stages. To capture this feature, we assume that the supplier produces products at a marginal cost k and incurs a sustainable investment cost C . When the supplier completes the sustainable improvement, the marginal cost decreases to $k - \varepsilon e_i$. For convenience, ε is normalized to 1. We classify the supplier into two types of investment efficiency, denoted as e_i , with $i \in \{H, L\}$: a high-efficiency type e_H (denoted as H-type) and a low-efficiency type e_L (denoted as L-type), where $e_H > e_L$. The efficiency difference is denoted as $\theta = e_H - e_L$. The efficiency e_i is the supplier's private information that is not observable to the brander. The brander holds a prior belief that the supplier is either the H-type e_H with a probability $\Pr(i = H) = \beta$ or the L-type e_L with

TABLE 1. Comparative analysis of the literature related to the present work.

Literature	Sustainability	Asymmetric information setting	Game players	Sustainable investment	Quotation mode (Signaling)	Bidding mode (Screening)
Ding <i>et al.</i> [6]	✓	–	Manufacturer–supplier–government	–	–	–
Lai <i>et al.</i> [11]	✓	Demand information	Port–carrier	✓	–	–
Li <i>et al.</i> [17]	✓	–	Manufacturer–retailer	–	–	–
Sarkar <i>et al.</i> [23]	✓	–	Supplier–manufacturer–multiple retailers	✓	–	–
Zhao <i>et al.</i> [29]	✓	Cost information	Manufacturer–retailer	–	–	–
Löffler <i>et al.</i> [18]	–	Cost information	Firm–supplier	–	–	✓
Xiao and Yang [24]	–	Risk sensitivity information	Manufacturer–retailer	–	–	✓
Zhou <i>et al.</i> [27]	–	Demand information	Manufacturer–retailer	–	–	✓
Bakshi <i>et al.</i> [2]	–	Reliability information	Vendor–consumer	–	–	✓
Jiang <i>et al.</i> [10]	–	Demand information	Supplier–retailer	–	✓	–
Hu and Qi [9]	–	Cost information	Supplier–manufacturer	–	✓	–
Li and Zhou [12]	–	Capacity information	Manufacturer–pure-play foundry	–	✓	–
Gao <i>et al.</i> [7]	–	Cost information	Supplier–retailer	–	✓	–
Our work	✓	Investment efficiency information	Supplier–brander	✓	✓	✓

Notes. ✓ = covered, – = uncovered.

a probability $\Pr(i = L) = 1 - \beta$, where $\beta \in (0, 1)$. Therefore, the expected investment efficiency is expressed as $\mu = \beta e_H + (1 - \beta)e_L$. Additionally, e_j , $j \in \{H, L\}$ is assumed to denote the brander's judgment of the supplier's type. $i = j$ implies that the brander accurately identifies the supplier's type. In this paper, two parties engage in an asymmetric information game and expect to achieve the perfect Bayesian Nash equilibrium.

As depicted in Figure 1, two potential cooperation modes exist between the brander and the supplier: bidding and quotation. Under the quotation mode, the supplier announces the wholesale price w , and then, the brander decides the order quantity q . Thus, the selling price is given by $p = a + \delta e_i - q$, where a denotes the basic market size, δe_i denotes additional demand from consumers under sustainable investment, and δ signifies consumer sensitivity to the supplier's sustainable investment efficiency. A higher investment efficiency attracts more consumers, assuming the same sustainable investment cost. By contrast, the bidding mode entails the brander initially presenting a menu of quantity-payment contracts $\{q_i, T_i\}$, $i \in \{H, L\}$, where q_i denotes the order quantity of the brander and T_i denotes the transfer payment to the supplier. Based on the reserved utility, the supplier decides whether to accept the contract.

Under the quotation mode, the brander waits for the supplier to voluntarily disclose their type, which is regarded as a signaling model. Under the bidding mode, the brander proactively screens the supplier's type, which can be regarded as a screening model. Thus, the brander faces a tradeoff between the two modes.

Figure 2 illustrates the sequence of the multistage game.

As illustrated in Figure 2, the brander first selects the cooperation mode and communicates this choice to the supplier. When cooperating with the supplier under the quotation mode, the brander awaits the supplier's offer of a wholesale price, denoted as w . Subsequently, the brander updates their prior belief based on the observed wholesale price w and determines the order quantity q . When cooperating with the supplier under the bidding mode, the brander provides a menu of quantity-payment contracts $\{q_i, T_i\}$, $i \in \{H, L\}$ and infers the supplier's

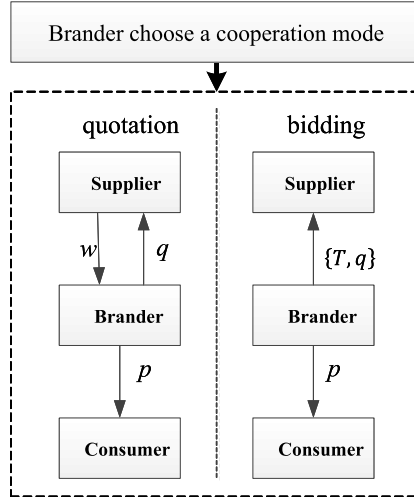


FIGURE 1. Cooperation mode of brander.

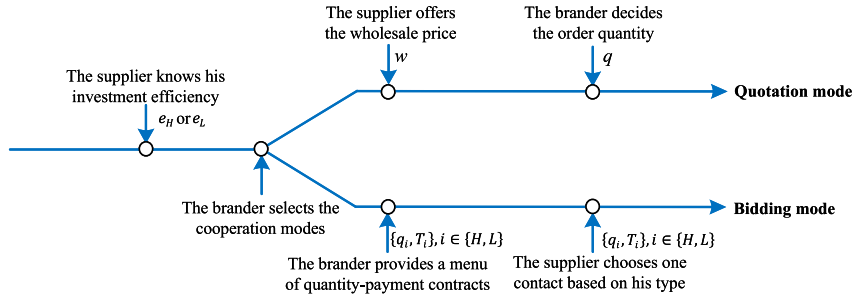


FIGURE 2. Sequence of the events.

investment efficiency through the supplier's choice. Finally, the demand is realized, and the supplier and the brander obtain corresponding profits. Table 2 lists the notations used in this paper.

4. BENCHMARK CASE UNDER INFORMATION SYMMETRY

Under information symmetry, the brander can directly observe the supplier's investment efficiency before making decisions. Consequently, the prior belief aligns with the true type of the supplier, *i.e.*, $i = j$. In this paper, the superscript $\square$ indicates the benchmark case. The superscripts "sig" and "scr" indicate the signaling game under the quotation mode and the screening game under the bidding mode, respectively. To simplify the calculation process, we omit the superscripts in subsequent calculations.

4.1. Benchmark case under the quotation mode

Under information symmetry, the investment efficiency of the supplier is common knowledge. Accordingly, the supplier and brander's profits are expressed as follows:

$$\pi^{\text{sig}} = (a + \delta e_i - q - w)q \quad (1)$$

$$\Pi^{\text{sig}} = (w - (k - e_i))q - C. \quad (2)$$

TABLE 2. Key notations.

Symbols	Description
C	Supplier's sustainable investment cost
e_i	Supplier's investment efficiency in sustainability, $i = \{H, L\}$
k	Unit production cost before sustainability improvement
q	Brander's order quantity
w	Wholesale price of the product
T	Transfer payment from the brander
a	Basic market demand
δ	Consumer sensitivity to supplier's investment efficiency, $\delta \in [0, 1]$
β	Probability of H-type
θ	Efficiency difference between the two types of suppliers
μ	Expected investment efficiency about two types of suppliers

Proposition 4.1. *Under information symmetry, an optimal quotation mode exists:*

- (1) *Optimal wholesale price and profit for the supplier are $\bar{w}_i^{\text{sig}^*} = \frac{1}{2}(a + k - e_i + \delta e_i)$, $\bar{\Pi}_i^{\text{sig}^*} = \frac{1}{8}(a - k + e_i + \delta e_i)^2 - C$;*
- (2) *Optimal order quantity and profit for the brander are $\bar{q}_i^{\text{sig}^*} = \frac{1}{4}(a - k + e_i + \delta e_i)$, $\bar{\pi}_i^{\text{sig}^*} = \frac{1}{16}(a - k + e_i + \delta e_i)^2$.*

Proposition 4.1 characterizes the optimal wholesale price for the supplier and the optimal order quantity for the brander. When the brander can observe the supplier's type, the H-type supplier sets a lower wholesale price than the L-type supplier. This is because the H-type supplier, with a higher investment efficiency, enjoys a cost advantage in reducing production costs despite having the same investment cost C . Therefore, the H-type supplier is inclined to set a lower wholesale price to attract a higher order quantity from the brander. In the green consumption market, a higher demand for products exists that exhibits high sustainability. Specifically, a higher consumer sensitivity parameter δ corresponds to a more advantageous situation for the supply chain. Hence, the brander has an incentive to procure more products from the H-type supplier.

4.2. Benchmark case under the bidding mode

In this mode, the brander provides a menu of contracts, from which the supplier selects the contract based on the true type. The supplier's and brander's profits are expressed as follows:

$$\pi^{\text{scr}} = (a + \delta e_i - q)q - T \quad (3)$$

$$\Pi^{\text{scr}} = T - (k - e_i)q - C. \quad (4)$$

The brander offers quantity-payment contracts based on the supplier's reserved utility π_0 . The transfer payment and the order quantity are indicated in Proposition 4.2.

Proposition 4.2. *Under information symmetry, the optimal quantity-payment contracts are $\{\bar{q}_H^{\text{scr}^*}, \bar{T}_H^{\text{scr}^*}\}$ and $\{\bar{q}_L^{\text{scr}^*}, \bar{T}_L^{\text{scr}^*}\}$, where $\bar{q}_i^{\text{scr}^*} = \frac{1}{2}(a - k + e_i + \delta e_i)$, $\bar{T}_i^{\text{scr}^*} = (k - e_i)q_i^* + \pi_0 + C$.*

Proposition 4.2 illustrates the brander's quantity-payment contracts. Consumers are more willing to buy products with high sustainability such that the brander places more orders with the H-type supplier. Furthermore, from the wholesale price $w = \frac{T_i^*}{q_i^*} = (k - e_i) + \frac{\pi_0 + C}{q_i^*}$, it can be easily acquired that $\bar{w}_H^{\text{scr}^*} < \bar{w}_L^{\text{scr}^*}$ under the same reserved utility π_0 , consistent with that under the quotation mode.

