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# Optimal Contract Design for a National Brand Manufacturer under Store Brand Private Information

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**Problem Definition**: We study an optimal contract design problem for a national brand (NB) manufacturer, which sells her product via a retailer. The retailer may introduce his store brand (SB) with private cost information. The manufacturer estimates that the retailer's SB cost may be high or low with certain probabilities, and offers a menu of two-part tariff contracts to screen the retailer's cost information.

**Methodology/Results**: Following the mechanism design theory, we formulate the problem as a two-stage screening game to analyze the strategic interaction between the two players under asymmetric information. Despite the complexity due to type-dependent reservation profit of the retailer, we derive the NB manufacturer's optimal contracts analytically. We prove that there exists a unique threshold such that when the NB cost is below the threshold, the manufacturer offers both types of retailers incentive-compatible contracts; when the NB cost is above the threshold, the manufacturer offers a menu of contracts to shut down the low-type retailer and engage the high-type retailer only.

**Managerial Implications**: We find that when the NB product becomes more competitive (i.e., a higher quality or a lower cost), both the NB manufacturer and the retailer are better off. This result implies that under asymmetric information, the retailer has incentive to enhance the NB product quality or reduce its cost. Additionally, the private information is valuable to both members only when a contract without shutdown is offered. Moreover, such information is more valuable to both players when the NB product becomes more competitive. However, when SB quality improves or when SB cost decreases, the value of information may increase or decrease to both supply chain members. Finally, we derive a surprising result that under asymmetric information, the expected consumer surplus may increase due to a lower SB quality or a higher low-type SB cost.

*Key words*: Store brand, asymmetric information, mechanism design

## 1. Introduction

Over the past few decades, store brand (SB) products, also known as private labels or generic brands, have been steadily earning trust among consumers, and they are now recognized as good alternatives to national brand (NB) products. Realizing that SBs can be used as an efficient instrument to improve gross margin and market share, many retailers have been developing their own SBs (Mills

1995). Successful cases include Costco's Kirkland Signature, Whole Foods' 365 Everyday Value, Wal-Mart's Great Value, etc. At Trader Joe's, a renowned chain of grocery stores, 80% of products are store brands (Tyler and Taylor 2018), and for certain types of products, there is only one SB product offered. Not only limited to grocery retailers, store brands have also been deployed by retail firms in many other industries, such as mattress (e.g., Mattress Firm's own brand *Tulo*), clothing (e.g., Macy's *Alfani*, Nordstrom's *Zella*), and furniture (e.g., Amazon's *Amazon Basics* furniture series). A recent article published on the official website of Private Label Manufacturers Association (PLMA) reports that in the U.S. market, SB sales grew by 4.1% in 2019, three times of the NB growth rate, and SBs comprised 19.2% in the dollar share and 23.1% in the unit share (PLMA 2020). Meanwhile, SBs enjoy tremendous success in European countries as well, with volume shares ranging from 22.3% in Italy to 49.6% in Spain (PLMA International 2020).

While SBs are branded and managed solely by retailers or wholesalers, they could be supplied by various types of manufacturers. PLMA identifies three general categories of SB manufacturers: (1) large manufacturers who produce their own NB products and utilize the excess capacity to produce SB products, (2) smaller-size and regional manufacturers that concentrate on producing SBs almost exclusively, and (3) manufacturing facilities run by major retailers and wholesalers to provide SBs for themselves and other retail chains (PLMA International 2020). In the latter two cases, SBs and NBs produced by different manufacturers may compete with each other in the same brick-and-mortar and/or online retail stores. For instance, in Costco Wholesale stores, Kind Bars, a brand of fruit and nut snacks manufactured in the U.S., faces competition from Costco's Kirkland Signature Nut Bars, made by a different manufacturer that is owned by a Canadian company (Nassauer 2017). Procter & Gamble (P&G), which does not manufacture SB products, also has their products competing with similar products from the Kirkland Signature brand (Nassauer 2017). Similarly, Amazon sells both Duracell batteries that are made in China and AmazonBasics batteries that are made in Indonesia.

When retailers procure their SBs from smaller-size/regional manufacturers or produce SBs in their own manufacturing facilities, NB manufacturers would have limited knowledge about retailers' SB production costs. Retailers who used to be simply distributors for NBs have also become competitors to NB manufacturers. Naturally, NB manufacturers and retailers nowadays have more conflicts of interest due to SB introduction. As a result, retailers often have no incentive to reveal their (SB) cost structure to NB manufacturers. For instance, Trader Joe's is famous for keeping the secrecy of its relationships with private-label vendors. According to a Master Vendor Agreement between Trader Joe's and its supplier Stonegate Foods, any proprietary information such as production specification disclosed by Trader Joe's to Stonegate Foods "shall be kept strictly confidential and shall not be disclosed to any other party for any reason" (SEC 2018b). Moreover, it is noted in the literature that supply chain members often try to hide their private cost information from one another in decentralized supply chains (see Ha 2001, Corbett and De Groote 2000). Since a retailer does not voluntarily share its SB cost information with an NB manufacturer, such cost information asymmetry may significantly complicate the NB manufacturer's contract design and affect the profitability of each member within the value chain.

Motivated by the above discussions, we aim to explore an optimal contract design problem for an NB manufacturer (she) to deal with a retailer (he), who may introduce his own SB, in the presence of the retailer's private SB cost information. More specifically, we would like to understand the following research questions: How can the NB manufacturer adjust her contracting strategy to cope with the retailer with private cost information? How much does the retailer value his private SB cost information, and how much does it cost the NB manufacturer to eliminate information asymmetry? How does information asymmetry influence each member's profitability and consumer surplus? Furthermore, how do answers to the above questions depend on the NB and SB product characteristics (quality/cost)?

To address the aforementioned research questions, we consider a decentralized supply chain with an NB manufacturer distributing her product to consumers via a retailer. Meanwhile, the retailer intends to develop and produce his own SB, and the SB production cost is the retailer's private information. The NB manufacturer estimates that the retailer has two types, i.e., high-type (high SB cost) and low-type (low SB cost), with certain probabilities. The NB manufacturer first offers the retailer a menu of two-part tariff contracts. Then, the retailer decides whether to accept the contract and whether to introduce his SB. Following the mechanism design theory, we formulate the problem as a two-stage screening game to analyze the strategic interaction between the two players under asymmetric information.

Two-part tariff pricing schedules are common practice in various markets, including credit card, membership retail, wholesale, and technology licensing (Vettas et al. 2011, Tamayo and Tan 2021). There are various forms of two-part tariff contracts in the retail industry. In the supermarket settings, some retailers charge suppliers a slotting fee for stocking their products or for preferred display locations (Klein and Wright 2007). In the practice of franchising, an upstream franchisor (e.g., a manufacturer or supplier) charges downstream franchisees (e.g., retailers) an upfront fixed payment (known as franchise fee) and a wholesale price (Gurnani and Erkoc 2008, Rubin 1978, Dhar 2013). Two-part tariff contracts, also referred to as franchise contracts, "have had remarkable success and it is estimated that more than 40% of retail sales in the U.S. pass through some franchised operations" (Gurnani and Erkoc 2008). Studies in the supply chain management field have shown that under bilateral monopoly settings, two-part tariff contracts work to the advantage of the manufacturers by performing better on supply chain coordination and profit extraction compared to wholesales contracts, another popular contract type owing to its simple form (Cachon and Kök 2010). Meanwhile, two-part tariff contracts have been utilized as an instrument to tackle information asymmetry (see Bolandifar et al. 2018, Davis et al. 2021, Hu and Qi 2018). Corbett et al. (2004) point out that under asymmetric information, "better information and two-part contracts are strategic complements: Achieving one increases the incremental value of the other." For instance, Xerox Corporation, a managed-print-service provider, offers two-part tariff contracts to its downstream customer companies. The contracting negotiation processes can be modeled as a screening game to extract the customer companies' private information of willingness-to-pay (Ning et al. 2018). Inspired by the above studies and practical examples in the retail industry, our study adopts a two-part tariff contract to screen the retailer's private cost information.

As a benchmark, we first solve the NB manufacturer's optimal contracts under symmetric information, i.e., the SB cost is common knowledge to both members in the supply chain. In this case, the NB manufacturer always offers a contract to achieve her first best profit and leaves the retailer with his reservation profit. Under asymmetric information, however, to elicit the private SB cost information from the retailer, the NB manufacturer has to pay the high-type retailer information rent above his reservation profit to prevent him from mimicking the low-type retailer, whereas the low-type retailer still gets his reservation profit. We find that the NB manufacturer's contractual problem is fairly complicated due to the fact that the retailer's reservation profit is type-dependent. Despite the complexity, we are able to derive the NB manufacturer's optimal contracts analytically. We prove that there exists a unique threshold of the NB production cost. When the NB cost is below the threshold, the NB manufacturer offers both types of retailers profitable contracts and induces them to truthfully reveal their private information. When the NB cost is above the threshold, the information rent to induce truthful information and engage both types of retailers is so high that it is optimal for the NB manufacturer to shut down the low-type retailer and engage the high-type retailer only.

Based on our model solution, we conduct a comprehensive sensitivity analysis to understand how model parameters (NB quality/cost, SB quality/cost) affect the profitability of the NB manufacturer and the retailer with or without private information. Our results demonstrate interesting managerial insights, some of which are highlighted below. First, when the NB product (perceived) quality improves, both the NB manufacturer and the retailer are better off under asymmetric information, while only the NB manufacturer benefits under symmetric information. Second, when the NB product cost increases, both the NB manufacturer and the retailer suffer under asymmetric information, while only the NB manufacturer is worse off under symmetric information. These two results indicate that under asymmetric information, the retailer also has incentive to help the NB manufacturer to enhance the NB product quality or reduce its cost. Third, under asymmetric information, both the manufacturer and the retailer may be better off with a higher low-type SB cost under certain conditions. By contrast, under symmetric information, when the SB cost increases, the manufacturer always benefits, but the retailer always suffers.

By comparing the equilibrium expected profits of the NB manufacturer and the retailer under symmetric information with those under asymmetric information, we can further quantify the value of information to each member of the supply chain. We show that the private SB cost information becomes more valuable to both the NB manufacturer and the retailer when the NB product quality improves or when the NB production cost reduces. However, when the SB product quality improves or when the low-type retailer's SB cost decreases, the value of information to both parties might increase or decrease. When the high-type retailer SB cost increases, the value of information to the NB manufacturer increases, but the private information might become more or less valuable to the retailer. Furthermore, we find that although consumers always benefit from the quality improvement or the cost reduction of either NB or SB product under symmetric information, it may not be true under asymmetric information. Specifically, our results show that consumers might be worse off when the SB product quality improves or when the low-type retailer reduces his SB cost.

The rest of the paper proceeds as follows. We review the related literature in Section 2, and introduce the model in Section 3. Section 4 solves the NB manufacturer's problem with complete information as a benchmark case. In Section 5, we design the optimal menu of contracts under asymmetric information and explore the impact of model parameters on each party's optimal profit. Section 6 investigates how the value of information to each party and consumer surplus are affected by product cost and quality. Section 7 concludes the paper with major results and future research directions. All mathematical notations in this paper are listed in Table $A1$ in Appendix A. All proofs are relegated to Appendix B. Throughout the paper, we use "decrease" and "increase" in the weak sense.

## 2. Literature Review

Our work falls in the broad literature on product line design and vertically differentiated products. Studies on product line design have extensively examined how a firm's product quality and pricing decisions are impacted by various factors, such as assortment competition (Federgruen and Hu 2015), customer's valuation uncertainty (Huang and Zhang 2020), seller-induced learning (Xiong and Chen 2014), green co-product (Lin et al. 2020), technology choice (Wang et al. 2019), and ancillary service (Wang and Cui 2017). Meanwhile, another group of recent papers consider a single firm selling a line of vertically differentiated products under different settings, such as channel-coordinating contracting (Altug 2016), assortment planning (Pan and Honhon 2012), probabilistic selling (Zheng et al. 2019), and crowdfunding (Hu et al. 2015). Different from above, Liu and Zhang (2013) examine the dynamic pricing competition between two firms that offer vertically differentiated products to strategic consumers. Altug and Sahin (2019) examine a setting, similar to ours, in which a pharmaceutical company makes pricing and launching decisions for a drug under the competition from a parallel-imported drug with a lower perceived quality. However, all of these papers do not consider asymmetric information in their models, while our paper studies vertically differentiated products (NB and SB) under asymmetric information. Hence, our paper specifically sprouts from two streams of literature: (1) SB retailing and (2) applications of mechanism design in the presence of asymmetric information.

