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The Informational Role of Buyback Contracts

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Abstract. Manufacturers often offer retailers buyback contracts to reduce retailers' inventory costs by repurchasing unsold inventory at a prespecified returns price. We examine the signaling role of buyback contracts when the retailer is less informed about either the manufacturer's reliability of honoring the buyback commitment (e.g., for a small/less-established manufacturer) or its product's market potential (e.g., for a national brand manufacturer). We find that these two situations yield contrasting buyback designs: the manufacturer must distort the wholesale and returns prices downward to signal higher reliability, but upward to signal higher market potential. Nevertheless, the signaling mechanism in both cases hinges on suitably distorting the manufacturer's returns cost (i.e., the cost of repurchasing a retailer's unsold inventory) by influencing the retailer's regular stock (i.e., the portion of inventory carried to meet average demand) and safety stock (i.e., the extra inventory carried to meet potential high demand). Notably, although prior research has highlighted the signaling role of the wholesale price, we show how and why, in a channel with inventory, the returns price plays a relatively more important role. In particular, efficient signaling entails that the returns price is used to distort the manufacturer's returns cost, whereas the wholesale price is used only to mitigate the resulting distortion in the retailer's order quantity. In fact, the returns price emerges as a more efficient signaling instrument and reverses the direction of wholesale price distortion from what is necessary if wholesale price alone is used to signal. We also examine the implications when the two dimensions of manufacturer's private information are correlated.

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1. Introduction

In many product categories, market demand is often stochastic, and an upstream manufacturer has to design suitable mechanisms to ensure that the downstream retailer carries sufficient inventory of its product to meet potential demand. One such mechanism is the buyback contract, wherein the manufacturer offers to repurchase any unsold inventory at the end of the selling season at a prespecified returns price. Careful design of the buyback contract can increase product sales and can, thus, be crucial for the manufacturer's success and profitability. Accordingly, researchers have studied how the manufacturer can optimally structure the terms of the buyback arrangement under the assumption that the retailer is equally knowledgeable about demand conditions as the manufacturer, and can trust the buyback commitment to be honored (e.g., Marvel and Peck 1995, Padmanabhan and Png 1997, Wang 2004, Gurnani et al. 2010, Tran et al. 2018). Yet, in practice, the retailer may often be less informed about market conditions (e.g., compared with large manufacturers who invest considerable resources in proprietary market research) or unsure about the manufacturer's intrinsic reliability of honoring the buyback commitment (e.g., in the case of small or foreign manufacturers or because of adverse economic environment). Therefore, the implications of designing buyback contracts under these practical situations need to be understood. Indeed, prior literature has highlighted the role of wholesale price contracts in signaling a manufacturer's demand information to the retailer (e.g., Chu 1992, Desai 2000, Gal-Or et al. 2008, Jiang et al. 2016). However, in situations in which the retailer must carry inventory because of stochastic demand, it is more natural for the manufacturer to offer a buyback contract. Whether and how the buyback contract can be structured to credibly signal demand conditions or the intrinsic reliability of the buyback commitment, and how such a strategy compares with using the wholesale price alone to signal (as examined in prior research) remain as open questions. In this paper, we aim to shed light on these questions. Our results offer an understanding of the informational role of buyback arrangements over and above its oft-studied transactional role.

In the context of buyback contracts, a retailer faces two types of inventory-related risks. The first type of risk, which we refer to as *demand risk*, occurs because of the stochastic nature of demand at the time of ordering the product (ahead of the selling season), which can result in the retailer having unsold inventory at the end of the selling season. The buyback arrangement aims to lower the retailer's demand risk by sharing in the retailer's costs of carrying any excess inventory. The buyback arrangement itself, however, leads to a second type of risk, which we refer to as the *returns risk* and occurs because of the buyback commitment not being met at the time of returning the inventory (at the end of the selling season). The returns risk, which is typically inherent to the specific manufacturer, arises because of contingencies or exceptional events that could not be fully anticipated at the time that the buyback contract was offered. For example, as evidenced from multiple lawsuits (e.g., Biddle 2003; Drywall Supply Central, Inc. v. Trex Company 2007; American Suzuki Motor Corporation 2013), a manufacturer may not meet the commitment because of unexpectedly facing bankruptcy or financial distress as a result of economic downturn or mismanagement or, in certain cases, because of contractual caveats or legal loopholes that exonerate the manufacturer from fulfilling its buyback commitment.