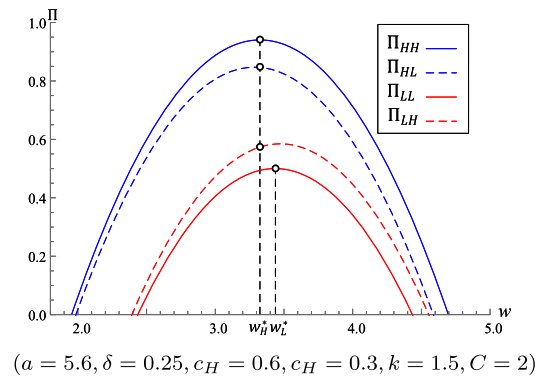


FIGURE 3. The supplier's profits.

4.3. Cooperation mode selection of the brander

When the brander exactly knows the investment efficiency in sustainability of the supplier, the brander's profits are $\bar{\pi}_i^{\text{sig}*} = \frac{1}{16}(a - k + e_i + \delta e_i)^2$ under the quotation mode and $\bar{\pi}_i^{\text{scr}*} = \frac{1}{4}(a - k + e_i + \delta e_i)^2 - \pi_0 - C$ under the bidding mode. The brander prefers the bidding mode if and only if $\bar{\pi}_i^{\text{sig}*} \leq \bar{\pi}_i^{\text{scr}*}$; otherwise, they prefer the quotation mode.

Corollary 4.3. *Under information symmetry, there exists a threshold $\bar{\pi}_0^i = \frac{3}{16}(a - k + e_i + \delta e_i)^2 - C$. When $\pi_0 > \bar{\pi}_0^i$, the brander selects the quotation mode and vice versa.*

Corollary 4.3 determines that under information symmetry, the brander's mode selection is only related to the supplier's reserved utility under the bidding mode. The brander prefers the quotation mode when the utility that the supplier can achieve is higher than the threshold value $\bar{\pi}_0^i$. The supplier's profit is derived from the overall profit of the supply chain. When the supplier's reserved utility is higher, the supplier is considered to be more concerned about their own profit and less inclined to share surplus with the brander. Therefore, when the supplier's reserved utility reaches a sufficiently high level, it becomes advantageous for the brander to choose the quotation mode. In addition, Corollary 4.3 suggests that the brander should not only focus on maximizing profits under the bidding mode but also consider the reserved utility of the supplier. Consensus on the cooperation mode between the supplier and the brander can be achieved under the quotation mode only when the supplier obtains a sufficiently high reserved utility.

5. QUOTATION MODE UNDER INFORMATION ASYMMETRY

Under the quotation mode, the supplier's investment efficiency is not directly observed by the brander; however, the brander can infer it from the supplier's wholesale price under information asymmetry. The L-type supplier may have an incentive to mimic the H-type supplier's wholesale price to induce a higher order quantity when the brander regards the L-type supplier as the H-type supplier.

In Figure 3, Π_{ij} denotes the supplier's profit when the true type is i and the brander considers it as j . Specifically, Π_{HL} denotes the H-type supplier's profit when the H-type supplier is mistaken for the L-type supplier. Figure 3 depicts the supplier's possible profits $\Pi_{ij}(w_i)$, $i, j \in [H, L]$. As observed, mimicking the H-type supplier makes the L-type supplier better off by setting a lower wholesale price; however, the H-type supplier may be worse off because of mimicking the L-type supplier.

Next, we analyze the perfect Bayesian equilibria (PBE) and identify two types of equilibria: separating and pooling. In the separating equilibrium, the supplier types (H-type and L-type) choose different wholesale prices that allow the brander to infer the supplier's type. In the pooling equilibrium, both types of suppliers set the same

wholesale price, making it impossible for the brander to infer the supplier's type based solely on the wholesale price. Accordingly, the brander places orders based on their prior belief. The unique separating equilibrium and the unique pooling equilibrium are characterized in Sections 5.1 and 5.2, respectively. To distinguish between the two equilibria, the superscript "sd" is used to denote the separating equilibrium and "p" is used to denote the pooling equilibrium in this paper.

5.1. Separating equilibrium

In this case of a separating equilibrium, the two types of suppliers adopt distinct wholesale prices. A threshold value w_H^{sd*} exists in this equilibrium. If the brander observes a wholesale price $w \leq w_H^{sd*}$, the brander updates their belief from $\Pr(i = H) = \beta$ to $\Pr(i = H) = 1$ and regards the supplier as H-type; otherwise, they regard the supplier as L-type.

The separating equilibrium can be either costless or costly. In the case where the efficiency difference is considerable, the L-type supplier has no incentive to mimic the H-type supplier owing to high mimicking costs. Hence, the optimal wholesale price coincides with that under the benchmark case in Proposition 4.1. In other words, costless separating can be called the natural separating equilibrium, where distortion of the wholesale price is not needed. In the costly separation scenario, the L-type supplier has an incentive to mimic the H-type supplier, creating a need for the H-type supplier to set a lower wholesale price to successfully signal their true type to the brander. Thus, the H-type supplier's profit decreases because of the need to pay an information rent for successfully signaling their true type.

In the separating equilibrium, the L-type supplier will be worse off when mimicking the optimal wholesale price of the H-type supplier. Thus, the condition that ensures the existence of the separating equilibrium is summarized as follows:

$$\Pi_{LH}(w_H^*) < \Pi_{LL}(w_L^*). \quad (5)$$

In inequality (5), $\Pi_{LH}(w_H^*)$ denotes the L-type supplier's profit under mimicking and $\Pi_{LL}(w_L^*)$ denotes the L-type supplier's optimal profit with $\Pr(i = H) = 0$.

The aforementioned condition is satisfied when $\theta > \bar{\theta}$, where $\bar{\theta} = \frac{2(a\delta + e_H\delta - k\delta + \delta^2 e_H)}{(1+\delta)^2}$. When $\theta \leq \bar{\theta}$, to distinguish from the L-type supplier, the H-type supplier sends a signal to the brander by distorting the wholesale price downward as well as by paying the information rent. Furthermore, the optimal order quantity for the brander is $q^{sd*} = \frac{1}{2}(a - w_H^{sd*} + \delta e_H)$. Accordingly, the optimal profit function for the H-type supplier is given as follows:

$$\begin{aligned} \max_w \Pi(w_H^{sd}) &= \frac{1}{2}(w_H^{sd} - k + e_H)(a - w_H^{sd} + \delta e_H) - C \\ \text{s.t. } &\begin{cases} \Pi_{LH}(w_H^{sd}) < \Pi_{LL}(w_L^*) \\ \Pi_{HH}(w_H^{sd}) > 0. \end{cases} \end{aligned} \quad (6)$$

Solving this objective function (6), the equilibrium results are summarized in Lemma 5.1.

Lemma 5.1. *Under information asymmetry, the optimal pricing and profit for the supplier are as follows:*

- (1) the optimal wholesale price and profit for the L-type supplier are $w_L^{sd*} = \bar{w}_L^{\text{sig}*}$, $\Pi_L^{sd*} = \bar{\Pi}_L^{\text{sig}*}$;
- (2) the optimal wholesale price and profit for the H-type supplier are

$$w_H^{sd*} = \begin{cases} \bar{w}_H^{\text{sig}*}, & \theta > \bar{\theta} \\ \hat{w}^{sd*}, & \theta \leq \bar{\theta} \end{cases}, \quad \Pi_H^{sd*} = \begin{cases} \bar{\Pi}_H^{\text{sig}*}, & \theta > \bar{\theta} \\ \hat{\Pi}_H^{sd*}, & \theta \leq \bar{\theta} \end{cases},$$

where $\hat{w}^{sd*} = \bar{w}_H^{\text{sig}*} - \underbrace{E_w^{\text{sd}}}_{\text{asymmetric information effect}},$

$$E_w^{\text{sd}} = \frac{1}{2}\sqrt{\delta(e_H - e_L)(2a - 2k + 2e_L + \delta e_H + \delta e_L)} - \frac{1}{2}(e_H - e_L).$$

Lemma 5.1 characterizes the supplier's wholesale price strategy in the separating equilibrium. The wholesale price and optimal profit for the L-type supplier coincide with that under information symmetry. The H-type supplier's wholesale price and profit relate to the efficiency difference. When $\theta > \bar{\theta}$, the L-type supplier needs to significantly reduce the wholesale price such that it is unprofitable for the L-type supplier to mimic. A significant efficiency difference results in a difference in the wholesale price, making the mimicry cost so high that the L-type supplier prefers not to mimic. Therefore, as $\theta > \bar{\theta}$, a natural separating equilibrium exists, where there is no need to distort the wholesale prices. When $\theta \leq \bar{\theta}$, the wholesale price difference between the two types of suppliers is smaller. In this case, the L-type supplier has an incentive to mimic the H-type supplier. The H-type supplier sets a lower wholesale price to make the L-type's mimicry unprofitable and pays the cost for separating the L-type supplier ($\hat{\Pi}_H^{\text{sd}*} < \bar{\Pi}_H^{\text{sig}*}$). Thus, the greater the efficiency difference, the more significant the asymmetric information effect E_w^{sd} . In the separating equilibrium, when observing $\hat{w}^{\text{sd}*}$, the brander can successfully identify the supplier's type.

Corollary 5.2. *The asymmetric information effect E_w^{sd} increases in δ .*

Corollary 5.2 indicates that the separating equilibrium is affected by consumer sensitivity δ . As δ increases, the additional demand from consumers increases. With a larger consumer sensitivity δ , the L-type supplier can acquire more profits from mimicking. Thus, the H-type supplier needs to enhance the distortion level of the wholesale price so that E_w^{sd} increases in δ .