Motivated by the emerging popularity of SB products, there has been a growing body of theoretical and empirical work on SB. Mills (1995) shows that a retailer can use SB as an effective instrument to mitigate the well-known double marginalization problem under the simple wholesale price contract. Although SB performance varies by category (Raju et al. 1995) and across retailers

(Dhar and Hoch 1997), empirical research has shown that SB introduction yields higher margins for the retailer (Chintagunta et al. 2002, Pauwels and Srinivasan 2004) and enhances retailers' bargaining power with NB manufacturers (Meza and Sudhir 2010). Moreover, recent analytical works also show that SB introduction has a critical influence on the interactions between retailers and NB manufacturers (Groznik and Heese 2010). Ru et al. (2015) demonstrate that SB introduction may benefit the NB manufacturer under a retailer-led Stackelberg game. Jin et al. (2017) reveal that a manufacturer's channel strategy and retailers' SB decisions may vary under different wholesale price schemes. Zheng et al. (2021) consider a setting where two NB manufacturers simultaneously or sequentially contract with a common retailer with SB introduction. Fang et al. (2013) study an NB supplier's contracting decision and a retailer's corresponding carrying decisions regarding NB and SB. While Fang et al. (2013) assume complete information in the supply chain, we relax this assumption by considering a more realistic scenario with private SB cost information. We aim to discover how information asymmetry affects the interactions between the NB manufacturer and the retailer and their profitability.

It is also worth noting that the aforementioned analytical studies on SB introduction all assume the same setting as ours, in which the SB product is not produced by the NB manufacturer, such that the SB introduction presents a threat to the NB manufacturer. However, it is important to acknowledge that some retailers outsource the SB production to large NB manufacturers whose products the SBs compete with (PLMA International 2020). Based on a valuable data set obtained by Ter Braak et al. (2013) from a major European retailer, as many as 564 out of 1,545 in their study were manufactured by dedicated SB suppliers, and the rest by *dual branders* who produce both NB and SB. Despite the large market shares by dedicated suppliers and dual branders, a recent survey (Wu et al. 2021) pointed out that literature discussing SB sourcing decisions is relatively scarce. Among others, Yano et al. (2017) study whether a retailer can benefit from selling its SB factory to a third party. Ter Braak et al. (2013) empirically examine the impact of SB supplier's identity (dedicated supplier v.s. dual brander) on the retailer and find that an SB supplier with higher extent of NB focus would lower the retailer's SB margin. Kumar et al. (2010) consider a retailer's SB sourcing decision between an NB manufacturer and an independent manufacturer, and conclude that retailers with more quality-sensitive customers would choose the NB manufacturer to supply SB, whereas those with more price-sensitive customers would choose the independent manufacturer as the SB supplier. Our study distinguishes from these studies not only from the perspective of SB sourcing structure, but also due to a unique characteristic of information asymmetry engendered by sourcing from a fringe SB manufacturer.

Recently, the practical relevance of information asymmetry has gained rising attention in the field of supply chain and operations management. Shen et al. (2019) report that two most examined information asymmetry structures in the supply chain literature are demand information asymmetry (e.g., Li et al. 2014, Feng et al. 2015, Xiong and Chen 2014, Belloni et al. 2017) and cost information asymmetry (e.g., Corbett and De Groote 2000, Ha 2001, Corbett et al. 2004). For instance, Davis et al. (2021) adopt a dynamic bargaining game as one of the approaches to address the procurement problem in an assembly system where suppliers hold private cost information. Li (2020) analyzes a mixed-strategy equilibrium for a procurement problem where competing suppliers have private cost information. While a number of modeling frameworks have been applied to resolve information asymmetry, we employ a screening game (i.e., the principal-agent model) to tackle the issue of cost information asymmetry, in which a principal initiates the actions to extract the agent's private information (Laffont and Martimort 2009). This framework has been implemented under various settings. For instance, Dai and Jerath (2013) and Dai et al. (2020) investigate how a firm incentivizes an employee to reveal one's effort information; Wang et al. (2016) examine a setting under which a regulator aims to induce environmental disclosures from a firm being audited. Fang et al. (2014) study an assembly system with suppliers' private cost information using independent quantity-payment contracts. Hu and Qi (2018) investigate optimal procurement mechanisms for assembly among all possible contract types. Li and Debo (2009) discuss a manufacturer's sourcing decision in the presence of suppliers' private cost information. Our work differs from these studies in several ways. First, in our model, we capture the competition and interaction between an NB manufacturer and a retailer with vertically differentiated products (NB and SB). Second, most papers of the screening-game literature assume a zero or fixed reservation profit for the agent, whereas in our model, the retailer's reservation profit is nonzero and type dependent, which generates interesting results and insights in spite of additional analytical complexity.

Finally, a few papers have explored type-dependent reservation utilities in principal-agent models. When an agent's reservation utility is contingent on his type, countervailing incentives may arise such that an agent may be incentivized to both overstate and understate his private information, depending on its realization. Lewis and Sappington (1989) pioneer the study of countervailing incentives and illustrate the analysis through an example of conflicting effects from an agent's marginal cost and fixed cost. Laffont and Martimort (2009) demonstrate the analysis of countervailing incentives problems by including more examples, such as bypass, insurance contracts, etc. Jullien (2000) explores more general problems in which there is no restriction on the relationship between the agent's type and his reservation utility. Similarly, Maggi and Rodriguez-Clare (1995) characterize the optimal contracts under countervailing incentives based on whether the agent's reservation utility is quasiconcave or quasiconvex in the private information. Gan et al. (2019) further complement the above line of research by discussing the degree of convexity of the agent's utility function. In contrast to the aforementioned studies, the agent's reservation profit in our model is monotonic in his type, which results in better tractability of the model solution and lends us more power to focus on the discussion of the strategic interaction between the NB manufacturer and the retailer.

## 3. Model Setup

We consider a decentralized bilateral supply chain with one NB manufacturer and one retailer. The NB manufacturer produces a product at a cost of $c_n$ per unit with a perceived quality value $q_n$.

To avoid the trivial case of incurring zero demand for the product, we assume $q_n > c_n$. The NB manufacturer distributes her product to consumers via the retailer. In addition to selling the NB product from the manufacturer, the retailer can also produce and sell his SB product at a cost of $c_s$ per unit with a perceived quality value $q_s$. The unit production cost of SB, $c_s$, is private information for the retailer only. The NB manufacturer estimates that $c_s$ takes one of the two possible values, denoted by $c_s^H$ and $c_s^L$ (where $c_s^H > c_s^L$), with respective probabilities $v$ and $1 - v$. For convenience, we call these two cost types as "high cost" and "low cost" in the remainder of this paper. Similarly, we assume $q_s > c_s^H$.

As pointed out by Berges-Sennou et al. (2004), consumers usually perceive SB products as having lower quality than NB products. Chung and Lee (2017) also comment that in reality, NBs often demonstrate superior brand equity to the SBs, which leads to a higher perceived quality. Following the literature, we assume that $q_s < q_n$. The perceived quality, which can be obtained through surveys to consumers (Babakus et al. 2004), "is interpreted as a summary statistics that captures any intangible and tangible attributes of a product that may imperfectly observable by consumers" (Erdem et al. 2004). It is distinguished from a product's *objective quality*, defined as "the aggregate performance of all vector product attributes", although a change in objective quality has a positive yet lagged effect on the perceived quality (Mitra and Golder 2006).

In addition, we assume that the SB's product quality is invariant to its cost, which is commonly adopted in the related literature on cost information asymmetry. For instance, Jiang et al. (2021) and Guo (2015) study the settings where a privately informed firm uses pricing strategies to convey its private cost information, and the product quality is independent of the cost difference. Our cost term can be interpreted as the total cost, which consists of both material cost and other related production and logistics cost. Our model captures the case that both types of retailers use the same material and produce the same product with identical quality, but they may adopt different sourcing/logistic strategies and/or production technologies, leading to the difference between the H-type's and the L-type's total costs. Therefore, similar to Chen et al. (2011), Liu and Zhang (2013), Altug and Sahin (2019) and many other studies, we assume that $q_n$ and $q_s$ are exogenously given and not related to other model parameters.

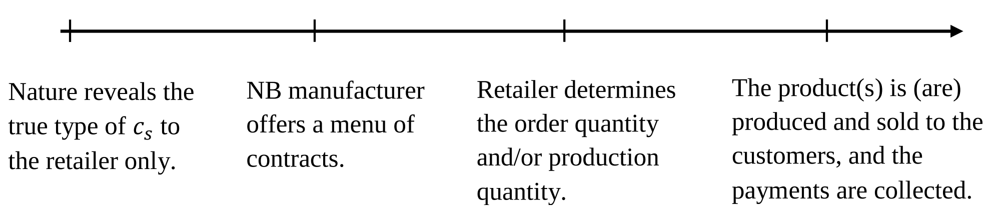


**Figure 1 Sequence of events.**

The sequence of events is depicted in Figure 1. In what follows, we explain each stage in more detail. First, nature reveals the true type of $c_s$ to the retailer only. Second, the NB manufacturer offers a menu of two-part tariff contracts to the retailer. This menu of contracts consists of two contracts, each corresponding to a specific type of retailer. Each of these two contracts specifies a wholesale price $w$ and a lump-sum payment $T$ to be charged to the retailer. Third, the retailer subsequently decides whether to accept the contract and which contract to accept. The retailer also simultaneously decides whether to produce his own SB product. That is, the retailer has three options to choose from: (I) accepting a contract from the NB manufacturer and carrying the NB product only (denoted as case I in the remainder of this paper); (II) accepting a contract from the NB manufacturer, carrying the NB product, and also introducing his own SB product (denoted as case II); (III) rejecting the NB manufacturer's contract and selling his SB product only (denoted as case III). Once the carrying decision is made, the retailer decides the retail price and order quantity $(p_i, Q_i)$ for the carried product(s), where $i \in \{s, n\}$ represents SB$(i = s)$ and NB$(i = n)$ respectively. Finally, the product(s) is (are) sold to consumers, and payments are collected.

Next, we describe the respective demand for the NB and SB products. Without loss of generality, we normalize the population of potential consumers to 1. Following Mills (1995), Chen et al. (2011), and Fang et al. (2013), we assume that consumers who are interested in purchasing the NB or SB product are vertically heterogeneous with respect to their evaluations $(\theta)$ on the product quality. $\theta$ is assumed to be uniformly distributed between 0 and 1. From now on, we refer to a consumer with a quality evaluation parameter $\theta$ as "consumer $\theta$" for brevity. Consumers make purchasing decisions based on their evaluations of the product quality and price. When a product with quality level $q$ is sold for \$$p$ per unit, consumer $\theta$ derives a utility function, $U(\theta) = \theta q - p$. Clearly, in order for product $i \in \{s, n\}$ to be attractive to some consumers (with positive utility), $p_i < q_i$. If there is only one product available on the market (i.e., case I or III), the consumer purchases the product if and only if he/she receives a positive utility $U(\theta)$ from the product. Under such circumstances, we define $U_i(\theta) = \theta q_i - p_i$ as the utility that consumer $\theta$ derives from product $i \in \{s, n\}$. Following $U_i(\theta) > 0$ and the uniform distribution of $\theta$ on $[0, 1]$, the demand for product $i \in \{s, n\}$ is $1 - p_i/q_i$. If both NB and SB products are available on the market (i.e., case II), consumer $\theta$ derives utility $U_i(\theta) = \theta q_i - p_i$ from both products $i \in \{s, n\}$ simultaneously, and purchases the one with a higher positive utility. We show that in order to ensure positive demands for both products, the retailer has to set the retail prices such that $\frac{p_s}{q_s} < \frac{p_n - p_s}{q_n - q_s} < 1$. For the consumers who value higher utilities from the NB product, it follows directly from $U_n(\theta) > U_s(\theta)$ that $\theta > \frac{p_n - p_s}{q_n - q_s}$. Figure 2 shows the market segmentation for NB and SB under such conditions. When the condition that $\frac{p_s}{q_s} < \frac{p_n - p_s}{q_n - q_s} < 1$ is not satisfied, only one brand (either NB or SB) has positive demand, i.e., case I or case III occurs.