One type of risk may be more prominent than the other in a particular situation, depending on factors such as the manufacturer's characteristics, nature of the product, and economic conditions. For example, returns risk is likely to be more prominent in the case of small and less-established manufacturers or foreign manufacturers or during an economic downturn. Small manufacturers are often liquidity constrained and, thus, may not be able to repurchase unsold inventory from the retailer. Similarly, less-established foreign manufacturers may lack the operational wherewithal to reliably handle returns; in addition, their proprietary familiarity with their home-country legal systems may also affect the likelihood of fulfilling their contractual obligations.[1] Consequently, retailers are justifiably wary of buyback arrangements offered by such manufacturers, as exemplified by the following comment from a former vice president of the convenience store chain 7-Eleven:

> Many retailers have been burned on these buyback guarantees that there is a sense of distrust when it comes to secondary or smaller manufacturers. . . . The retailers are not sure whether the manufacturer will be able to take the product back if the product does not sell.[2]

Although some small or less-established manufacturers may pose lower returns risk than others, for example, because of better financial and operational health, a retailer typically lacks the resources and expertise to investigate the intrinsic risks of individual manufacturers. Consequently, the retailer is less knowledgeable about the returns risk than the manufacturer and, thus, skeptical of the manufacturer's buyback commitment. In such situations, can a more reliable manufacturer address the retailer's lack of trust by suitably designing the buyback arrangement? If so, how does the buyback arrangement of a more reliable manufacturer differ from that of a less reliable manufacturer? What is the impact on the manufacturer, the retailer, and channel performance? These are some of the questions that we wish to answer in this paper.

In contrast to small or less-established manufacturers, large and well-established manufacturers, who regularly introduce new products, face a different challenge, namely to convince a retailer about the market potential for their products. In this case, the manufacturer's returns risk, if any, is likely to be minimal and well known to the retailer given past interactions or the manufacturer's reputation in the marketplace. However, the retailer is likely to be less informed than the manufacturer about the market potential and, hence, the extent of demand risk, especially for the case of new products. Indeed, even for large manufacturers, not all products are guaranteed to be equally successful (e.g., Schneider and Hall 2011, York 2013). Moreover, a large manufacturer (e.g., Proctor & Gamble, Kraft) often invests considerable resources in proprietary market research and, therefore, has superior information about its product's market potential than the retailer (e.g., ACNielsen 2006, Guo and Iyer 2010). Intuitively, all else being equal, a product with higher demand potential poses lower demand risk for the retailer and warrants carrying higher inventory. However, a retailer that is uninformed about the product's market potential requires convincing that the product's market potential is truly high. In such situations, how should a manufacturer, whose product has higher demand potential, structure its buyback arrangement to credibly signal the demand potential? How are the implications similar to or different than those in the case in which the manufacturer signals lower returns risk? We address these questions as well.

At this juncture, we should note that, although the importance and relevance of studying the strategies of large and established manufacturers may be self-evident, some remarks for the case of small and less-established players may be in order. Small and less-established manufacturers are often an important source of innovation, product variety, and competition in the marketplace. Even though they may not account for a substantial portion of the market at a particular point in time, they may eventually grow to have substantial impact on the entire category; examples include Greek yogurt maker Chobani (Fast Company Staff 2017), 5-Hour Energy producer Living Essentials (Klara 2016), and White Wave, the brand owner of Silk soy and almond milk (Adamy 2005). In this context, a well-designed buyback contract can, in fact, help small and less-established manufacturers penetrate the market by encouraging the retailer to carry more inventory. At the same time, a challenge for such manufacturers is that a retailer may not trust their buyback commitment. Thus, understanding how a small or less-established manufacturer can leverage the buyback arrangement to her advantage is both important and relevant.