5.2. Pooling equilibrium

In the pooling equilibrium, both the H-type and L-type suppliers choose to set the same wholesale price denoted as w^{p*} , leading to the brander's inability to infer the supplier's type and maintaining the prior belief, that is, $e_j = \mu$. In this case, the order quantity for the brander is $q^p = \frac{1}{2}(a - w^{p*} + \delta\mu)$. To ensure pooling equilibrium exists, the supplier's profit derived from deviating from w^p should be less than the pooling profit. If the supplier deviates from the pooling equilibrium, the brander will believe that the supplier is L-type and places a lower order quantity.

Based on the aforementioned arguments, the profit function for the supplier is expressed as follows:

$$\begin{aligned} \max_w \Pi(w^p) &= \frac{1}{2}(w^p - k + e_H)(a - w^p + \delta\mu) \\ \text{s.t. } &\begin{cases} \Pi_{\text{HN}}(w^p) > \Pi_{\text{HL}}(w, c_H) \\ \Pi_{\text{LN}}(w^p) > \Pi_{\text{LL}}(w, c_L) \end{cases} \end{aligned} \quad (7)$$

Solving the above constraints, the pooling equilibrium is summarized in Lemma 5.3.

Lemma 5.3. *There exists a threshold $\bar{\beta} \in [0, 1]$, and the pooling equilibrium exists if $\beta \geq \bar{\beta}$:*

- (1) *The i -type supplier will pool at $w^{p*} = \bar{w}_H^{\text{sig}*} - \underbrace{E_w^p}_{\text{asymmetric information effect}}$. The i -type supplier's optimal profit is $\Pi_i^{p*} = \frac{1}{8}(w^{p*} - k + e_i)(a - w^{p*} + \delta\mu)$, where $E_w^p = \frac{\delta e_H - \delta\mu}{2}$;*
- (2) *The pooling wholesale price w^{p*} increases in both β and δ .*

Lemma 5.3 interprets the pooling equilibrium under information asymmetry. The supplier chooses the same wholesale price w^{p*} ($w^{p*} < \bar{w}_H^{\text{sig}*} < \bar{w}_L^{\text{sig}*}$) regardless of their type. This results in the brander's inability to accurately distinguish the supplier's exact type. In this case, the brander makes decisions on the order quantity based on the expected investment efficiency $\mu = \beta e_H + (1 - \beta)e_L$. When the probability of H-type β increases, the brander's belief about the expected investment efficiency is closer to the H-type supplier. Thus, deviating from the pooling equilibrium considerably reduces the order quantity for the H-type supplier, while the L-type supplier will gain a higher profit under the pooling equilibrium. Therefore, a larger β boosts the willingness to

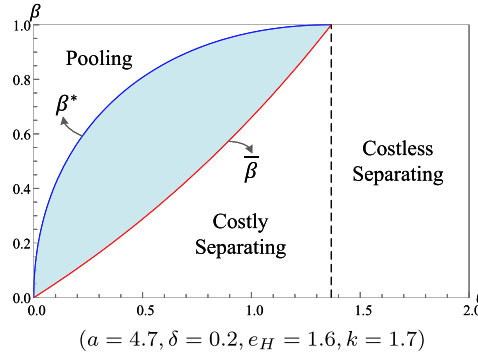


FIGURE 4. Optimal equilibrium under the quotation mode.

pool for both types of suppliers. Conversely, a smaller β means a lower expected investment efficiency, under which the order quantity placed by the brander will be lower. Accordingly, the supplier will set a lower pooling wholesale price to motivate the brander to place more order quantity. In this case, the supplier has a strong incentive to deviate from the pooling equilibrium with a higher wholesale price. Hence, the pooling equilibrium exists if and only if the probability of H-type is sufficiently large. In addition, an increasing consumer sensitivity δ will produce more demands, prompting the supplier to raise the wholesale price and gain more profits.

5.3. Comparison of separating and pooling under the quotation mode

The separating and the pooling equilibria have been investigated in the previous sections. In this section, two equilibria are refined and the optimal equilibrium is extracted.

Comparing the H-type supplier's profits under the two equilibria, the optimal profit for the H-type supplier is expressed as follows:

$$\Pi_H^{\text{sig}} = \max\{\Pi_H^{p*}, \Pi_H^{\text{sd}*}\}. \quad (8)$$

Proposition 5.4. *Under information asymmetry, there exists a threshold value $\beta^* \in [0, 1]$. When $\beta < \beta^*$, the separating equilibrium is optimal for the H-type supplier and when $\beta^* \leq \beta < 1$, the pooling equilibrium is optimal.*

Figure 4 depicts the optimal equilibrium under different parameter regions. When the efficiency difference is more significant ($\theta \geq \bar{\theta}$), the L-type supplier has no incentive to mimic, resulting in a costless separating equilibrium. When the efficiency difference is not sufficiently large, the H-type supplier considers whether to signal his type to the brander. As indicated in Proposition 5.4, when $\beta < \bar{\beta}$, the pooling equilibrium does not exist. In this case, the H-type supplier can only select the separating equilibrium. With $\beta \geq \bar{\beta}$, pooling and the separating equilibria exist. As β increases, there exists a threshold value β^* . When $\beta < \beta^*$ in Figure 4, the profit from the separating equilibrium outweighs that from the pooling equilibrium. In this case, the H-type supplier prefers the separating equilibrium to signal their type to the brander. When $\beta \geq \beta^*$, the cost paid by the H-type supplier in the separating equilibrium is greater than the loss of profit in the pooling equilibrium, leading the supplier to choose the pooling equilibrium.

The above analysis indicates that the H-type supplier will be no longer eager to reveal their true type to the brander when β increases. When $\beta < \beta^*$, the H-type supplier distorts his wholesale price downward to disclose the brander's true type and derives a higher order quantity. When $\beta \geq \beta^*$, the H-type supplier gives up revealing their true type to the brander. Thus, the brander places an order quantity based on the expected investment efficiency. Sending a signal to the brander under the quotation mode is not always beneficial for

the supplier. When observing a high probability of H-type and a small efficiency difference, the brander should switch information strategies from the separating equilibrium to the pooling equilibrium.

6. BIDDING MODE UNDER INFORMATION ASYMMETRY

This section presents the brander's bidding strategies under information asymmetry. The brander will take the initiative to separate the suppliers by offering two contracts $\{\bar{q}_H^{\text{scr}}, \bar{T}_H^{\text{scr}}\}$ and $\{\bar{q}_L^{\text{scr}}, \bar{T}_L^{\text{scr}}\}$. In this case, the supplier's motivation to mimic is characterized as follows:

- (1) The profit for the H-type supplier is $U_H = \pi_0$ when accepting the contract $\{\bar{q}_H^{\text{scr}}, \bar{T}_H^{\text{scr}}\}$, whereas it is $U_{HL} = \frac{1}{2}(e_H - e_L)(a - k + e_L + \delta e_L) + \pi_0$ when accepting the contract $\{\bar{q}_L^{\text{scr}}, \bar{T}_L^{\text{scr}}\}$. The profit difference under two contracts $\Delta\bar{U} = \frac{1}{2}(e_H - e_L)(a - k + e_L + \delta e_L) > 0$.
- (2) The profit for the L-type supplier is $U_L = \pi_0$ when accepting the contract $\{\bar{q}_L^{\text{scr}}, \bar{T}_L^{\text{scr}}\}$ and $U_{LH} = -\frac{1}{2}(e_H - e_L)(a - k + e_H + \delta e_H) + \pi_0$ when accepting the contract $\{\bar{q}_H^{\text{scr}}, \bar{T}_H^{\text{scr}}\}$. The profit difference under two contracts $\Delta U = -\frac{1}{2}(e_H - e_L)(a - k + e_H + \delta e_H) < 0$.

Under the bidding mode, the H-type supplier may have an incentive to mimic the L-type supplier by selecting the contract $\{\bar{q}_L^{\text{scr}}, \bar{T}_L^{\text{scr}}\}$. To solve this problem, the separating, pooling, and closing strategies are analyzed in the following subsections. In the separating strategy, the brander offers two different contracts to the supplier. Subsequently, the brander can infer the supplier's type based on the supplier's choice. In the pooling strategy, the brander offers only one quantity-payment contract that both types of suppliers can accept. However, the brander is unable to infer the supplier's type. In the closing strategy, the brander offers one quantity-payment contract that the H-type supplier will accept. However, the L-type supplier will not accept the contract, from which the brander can screen the H-type supplier and expel the L-type supplier. Next, the brander's performance under the three strategies will be discussed. The superscripts "sep," "pool," and "cl" denote separating, pooling, and closing strategies, respectively.

6.1. Separating strategy

In this subsection, two different contracts offered by the brander aim to screen the supplier's type. Both types of suppliers will select the contract corresponding to their types.

The brander's expected profit is expressed as follows:

$$\begin{aligned} \pi = & \max_{\substack{\{q_H, T_H\} \\ \{q_L, T_L\}}} \beta((a + \delta e_H - q_H)q_H - T_H) + (1 - \beta)((a + \delta e_L - q_L)q_L - T_L) \\ \text{s.t. } & \begin{cases} T_H - (k - e_H)q_H - C \geq \pi_0 \\ T_L - (k - e_L)q_L - C \geq \pi_0 \\ T_H - (k - e_H)q_H - C \geq T_L - (k - e_H)q_L - C \\ T_L - (k - e_L)q_L - C \geq T_H - (k - e_L)q_H - C. \end{cases} \end{aligned} \quad (9)$$

The first and second constraints ensure a minimum profit π_0 for the supplier, which incentivizes them not to reject the contract. The last two constraints ensure that the supplier will be better off when choosing the contract corresponding to their types.

In the case where the H-type supplier would benefit from mimicking the L-type supplier by selecting the L-type contract ($\Delta U > 0$), the brander needs to provide an additional profit ΔU (denoted as the information rent) to the H-type supplier. By paying this extra profit, the brander induces the supplier to select the contract based on their true types.