Let $(p_n^j, Q_n^j, p_s^j, Q_s^j)$ , $j \in \{I, II, III\}$ denote the respective retail prices and demands for the NB and SB products under cases I, II, and III. The overall demand function $(Q_n, Q_s)$ is summarized below:

$$(Q_n,Q_s) \overset{\text{def}}{=} \begin{cases} (Q_n^I,Q_s^I) = \left(1-\frac{p_n}{q_n},0\right), & \text{if } \frac{p_s}{q_s} \geq \frac{p_n-p_s}{q_n-q_s} \text{ (Case I)} \\ (Q_n^{II},Q_s^{II}) = \left(1-\frac{p_n-p_s}{q_n-q_s},\frac{p_n-p_s}{q_n-q_s}-\frac{p_s}{q_s}\right), & \text{if } \frac{p_s}{q_s} < \frac{p_n-p_s}{q_n-q_s} < 1 \text{ (Case II)} \\ (Q_n^{III},Q_s^{III}) = \left(0,1-\frac{p_s}{q_s}\right), & \text{if } \frac{p_n-p_s}{q_n-q_s} \geq 1 \text{ (Case III).} \end{cases} \tag{1}$$

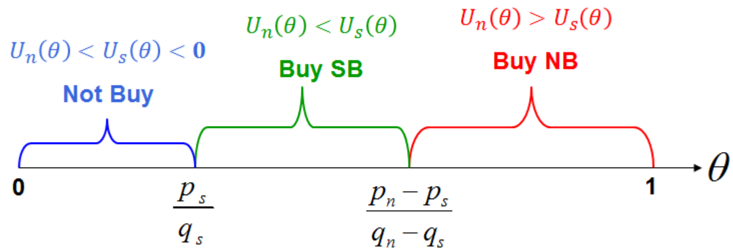


**Figure 2** **Market segmentation for NB and SB when** $\frac{p_s}{q_s} < \frac{p_n-p_s}{q_n-q_s} < 1$.

## 4. Symmetric Information

In this section, we analyze the problem under symmetric information as the benchmark case, i.e., the retailer's SB production cost is known to the NB manufacturer. We solve the game via backward induction and use "ˆ" over a profit function to denote the symmetric information case.

Given any contract $(w,T)$ offered by the NB manufacturer, we analyze the retailer's optimal product carrying and selling decisions. There are three potential scenarios to consider: (I) the retailer accepts the manufacturer's contract and only sells the NB product with profit $\hat{\Pi}_r^I(p_n,Q_n) = (p_n - w)Q_n - T$; (II) the retailer accepts the manufacturer's contract and sells both NB and SB products with profit $\hat{\Pi}_r^{II}(p_n,Q_n,p_s,Q_s) = (p_n - w)Q_n - T + (p_s - c_s)Q_s$; and (III) the retailer rejects the manufacturer's contract and only sells his own SB product with profit $\hat{\Pi}_r^{III}(p_s,Q_s) = (p_s - c_s)Q_s$. The retailer's optimal decisions are fully characterized in Lemma 1 below.

**Lemma 1.** *For any given wholesale price $w$, there exists a threshold lump-sum payment*

$$\bar{T}(w) \overset{def}{=} \begin{cases} \bar{T}^I(w) \overset{def}{=} \dfrac{(q_n-w)^2}{4q_n} - \dfrac{(q_s-c_s)^2}{4q_s}, & \text{if } 0 \leq w < \dfrac{c_sq_n}{q_s}; \\ \bar{T}^{II}(w) \overset{def}{=} \dfrac{(q_n-w+c_s-q_s)^2}{4(q_n-q_s)}, & \text{if } \dfrac{c_sq_n}{q_s} \leq w \leq c_s+q_n-q_s; \\ 0, & \text{if } w > c_s+q_n-q_s, \end{cases} \tag{2}$$

*such that:*

*(i) If $T > \bar{T}(w)$, the retailer carries the SB product only (i.e., Case III) with $(p_s^{III*},Q_s^{III*}) = \left(\frac{c_s+q_s}{2},\frac{1}{2}-\frac{c_s}{2q_s}\right)$ and $\hat{\Pi}_r^{III*} = \frac{(q_s-c_s)^2}{4q_s}$.*

*(ii) If $T < \bar{T}(w)$ and $0 \leq w < \frac{c_sq_n}{q_s}$, then the retailer carries the NB product only (i.e., Case I) with $(p_n^{I*},Q_n^{I*}) = \left(\frac{w+q_n}{2},\frac{1}{2}-\frac{w}{2q_n}\right)$ and $\hat{\Pi}_r^{I*} = \frac{(q_n-w)^2}{4q_n} - T$.*

*(iii) If $T < \bar{T}(w)$ and $\frac{c_s q_n}{q_s} \le w \le c_s + q_n - q_s$, then the retailer carries both NB and SB products (i.e., Case II) with $(p_n^{II*}, Q_n^{II*}, p_s^{II*}, Q_s^{II*}) = \left(\frac{w+q_n}{2}, \frac{1}{2} - \frac{w-c_s}{2(q_n-q_s)}, \frac{c_s+q_s}{2}, \frac{w-c_s}{2(q_n-q_s)} - \frac{c_s}{2q_s}\right)$ and $\hat{\Pi}_r^{II*} = \frac{q_n-w}{2}\left(\frac{1}{2} - \frac{w-c_s}{2(q_n-q_s)}\right) + \frac{q_s-c_s}{2}\left(\frac{w-c_s}{2(q_n-q_s)} - \frac{c_s}{2q_s}\right) - T$.*

*(iv) In the boundary case that $T = \bar{T}^i(w), i \in \{I, II\}$, the retailer is indifferent between case i and case III.*

*Moreover, $\bar{T}(w)$ is a continuous and decreasing function of $w$.*

Lemma 1 fully characterizes the retailer's best response for any contract $(w, T)$ offered by the NB manufacturer (see Figure 3 for an illustration). For a given wholesale price $w$, if the lump-sum payment exceeds a threshold value $\bar{T}(w)$, the retailer finds it not profitable to accept the contract and, thus, carries his own SB product only. On the other hand, if the lump-sum payment is below the threshold value, the retailer carries the NB product. In this case, the decision regarding whether to carry the SB product reflects the classic tension between market expansion and product cannibalization effects, and critically depends on the wholesale price $w$. More specifically, when $w$ is low, the retailer is endowed with more flexibility in selecting the retail price to sell the NB product with sufficient margin. Consequently, he has no incentive to cannibalize the sales by introducing the SB product. By contrast, when $w$ is high, the retailer has to charge a high sales price for the NB product to protect his margin, which results in a low market coverage. As such, the retailer introduces his own SB product to further expand market even at the expense of cannibalizing the NB product sales. Finally, if the lump-sum payment is at the threshold value, the retailer is indifferent about carrying the NB product or not.

It is worth noting that, although the threshold lump-sum payment $\bar{T}(w)$ is a piecewise function, it is continuous at the breakpoints. Actually, the retailer's optimal decisions at the breakpoint $w = \frac{c_s q_n}{q_s}$ [$w = c_s + q_n - q_s$] can be interpreted as the limiting case that he carries both SB and NB products where the optimal quantities for the SB [NB] product is zero. Therefore, Lemma 1 includes the breakpoint values in the wholesale price range in which the retailer carries both products. Moreover, $\bar{T}(w)$ is decreasing in $w$, which implies a trade-off between the two price parameters: Increasing wholesale price reduces the threshold lump-sum payment. In particular, when the wholesale price is very high ($w > c_s + q_n - q_s$), the threshold lump-sum payment is zero, so the retailer rejects every contract with a positive lump-sum payment.

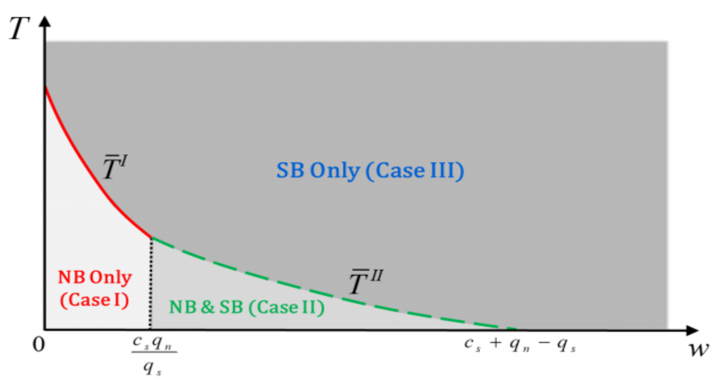


**Figure 3** Retailer's best response given any $(w, T)$

Given the retailer's optimal responses, we proceed to analyze the NB manufacturer's optimal contract offering decision. With the exclusive power of offering a take-it-or-leave-it contract, the NB manufacturer can proactively influence the retailer's product carrying decision by adjusting the contract parameters. If the retailer agrees to carry NB (i.e., case I or II), then the NB manufacturer's profit function is $\hat{\Pi}_n^j = (w - c_n)Q_n^j + T, j \in \{I, II\}$; otherwise, $\hat{\Pi}_n = 0$. As shown in Proposition 1 below, unless the NB product is too cost inefficient compared to the SB product, the manufacturer always charges a wholesale price equal to her production cost and a fixed payment as high as the threshold payment identified in Lemma 1 to earn her first-best profit, leaving the retailer with his reservation profit $\hat{\Pi}_r^{III*}$ only. As discussed after Lemma 1, the NB manufacturer's cost efficiency also affects the retailer's SB introduction decision: The retailer has no incentive to introduce the SB product if and only if the NB manufacturer is sufficiently cost efficient ($c_n < \frac{c_s q_n}{q_s}$). All the above discussions are formally characterized in Proposition 1 below.

**Proposition 1.** *Under symmetric information, the following statements hold:*

*(i) If $c_n < \frac{c_s q_n}{q_s}$, the manufacturer's optimal contract $(w^*, T^*) = \big(c_n, \bar{T}^I(c_n)\big)$, in which the retailer carries the NB product only, with $\hat{\Pi}_n^* = \bar{T}^I(c_n) = \frac{(q_n - c_n)^2}{4q_n} - \frac{(q_s - c_s)^2}{4q_s}$ and $\hat{\Pi}_r^* = \hat{\Pi}_r^{III*} = \frac{(q_s - c_s)^2}{4q_s}$.*

*(ii) If $\frac{c_s q_n}{q_s} \le c_n \le c_s + q_n - q_s$, the manufacturer's optimal contract $(w^*, T^*) = \big(c_n, \bar{T}^{II}(c_n)\big)$, in which the retailer carries both NB and SB products, with $\hat{\Pi}_n^* = \bar{T}^{II}(c_n) = \frac{(q_n - c_n - q_s + c_s)^2}{4(q_n - q_s)}$ and $\hat{\Pi}_r^* = \hat{\Pi}_r^{III*} = \frac{(q_s - c_s)^2}{4q_s}$.*

*(iii) If $c_n > c_s + q_n - q_s$, it is not profitable for the manufacturer to sell the NB product to the retailer, and the retailer carries the SB product only, with $\hat{\Pi}_n^* = 0$ and $\hat{\Pi}_r^* = \hat{\Pi}_r^{III*} = \frac{(q_s - c_s)^2}{4q_s}$.*

*(iv) The manufacturer's optimal profit $\hat{\Pi}_n^* = \bar{T}(c_n)$, which is continuous and decreasing in $c_n$.*

We further present the properties of the NB manufacturer's and retailer's respective equilibrium profits in the following corollary.