In this paper, we conduct a model-based examination of the signaling role of the buyback contract in two distinct scenarios, namely where the retailer is uninformed either about the manufacturer's returns risk or the demand risk.[3] To our knowledge, our paper is the first to examine the informational role of the buyback arrangement over and above its oft-studied transactional role. In particular, we introduce the analysis of manufacturer returns risk to the literature and study how to optimally design the buyback contract to signal returns risk. By studying a channel that faces stochastic demand and, hence, carries inventory, we uncover a novel signaling mechanism across the two types of manufacturer's private information.

In the presence of stochastic demand and inventory considerations, we find that what distinguishes the manufacturer based on its returns or demand risk is the probability of incurring the returns cost under the buyback contract (i.e., the manufacturer's cost of repurchasing the retailer's unsold inventory). We show that, as a result, efficient signaling relies on distorting the manufacturer's returns cost by suitably influencing both the retailer's regular stock (portion of inventory that is carried to meet the average demand) and safety stock (excess inventory carried to meet potential high demand). Interestingly, this signaling mechanism entails that the returns price is used to distort the returns cost, whereas the wholesale price is used only to offset the resulting distortion in the retailer's order quantity. In fact, the returns price emerges as a more efficient signaling instrument and reverses the direction of wholesale price distortion from what is necessary if the wholesale price alone is used to distort the returns cost. Thus, although prior research has highlighted the signaling role of the wholesale price, we find that, in a channel with inventory, it is the returns clause of a buyback contract that plays a more important role.

As a result, the two types of manufacturer private information (i.e., returns and demand risk) lead to contrasting designs of the buyback contract. Specifically, signaling higher reliability (which corresponds to higher probability of incurring the returns cost) entails that the returns cost is distorted downward, whereas signaling higher market potential (which corresponds to lower probability of incurring the returns cost) entails that the returns cost is distorted upward. We find that a manufacturer must distort both the wholesale and returns prices downward to signal higher reliability but upward to signal higher market potential. We also examine the implications when these two dimensions of private information are correlated and show that our main insights extend to this setting in a natural manner under certain conditions.

The plan for the rest of the paper is as follows. We discuss the relevant literature in the next section and set up the model in Section 3. We dedicate Section 4 to the case of signaling manufacturer's returns risk and Section 5 to the case of signaling demand potential. Section 6 extends the analysis to the case of signaling both types of private information. Section 7 concludes the paper. All the proofs are relegated to the electronic companion.

2. Literature Review

Research on buyback contracts have mostly studied the transactional role of buyback contracts in facilitating trade in distribution channels. One research stream is based on manufacturers using returns to provide incentive for retailers who face unpredictability in consumer preferences and have to make inventory ordering decisions long before the resolution of demand uncertainty (Marvel and Peck 1995, Padmanabhan and Png 1997, Wang 2004, Gurnani et al. 2010, Tran et al. 2018).[4] In particular, Gurnani et al. (2010) generalize prior work comparing no returns versus full returns policies to explicitly allow for partial returns and form the building block of our model. The analysis in their study, however, does not include any returns risk or private information about demand potential, which is the focus of our paper. Another research stream has studied the use of return policies to achieve channel coordination (Jeuland and Shugan 1983, Pasternack 1985, Cachon 2003, Krishnan et al. 2004). The focus of our paper, however, is on studying the informational role of returns policies in communicating upstream proprietary information, such as manufacturer risk and demand potential. Relatedly, Arya and Mittendorf (2004) examine the situation in which the retailer has private information on market conditions and the manufacturer uses a variety of return policies to elicit that information. We focus instead on the case in which the manufacturer has superior demand information.