Lemma 6.1. *There exists a threshold $\hat{\beta} \in [0, 1]$. The separating strategy exists if and only if $\beta < \hat{\beta}$:*

- (1) In the separating strategy, the optimal contracts are $\{q_H^{\text{sep}*}, T_H^{\text{sep}*}\}$ and $\{q_L^{\text{sep}*}, T_L^{\text{sep}*}\}$, where $T_i^{\text{sep}*} = (k - e_i)q_i^{\text{sep}*} + U_i$, $q_H^{\text{sep}*} = \bar{q}_H^{\text{scr}*}$, $q_L^{\text{sep}*} = \bar{q}_L^{\text{scr}*} - \underbrace{E_q^{\text{sep}}}_{\text{asymmetric information effect}}$, where $E_q^{\text{sep}} = \frac{\beta(e_H - e_L)}{2(1-\beta)}$;
- (2) The L-type supplier can get zero information rent, while the H-type supplier can get information rent $\Delta U = \frac{(e_H - e_L)((a - k + e_L + \delta e_L) - \beta(a - k + e_H + \delta e_L))}{2(1-\beta)}$.

Lemma 6.1 characterizes the brander's separating strategy. The order quantity $q_H^{\text{sep}*}$ in the H-type contract coincides with that under information symmetry. The order quantity $q_L^{\text{sep}*}$ in the L-type contract decreases ($q_L^{\text{sep}*} < \bar{q}_L^{\text{scr}*}$). As the L-type supplier has no incentive to mimic, the brander will not pay any information rent to motivate the L-type to reveal the exact type. Conversely, the H-type supplier will be better off when selecting the L-type contract. The brander reduces the order quantity and the transfer payment in the L-type contract, thereby affecting the H-type supplier's mimicking motivation. However, this selection improves the transfer payment in the H-type contract. Specifically, the extra profit ΔU that the H-type supplier obtains is regarded as the information rent paid by the brander to motivate the H-type supplier to reveal the true type. In addition, given that the order quantity in the L-type contract $q_L^{\text{sep}*} = \bar{q}_L^{\text{scr}*} - E_q^{\text{sep}}$ must be non-negative, the threshold $\hat{\beta} = \frac{a - k + e_L + \delta e_L}{a - k + e_H + \delta e_L}$ is obtained, resulting in the existence of the separating strategy. If $\beta \geq \hat{\beta}$, the brander cannot efficiently prevent the H-type supplier's mimicking motivation by lowering the order quantity in the L-type contract.

Based on Lemma 6.1, Corollary 6.2 is obtained.

Corollary 6.2. When $\beta < \hat{\beta}$, the asymmetric information effect E_q^{sep} increases in β but the information rent ΔU decreases in β .

Corollary 6.2 indicates the impact of the probability of H-type on the brander's screening contract. Given that the H-type supplier's mimicking motivation decreases in β , the brander focuses on obtaining profits from the H-type supplier. Therefore, in the L-type contract, the brander will provide a smaller order quantity by increasing E_q^{sep} . In addition, with a lower mimicking motivation, the brander pays less information rent to encourage the supplier to give up mimicking motivation and disclose the exact type.

6.2. Pooling strategy

In this case, the brander offers one quantity-payment contract $\{q^{\text{pool}*}, T^{\text{pool}*}\}$ to be accepted by both types of suppliers. In this contract, the brander gives up screening the supplier's true type and maintains the expected investment efficiency $e_j = \mu$.

The optimal profit function of the brander is expressed as follows:

$$\begin{aligned} \pi &= \max_{\{q^{\text{pool}}, T^{\text{pool}}\}} (a + \delta\mu - q^{\text{pool}})q^{\text{pool}} - T^{\text{pool}} \\ \text{s.t. } &\begin{cases} T^{\text{pool}} - (k - e_H)q^{\text{pool}} - C \geq \pi_0 \\ T^{\text{pool}} - (k - e_L)q^{\text{pool}} - C \geq \pi_0. \end{cases} \end{aligned} \quad (10)$$

Rationally, the aforementioned two constraints indicate that if the pooling contract exists, the profits of two types of suppliers accepting this contract should be better than their reserved utility. Solving (10), Lemma 6.3 is obtained.

Lemma 6.3. In the pooling strategy, the pooling contract is as follows:

- (1) The optimal pooling contract is $\{q^{\text{pool}*}, T^{\text{pool}*}\}$, and the brander's profit is $\pi^{\text{pool}*} = (a + \delta\mu - q^{\text{pool}*})q^{\text{pool}*} - T^{\text{pool}*}$, where $q^{\text{pool}*} = \bar{q}_L^{\text{scr}*} + \underbrace{E_q^{\text{pool}}}_{\text{asymmetric information effect}}$ with $E_q^{\text{pool}} = \frac{1}{2}\beta\delta(e_H - e_L)$, $T^{\text{pool}*} = (k - e_L)q^{\text{pool}*} + U_i + C$;

- (2) The L-type supplier's profit is $U_L = \pi_0$ and the H-type supplier's profit is $U_H = \frac{1}{2}(e_H - e_L)(a + e_L - k + \delta e_L + \beta\delta(e_H - e_L)) + \pi_0 + C$.

Lemma 6.3 characterizes the brander's pooling strategy and the supplier's profit. The order quantity in the pooling strategy is larger than that in the L-type contract but is less than that in the H-type contract, that is, $q_L^{\text{sep}*} \leq q^{\text{pool}*} < q_H^{\text{sep}*}$. Similar to the separating strategy, the L-type supplier has no incentive to mimic. The H-type supplier can gain additional profits from the pooling contract owing to a low unit production cost. Under the same order quantity and transfer payment, the H-type supplier can achieve a higher profit than the L-type. The brander's profit in the separating strategy is always higher than that in the pooling strategy ($\pi^{\text{pool}*} \leq \pi^{\text{sep}*}$). Thus, the pooling strategy reduces flexibility in resource allocation, and the brander loses the advantage to screen the supplier's type.

6.3. Closing strategy

In the closing strategy, differing from the pooling and separating strategies, the brander offers one contract $\{q^{\text{cl}*}, T^{\text{cl}*}\}$. The contract will be accepted by the H-type supplier and rejected by the L-type supplier.

Hence, the expected profit function for the brander is expressed as follows:

$$\begin{aligned} \pi = & \max_{\{q^{\text{cl}}, T^{\text{cl}}\}} \beta((a + \delta e_H - q^{\text{cl}})q^{\text{cl}} - T^{\text{cl}}) \\ \text{s.t. } & \begin{cases} T^{\text{cl}} - (k - e_H)q^{\text{cl}} - C \geq \pi_0 \\ T^{\text{cl}} - (k - e_L)q^{\text{cl}} - C \leq 0. \end{cases} \end{aligned} \quad (11)$$

The above constraints in the closing contract require that the H-type supplier's profit is higher than the reserved utility and the L-type supplier's profit is lower than zero. Lemma 6.4 is obtained by solving the above objective function.

Lemma 6.4. *There exists a threshold $\hat{\theta} = \frac{2\pi_0}{a - k + e_H + \delta e_H}$. When $\theta \geq \hat{\theta}$, there exists a closing strategy; otherwise, the closing strategy does not exist. The optimal closing contract is $\{q^{\text{cl}*}, T^{\text{cl}*}\}$, where $q^{\text{cl}*} = \bar{q}_H^{\text{scr}*}$, $T^{\text{cl}*} = (k - e_H)q^{\text{cl}*} + \pi_0 + C$.*

In the closing strategy, the order quantity and transfer payment equal those in the H-type contract under information symmetry, that is, $q^{\text{cl}*} = \bar{q}_H^{\text{scr}*}$ and $T^{\text{cl}*} = \bar{T}_H^{\text{scr}*}$. With this contract, the L-type supplier will acquire a negative profit. If $\theta < \hat{\theta}$, when accepting this contract, the L-type supplier can obtain the profit less than π_0 but larger than zero. In this case, the brander cannot successfully screen the supplier's type. When $\theta \geq \hat{\theta}$, the closing strategy exists, in which the H-type supplier's profit equals that under information symmetry. The L-type supplier will reject this contract due to the negative profit. Compared with the benchmark case, the closing strategy may not always exist, implying that the brander loses the opportunity to cooperate with the L-type supplier.

6.4. Brander's choice of equilibrium strategy

In this subsection, we refine the multiple strategies by comparing the benefits under three strategies. The separating strategy exists only when $\beta < \hat{\beta}$, and the closing strategy exists only when $\theta \geq \hat{\theta}$. Therefore, there can be four scenarios for the brander when making decisions.

- (I) When $\theta < \hat{\theta}$, $\beta \geq \hat{\beta}$, the closing and separating strategies do not exist. The optimal profit that the brander can obtain is $\pi^{\text{scr}*} = \pi^{\text{pool}*}$.
- (II) When $\theta < \hat{\theta}$, $\beta < \hat{\beta}$, the closing strategy does not exist; hence, the optimal profit that the brander can obtain is $\pi^{\text{scr}*} = \max\{\pi^{\text{sep}*}, \pi^{\text{pool}*}\}$.
- (III) When $\theta \geq \hat{\theta}$, $\beta \geq \hat{\beta}$, the separating strategy does not exist; hence, the optimal profit that the brander can obtain is $\pi^{\text{scr}*} = \max\{\pi^{\text{cl}*}, \pi^{\text{pool}*}\}$.

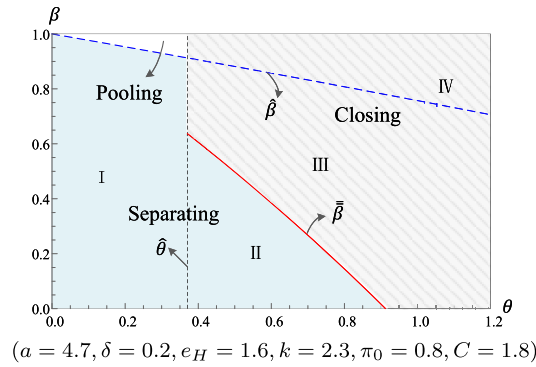


FIGURE 5. Optimal strategy under the bidding mode.

- (IV) When $\theta \geq \hat{\theta}$, $\beta < \hat{\beta}$, all three strategies exist; hence, the optimal profit that the brander can obtain is $\pi^{\text{scr}*} = \max\{\pi^{\text{cl}*}, \pi^{\text{sep}*}, \pi^{\text{pool}*}\}$.

With the given parameters, Proposition 6.5 characterizes the brander's optimal strategy.