**Corollary 1.** *Under symmetric information, the following statements hold:*

*(i) The NB manufacturer's equilibrium profit increases in the NB's quality $q_n$ and the SB's cost $c_s$, and decreases in the NB's cost $c_n$ and the SB's quality $q_s$.*

*(ii) The retailer's equilibrium profit increases in the SB's quality $q_s$, decreases in the SB's cost $c_s$, and is independent from the NB's quality $q_n$ and cost $c_n$.*

Given the equilibrium behavior of the two firms, Corollary 1 summarizes how the key model parameters affect both firms' profitability. The NB manufacturer always benefits from being more competitive, such as increasing her product quality or decreasing her production cost, and suffers as the retailer becomes more competitive. Meanwhile, a notable property of two-part contracts is that under complete information, the Stackelberg leader (i.e., the NB manufacturer) can always achieve her first-best profit in equilibrium and let the follower (i.e., the retailer) break even by obtaining his reservation profit (Corbett et al. 2004). The retailer's reservation profit is also known as *disagreement point*, which is the profit the retailer would earn when the NB manufacturer and the retailer fail to reach an agreement (Feng and Lu 2013). Such reservation profit is usually related to the retailer's own parameters only, unless there is competition among retailers (Feng and Lu 2013) or negotiation involved (Bernstein and Marx 2005). In our model, the retailer's reservation profit is obtained in case III when he only carries SB product, which is irrelevant to the NB's quality or cost. As such, under symmetric information, both firms have strong incentives to enhance their own competitive position at the expense of (weakly) hurting the other. In the next section, we will further illustrate how the presence of information asymmetry alters the aforementioned optimal contract design and the competitive relationship between the two firms.

## 5. Asymmetric Information

In this section, we analyze the NB manufacturer's optimal contract design in the presence of asymmetric information, i.e., the retailer holds his own SB production cost as private information. We first formulate the problem and discuss its properties in Section 5.1, and then present the optimal contract design and conduct sensitivity analysis in Sections 5.2 and 5.3, respectively.

### 5.1. Problem Formulation and Property

Without the transparency of the SB cost information, the NB manufacturer only has an estimate that $c_s$ has two possible values, $c_s^H$ and $c_s^L$, with respective probabilities $v$ and $1-v$. In the remainder of the paper, we refer to a retailer with an SB cost of $c_s^H$ [$c_s^L$] as high or H [low or L] type retailer. It follows from Proposition 1 that if $c_n > c_s^H + q_n - q_s$, the NB product is the least competitive (among NB, H-type SB, and L-type SB) such that it is not carried by either type of retailer. On the other hand, if $c_n < \frac{c_s^L q_n}{q_s}$, then the NB product is so competitive that either type of retailer has little incentive to introduce his SB product. To avoid these uninteresting cases, we focus our analysis in the range that $c_n \in \left[\frac{c_s^L q_n}{q_s}, c_s^H + q_n - q_s\right]$ in the remainder of the paper.

When the retailer holds his SB cost information privately, the NB manufacturer needs to design a menu of contracts for the retailer to choose from. With the assist of the Revelation Principle (Myerson 1981), the manufacturer can safely focus on offering a menu of two contracts, i.e., $(w^H, T^H)$ and $(w^L, T^L)$, each dedicating to a cost type, to maximize her expected profit. Two additional sets of constraints should be imposed: (1) incentive compatibility (IC) constraint, following which each type cannot be more profitable from mimicking the other; and (2) individual rationality (IR) constraint, following which each type earns at least the reservation profit from accepting the contract. Combining all the above discussions, the manufacturer's problem can be formulated in Equations (3a)-(3e) below, in which $\Pi_n(w^i, T^i, c_s^i)$ $(i \in \{L, H\})$ represents the manufacturer's profit when the type-$i$ retailer chooses contract $(w^i, T^i)$, and $\Pi_r(w^i, T^i, c_s^j)$ $(i, j \in \{L, H\})$ denotes the type-$j$ retailer's corresponding profit when choosing contract $(w^i, T^i)$.

$$\max_{(w^H,T^H),(w^L,T^L)} \Pi_n = v\Pi_n(w^H, T^H, c_s^H) + (1-v)\Pi_n(w^L, T^L, c_s^L) \tag{3a}$$

subject to

$$\text{(ICH)} \quad \Pi_r(w^H, T^H, c_s^H) \geq \Pi_r(w^L, T^L, c_s^H) \tag{3b}$$

$$\text{(ICL)} \quad \Pi_r(w^L, T^L, c_s^L) \geq \Pi_r(w^H, T^H, c_s^L) \tag{3c}$$

$$\text{(IRH)} \quad \Pi_r(w^H, T^H, c_s^H) \geq \Pi_r^{III*}(c_s^H) \tag{3d}$$

$$\text{(IRL)} \quad \Pi_r(w^L, T^L, c_s^L) \geq \Pi_r^{III*}(c_s^L) \tag{3e}$$

Note that the set of IR constraints in our setting is type-dependent. That is, the reservation profit for type $i$ retailer, i.e., $\Pi_r^{III*}(c_s^i)$, critically depends on his SB cost $c_s^i$. Since the L-type retailer is more cost efficient, his reservation profit is higher than that of the H-type. As noted in Cakanyıldırım et al. (2012), type-dependent reservation profit has been studied in the economics literature but has not been vastly explored in the operations management domain. As illustrated later, type-dependent reservation level increases the complexity in the optimal contract structure and may lead to the case that the manufacturer strategically chooses to shut down the L-type and only deals with the H-type by extracting the first-best outcome. Despite the analytical complexity from the type-dependent reservation profits, we are able to fully characterize the NB manufacturer's optimal menu of contracts. Before proceeding to the detailed equilibrium analysis, we define additional notations and derive some fundamental properties of the aforementioned mechanism design problem. For expositional convenience, we specify the threshold fixed payment $\bar{T}(w)$ in Lemma 1 for type $i$ ($i \in \{L, H\}$) below.

$$\bar{T}^i(w) \stackrel{\text{def}}{=} \begin{cases} \bar{T}^{Ii}(w) = \dfrac{(q_n - w)^2}{4q_n} - \dfrac{(q_s - c_s^i)^2}{4q_s}, & \text{if } 0 \leq w < \dfrac{c_s^i q_n}{q_s}; \\ \bar{T}^{IIi}(w) = \dfrac{(q_n - w + c_s^i - q_s)^2}{4(q_n - q_s)}, & \text{if } \dfrac{c_s^i q_n}{q_s} \leq w \leq c_s^i + q_n - q_s; \\ 0, & \text{if } w > c_s^i + q_n - q_s. \end{cases} \tag{4}$$

It can be shown that for given wholesale price $w$, $\bar{T}^H(w) > \bar{T}^L(w)$, indicating that the NB manufacturer is always able to charge a higher fixed payment as the retailer's production cost increases.

To conclude this subsection, we examine constraints (3b)-(3e) to reduce the complexity of the optimality search. We first establish some fundamental properties of this mechanism design problem. Specifically, Lemma 2 below shows that the (IRH) constraint is redundant. This is because the H-type retailer has an incentive to mimic the L-type retailer, since the L-type is more cost efficient and has a higher reservation profit. As a result, the NB manufacturer has to offer the H-type an information rent, i.e., the additional profit above his reservation profit, to prevent him from lying about his type.

**Lemma 2.** *Following (ICH) and (IRL), (IRH) is a redundant constraint.*

### 5.2. Optimal Contracts

In this subsection, we characterize the NB manufacturer's optimal contract choice. By Lemma 2, it is clear that the NB manufacturer needs to pay the H-type retailer a positive information rent in order to prevent him from mimicking the L-type. Under extreme conditions, e.g., when the H-type retailer's probability is very high, the NB manufacturer would give up doing business with the L-type retailer to eliminate the information rent to be paid to the H-type retailer. We refer to this case as *shutting down L-type* in the subsequent analysis. Such shutdown policy is a unique feature resulting from the type-dependent IR constraints (Laffont and Martimort 2009). When offering a first-best contract to only one type of the agent (i.e., H-type in our setting) is more profitable than offering second-best contracts to both types, the NB manufacturer would prefer to deploy the shutdown policy. In the following analysis, we first analyze the NB manufacturer's subgame contract design problem with and without shutdown, and then compare them to derive her globally optimal contract offering decision.

**Contract with shutdown**

Since the L-type retailer has a higher reservation profit than the H-type retailer, the NB manufacturer, when considering giving up business with one firm, would prefer to shut down the L-type instead of the H-type. According to Proposition 1, the manufacturer can choose to shut down the L-type retailer by offering only one type of contract, which is the H-type contract, to extract her first-best profit by setting $(w^H, T^H) = \left(c_n, \bar{T}^H(c_n)\right)$. Since $\bar{T}^H(w)$ is strictly higher than $\bar{T}^L(w)$ for any wholesale price $w$, it is not profitable for the L-type retailer to accept the H-type retailer's contract, i.e., $\left(c_n, \bar{T}^H(c_n)\right)$. Consequently, the L-type retailer chooses to carry his SB product only. Under this *contract with shutdown*, instead of a menu of two contracts, only one contract is offered by the NB manufacturer to the retailer who would automatically reject the contract if he is L type. Then the NB manufacturer's expected profit is $\Pi_n = v\bar{T}^H(c_n)$, and both types of retailers earn their reservation profits, i.e., $\Pi_r(c_s^i) = \hat{\Pi}_r^{III*}(c_s^i), i \in \{H, L\}$, respectively.

**Contract without shutdown**

Without shutting down any type, the NB manufacturer needs to design the optimal contracts for both types of retailers, and each contract includes two parameters, i.e., wholesale price $w^i$ and fixed payment $T^i$, $i \in \{H, L\}$. Hence, we have a four-dimensional constrained optimization problem. Clearly, the NB manufacturer's profit $\Pi_n$ is increasing in the fixed payments $T^H$ and $T^L$ paid by the retailers. It can be shown that both (ICH) and (IRL) are binding in the optimal solution. Otherwise, the NB manufacturer could further improve her profit by charging higher fixed payments until both (ICH) and (IRL) become binding. This result is formally presented in the following Lemma.

**Lemma 3.** *(ICH) and (IRL) are binding at optimality.*

As such, we recognize four possible contract options offered by the NB manufacturer. Let $(H^i, L^j)$ denote a menu of contracts that induces the H-type to react as in Case $i$ and the L-type as in Case $j$, where $i, j \in \{I, II\}$, specified in Lemma 1. Although we have four contract options, Lemma 4 below shows that contract $(H^{II}, L^I)$ is not a feasible option of the NB manufacturer. Contract $(H^{II}, L^I)$ indicates that the H-type retailer would carry both brands, while the L-type retailer would carry NB only. If the $L^I$ contract is profitable enough for the L-type retailer to carry NB only, then it must be profitable enough for the H-type retailer to carry NB only. In this case, the H-type retailer would choose $L^I$ contract instead of $H^{II}$ contract. Hence, $(H^{II}, L^I)$ cannot satisfy (ICH) constraint, and is not a feasible option for the NB manufacturer.