Researchers have examined the role of channel contracts as signals of the manufacturer's demand information to influence the retailer's decision to carry the manufacturer's product. The common premise therein is the absence of stochastic demand and inventory considerations. Hence, buyback arrangements were not considered. For instance, Chu (1992) finds that the manufacturer with higher demand signals by setting a higher wholesale price and higher advertising. Desai (2000) compares wholesale price, slotting allowance and advertising as signaling instruments (see also the earlier work by Lariviere and Padmanabhan 1997). He finds that the wholesale price is a more efficient signaling instrument than a slotting allowance. A slotting allowance is used only to compensate the retailer if the stocking costs are high and advertising effectiveness is low. Advertising is also used to signal if the high demand manufacturer also has higher advertising effectiveness (which is unknown to the retailer). In contrast to the upward distortion of the wholesale price in these two papers, we show that, in the presence of stochastic demand and buyback considerations, a high-demand potential manufacturer downward distorts its wholesale price if used alone to signal. Instead, it is the returns price signal that features an upward distortion and plays a more important role than the wholesale price in conveying the manufacturer's demand information. Moreover, the joint use of both price signals reverses the direction of distortion in the wholesale price compared with when it is used alone. Most significantly, we show that, when the retailer must carry inventory to tackle demand risk, the buyback component plays an important role in signaling the manufacturer's private information through a characteristically different mechanism.

With the focus on the manufacturer's information sharing incentives in a distribution channel, researchers (e.g., Gal-Or et al. 2008, Jiang et al. 2016, Dukes et al. 2017) have also examined the wholesale price signal of the manufacturer's demand information (also in the absence of stochastic demand and inventory conditions). This body of literature considers that truthful information sharing can be sustained by the manufacturer's reputational concerns or initial capital investment, and hence, information sharing can serve as an alternative to demand signaling. We instead focus on situations in which such commitment is impractical or insufficient to sustain truthful information sharing. Moreover, we study the roles of both wholesale and returns prices in signaling demand and returns risk by explicitly accounting for stochastic demand and inventory considerations.

Research on signaling product quality to consumers through prices has also, by and large, found that higher prices are a signal of higher quality (e.g., Bagwell and Riordan 1991, Judd and Riordan 1994, Daughety and Reinganum 1995, Wang and Özkan-Seely 2018) with a few exceptions (e.g., Milgrom and Roberts 1986). In a B2C setting, Moorthy and Srinivasan (1995) show that a full money-back guarantee to consumers can serve as a high-quality signal even if price alone cannot signal. However, price can be a more efficient signal if consumers are heterogeneous in their product valuation, and a higher price can still signal higher quality even with a full money-back guarantee. A full money-back guarantee is analogous to a buyback contract in which the returns price is set equal to the wholesale price. In contrast, we study buyback contracts in a B2B setting with inventory concerns. By allowing for a flexible returns price, we find that the returns price is always a more efficient signal than the wholesale price and that the use of the returns price to signal reverses the direction of distortion in the wholesale price.

In addition to price, researchers have also examined the role of other marketing levers to influence consumers' quality inference. For example, Miklós-Thal and Zhang (2013) show that a demarketing selling effort can improve product quality image ex post as consumers attribute good sales to high quality and lower sales to lack of marketing effort. When a manufacturer markets multiple products, Miklós-Thal (2012) shows that umbrella branding can be used to credibly signal positive correlation between the qualities of the products. Guo and Jiang (2016) study the effect of fairness concerns on a firm's signaling strategy when consumers experience some psychological disutility while buying products at unfair prices.

To conclude our literature review, we note that the past literature has neither examined the use of buyback contracts as signaling mechanism, nor explicitly considered manufacturers' returns risk. By demonstrating the contrasting effects between signaling product demand condition versus manufacturer reliability, our work sheds some light on the informational role of buyback contracts in channel management practice.

3. Model

We start with an overview of our model. Consider a manufacturer (hereafter referred to as "she"), who supplies a product to the end market through a retailer (hereafter referred to as "he"). The demand for the product is stochastic and is not realized prior to the selling season. The retailer, however, must order the product ahead of the selling season. The manufacturer offers the retailer a buyback contract, specifying a wholesale price $w \geq 0$ at which the retailer can order the product prior to the selling season and a returns price $r \geq 0$ at which the manufacturer promises to repurchase any unsold inventory at the end of the selling season. We set the manufacturer's marginal production cost to zero.[5] As a novel feature in our model, there is an intrinsic risk that the manufacturer may fail to honor the buyback commitment at the end of the selling season, either because she is not able to (e.g., bankruptcy, financial distress) or because she has the opportunity not to without attracting legal sanctions (e.g., contractual caveats, legal loopholes). We model the following decisions. The manufacturer chooses the buyback contract terms to offer. The retailer decides how much of the product to order and the retail price to sell them. As discussed in the Introduction, our main interest is to examine the design of the buyback contract in two distinct information scenarios: one in which the manufacturer is better informed (than the retailer) about her intrinsic reliability of honoring the returns and the other in which the manufacturer is better informed about her product demand potential.