Proposition 6.5. *Under the bidding mode, a threshold $\bar{\beta} \in [0, 1]$ exists:*

- (1) *When $\theta < \hat{\theta}$, the brander will choose the pooling strategy if $\beta \geq \hat{\beta}$ and choose the separating strategy otherwise;*
- (2) *When $\theta \geq \hat{\theta}$, the brander will choose the closing strategy if $\beta \geq \bar{\beta}$ and choose the separating strategy otherwise, where $\bar{\beta} = \frac{a+e_H-k+\delta e_H-\theta-\delta\theta-2\sqrt{\pi_0}}{a+e_H-k+\delta e_H-\delta\theta-2\sqrt{\pi_0}}$.*

Figure 5 illustrates the brander's decisions under three strategies. In the blank region of Figure 5, the pooling strategy is optimal for the brander. In regions I and II, the brander chooses the separating strategy. Furthermore, in regions III and VI, the closing strategy is adopted. As $0 < \theta < \hat{\theta}$ and $\hat{\beta} < \beta < 1$, the pooling strategy is the only choice for the brander. As indicated in region I, when the efficiency difference $\beta < \hat{\beta}$, choosing the separating strategy is always more beneficial than the pooling strategy for the brander. The brander can screen the supplier's type in the separating strategy and optimize resource allocation strategy.

With a large θ , the brander adopts the closing strategy. In region VI, the separating strategy does not exist. The brander prefers the closing strategy to the pooling strategy. In the pooling strategy, the brander places a lower order quantity ($q_L^{\text{sep}*} \leq q^{\text{pool}*} < q_H^{\text{sep}*} = \bar{q}_H^{\text{scr}*}$) to cooperate with the two types of suppliers. When accepting this contract, the H-type supplier can derive a higher profit from the pooling strategy than from the closing strategy. The failure to screen the supplier's type in the pooling strategy results in partial loss of profits for the brander compared with that in the closing strategy. Thus, in region VI, the brander chooses the closing strategy with less loss.

When the efficiency difference is sufficiently large and the probability of H-type is lower than $\hat{\beta}$ (as in regions II and III), all three strategies exist. There exists a threshold $\bar{\beta}$, such that when $\beta \geq \bar{\beta}$, the brander is better off in the closing strategy. As $\beta < \bar{\beta}$, the brander is better off in the separating strategy. When a separating strategy exists, the brander's profit in the separating or closing strategy is always higher than that in the pooling strategy. Hence, in this paper, we restrict the analysis to the separating and closing strategies. In the separating strategy, the brander's profit is less than that under information symmetry, which impels the brander to pay the information rent and motivates the H-type supplier to reveal his true type. In the closing strategy, the brander's profit is less than that under information symmetry because the brander gives up the profit from the L-type supplier and the expected profit increases in β . As β is relatively low in region II, the brander's expected profit in the closing strategy is less than that in the separating profit. As β increases in the separating strategy, the

decrease in information rent can increase the brander's expected profit. As $\beta \geq \bar{\beta}$, the brander's profit in the separating strategy is lower than that in the closing strategy. Therefore, the brander will choose the closing strategy in region III.

Based on the above analysis, the brander's information screening strategy depends on the interaction between the probability of the supplier being of the H-type and the efficiency difference. In some cases, the pooling and closing strategies may be better than the separating strategy under the bidding mode, leading to the brander to focus more on the interaction between key factors in the market when choosing the bidding mode.

7. BRANDER'S CHOICE IN COOPERATION MODE

This section compares two cooperation models and seeks the optimal cooperation mode and information strategy from the perspective of brander.

7.1. Brander's profit

Under the quotation mode, the brander's profit π^{p*} is irrelevant to the supplier's type in the pooling equilibrium. In the separating equilibrium, the brander's profit is π_H^{sd*} when the supplier is H-type, whereas it is π_L^{sd*} when the supplier is L-type. As the supplier's exact type cannot be observed ex-ante, the brander's expected profit is $\pi^{sd*} = \beta\pi_H^{sd*} + (1 - \beta)\pi_L^{sd*}$. Under the bidding mode, the brander's profits under the closing, pooling, and separating contracts are expressed as π^{cl*} , π^{pool*} , and π^{sep*} , respectively.

With Proposition 5.4, as $\beta < \beta^*$, the H-type supplier will have an incentive to separate from the L-type supplier under the quotation mode. Otherwise, the H-type supplier will choose to pool with the L-type supplier. Thus, the brander's profit is expressed as follows:

$$\pi^{sig} = \begin{cases} \pi^{sd*}, & \beta < \beta^* \\ \pi^{p*}, & \beta \geq \beta^*. \end{cases} \quad (12)$$

With Proposition 6.5, under the bidding mode, the brander's profit is expressed as follows:

$$\pi^{scr} = \max\{\pi^{cl*}, \pi^{sep*}, \pi^{pool*}\}. \quad (13)$$

Figure 6a characterizes the brander's expected profit π^{sig} under the quotation mode. As depicted in Figure 6a, the brander's expected profit is higher when the supplier is H-type, resulting from the H-type supplier's lower wholesale price and the higher extra demand. Accordingly, the brander prefers to cooperate with the H-type supplier. Meanwhile, the H-type supplier will pay the information rent to the brander when signaling the exact type in the costly separating equilibrium. In addition, the choice between the separating and pooling equilibria under the quotation mode is irrelevant to the brander. In the pooling equilibrium, the brander obtains a lower profit and cannot screen the supplier's types. Thus, the brander has no preference over the pooling equilibrium.

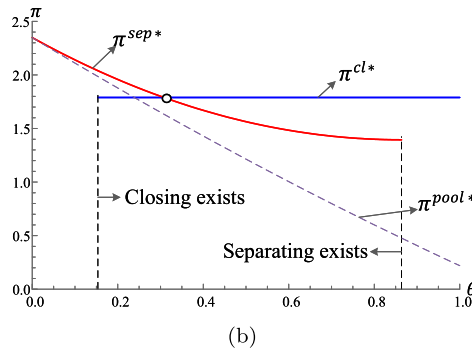
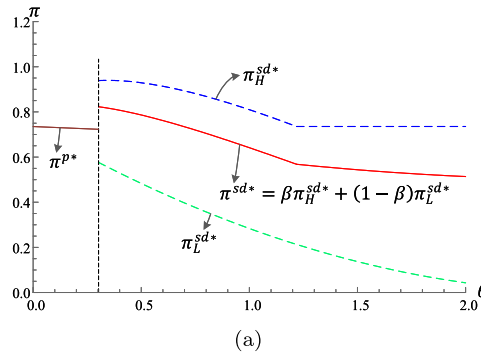
Figure 6b characterizes the brander's expected profit π^{scr} under the bidding mode. As depicted in Figure 6b, with the given parameters, the brander restricts the choice between the closing strategy and the separating strategy when all three strategies exist. Next, the brander's decisions between the quotation and bidding modes are further analyzed.

7.2. Bidding mode vs. quotation mode

In actual commercial operation, the brander needs to weigh the bidding mode against the quotation mode to maximize profits. Thus, the brander's tradeoff is expressed as follows:

$$\pi = \max\{\pi^{sig}, \pi^{scr}\}. \quad (14)$$

Comparing π^{sig} and π^{scr} , the brander's optimal strategies are summarized in Corollary 7.1.



$$(a = 5.6, \delta = 0.28, e_H = 0.75, k = 2, \beta = 0.8, \pi_0 = 0.35)$$

FIGURE 6. Brander's profit under two modes.

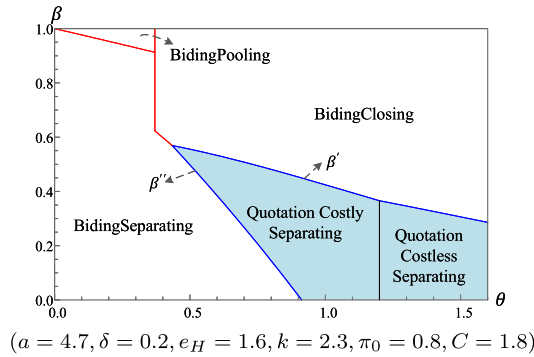


FIGURE 7. Brander's choice in cooperation mode.

Corollary 7.1. When $\beta' \in [0, 1]$ and $\beta'' \in [0, 1]$, the brander will choose the quotation mode only if $\beta < \beta'$ and $\beta > \beta''$. Otherwise, the brander will choose the bidding mode.

Intuitively, it can be inferred that the brander prefers the quotation mode because the bidding mode requires the brander to pay information rent. Under the quotation mode, the brander awaits a signal from the supplier and does not pay any information rent. However, as depicted in Figure 7, the brander has a greater preference over the bidding mode with the given parameters. Only when the efficiency difference is large and the probability of H-type is sufficiently small, the brander chooses the quotation mode and waits for the supplier to reveal the

exact type. A lower β implies that the brander may derive a lower profit under the bidding mode, leading to a weaker motivation for the brander to screen. In this case, the brander prefers waiting for the supplier to send a signal rather than paying the information rent to screen the supplier's type. Thus, only the separating equilibrium exists, implying that the brander must await a signal from the supplier to disclose their exact type when the brander chooses the quotation mode. The pooling equilibrium does not appear in Figure 7 when the quotation mode is employed. This is evident that the bidding mode shows greater advantage relative to the quotation mode when $\beta > \beta'$ and $\beta < \beta''$. The brander's profit derived from the bidding mode covers the profit acquired from the pooling equilibrium.

According to Corollary 7.1, the optimal cooperation mode between the supplier and the brander is not constant. Relying on only one cooperation mode may cause unnecessary losses. When the brander is at an information disadvantage, the probability of the supplier being of the H-type and the efficiency difference play significant roles in the brander's profit. To maximize profits, the brander should dynamically adjust the cooperation modes and choose corresponding information strategies because key factors change in market. For example, when the probability of the supplier being of the H-type and the efficiency difference are small, the bidding mode is optimal and the separating strategy should be adopted by the brander to positively screen information.