**Lemma 4.** *$(H^{II}, L^I)$ contract is not a feasible option for the NB manufacturer.*

Based on Lemma 4, the optimality search can be conducted among three contract options: $(H^I, L^I)$, $(H^I, L^{II})$, and $(H^{II}, L^{II})$. We can further eliminate the contract option $(H^I, L^I)$ from consideration. By Lemma 1, it is straightforward that in our range of discussion, i.e., $c_n \in \left[\frac{c_s^L q_n}{q_s}, c_s^H + q_n - q_s\right]$, contract $(H^I, L^I)$ is not optimal. As such, the NB manufacturer's profit $\Pi_n$ as functions of $(w^i, T^i)$, $i \in \{L, H\}$, can now be formulated in Equation (5) below.

$$\Pi_n(w^i, T^i) = \begin{cases} v\left[(w^H - c_n)(\frac{1}{2} - \frac{w^H}{2q_n}) + T^H\right] + (1-v)\left[(w^L - c_n)(\frac{1}{2} - \frac{w^L - c_s^L}{2(q_n - q_s)}) + T^L\right], & \text{if offering}(H^I, L^{II}); \\ v\left[(w^H - c_n)(\frac{1}{2} - \frac{w^H - c_s^H}{2(q_n - q_s)}) + T^H\right] + (1-v)\left[(w^L - c_n)(\frac{1}{2} - \frac{w^L - c_s^L}{2(q_n - q_s)}) + T^L\right], & \text{if offering}(H^{II}, L^{II}). \end{cases} \tag{5}$$

Utilizing Lemma 3, we can detail the manufacturer's optimal choice of fixed payment $T^i$ for each contract type given the wholesale price $w^i$, $i \in \{L, H\}$. For the L-type, the binding (IRL) constraint, together with the fact that $\bar{T}^H(w) > \bar{T}^L(w)$ for any given $w$, immediately implies that $T^L = \bar{T}^L(w^L) < \bar{T}^H(w^L)$. As such, $T^L$ is always set to the threshold value $\bar{T}^{IIL}(w^L)$. For the H-type, given $w^L$ and $\bar{T}^{IIL}(w^L)$ with $\bar{T}^{IIL}(w) < \bar{T}^H(w)$, we can predict the H-type retailer's carrying decision by mimicking the L-type, i.e., the function format of $\Pi_r(w^L, T^L, c_s^H)$. Then in conjunction with the binding (ICH) constraint, we can express $T^H$ as functions of $w^H$ and $w^L$ in Table 1.

| | | **Optimal $T^H(w^H, w^L)$ Functions** |
|---|---|---|
| $(H^I, L^{II})$ | $w^L < \frac{c_s^H q_n}{q_s}$ | $\frac{(c_s^L + q_n - q_s - w^L)^2}{4(q_n - q_s)} + \frac{(q_n - w^H)^2}{4q_n} - \frac{(q_n - w^L)^2}{4q_n}$ |
| | $\frac{c_s^H q_n}{q_s} \le w^L \le c_s^L + q_n - q_s$ | $\frac{(q_n - w^H)^2}{4q_n} - \frac{q_n - w^L}{2}\left(\frac{1}{2} - \frac{w^L - c_s^H}{2(q_n - q_s)}\right) + \frac{q_s - c_s^H}{2}\left(\frac{w^L - c_s^H}{2(q_n - q_s)} - \frac{c_s^H}{2q_s}\right) + \frac{(c_s^L + q_n - q_s - w^L)^2}{4(q_n - q_s)}$ |
| $(H^{II}, L^{II})$ | $w^L < \frac{c_s^H q_n}{q_s}$ | $\frac{q_n - w^H}{2}\left(\frac{1}{2} - \frac{w^H - c_s^H}{2(q_n - q_s)}\right) + \frac{q_s - c_s^H}{2}\left(\frac{w^H - c_s^H}{2(q_n - q_s)} - \frac{c_s^H}{2q_s}\right) + \frac{(c_s^L + q_n - q_s - w^L)^2}{4(q_n - q_s)} - \frac{(q_n - w^L)^2}{4q_n}$ |
| | $\frac{c_s^H q_n}{q_s} \le w^L \le c_s^L + q_n - q_s$ | $\frac{{c_s^L}^2 + (w^H - q_n + q_s)^2 + 2c_s^L(q_n - q_s - w^L) - 2c_s^H(w^H - w^L)}{4(q_n - q_s)}$ |

**Table 1** **Optimal $T^H(w^H, w^L)$ under Supply Contracts without Shutdown**

Applying the above analysis, we are able to reduce problem (3a) to a two-dimensional problem, which optimizes over the wholesale price pair $(w^H, w^L)$. To solve this reduced problem, we first derive local optimal solutions under each contract type, and then compare the manufacturer's optimal profits across all candidate contract types to derive the optimal contract without shutdown. Our result shows that there exists a unique threshold $\tilde{c}_n$ such that if $c_n \ge \tilde{c}_n$, the L-type retailer receives a *boundary contract*, which he still accepts but carries zero NB product. $\tilde{c}_n$ is expressed as

$$\tilde{c}_n = \begin{cases} c_s^L + q_n - q_s - \frac{v(q_n - q_s)(q_s - c_s^L)}{(1-v)q_n}, & \text{if } c_s^L + q_n - q_s \le \frac{c_s^H q_n}{q_s}; \\ c_s^L + q_n - q_s - \frac{v(c_s^H - c_s^L)}{1-v}, & \text{if } c_s^L + q_n - q_s > \frac{c_s^H q_n}{q_s}. \end{cases}$$

It follows that $\tilde{c}_n < c_s^L + q_n - q_s$, and that $\tilde{c}_n$ may be greater than or less than $\frac{c_s^L q_n}{q_s}$ or $\frac{c_s^H q_n}{q_s}$. At the breakpoint, i.e., $c_n = \tilde{c}_n$, the NB manufacturer's optimal profit without shutdown is strictly less than her optimal profit with shutdown. It implies that when the NB cost is higher than $\tilde{c}_n$, the NB product completely loses competitiveness to the L-type SB product, so the NB manufacturer would definitely shut down the L-type. In the remaining case that $c_n < \tilde{c}_n$, we need to compare the NB manufacturer's optimal contract without shutdown to that with shutdown to derive her globally optimal contract. The detailed analysis is presented in the next subsection.

**Optimal Menu of Contracts**

By comparing the manufacturer's optimal expected profits with and without shutdown, we establish a threshold for the NB cost, denoted as $\bar{c}_n$. Lemma 5 below characterizes the threshold $\bar{c}_n$ and its properties.

**Lemma 5.** *(i) There exists a unique threshold* $\bar{c}_n \in \left[\frac{c_s^L q_n}{q_s}, \max\{\frac{c_s^L q_n}{q_s}, \tilde{c}_n\}\right]$*, such that the NB manufacturer prefers to offer the contract without shutdown if* $\frac{c_s^L q_n}{q_s} \le c_n < \bar{c}_n$*, and the contract with shutdown if* $c_n \ge \bar{c}_n$*.*

*(ii) The threshold* $\bar{c}_n$ *is increasing in* $c_s^L$ *and decreasing in* $c_s^H$*.*

Since $\bar{c}_n < \tilde{c}_n < c_s^L + q_n - q_s$, Lemma 5(i) and Proposition 1 jointly imply that the NB manufacturer is more likely to shut down the L-type retailer in the presence of information asymmetry. This is driven by the downward distortion on the manufacturer's expected profit from the L-type retailer and the information rent given up to the H-type retailer. As the NB cost increases, the NB product becomes less competitive relative to the SB product, and the NB manufacturer tends to be more reluctant to pay the information rent to the H-type. This is further confirmed by part (ii). That is, when the L-type SB cost increases, NB becomes relatively more competitive to the L-type SB, and the NB manufacturer is less likely to shut down the L-type. On the other hand, if the H-type SB cost increases, the H-type retailer has more incentive to mimic the L-type, and consequently demands a higher information rent. In this case, the NB manufacturer inclines to shut down the L-type to maintain her expected profit. This result may help us understand the rationale behind Trader Joe's action of discontinuing certain products due to the change in production cost and the resulting compromised profit (FAQ 2022).

In the following proposition, we characterize the NB manufacturer's global optimal contract offering decision.

**Proposition 2.** *Under asymmetric information, the following statements hold:*

*(i) If* $\frac{c_s^L q_n}{q_s} \le c_n < \bar{c}_n$*, the NB manufacturer's optimal contract type* $(H^*, L^*)$ *is given by*

$$(H^*, L^*) = \begin{cases} (H^I, L^{II}), & \text{if} \quad c_n < \frac{c_s^H q_n}{q_s}; \\ (H^{II}, L^{II}), & \text{if} \quad c_n \ge \frac{c_s^H q_n}{q_s}. \end{cases}$$

*(ii) If* $\bar{c}_n \le c_n \le c_s^H + q_n - q_s$*, the NB manufacturer chooses to shut down the L-type and only offers* $H^*$ *contract to the H-type where*

$$H^* = \begin{cases} H^I, & \text{if} \quad c_n < \frac{c_s^H q_n}{q_s}; \\ H^{II}, & \text{if} \quad c_n \ge \frac{c_s^H q_n}{q_s}. \end{cases}$$

Proposition 2 fully characterizes the NB manufacturer's optimal contract offering decision under asymmetric information. In the presence of asymmetric information, the optimal contract shares a qualitatively similar trend as that in the symmetric information case. That is, the manufacturer offers Case $I$ contract to the H-type retailer if the NB manufacturer is more cost efficient, i.e., $c_n < \frac{c_s^H q_n}{q_s}$. Otherwise, the NB manufacturer provides Case $II$ contract under which the H-type retailer carries both products. By contrast, the NB manufacturer only extends Case $II$ contract to the L-type retailer when the NB cost is competitive, and shuts down the L-type otherwise.

This result echos with many practices in the retail industry. For instance, Louis Vuitton, a French luxury fashion brand, only authorizes the retail of its product (other than accessories) to high-end retailers, such as Neiman Marcus and Nordstrom, but does not engage in business with relatively lower-end retailers such as Walmart and Target. Moreover, for retailers and NB manufacturers who have established purchasing agreements, the shutdown by an NB manufacturer (or the rejection of contract by an L-type retailer) can cause termination or temporary discontinuation of procurement activities. Many manufacturers and retailers consider this possibility at the time of contracting and have it written into contracts to ensure flexibility. For instance, according to a Master Vendor Agreement between Trader Joe's and its vendor, it is mutually agreed between the two parties that "Trader Joe's may from time to time issue, but has not committed to issue, purchase orders to VENDOR" (SEC 2018b). Thus, Trader Joe's may pause issuing orders if rejecting a vendor's offer. Similarly, it is documented in the Master Retailer Agreement between Purple Innovation, a mattress manufacturer, and Mattress Firm, a mattress retailer who owns an SB mattress Tulo, that "Retailer shall have the right to reject for any reason any product line proposed to be offered" (SEC 2018a).

Finally, to facilitate subsequent analysis, we provide the manufacturer's equilibrium contract parameters, which are the optimal solution to her contract design problem in Equations (3), in Corollary 2 below.

**Corollary 2.** *The NB manufacturer's optimal menu of contracts* $\{(w^{H*}, T^{H*}), (w^{L*}, T^{L*})\}$ *is given as follows:*

*(i) If* $\frac{c_s^L q_n}{q_s} \le c_n < \bar{c}_n$, *then*

$$(w^{H*}, w^{L*}) = \begin{cases} \left(c_n, \frac{(c_n - vc_n - vc_s^L)q_n}{q_n - vq_n - vq_s}\right), & \text{if } c_n \le \frac{c_s^H q_n}{q_s} - \frac{v(c_s^H - c_s^L)}{1-v}; \\ \left(c_n, c_n + \frac{v(c_s^H - c_s^L)}{1-v}\right), & \text{if } \frac{c_s^H q_n}{q_s} - \frac{v(c_s^H - c_s^L)}{1-v} < c_n \le \bar{c}_n. \end{cases}$$

*In addition,* $T^{L*} = \bar{T}^L(w^{L*})$, *and* $T^{H*}$ *can be found by substituting* $w^{H*}$ *and* $w^{L*}$ *into the optimal* $T^H$ *function in Table 1 under the optimal contract* $(H^*, L^*)$, $i \in \{H, L\}$.