We now describe the product demand. The product demand is given by $d_i = \alpha_i - \beta p_i$, where α_i is the baseline demand, $\beta > 0$ is the price sensitivity, and $p_i \in [0, \alpha_i/\beta]$ is the retail price. The baseline demand α_i is stochastic and can be high (α_h) with probability $\lambda \in (0,1)$ or low (α_l with $\alpha_l < \alpha_h$) with complimentary probability $\lambda^c := 1 - \lambda$. A product with higher λ is more likely to have higher demand. We, therefore, refer to λ as the *demand potential*. For notational convenience, we introduce $\Delta\alpha := \alpha_h - \alpha_l$.

We capture the manufacturer's intrinsic reliability of honoring the buyback commitment as follows. There is an exogenous probability $\theta \in [0,1]$ that the manufacturer repurchases the retailer's unsold inventory if any. We refer to θ as the manufacturer's *returns risk*. In particular, $\theta = 1$ corresponds to a manufacturer who always honors the repurchase clause (as is considered in prior work), whereas $\theta = 0$ corresponds to a manufacturer who never honors the contract; that is, the returns clause is irrelevant. The situation in practice is likely to be in between these two extremes.

As mentioned before, we focus on the following two distinct information scenarios:

Asymmetric Information About Returns Risk

In this scenario, the retailer is only uncertain about the manufacturer's returns risk (θ), and the demand potential (λ) is common knowledge. The manufacturer is either of a *less risky* type (with higher probability $\theta = \bar{\theta}$ of accepting returns) or of a *riskier* type (with lower probability $\theta = \underline{\theta} < \bar{\theta}$ of accepting returns); we denote $\Delta\theta := \bar{\theta} - \underline{\theta}$. The manufacturer knows her returns risk, and the retailer does not. The retailer only knows the probability that the manufacturer is less risky, denoted as $\mu \in (0,1)$. We analyze this scenario in Section 4.

Asymmetric Information About Demand Potential

In this scenario, the retailer is only uncertain about the manufacturer's demand potential (λ), and the returns risk (θ) is common knowledge. The manufacturer's demand potential is either *high* with $\lambda = \bar{\lambda}$ or *low* with $\lambda = \underline{\lambda} < \bar{\lambda}$; we denote $\Delta\lambda := \bar{\lambda} - \underline{\lambda}$. The manufacturer knows her demand potential, and the retailer does not. The retailer only knows the probability that the demand potential is high, denoted as $\gamma \in (0,1)$. We analyze this scenario in Section 5.

We extend our analysis to the combination of both types of private information in Section 6.

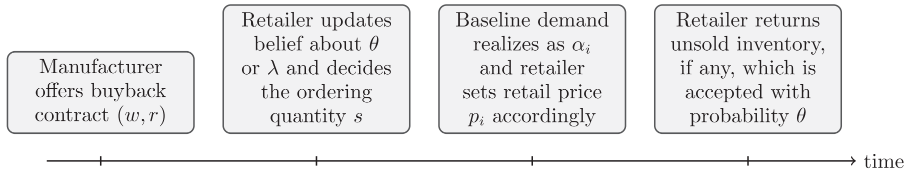
Following the buyback contracting literature (e.g., Padmanabhan and Png 1997, Gurnani et al. 2010, Tran et al. 2018), the sequence of events in both scenarios is as follows (see Figure 1). Prior to the selling season, the baseline demand is uncertain to both the manufacturer and the retailer. The manufacturer offers the retailer a buyback contract (w, r). Based on the contract, the retailer updates his belief about the manufacturer's type and then decides the order quantity, denoted as $s \geq 0$. During the selling season, the baseline demand α_i $(i \in \{h, l\})$ realizes; accordingly, the retailer sets the retail price p_i and sells $\min\{d_i, s\}$. At the end of the selling season, the retailer returns any unsold inventory to the manufacturer at the returns price r, provided that the manufacturer honors the buyback commitment.[6] Otherwise, the retailer retains the unsold inventory, which is assumed to have no salvage value.