8. CONCLUSION

This study investigates the interaction between a brander and a supplier under the setting of asymmetric sustainable investment efficiency. First, the study proposes two cooperation modes, namely quotation and bidding. Under the quotation mode, the supplier's signaling strategies (separating equilibrium and pooling equilibrium) are analyzed. Under the bidding mode, the paper examines the brander's screening strategies, including separating contract, pooling contract, and closing contract. Finally, the brander's cooperation mode preference is analyzed. The main results and managerial implications can be summarized as follows:

First, the brander's choice in cooperation modes is related only to the supplier's reserved utility under information symmetry. When the brander formulates business modes, more attention should be paid to the supplier's reserved utility. Second, under the quotation mode, sending a signal to the brander may not be beneficial for the supplier. Accordingly, the supplier should give up the separating strategy and adopt the pooling strategy when the probability of H-type is at a high level and the efficiency difference is small. Third, under the bidding mode, the brander's screening strategies depend on the efficiency difference and the probability of the supplier being of H-type. To avoid losses, the brander should focus on the interaction between key factors in the market when formulating screening strategies. Finally, the brander prefers the closing strategy under the bidding mode and pays information rent to screen information when the efficiency difference and the probability of the supplier being of H-type are high. Under information asymmetry, the brander should make efforts to actively grasp market information rather than wait for the supplier to send information.

This study deepens our understanding of the cooperation mode in the sustainable supply chain and provides valuable references for managers. However, this work has a limitation. It overlooks the proportion of sustainable consumers and sustainable investment risk. In practice, because the brander is closer to consumers than the supplier and can better observe exact market demand, asymmetric demand information is prominent between the brander and the supplier. Therefore, asymmetric demand information should be considered in further research, which will complement the present work.

APPENDIX A. PROOFS

Proof of Proposition 4.1. The supplier's profit under the quotation mode and information symmetry can be written as $\pi = (a + \delta e_j - q - w)q$. Setting $\frac{\partial \pi}{\partial q} = 0$, we can derive the order quantity $q(w) = \frac{1}{2}(a - w + \delta e_j)$. Submitting $q(w)$ into the brander's profit function $\Pi = (w - (k - e_i))q - C$ and further setting $\frac{\partial \Pi}{\partial w} = 0$, we obtain the supplier's optimal wholesale price $w^*(e_i) = \frac{1}{2}(a + k - e_i + \delta e_j)$. Submitting $w^*(e_i)$ into $q(w)$, we

obtain the optimal quantity order $q^* = \frac{1}{4}(a - k + e_i + \delta e_j)$. Submitting q^* and $w^*(e_i)$ into $\pi(q)$ and $\Pi(w)$, we obtain $\bar{w}_i^{\text{sig}^*}$, $\bar{\Pi}_i^{\text{sig}^*}$, $\bar{q}_i^{\text{sig}^*}$ and $\bar{\pi}_i^{\text{sig}^*}$. $\square$

Proof of Proposition 4.2. The supplier's and brander's profits under the bidding mode and information symmetry can be expressed as $\Pi = T - (k - e_i)q - C$ and $\pi = (a + \delta e_i - q)q - T$, respectively. Solving $\Pi = T - (k - e_i)q - C = \pi_0$, we know $T_i^* = (k - e_i)q + \pi_0 + C$. Submitting T_i^* into π , the optimal order quantity $q_i^* = \frac{1}{2}(a - k + e_i + \delta e_i)$. Thus, the brander's optimal contracts are $\{\bar{q}_H^{\text{scr}^*}, \bar{T}_H^{\text{scr}^*}\}$ and $\{\bar{q}_L^{\text{scr}^*}, \bar{T}_L^{\text{scr}^*}\}$. $\square$

Proof of Lemma 5.1. In the costless separating equilibrium, the L-type supplier has no incentive to mimic the H-type supplier's wholesale price. Therefore, if the costless separating equilibrium exists, the following constraint is satisfied:

$$\Pi_{\text{LH}}(\bar{w}_H^{\text{sig}^*}) \leq \bar{\Pi}_L^{\text{sig}^*}. \quad (\text{A.1})$$

From (A.1), we obtain $\theta \geq \frac{e_H - 2a\delta + 2k\delta - \delta^2 e_H}{e_H(1+\delta)^2}$. Thus, when $\theta < \frac{e_H - 2a\delta + 2k\delta - \delta^2 e_H}{e_H(1+\delta)^2}$, the L-type supplier can benefit from mimicking. To achieve the separating equilibrium, the H-type supplier may need to distort the wholesale price to discourage the L-type supplier's mimicking behavior. If the costly separating equilibrium exists, the wholesale price satisfies the following constraints:

$$\begin{aligned} \max_w \Pi(w_H^{\text{sd}}) &= \frac{1}{2}(w_H^{\text{sd}} - k + e_H)(a - w_H^{\text{sd}} + \delta e_H) - C \\ \text{s.t. } &\begin{cases} \Pi_{\text{LH}}(w_H^{\text{sd}}) < \bar{\Pi}_L^{\text{sig}^*} \\ \Pi_{\text{HH}}(w_H^{\text{sd}}) > 0 \end{cases} \end{aligned} \quad (\text{A.2})$$

where $\Pi_{\text{LH}}(w_H^{\text{sd}}) = \frac{1}{2}(w_H^{\text{sd}} - k + e_L)(a - w_H^{\text{sd}} + \delta e_H) - C$, $\bar{\Pi}_L^{\text{sig}^*} = \frac{1}{8}(a - k + e_L + \delta e_L)^2 - C$.

Solving (A.2), we obtain $w_H^{\text{sd}*} = \frac{1}{2}(a + k - e_L + \delta e_H) - \frac{1}{2}\sqrt{(e_H - e_L)(2\delta(a - k + e_L) + \delta^2(e_H + e_L))}$, $E_w^{\text{sd}} = \bar{w}_H^{\text{sig}^*} - \hat{w}^{\text{sd}*} = \frac{1}{2}\sqrt{\delta(e_H - e_L)(2a - 2k + 2e_L + \delta e_H + \delta e_L)} - \frac{1}{2}(e_H - e_L)$.

We define E_w^{sd} as the asymmetric information effect. Submitting $w_H^{\text{sd}*}$ into $\Pi_{\text{HH}}(w)$, we obtain the H-type supplier's optimal profit

$$\begin{aligned} \hat{\Pi}_H^{\text{sd}*} &= \Pi_{\text{HH}}(w_H^{\text{sd}}) = \frac{1}{8}\left(a + e_L - k + \delta e_H + \sqrt{\delta(e_H - e_L)(2(a - k) + \delta e_H + e_L(2 + \delta))}\right) \\ &\quad \times \left(a - e_L - k + \delta e_H(2 - \delta) - \sqrt{\delta(e_H - e_L)(2(a - k) + \delta e_H + e_L(2 + \delta))}\right). \end{aligned}$$

With $w_H^{\text{sd}*}$, the L-type supplier gives up mimicking the H-type. The optimal decision is the same as that under information symmetry, that is, $w_L^{\text{sd}*} = \bar{w}_L^{\text{sig}^*}$, $\Pi_L^{\text{sd}} = \bar{\Pi}_L^{\text{sig}^*}$. $\square$

Proof of Corollary 5.2. E_w^{sd} is given in Lemma 5.1, from $\frac{\partial E_w^{\text{sd}}}{\partial \delta} = \frac{(e_H - e_L)(2a - 2k + 2e_L + \delta e_H + \delta e_L)}{4\sqrt{\delta(e_H - e_L)(2a - 2k + 2e_L + \delta e_H + \delta e_L)}} > 0$, it can be inferred that E_w^{sd} increases in δ . $\square$

Proof of Lemma 5.3. In the pooling equilibrium, the brander's order quantity is expressed as $q^p = \frac{1}{2}(a - w^p + \delta \mu)$, where $\mu = \beta e_H + (1 - \beta)e_L$. Thus, the pooling profit functions for the H-type and L-type suppliers are as follows:

$$\max_w \Pi(w^p, e_H) = \frac{1}{2}(w^p - k + e_H)(a - w^p + \delta \mu) - C \quad (\text{A.3})$$

$$\max_w \Pi(w^p, e_L) = \frac{1}{2}(w^p - k + e_L)(a - w^p + \delta \mu) - C. \quad (\text{A.4})$$

Solving the above functions, the optimal wholesale prices for both suppliers are $w_H^{p*} = \frac{1}{2}(a + k - e_H + \delta\mu)$ and $w_L^{p*} = \frac{1}{2}(a + k - e_L + \delta\mu)$. The pooling equilibrium must satisfy $w^p \geq \max(w_H^{p*}, w_L^{p*}) = \frac{1}{2}(a + k - e_H + \delta\mu) = \underline{w}^p$.

When deviating from the pooling equilibrium, both types of suppliers would be taken as the L-type. The H-type supplier prefers to pool if and only if the pooling profit dominates the profit from deviating from the pooling wholesale price. If the pooling equilibrium exists, the wholesale price satisfies the following constraints:

$$\begin{aligned} \max_w \Pi(w^p) &= \frac{1}{2}(w^p - k + e_H)(a - w^p + \delta\mu) - C \\ \text{s.t. } &\begin{cases} \Pi_{HN}(w^p) > \Pi_{HL}(w; e_H) \\ \Pi_{LN}(w^p) > \Pi_{LL}(w; e_L) \end{cases} \end{aligned} \quad (\text{A.5})$$

where $\Pi_{HN}(w^p) = \frac{1}{2}(w^p - k + e_H)(a - w^p + \delta\mu) - C$, $\Pi_{LN}(w^p) = \frac{1}{2}(w^p - k + e_L)(a - w^p + \delta\mu) - C$.