*(ii) If* $\bar{c}_n \le c_n \le c_s^H + q_n - q_s$, *then the NB manufacturer chooses to shut down the L-type and offers the optimal contract* $(w^{H*}, T^{H*}) = \left(c_n, \bar{T}^H(c_n)\right)$ *to the H-type.*

By substituting $w^{H*}$ and $w^{L*}$ into $T^{H*}$, one can verify that $T^{H*} \ge \bar{T}^L(w^{H*})$. In conjunction with Lemma 1 and the binding (IRL) constraint, it is straightforward to obtain $\Pi_r(w^{L*}, T^{L*}, c_s^L) = \Pi_r^{III*}(c_s^L) \ge \Pi_r(w^{H*}, T^{H*}, c_s^L)$. That is, constraint (ICL) is indeed satisfied by the optimal solution.

To conclude this subsection, we further remark that the analysis in sections 5.2 and 5.3 is conducted under the assumption that only the retailer keeps his store brand cost as private information and the NB manufacturer's production cost is common knowledge. This assumption may appear to be restrictive since the NB manufacturer can also possess her cost as proprietary information. We here relax this assumption by discussing an *informed principal* case, in which the NB manufacturer (the principal) also holds his production cost as private information. According to Fudenberg and Tirole (1991, pp. 297-298), the scenario of private NB cost is considered as a *private value* case such that the principal's private information does not directly enter the agent's preferences (i.e., the retailer's profit function). Since the NB manufacturer's and retailer's profit functions in our model are both quasi-linear in transfers, it follows from Maskin and Tirole (1990, Proposition 11) that the NB manufacturer is not better off or worse off if her cost information is revealed to public. In other words, the equilibrium in our analysis continues to hold under the informed principal case.

### 5.3. Sensitivity Analysis

In this section, we conduct sensitivity analysis to understand how the key model parameters affect each firm's equilibrium profit under asymmetric information. If the NB manufacturer chooses the contract by shutting down the L-type retailer, Corollary 1 continues to hold. That is, each firm benefits from improving its product quality or reducing its production cost, but such efforts may hurt the other firm. On the other hand, if the NB manufacturer offers a menu of contracts without shutting down the L-type, the H-type retailer earns an information rent in addition to his reservation profit. In this case, the effect of product quality and cost on the retailer's and manufacturer's respective profit becomes more involved. In what follows, we will analyze the impacts of the product quality (i.e., $q_s$ and $q_n$) and the production cost (i.e., $c_s^H, c_s^L$, and $c_n$) on the equilibrium profits of the NB manufacturer $\Pi_n^*$, the H-type retailer $\Pi_r^{H*}$, and the L-type retailer $\Pi_r^{L*}$, as well as the retailer's expected equilibrium profit $\Pi_r^* \stackrel{def}{=} v\Pi_r^{H*} + (1-v)\Pi_r^{L*}$. We will also contrast them with their corresponding effects under symmetric information to understand how the presence of asymmetric information alters the conventional wisdom regarding quality-cost trade-offs.

First, we discuss the impact of contract form change on each firm's equilibrium profit. Recall from Lemma 5 that the NB manufacturer's optimal contract offering decision critically depends on her production cost $c_n$. Particularly, the manufacturer is indifferent between offering a contract with shutdown and one without shutdown when $c_n = \bar{c}_n$, and her optimal profit is continuous in $c_n$ and other model parameters. Similarly, an L-type retailer earns his reservation profit regardless of the contract form due to the binding (IRL) constraint, so his equilibrium profit is continuous in $c_n$ and other model parameters. By contrast, an H-type retailer earns his reservation profit plus additional information rent under a contract without shutdown, but his reservation profit only under a contract with shutdown. Therefore, when the offered contract type switches from one without shutdown to one with shutdown, the H-type retailer's equilibrium profit is discontinuous with a downward drop. Consequently, a downward drop also happens in the retailer's expected equilibrium profit.

In the subsequent analysis, we first focus on the parameter region that $\frac{c_s^L q_n}{q_s} \le c_n < \bar{c}_n$, i.e., the NB manufacturer offers a contract without shutting down the L-type, to understand the impacts of various model parameters. Then, we include the case of shutting down the L-type, i.e., $\bar{c}_n \le c_n \le c_s^H + q_n - q_s$, and comment on how the switch of contract type affects the aforementioned impacts. We start with investigating the impacts of both the NB and the SB products' quality on each firm's equilibrium profit under asymmetric information in the following proposition.

**Proposition 3.** *Under asymmetric information, if* $\frac{c_s^L q_n}{q_s} \le c_n < \bar{c}_n$, *then*

*(i) the NB manufacturer's equilibrium profit* $\Pi_n^*$ *is increasing in* $q_n$ *and decreasing in* $q_s$*;*

*(ii) the L-type retailer's equilibrium profit* $\Pi_r^{L*}$ *is independent of* $q_n$ *and increasing in* $q_s$*;*

*(iii) the H-type retailer's equilibrium profit* $\Pi_r^{H*}$ *is increasing in* $q_n$ *and non-monotonic in* $q_s$*;*

*(iv) the retailer's expected equilibrium profit* $\Pi_r^*$ *is increasing in* $q_n$ *and non-monotonic in* $q_s$*.*

Consistent with the findings under symmetric information (i.e., Corollary 1), Proposition 3(i) shows that the NB manufacturer always benefits from the quality improvement of her own NB product, but suffers from an improved SB product quality. Similarly, since the L-type retailer always earns his reservation profit under asymmetric information, his equilibrium profit is increasing in his own SB product quality and independent of the NB product quality.

On the other hand, the H-type retailer's equilibrium profit depends on the quality of both NB and SB products. If an $(H^I, L^{II})$ contract is offered, the H-type retailer carries the NB product only, and a higher NB quality increases his equilibrium profit. By contrast, if an $(H^{II}, L^{II})$ contract is offered, the H-type retailer carries both NB and SB products, and the quality improvement of the NB product has two opposite consequences: It helps the retailer to earn more from selling the NB product, but reduces his profit from selling the SB product. Our result shows that his profit gain from selling the NB product dominates the loss from the SB product sales, so the H-type retailer always benefits from the quality improvement of the NB product. However, the impact of the SB product quality on the H-type retailer's equilibrium profit is more complicated. A higher SB product quality raises the reservation profit of the H-type retailer, and reduces the profitability of the NB manufacturer. Due to the higher H-type reservation profit, the NB manufacturer is under pressure to charge a lower lump-sum payment $T^H$. On the other hand, since the NB manufacturer's profit is decreasing in $q_s$, she would like to charge a higher lump-sum payment from the H-type retailer to maintain her profitability. Consequently, a higher SB product quality may have two competing effects on the equilibrium lump-sum payment $T^{H*}$: The higher reservation profit of the H-type retailer drives down $T^{H*}$, whereas the lower profitability of the NB manufacturer drives up $T^{H*}$. This intricate impact of the SB product quality is confirmed by our analysis: It follows from Corollary 2(i) that $w^{L*}$ is increasing in $q_s$ and from Table 2 that $T^{H*}$ depends on $q_s$ directly and indirectly (via $w^{L*}$). The overall impact of the SB product quality is quite involved. We demonstrate with numerical examples that the H-type retailer's equilibrium profit is non-monotonic in $q_s$. Finally, part (iv) follows directly from parts (ii) and (iii).

Proposition 3 reveals that under asymmetric information, both the NB manufacturer and the (H-type or L-type) retailer have aligned incentive to improve the NB product quality, the L-type retailer always has an incentive to improve his SB product quality, whereas the NB manufacturer suffers from the improved SB quality. Interestingly, the impact of the SB product quality on the H-type retailer's equilibrium profit may go either way.

Next, we investigate the impacts of cost parameters on each firm's equilibrium profit in the following proposition.

**Proposition 4.** *Under asymmetric information, if* $\frac{c_s^L q_n}{q_s} \le c_n < \bar{c}_n$*, then*

*(i) the manufacturer's equilibrium profit* $\Pi_n^*$ *is decreasing in* $c_n$*, and increasing in both* $c_s^H$ *and* $c_s^L$*;*

*(ii) the L-type retailer's equilibrium profit* $\Pi_r^{L*}$ *is independent of* $c_n$ *and* $c_s^H$*, and decreasing in* $c_s^L$*;*

*(iii) the H-type retailer's equilibrium profit* $\Pi_r^{H*}$ *is decreasing in both* $c_n$ *and* $c_s^H$*, and non-monotonic in* $c_s^L$*;*

*(iv) the retailer's equilibrium expected profit* $\Pi_r^*$ *is decreasing in both* $c_n$ *and* $c_s^H$*, and non-monotonic in* $c_s^L$*.*

For the impact of the NB production cost $c_n$, Proposition 4 confirms the finding under symmetric information that a higher $c_n$ reduces the NB manufacturer's equilibrium profit and has no impact on the L-type retailer's equilibrium profit. Different from the case of symmetric information, the H-type retailer is worse off as $c_n$ increases. Note that the H-type retailer earns more than his reservation profit under asymmetric information, and an increase in $c_n$ leads to two opposite effects: On the one hand, it reduces the H-type's profit from selling the NB product as the equilibrium wholesale price increases; on the other hand, it also improves the competitiveness of the SB product, which may benefit the H-type retailer. In equilibrium, if the $(H^I, L^{II})$ contract is offered, the H-type retailer's profitability suffers since only the negative effect is present. By contrast, if the $(H^{II}, L^{II})$ contract is offered, both effects coexist as the H-type retailer carries both NB and SB products, but the negative one plays a dominating role such that the H-type is overall worse off as $c_n$ increases.

Next, we discuss the impacts of the SB costs $c_s^H$ and $c_s^L$. Regardless of its type, an increase in the SB cost indirectly enhances the competitiveness of the NB product and benefits the NB manufacturer, as shown in Proposition 4(i). Since the L-type retailer earns his reservation profit, his equilibrium profit is decreasing in his production cost $c_s^L$ and independent of $c_s^H$. Similarly, the H-type retailer's equilibrium profit decreases in his production cost $c_s^H$. Interestingly, part(iii) shows that the impact of the L-type cost $c_s^L$ on the H-type retailer's equilibrium profit is non-monotonic. Recall from Corollary 2 that it is optimal for the NB manufacturer to charge the H-type retailer the wholesale price $w^{H*} = c_n$. Since H-type retailer is indifferent between choosing his own contract $H^*$ and the L-type retailer's contract $L^*$ (i.e., the binding (ICH)), the trend in the H-type lump-sum payment $T^{H*}$ reflects the combined effects on $w^{L*}$ and $T^{L*}$ when $c_n$ remains constant. In order to induce the true cost information from the H-type retailer, the NB manufacturer allows the H-type retailer to earn his reservation profit plus an information rent, which depends on the L-type cost $c_s^L$. It follows from Corollary 2 and Equation (4) that as $c_s^L$ increases, $w^{L*}$ decreases whereas $T^{L*}$ increases. Indeed, when the L-type retailer becomes less competitive due to his rising cost, the NB manufacturer is able to offer a lower wholesales price $w^{L*}$ to capture a larger fraction of the market, which also leads to a higher unit margin for the L-type retailer from selling the NB product. Meanwhile, the lower

$w^{L*}$ is companied by a higher lump-sum payment $T^{L*}$ since the L-type retailer is only left with his reservation profit. Under certain parameter settings, as $c_s^L$ starts to increase, the benefit from the NB market expansion prevails over the higher lump-sum charge. As such, the L-type contract becomes more appealing to the H-type retailer so that he has more incentive to hide his type. In this case, the NB manufacturer may offer a lower $T^H$ to induce truthful cost information from the H-type retailer. Hence, the H-type may use the L-type cost as a leverage to obtain better contract terms. However, as $c_s^L$ further increases, the benefit from the decrease in $w^{L*}$ may be dominated by the increase in $T^{L*}$, which provides the H-type retailer with less incentive to hide his type. Therefore, the NB manufacturer can charge a higher $T^{H*}$, or equivalently, offer a lower information rent, to further improve her profitability. Indeed, our numerical results demonstrate that the H-type's profit may be concavely non-monotonic in $c_s^L$.