Solving the first constraint, we obtain $w_1 < w^p < w_2$, where

$$\begin{aligned} w_1 &= \frac{1}{2}\left(a - e_H + k + \delta\mu - \sqrt{2\delta(\mu - e_L)(a + e_H - k) + \delta^2(\mu^2 - e_L^2)}\right), \\ w_2 &= \frac{1}{2}\left(a - e_H + k + \delta\mu + \sqrt{2\delta(\mu - e_L)(a + e_H - k) + \delta^2(\mu^2 - e_L^2)}\right). \end{aligned}$$

The highest wholesale price is:

$$w_H^p = \frac{1}{2}\left(a - e_H + k + \delta\mu + \sqrt{2\delta(\mu - e_L)(a + e_H - k) + \delta^2(\mu^2 - e_L^2)}\right).$$

Solving the second constraint, we obtain $w_3 < w^p < w_4$, where

$$\begin{aligned} w_3 &= \frac{1}{2}\left(a - e_L + k + \delta\mu - \sqrt{2\delta(\mu - e_L)(a + e_L - k) + \delta^2(\mu^2 - e_L^2)}\right) \\ w_4 &= \frac{1}{2}\left(a - e_L + k + \delta\mu + \sqrt{2\delta(\mu - e_L)(a + e_L - k) + \delta^2(\mu^2 - e_L^2)}\right). \end{aligned}$$

The highest wholesale price where the L-type supplier is willing to pool is:

$$w_L^p = \frac{1}{2}\left(a - e_L + k + \delta\mu + \sqrt{2\delta(\mu - e_L)(a + e_L - k) + \delta^2(\mu^2 - e_L^2)}\right).$$

Then, we show that the lowest wholesale price in the pooling equilibrium needs to satisfy the following condition:

$$w^p \leq \min(w_H^p, w_L^p) = \frac{1}{2}\left(a - e_L + k + \delta\mu + \sqrt{2\delta(\mu - e_L)(a + e_L - k) + \delta^2(\mu^2 - e_L^2)}\right) = \bar{w}^p.$$

Hence, to ensure the existence of the pooling equilibrium, solving $\underline{w}^p \leq \bar{w}^p$, we obtain $\beta \geq \bar{\beta} = \frac{a - k + \theta e_H - \delta\theta e_H - \sqrt{e_H^2(1 - \theta)^2 + (a - k + e_H(1 + \delta)\theta)^2}}{\delta e_H(-1 + \theta)}$. Therefore, the pooling equilibrium exists if and only if $\beta \geq \bar{\beta}$. Both suppliers' optimal wholesale price is $w^{p*} = \frac{1}{2}(a + k - e_H + \delta\mu)$. $E_w^p = \bar{w}_H^{\text{sig}*} - w^{p*} = \frac{\delta e_H - \delta\mu}{2}$ is defined as the asymmetric information effect. $\square$

Proof of Proposition 5.4. Solving $\hat{\Pi}_H^{\text{sd}*} = \Pi_H^{p*}$, we obtain a threshold value

$$\beta^* = \frac{a + e_H - k + \delta\theta e_H - \sqrt{\left((a - k + e_H + e_H\delta\theta)^2 + e_H(1 - \theta)\right) \left(e_H(2\delta(1 - \theta) + \theta - 1) + 2\sqrt{e_H\delta(1 - \theta)(2a - 2k + e_H(\delta + 2\theta + \delta\theta))}\right)}}{e_H\delta(\theta - 1)}.$$

When $\beta < \beta^*$, $\hat{\Pi}_H^{\text{sd}*} > \Pi_H^{p*}$, the H-type supplier selects the separating strategy. $\square$

Proof of Lemma 6.1. The brander's expected profit is expressed as $\pi = \max \beta((a + \delta e_H - q_H)q_H - T_H) + (1 - \beta)((a + \delta e_L - q_L)q_L - T_L)$, and the supplier's profits can be written as $\Pi_H^{\text{scr}} = T_H^{\text{sep}} - (k - e_H)q_H^{\text{sep}} - C$ and $\Pi_L^{\text{scr}} = T_L^{\text{sep}} - (k - e_L)q_L^{\text{sep}} - C$. Substituting T_H^{sep} and T_L^{sep} in the brander's profit function, the maximum profit for the brander and the corresponding constraints can be expressed as follows:

$$\begin{aligned} \pi = & \max \beta((a + \delta e_H - q_H) - (k - e_H))q_H + (1 - \beta)((a + \delta e_L - q_L) - (k - e_L))q_L - (\beta \Pi_H^{\text{scr}} + (1 - \beta) \Pi_L^{\text{scr}}) \\ \text{s.t. } & \begin{cases} T_H^{\text{sep}} - (k - e_H)q_H^{\text{sep}} - C \geq \pi_0 \\ T_L^{\text{sep}} - (k - e_L)q_L^{\text{sep}} - C \geq \pi_0 \\ T_H^{\text{sep}} - (k - e_H)q_H^{\text{sep}} - C \geq T_L^{\text{sep}} - (k - e_H)q_L^{\text{sep}} - C \\ T_L^{\text{sep}} - (k - e_L)q_L^{\text{sep}} - C \geq T_H^{\text{sep}} - (k - e_L)q_H^{\text{sep}} - C. \end{cases} \end{aligned} \quad (\text{A.6})$$

Given that only the H-type supplier has an incentive to mimic, we tighten the above constraints and obtain $T_L^{\text{sep}} - (k - e_L)q_L^{\text{sep}} - C = \pi_0$ and $T_H^{\text{sep}} - (k - e_H)q_H^{\text{sep}} - C = \pi_0 + (e_H - e_L)q_L^{\text{sep}}$. Setting $\frac{\partial \pi}{\partial q_H} = 0$ and $\frac{\partial \pi}{\partial q_L} = 0$, we obtain the optimal q_H^* and q_L^* . Substituting q_H^* and q_L^* into the tightening constraints, the optimal $T_i^{\text{sep}*}$ is obtained. Further, to ensure that the separating contract is acceptable, solving $q_L^* = 0$, we obtain the threshold $\hat{\beta}$. If $\beta < \hat{\beta}$, the separating strategy exists. $\square$

Proof of Corollary 6.2. When $\beta < \hat{\beta}$, the asymmetric information effect $E_q^{\text{sep}} = \frac{\beta(e_H - e_L)}{2(1 - \beta)}$ and information rent $\Delta U = \frac{(e_H - e_L)((a - k + e_L + \delta e_L) - \beta(a - k + e_H + \delta e_L))}{2(1 - \beta)}$. When $\frac{\partial E_q^{\text{sep}}}{\partial \beta} = \frac{(e_H - e_L)}{2(1 - \beta)^2} > 0$ and $\frac{\partial \Delta U}{\partial \beta} = \frac{-(e_H - e_L)^2}{4(1 - \beta)^2} < 0$, the asymmetric information effect E_q^{sep} increases in β but the information rent ΔU decreases in β . $\square$

Proof of Lemma 6.3. In the pooling strategy, the brander's profit is expressed as follows: $\pi = \max(a + \delta \mu - q^{\text{pool}})q^{\text{pool}} - T^{\text{pool}}$, where $\mu = \beta e_H + (1 - \beta)e_L$. Setting $\frac{\partial \pi}{\partial q^{\text{pool}}} = 0$, we obtain the optimal pooling order quantity $q^{\text{pool}*}$. Substituting $q^{\text{pool}*}$ into $T^{\text{pool}} = (k - e_L)q^{\text{pool}} + \pi_0$, we obtain the brander's optimal pooling strategy $\{q^{\text{pool}*}, T^{\text{pool}*}\}$, $\pi^{\text{pool}*} = (a + \delta \mu - q^{\text{pool}*})q^{\text{pool}*} - T^{\text{pool}*}$, where $q^{\text{pool}*} = \bar{q}_L^{\text{scr}*} + \underbrace{E_q^{\text{pool}}}_{\text{asymmetric information effect}}$ with

$$E_q^{\text{pool}} = \frac{1}{2}\beta\delta(e_H - e_L) \text{ and } T^{\text{pool}*} = (k - e_L)q^{\text{pool}*} + U_i + C. \quad \square$$

Proof of Lemma 6.4. In the closing strategy, the brander's profit is expressed as follows: $\pi = \max \beta((a + \delta e_H - q^{\text{cl}})q^{\text{cl}} - T^{\text{cl}})$. To ensure that the closing strategy exists, the contract $(q^{\text{cl}}, T^{\text{cl}})$ satisfies the following constraints:

$$\begin{aligned} \pi = & \max \beta((a + \delta e_H - q^{\text{cl}})q^{\text{cl}} - T^{\text{cl}}) \\ \text{s.t. } & \begin{cases} T^{\text{cl}} - (k - e_H)q^{\text{cl}} - C \geq \pi_0 \\ T^{\text{cl}} - (k - e_L)q^{\text{cl}} - C \leq 0. \end{cases} \end{aligned} \quad (\text{A.7})$$

From the above constraints, $\bar{T}^{\text{cl}} = (k - e_L)q^{\text{cl}}$ and $\underline{T}^{\text{cl}} = \pi_0 + (k - e_H)q^{\text{cl}}$ are derived. To satisfy the condition $\underline{T}^{\text{cl}} < \bar{T}^{\text{cl}}$, we require $\theta \geq \frac{2\pi_0}{a - k + e_H + \delta e_H}$. Thus, as $\theta \geq \frac{2\pi_0}{a - k + e_H + \delta e_H}$, the closing strategy exists. $\square$

Proof of Proposition 6.5. Under the bidding mode, the problem of the brander's optimal strategy is divided into the following four scenarios:

- (1) When $\theta < \hat{\theta}$, $\beta \geq \hat{\beta}$, closing and separating strategies do not exist. The optimal profit that the brander can obtain is $\pi^{\text{scr}*} = \pi^{\text{pool}*}$; hence, the pooling strategy is optimal.
- (2) When $\theta < \hat{\theta}$, $\beta < \hat{\beta}$, the closing strategy does not exist. The optimal profit that the brander can obtain is $\pi^{\text{scr}*} = \max\{\pi^{\text{sep}*}, \pi^{\text{pool}*}\}$.

$$\text{Thus, } \pi^{\text{sep}*} = \frac{1}{4}\beta(a^2 - 4C + 2a(e_H - k + e_H\delta) + (e_H - k + e_H\delta)^2) + (1 - \beta)\left(\frac{(a - k - a\beta - e_H\beta + k\beta + e_L(1 + \delta - \beta\delta))(a - k - a\beta + e_H\beta + k\beta + e_L(1 + \delta - \beta(2 + \delta)))}{4(\beta - 1)^2} - C\right) + (\beta - 1)\pi_0 -$$

$$\beta \left(\frac{(e_H - e_L)(k + a(\beta - 1) + e_H\beta - k\beta + e_L((\beta - 1)\delta - 1))}{2(\beta - 1)} + \pi_0 \right), \quad \pi^{\text{pool}*} = \frac{1}{4}(2(e_L - k)(a - k + e_H\beta\delta + e_L(1 + \delta - \beta\delta)) + (a + k + e_H\beta\delta + e_L(\delta - \beta\delta - 1))(a - k + e_H\beta\delta + e_L(1 + \delta - \beta\delta)) - 4\pi_0 - 4C).$$

From $\pi^{\text{sep}*} - \pi^{\text{pool}*} = \frac{(e_H - e_L)^2\beta(1 + (1 - \beta)\delta)^2}{4(1 - \beta)} > 0$, it can be inferred that the brander prefers the separating strategy when $\theta < \hat{\theta}$ and $\beta < \hat{\beta}$.

- (3) When $\theta \geq \hat{\theta}$ and $\beta \geq \hat{\beta}$, the separating strategy does not exist. The optimal profit that the brander can obtain is $\pi^{\text{scr}*} = \max\{\pi^{\text{cl}*}, \pi^{\text{pool}*}\}$, where $\pi^{\text{cl}*} = \beta(\frac{1}{2}(e_H - k)(a + e_H - k + e_H\delta) + \frac{1}{2}(a + e_H - k + e_H\delta)(a + e_H\delta - \frac{1}{2}(a + e_H - k + e_H\delta)) - \pi_0 - C)$.

From $\pi^{\text{cl}*} - \pi^{\text{pool}*} = 4(C + \pi_0)(1 - \beta) + \beta(e_H - k + a + e_H\delta)^2 - \beta^2(a - k + e_H + \delta e_L + e_H\beta\delta - e_L\beta\delta)^2 > 0$, it can be inferred that the brander prefers the closing strategy when $\theta \geq \hat{\theta}$ and $\beta \geq \hat{\beta}$.

- (4) When $\theta \geq \hat{\theta}$ and $\beta < \hat{\beta}$, all three strategies exist. The optimal profit that the brander can obtain is $\pi^{\text{scr}*} = \max\{\pi^{\text{cl}*}, \pi^{\text{sep}*}, \pi^{\text{pool}*}\}$. With (2) and (3), we focus on $\pi^{\text{cl}*}$ and $\pi^{\text{sep}*}$. Assuming $\pi^{\text{cl}*} \geq \pi^{\text{sep}*}$, we obtain $\beta \geq \bar{\beta}$, where $\bar{\beta} = \frac{a + e_H - k + \delta e_H - \theta - \delta\theta - 2\sqrt{\pi_0}}{a + e_H - k + \delta e_H - \delta\theta - 2\sqrt{\pi_0}}$.

To sum up, when $\theta < \hat{\theta}$, the brander chooses the pooling strategy and the separating strategy if $\beta \geq \hat{\beta}$ and $\beta < \hat{\beta}$, respectively. When $\theta \geq \hat{\theta}$, the brander chooses the closing strategy if $\beta \geq \bar{\beta}$ and chooses the separating strategy if $\beta < \bar{\beta}$. $\square$

Proof of Corollary 7.1. With Propositions 5.4 and 6.5, when $\theta \leq \hat{\theta}$ and $\beta \geq \hat{\beta}$, we compare $\pi^{\text{pool}*}$ under the bidding mode and π^{p*} under the quotation mode, where $\pi^{p*} = \frac{1}{16}(a + e_H - k + e_L\delta + e_H\beta\delta - e_L\beta\delta)^2$, $\pi^{\text{pool}*} - \pi^{p*} = \frac{4(a - k + e_L\delta + e_L + \beta\delta(e_H - e_L))^2 - (a - k + e_L\delta + e_H + \beta\delta(e_H - e_L))^2}{16} - \pi_0 - C$.

With $\hat{\theta} = \frac{2\pi_0}{a - k + e_H + \delta e_H}$ and $\hat{\beta} = \frac{a + e_H - k + \delta(e_H - \theta) - \theta}{a + e_H - k + \delta(e_H - \theta)}$, we learn that $\pi^{\text{pool}*} - \pi^{p*} > 0$ holds true. Thus, the brander prefers the pooling strategy under the bidding mode.

When $\beta < \hat{\beta}$, we focus on $\pi^{\text{sep}*}$, π^{p*} and $\pi^{\text{sd}*}$.

$$\begin{aligned} \pi^{\text{sep}*} - \pi^{p*} &= \frac{1}{4}\beta(a^2 - 4C + 2a(e_H - k + e_H\delta) + (e_H - k + e_H\delta)^2) - \frac{1}{16}(a + e_H - k + e_L\delta + e_H\beta\delta - e_L\beta\delta)^2 + (1 - \beta) \\ &\quad \times \left(\frac{(a - k - a\beta - e_H\beta + k\beta + e_L(1 + \delta - \beta\delta))(a - k - a\beta + e_H\beta + k\beta + e_L(1 + \delta - \beta(2 + \delta)))}{4(\beta - 1)^2} - C \right) \\ &\quad + (\beta - 1)\pi_0 - \beta \left(\frac{(e_H - e_L)(k + a(\beta - 1) + e_H\beta - k\beta + e_L((\beta - 1)\delta - 1))}{2(\beta - 1)} + \pi_0 \right), \\ \pi^{\text{sep}*} - \pi^{\text{sd}*} &= \frac{1}{16}(\beta - 1)(a + e_L - k + e_L\delta)^2 + \frac{1}{4}\beta(a^2 - 4C + 2a(e_H - k + e_H\delta) + (e_H - k + e_H\delta)^2) \\ &\quad - \frac{1}{16}\beta(a + e_L - k + e_H\delta + \sqrt{e_H - e_L}\sqrt{\delta}\sqrt{2a - 2k + e_H\delta + e_L(2 + \delta)})^2 \\ &\quad + (1 - \beta) \left(\frac{(a - k - a\beta - e_H\beta + k\beta + e_L(1 + \delta - \beta\delta))(a - k - a\beta + e_H\beta + k\beta + e_L(1 + \delta - \beta(2 + \delta)))}{4(\beta - 1)^2} - C \right) \\ &\quad + (\beta - 1)\pi_0 - \beta \left(\frac{(e_H - e_L)(k + a(\beta - 1) + e_H\beta - k\beta + e_L((\beta - 1)\delta - 1))}{2(\beta - 1)} + \pi_0 \right). \end{aligned}$$

Because of the complexity of the model, it is difficult to judge the positive and negative of the above two formulas through mathematical analysis. From Figure 6, it can be inferred that $\pi^{\text{sep}*} - \pi^{p*} > 0$ and $\pi^{\text{sep}*} - \pi^{\text{sd}*} > 0$. Thus, when $\theta \leq \hat{\theta}$ and $\beta < \hat{\beta}$, the brander prefers the bidding mode and adopts the separating strategy.

When $\theta \geq \bar{\theta}$, we focus on $\pi^{\text{cl}*}$ under the bidding mode and $\pi^{\text{sd}*}$ under the quotation mode, where

$$\begin{aligned} \pi^{\text{cl}*} &= \beta \left(\frac{1}{2}(e_H - k)(a + e_H - k + e_H\delta) + \frac{1}{2}(a + e_H - k + e_H\delta) \left(a + e_H\delta - \frac{1}{2}(a + e_H - k + e_H\delta) \right) - \pi_0 - C \right), \\ \pi^{\text{sd}*} &= \frac{1}{16}\beta(a + e_H - k + e_H\delta)^2 + \frac{1}{16}(1 - \beta)(a + e_L - k + e_L\delta)^2. \end{aligned}$$

When $\pi^{\text{cl}*} = \pi^{\text{sd}*}$, $\pi^{\text{cl}*} > \pi^{\text{sd}*}$ if $\beta \geq \ddot{\beta}$ and $\pi^{\text{cl}*} < \pi^{\text{sd}*}$ otherwise.

When $\hat{\theta} < \theta < \bar{\theta}$, we focus on $\pi^{\text{sd}*}$ and $\pi^{\text{sep}*}$.

Solving $\pi^{\text{sd}*} = \pi^{\text{sep}*}$, we know that $\beta \geq \beta''$ means $\pi^{\text{sd}*} > \pi^{\text{sep}*}$. The brander prefers the quotation mode and selects the costly separating equilibrium. Thus,

$$\beta'' = \frac{a^2 - 4C + e_H^2 - 2e_H k + k^2 + 2e_H^2 \delta - 2e_H k \delta + e_H^2 \delta^2 - e_H \theta + k \theta - 3e_H \delta \theta + 2k \delta \theta - 2e_H \delta^2 \theta + \delta \theta^2 + \delta^2 \theta^2 - a(2k - 2e_H(1 + \delta) + \theta + 2\delta \theta) - 4\pi_0 - 2\sqrt{\theta^2(C + \pi_0)}}{a^2 - 4C + e_H^2 - 2e_H k + k^2 + 2e_H^2 \delta - 2e_H k \delta + e_H^2 \delta^2 - 2e_H \delta \theta + 2k \delta \theta - 2e_H \delta^2 \theta + \delta^2 \theta^2 + 2a(e_H - k + e_H \delta - \delta \theta) - 4\pi_0}.$$

Next, as $\beta \geq \beta''$, the closing strategy exists under the bidding mode and the costly separating equilibrium exists under the quotation mode. We compare $\pi^{\text{sd}*}$ and $\pi^{\text{cl}*}$. Solving $\pi^{\text{sd}*} = \pi^{\text{cl}*}$, we obtain the following expression:

$$\beta' = \frac{(a + e_H - k + e_H \delta - \theta - \delta \theta)^2}{\left(8(e_H - k)(a + e_H - k + e_H \delta) + 4(a + k - e_H(1 - \delta))(a + e_H - k + e_H \delta) + (a + e_H - k + e_H \delta - \theta - \delta \theta)^2 - \left(a + e_H - k + e_H \delta - \theta + \sqrt{\delta} \sqrt{\theta} \sqrt{2a - 2k + 2e_H(1 + \delta) - 2\theta - \delta \theta}\right)^2 - 16\pi_0 - 16C\right)}.$$

If $\beta < \beta'$, the brander prefers the quotation mode and selects the costly separating equilibrium. Otherwise, the brander adopts the closing strategy under the bidding mode.

Based on the above analysis, it can be concluded that the brander will choose the quotation mode only when $\beta < \beta'$ and $\beta < \beta''$; otherwise, the brander will choose the bidding mode. $\square$

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