Proposition 4(iv) follows from parts (ii) and (iii). Proposition 4 shows that, under asymmetric information, both the NB manufacturer and the (H-type or L-type) retailer benefit from a cost reduction on the NB product. A reduced H-type cost benefits the H-type retailer, hurts the NB manufacturer, and has no impact on the L-type retailer. As the L-type retailer reduces his cost, his equilibrium profit increases, whereas the NB manufacturer's equilibrium profit decreases. Surprisingly, the H-type retailer may benefit or suffer from a higher L-type cost $c_s^L$. Under certain circumstances, both the NB manufacturer and the H-type retailer may be better off with a higher L-type cost.

Previous discussions focus on the case when the NB manufacturer offers a menu of contracts without shutting down any type, i.e., $\frac{c_s^L q_n}{q_s} \le c_n < \bar{c}_n$. By contrast, when shutting down the L-type (i.e., $\bar{c}_n \le c_n \le c_s^H + q_n - q_s$), the impacts are essentially the same as those under symmetric information. Table 3 below summarizes the change in the contract form and equilibrium profits of the NB manufacturer and retailers as each model parameter increases.

| | **Contract Form Change** | $\Pi_n^*$ | | $\Pi_r^*$ | |
|---|---|---|---|---|---|
| | | w/o Shutdown | w/ Shutdown | w/o Shutdown | w/ Shutdown |
| $q_n$ | w/ Shutdown → w/o Shutdown | ↑ | ↑ | ↑ | irrelevant |
| $q_s$ | w/o Shutdown → w/ Shutdown | ↓ | ↓ | ↕ | ↑ |
| $c_n$ | w/o Shutdown → w/ Shutdown | ↓ | ↓ | ↓ | irrelevant |
| $c_s^H$ | w/o Shutdown → w/ Shutdown | ↑ | ↑ | ↓ | ↓ |
| $c_s^L$ | w/ Shutdown → w/o Shutdown | ↑ | irrelevant | ↕ | ↓ |

| | **Contract Form Change** | $\Pi_r^{H*}$ | | $\Pi_r^{L*}$ | |
|---|---|---|---|---|---|
| | | w/o Shutdown | w/ Shutdown | w/o Shutdown | w/ Shutdown |
| $q_n$ | w/ Shutdown → w/o Shutdown | ↑ | irrelevant | irrelevant | irrelevant |
| $q_s$ | w/o Shutdown → w/ Shutdown | ↕ | ↑ | ↑ | ↑ |
| $c_n$ | w/o Shutdown → w/ Shutdown | ↓ | irrelevant | irrelevant | irrelevant |
| $c_s^H$ | w/o Shutdown → w/ Shutdown | ↓ | ↓ | irrelevant | irrelevant |
| $c_s^L$ | w/ Shutdown → w/o Shutdown | ↕ | irrelevant | ↓ | ↓ |

**Table 2 Summary of Sensitivity Analysis Under Asymmetric Information**

To conclude, we remark that when considering the entire feasible range, i.e., $\frac{c_s^L q_n}{q_s} \leq c_n \leq c_s^H + q_n - q_s$, the change of a focal parameter may endogenously affect the equilibrium menu of contracts offered and result in non-monotonic profit implications. Table 2 documents how the equilibrium contract menu and the resulting equilibrium profits change as the chosen parameter increases. The NB manufacturer's and L-type retailer's respective equilibrium profit is continuous at the contract switching point, whereas the H-type retailer's equilibrium profit is discontinuous due to the addition/elimination of information rent. For instance, although an increased SB product quality $q_s$ may improve or hurt the H-type retailer's equilibrium profit, such an increase always weakens the relative competitiveness of the NB product. As a result, the NB manufacturer tends to shut down the L-type retailer and eliminate the information rent paid to the H-type retailer, which leads to a downward drop in the H-type retailer's profit. Similarly, a higher L-type cost $c_s^L$ may put the H-type retailer in a better or worse position, but it strengthens the NB product's competitiveness. Consequently, as $c_s^L$ increase, the NB manufacturer would switch to offering a contract without shutdown to involve the L-type retailer, which leads to an upward jump in the H-type retailer's equilibrium profit due to the addition of information rent. Likewise, a higher NB product quality $q_n$ or a lower NB cost $c_n$ would also motivate the NB manufacturer to offer a contract without shutdown, which benefits the H-type retailer. However, when the H-type cost $c_s^H$ increases, the H-type retailer is more likely to lie about his cost type. Consequently, the NB manufacturer has to offer an attractive information rent to induce truthful cost information from the H-type retailer. As $c_s^H$ increases, the NB manufacturer may find it beneficial to shut down the L-type retailer and preserve her profitability by eliminating the information rent, which causes a downward drop in the H-type retailer's equilibrium profit. Finally, the retailer's expected equilibrium profit follows the same trend as that of the H-type retailer.

The above discussions clearly indicate that when selling to retailers with different outside options contingent upon their respective types, the NB manufacturer could adjust the offered contract menu and shut down the more efficient type to restore information transparency without paying the information rent. Such strategic contracting decisions would further affect the retailer's expected profit by diminishing some of the commonly adopted profit improvement initiatives, including quality improvement and/or cost reduction.

## 6. Additional Discussions

In this section, we continue deriving additional managerial insights. Specifically, we discuss the value of information in Section 6.1; study how consumers are affected by cost information asymmetry in Section 6.2; and analyze an alternative setting in which the NB manufacturer sells her product directly to the market to compete with the SB in Section 6.3, respectively.

### 6.1. Value of Information

We now examine the value of information for the NB manufacturer $V_n$, the H-type retailer $V_r^H$, and the L-type retailer $V_r^L$, as well as the expected value of information for the retailer $V_r$. The value of information for a firm quantifies the difference between his [her] optimal expected profit under symmetric information and that under asymmetric information (for example, $V_n = \hat{\Pi}_n^* - \Pi_n^*$). With symmetric information, the NB manufacturer, acting as the game leader, extracts the first-best profit and leaves the retailer with his reservation profit alone. By contrast, the presence of private information complicates the manufacturer's optimal contract offering decision. When a menu of contracts that shuts down the L-type retailer is offered, the value of information for the NB manufacturer is the expected lump-sum payment from the L-type retailer (i.e., $(1-v)\bar{T}^L$), and the value of information for each type of retailer is zero. Whereas if the menu of contracts is offered to both types of retailers, the manufacturer would give up some information rent to elicit the retailer's private information. Combining the aforementioned facts, the value of information to the NB manufacturer $V_n$ is always non-negative, since her profit under symmetric information is higher than that under asymmetric information. On the contrary, the retailer weakly benefits from asymmetric information as his overall expected profit is always higher than or equal to that under symmetric information. That is, the retailer's valuation of his private cost information is $V_r = -vU$, where $U$ denotes the information rent. To simplify the interpretations, we hereafter refer to the absolute value of $V_r$ (i.e., $|V_r|$) as the value of information to the retailer, i.e., the expected increase in his profit from withholding his private cost information.

Comparing the value of information for both the NB manufacturer and the retailer, it can be easily shown that $V_n \geq |V_r|$, which implies that besides giving up information rent to the retailer, the NB manufacturer further incurs a downward profit distortion by information asymmetry. In addition, $V_n \geq |V_r|$ further indicates that the channel suffers from asymmetric information, i.e., $\hat{\Pi}_n^* - \Pi_n^* \geq \Pi_r^* - \hat{\Pi}_r^*$ or, equivalently, $\hat{\Pi}_C \geq \Pi_C$, where $\hat{\Pi}_C$ and $\Pi_C$ are defined as the channel profit under symmetric and asymmetric information, respectively. Note that $V_n = |V_r| = 0$, or equivalently $\hat{\Pi}_C = \Pi_C$, could occur in our model when the L-type retailer does not carry NB, i.e., $c_n \geq c_s^L + q_n - q_s$. This observation echos with Cakanyıldırım et al. (2012) that there may not be channel efficiency loss caused by the information asymmetry. Moreover, albeit the reduction in channel profit, the retailer takes a larger portion of the channel profit and obtains a weakly higher expected profit when his cost information is private.

Besides the aforementioned properties, we would like to further understand how the value of information for both the NB manufacturer and the retailer are affected by the private cost information $c_s^H$ and $c_s^L$. Leveraging the sensitivity analysis results captured in both Corollary 1 and Proposition 4, we can fully characterize the impact of private cost information in Proposition 5 below, which shows that as cost information becomes more dispersed by increasing $c_s^H$, obtaining such information becomes more valuable for the NB manufacturer whereas withholding it may not always benefit the retailer. By contrast, the impact of $c_s^L$ is quite involved, as increasing cost uncertainty by reducing $c_s^L$ may not strengthen the value of information for either firm.

**Proposition 5.** *(i) The value of information for the NB manufacturer $V_n$ is increasing in $c_s^H$ and non-monotonic in $c_s^L$;*

*(ii) the value of information for the L-type retailer $|V_r^L|$ is independent of both $c_s^H$ and $c_s^L$;*
*(iii) the value of information for the H-type retailer $|V_r^H|$ is non-monotonic in both $c_s^H$ and $c_s^L$;*
*(iv) the expected value of information for the retailer $|V_r|$ is non-monotonic in both $c_s^H$ and $c_s^L$.*

To conclude, we provide additional results on how other model parameters affect the value of information for both firms. More specifically, if the manufacturer offers a menu of contracts without shutting down the L-type, the respective value of information to the manufacturer and the retailer is decreasing in $c_n$, increasing in $q_n$, and non-monotonic in $q_s$. On the other hand, if the L-type is shut down under the optimal menu of contracts, the value of information to the manufacturer is increasing in $q_n$ and decreasing in $c_n$ and $q_s$, whereas that to the retailer is irrelevant to these parameters. The aforementioned results are summarized in Table 3 below.

| | **Contract Form Change** | $V_n$ | | $\|V_r\|$ | |
|---|---|---|---|---|---|
| | | w/o Shutdown | w/ Shutdown | w/o Shutdown | w/ Shutdown |
| $q_n$ | w/ Shutdown → w/o Shutdown | ↑ | ↑ | ↑ | irrelevant |
| $q_s$ | w/o Shutdown → w/ Shutdown | ↕ | ↓ | ↕ | irrelevant |
| $c_n$ | w/o Shutdown → w/ Shutdown | ↓ | ↓ | ↓ | irrelevant |
| $c_s^H$ | w/o Shutdown → w/ Shutdown | ↑ | irrelevant | ↕ | irrelevant |
| $c_s^L$ | w/ Shutdown → w/o Shutdown | ↕ | ↑ | ↕ | irrelevant |

| | **Contract Form Change** | $\|V_r^H\|$ | | $\|V_r^L\|$ | |
|---|---|---|---|---|---|
| | | w/o Shutdown | w/ Shutdown | w/o Shutdown | w/ Shutdown |
| $q_n$ | w/ Shutdown → w/o Shutdown | ↑ | irrelevant | irrelevant | irrelevant |
| $q_s$ | w/o Shutdown → w/ Shutdown | ↕ | irrelevant | irrelevant | irrelevant |
| $c_n$ | w/o Shutdown → w/ Shutdown | ↓ | irrelevant | irrelevant | irrelevant |
| $c_s^H$ | w/o Shutdown → w/ Shutdown | ↕ | irrelevant | irrelevant | irrelevant |
| $c_s^L$ | w/ Shutdown → w/o Shutdown | ↕ | irrelevant | irrelevant | irrelevant |

**Table 3 Impact of model parameters on $V_n$, $|V_r|$, $|V_r^H|$, and $|V_r^L|$**

## 6.2. Consumer Surplus

In this section, we proceed to investigate how cost information asymmetry affects consumers' total surplus, which is defined as the aggregated utility received by the entire population. Given the optimal menu of contracts offered, the consumer surplus varies depending on the retailer's product carrying decision. Particularly, for a $j \in \{H, L\}$ type retailer under Case $i \in \{I, II, III\}$, the ex post consumer surplus is given respectively below:

$$CS^I(w^j) = \int_{\frac{1}{2}+\frac{w^j}{2q_n}}^{1} (\theta_n q_n - \frac{w^j + q_n}{2}) d\theta_n,$$

$$CS^{II}(w^j) = \int_{\frac{1}{2}+\frac{w^j - c_s^j}{2(q_n - q_s)}}^{1} (\theta_n q_n - \frac{w^j + q_n}{2}) d\theta_n + \int_{\frac{1}{2}+\frac{c_s^j}{2q_s}}^{\frac{1}{2}+\frac{w^j - c_s^j}{2(q_n - q_s)}} (\theta_s q_s - \frac{c_s^j + q_s}{2}) d\theta_s,$$

$$CS^{III} = \int_{\frac{1}{2}+\frac{c_s^j}{2q_s}}^{1} (\theta_s q_s - \frac{c_s^j + q_s}{2}) d\theta_s.$$

Given the above definitions, the expected equilibrium consumer surplus under asymmetric cost information can be presented as follows:

$$CS(w^{H*},w^{L*})=\begin{cases} vCS^{I}(w^{H})+(1-v)CS^{I}(w^{L}), & \text{if } (H^{I},L^{I}) \text{ is offered;}\\ vCS^{I}(w^{H})+(1-v)CS^{II}(w^{L}), & \text{if } (H^{I},L^{II}) \text{ is offered;}\\ vCS^{II}(w^{H})+(1-v)CS^{II}(w^{L}), & \text{if } (H^{II},L^{II}) \text{ is offered;}\\ vCS^{I}(w^{H})+(1-v)CS^{III}, & \text{if } H^{I} \text{ is offered;}\\ vCS^{II}(w^{H})+(1-v)CS^{III}, & \text{if } H^{II} \text{ is offered.} \end{cases} \tag{6}$$

Under symmetric information, one can easily verify that consumers always benefit as either the perceived product quality (e.g., $q_s$ and $q_n$) improves or the production cost (e.g., $c_s$ and $c_n$) drops. However, when the retailer holds his private cost information, the aforementioned initiatives, including improving product quality and/or reducing cost, may lead to the opposite of desired outcomes, as shown in the following proposition.

**Proposition 6.** *(i) The expected equilibrium consumer surplus $CS(w^{H*},w^{L*})$ is non-monotonic in $q_s$;*

*(ii) the expected equilibrium consumer surplus $CS(w^{H*},w^{L*})$ is decreasing in $c_n$ and $c_s^H$, and non-monotonic in $c_s^L$.*

Conventional wisdom suggests that consumers always benefit from a higher product quality, which holds under symmetric information. In the presence of asymmetric information, Proposition 6(i) implies that consumers may suffer when the quality of the SB product increases under certain circumstances. For instance, when a $(H^I,L^{II})$ contract is offered by the NB manufacturer in equilibrium, the wholesale price charged to the L-type retailer increases in $q_s$. As an indirect result, demand quantity for the L-type retailer's SB product increases, leading to an increase in the corresponding surplus. Meanwhile, the L-type retailer's NB sales quantity is diminished, and the corresponding surplus decreases as well. Counterbalancing the two opposite effects, the overall consumer surplus may decrease when the loss from the NB product dominates the gain from the SB product. Additionally, our numerical results confirm that improving the NB product quality would continue to benefit consumers under asymmetric information, although we are not able to prove this result analytically due to the piecewise nature of the consumer surplus function.

In a similar vein, the discussion on the case of symmetric information suggests that a higher production cost is usually passed onto consumers in the form of a higher retail price, which leads to a declined sales and a lower consumer surplus. Under asymmetric information, this intuition holds true when the NB manufacturer's or H-type retailer's cost increases. However, Proposition 6(ii) also shows that when the L-type retailer's cost increases, consumers may even benefit, which is observed when an $(H^I,L^{II})$ or $(H^{II},L^{II})$ contract is offered in equilibrium. Specifically, when the L-type retailer's cost increases, the NB manufacturer should indirectly compensate him by offering a lower wholesale price. As a result, a lower retail price for the NB product is charged to the consumers. It follows that the per-unit utility and total sales quantity increase so that the corresponding surplus generated from the NB product increases. By contrast, the sales of the L-type SB product is cannibalized while his retail price increases with the cost. As such, the corresponding surplus from purchasing the SB product decreases. When the decrease from the L-type SB product is dominated by the increase from the NB product, the overall consumer surplus could be improved.

### 6.3. Competition Case

Our main model considers the setting where the NB manufacturer and the retailer interact with each other through contracting. We are also keen to analyze another possible scenario in practice that the NB manufacturer directly sells her products to consumers without going through the retailer. For instance, the cosmetic brand MAC does not sell their products through a popular cosmetic retailer Sephora, which sells its own store brand Sephora Collection, but instead opens its own stores to directly serve customers and competes with Sephora. In this case, instead of the retailer making retail price decisions for both products, the NB manufacturer makes the retail price decision for her own NB product to compete with SB product.

In this subsection, we analyze the above setting in which an NB manufacturer first decides the retail price of her NB product $\tilde{p}_n$ to maximize her profit $\tilde{\Pi}_n$, and then a retailer decides whether to introduce his SB product and, if so, the retail price of the SB product $\tilde{p}_s$ to maximize his profit $\tilde{\Pi}_r$, where the superscription "$\tilde{}$" over a decision/profit function is used to denote this case. To highlight the impact of the channel structure, we here assume a symmetric-information scenario to compare with the benchmark case in Section 4. We refer to the case in this subsection as the *competition* case and the case in Section 4 as the *contracting* case. After fully solving the sequential pricing game in the competition case, we compare the equilibrium with that in the contracting case and summarize the comparison results in the following proposition.

**Proposition 7.** *(i) It is more likely for the retailer to introduce SB product under the competition case than under the contracting case;*

*(ii) the NB manufacturer's equilibrium profit under the competition case is greater than or equal to that under the contracting case, i.e., $\tilde{\Pi}_n \geq \hat{\Pi}_n$;*

*(iii) the retailer's equilibrium profit under the competition case is less than or equal to that under the contracting case, i.e., $\tilde{\Pi}_r \leq \hat{\Pi}_r$;*

*(iv) the channel profit under the competition case is less than or equal to that under the contracting case, i.e., $\tilde{\Pi}_n + \tilde{\Pi}_r \leq \hat{\Pi}_n + \hat{\Pi}_r$.*

Recall that under the contracting setting, the retailer pays the NB manufacturer a wholesale price and a lump sum payment in order to carry the NB product and make profit from the resale. In that case, Proposition 1 shows that the retailer introduces his own SB product only if $c_n \geq \frac{c_s q_n}{q_s}$; otherwise, the NB product is very competitive (i.e., $c_n < \frac{c_s q_n}{q_s}$), and the retailer can comfortably earn profit from selling the NB product only. However, under the competition setting where the NB sales is fully controlled by the NB manufacturer, the retailer's profit solely relies on the sales of his SB products. Consequently, the retailer, in order to maintain his profitability, starts to introduce the SB product when $c_n$ is higher than a threshold that is lower than $\frac{c_s q_n}{q_s}$. In fact, our analysis shows that if the SB product is very competitive (i.e., $c_s$ is very low), the retailer always sells the SB product regardless of the NB cost.

Proposition 7(ii) confirms our intuition that the NB manufacturer is the beneficiary in the competition setting. By directly selling NB product to consumers, the NB manufacturer can eliminate the double marginalization resulting from the retail channel and earn the entire profit from the sales of NB products. Indeed, by skipping the retailer, NB products are sold at a lower price than that under the contracting setting. The retailer, on the other hand, only carries his own SB product, and faces direct competition from the NB manufacturer. As such, the retailer becomes worse off since he can no longer earn his monopoly profit as the outside option in the contracting case. Moreover, the channel also suffers when the manufacturer sells directly to the market. This is because in the contracting case, the channel could achieve its first best outcome under a two-part tariff contract, with the retailer obtaining his reservation and the manufacturer gaining the remaining surplus. Apart from this coordinated situation, the channel profit drops due to product competition.

## 7. Conclusion

In recent years, store brands have gained tremendous popularity all over the world. Retailers nowadays heavily rely on SBs to improve their profitability. Due to the intense competition between NBs and SBs, retailers often have no incentive to share their SB cost structure with NB manufacturers. As a result, NB manufacturers often incur cost overruns due to their limited knowledge about retailers' SB costs. Coping with retailers' SB introduction under asymmetric information becomes an essential problem for NB manufacturers. Our research is motivated by this common problem faced by numerous NB manufacturers. Specifically, we study a decentralized supply chain with an NB manufacturer and a retailer. The retailer holds his SB cost as private information, and the NB manufacturer only has an estimation on the likelihood of the SB cost being high-type or low-type. Using the principal-agent modeling framework, we solve the NB manufacturer's problem of designing a menu of two-part tariff contracts to maximize her expected profit and reveal the retailer's private information simultaneously. Despite the technical challenge due to the type-dependent reservation profit of the agent, we derive the optimal contracts for the NB manufacturer analytically.

Our results demonstrate that it is not always optimal for NB manufacturers to do business with both types of retailers under asymmetric information, although this would never happen under symmetric information. Specifically, we obtain a unique threshold of the NB production cost which divides the NB manufacturer's optimal contracts into two distinct types: When the NB cost is higher than the threshold, the NB manufacturer should offer a profitable contract to the high-type retailer only and shut down her business with the low-type retailer; otherwise, i.e., when the NB cost is below the threshold, an optimal contract without shutdown should be offered by the NB manufacturer to engage both types of retailers.

We further conduct a comprehensive sensitivity analysis to illustrate how different model parameters affect the equilibrium profits of the NB manufacturer and the retailer under asymmetric information. In particular, we find that when the NB product becomes more competitive (i.e., a higher quality or a lower cost), both the NB manufacturer and the retailer are better off. This result implies that under asymmetric information, the retailer also has incentive to help the NB manufacturer to enhance the NB product quality or reduce its cost. However, when the SB product quality improves or when the SB cost decreases, it hurts the NB manufacturer. Hence, the NB manufacturer has no incentive to help the retailer to improve his SB product quality or reduce its cost.

To understand the value of information to both firms, we solve the optimal contract for the NB manufacturer under symmetric information as well. We then define the value of information to each player as the difference between his/her equilibrium profit under symmetric information and that under asymmetric information. Conventional wisdom suggests that private information in a supply chain is generally valuable to all members in the supply chain. This statement is only true in our model when a contract without shutdown is optimal to the NB manufacturer. When an optimal contract with shutdown is offered to the retailer, both types of retailers earn exactly their respective reservation profits as they do under symmetric information, so the private information does not generate any additional value to the retailer in this case. However, the private information is still valuable to the NB manufacturer because she loses part of her profit due to shutting down the low-type retailer under asymmetric information, which does not occur under symmetric information.

Our sensitivity analysis generates interesting insights regarding the value of information. Specifically, we find that if a contract without shutdown is optimal, then the private information becomes more valuable not only to the NB manufacturer but also to the retailer when the NB product becomes more competitive, i.e., the NB quality improves or the NB cost reduces. However, when the SB product quality improves or when the low-type retailer's SB cost decreases, the value of information to both parties might increase or decrease. When the high-type retailer SB cost increases, the value of information to the NB manufacturer increases, but the private information might become more or less valuable to the retailer. Finally, a surprising result arises that under asymmetric information, the expected equilibrium consumer surplus may increase due to a lower SB quality or a higher low-type SB cost, which contradicts the conventional wisdom under symmetric information.

Our model certainly has its limitations due to our model assumptions. There are a number of ways to extend this study by relaxing one or more of these assumptions. First, we assume a Stackelberg game that the NB manufacturer offers take-it-or-leave-it contracts to the retailer who does not make a counteroffer. In a more realistic case, there can be back-and-forth negotiations between the two parties. It will be fruitful if a dynamic bargaining game framework is utilized to derive more insights. Second, we assume that the two types of SB product quality are invariant to the SB costs. Future studies can incorporate asymmetric quality information to generate more insights. In addition, we assume the NB manufacturer uses a two-part tariff contract with the retailer. Other types of contracts are also worthwhile to be explored in the future.

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