In all information scenarios (including the one we consider in Section 6), the manufacturer's buyback contract terms offered at the start of the game can "signal" her private information. We use *perfect Bayesian equilibrium* (PBE) as our solution concept to analyze the strategic interaction in the channel. Both firms are profit maximizing and risk neutral. Before proceeding, it is useful to consider the retailer's ordering strategy in response to the manufacturer's buyback contract, which is common to all scenarios.

3.1. Retailer's Ordering Strategy.

Upon being offered a buyback contract (w, r), the retailer updates his belief that the manufacturer is less risky with probability $\widehat{\mu} := \widehat{\mu}(w, r) = \mathbb{P}[\theta = \bar{\theta} \mid w, r]$ and has a high demand

Figure 1. Sequence of Events



potential with probability $\widehat{\gamma} := \widehat{\gamma}(w,r) = \mathbb{P}[\lambda = \bar{\lambda} \mid w,r]$. Therefore, the manufacturer's returns risk and likelihood of high baseline demand (α_h) perceived by the retailer are $\widehat{\theta} := \widehat{\theta}(w,r) =: \widehat{\mu}\bar{\theta} + (1-\widehat{\mu})\underline{\theta} \in [\underline{\theta}, \bar{\theta}]$ and $\widehat{\lambda} = \widehat{\lambda}(w,r) := \widehat{\gamma}\bar{\lambda} + (1-\widehat{\gamma})\underline{\lambda} \in [\underline{\lambda}, \bar{\lambda}]$, respectively. Based on his inference, the retailer makes the ordering decision, which is documented in the following lemma. For the rest of the paper, we adopt the convention that $x^+ := \max\{x, 0\}$ for any real number x.

Note that, because $\widehat{\theta}$ is the probability of return perceived by the retailer, $\widehat{\theta}r$ is essentially his perceived expected unit returns price. Thus, $w - \widehat{\theta}r$ is the retailer's perceived cost of ordering an additional unit of unsold inventory. Therefore, we find that, if $w - \widehat{\theta}r < 0$, then the retailer would order an infinite amount of inventory and result in negative profit for the manufacturer, who, thus, would never offer such contracts. Consequently, it suffices only to consider contracts with $w - \widehat{\theta}r \geq 0$. Following the analysis as in Gurnani et al. (2010), we characterize the retailer's ordering strategy in this case.[7]

Lemma 1. *If $w - \widehat{\theta}r \geq 0$, the retailer's optimal order quantity is given by*

$$s^R\left(w,r,\widehat{\theta},\widehat{\lambda}\right) = \frac{1}{2}\left(\widehat{\lambda}\alpha_h + \widehat{\lambda}^c\alpha_l - \beta w\right) + \frac{\widehat{\lambda}^c}{2}\left[\Delta\alpha - \left(\beta/\widehat{\lambda}\right)\left(w - \widehat{\theta}r\right)\right]^+. \tag{1}$$

No unsold inventory is left at the retailer if the baseline demand is high (α_h), whereas inventory of an amount $\frac{1}{2}[\Delta\alpha - (\beta/\widehat{\lambda})(w - \widehat{\theta}r)]^+$ is unsold if the baseline demand is low (α_l).

The retailer's order quantity in (1) can be thought to consist of two parts: a "regular stock" $\frac{1}{2}(\widehat{\lambda}\alpha_h + \widehat{\lambda}^c\alpha_l - \beta w)$ that is ordered based on the *average* baseline demand $\widehat{\lambda}\alpha_h + \widehat{\lambda}^c\alpha_l$ and a "safety stock" $\frac{\widehat{\lambda}^c}{2}[\Delta\alpha - (\beta/\widehat{\lambda})(w - \widehat{\theta}r)]^+$ that is carried in anticipation of high baseline demand realization.[9] Note that, in the absence of stochastic demand (e.g., $\widehat{\lambda} \in \{0,1\}$ or $\Delta\alpha = 0$), the retailer does not hold safety stock. The retailer orders positive safety stock if and only if his net expected unit cost of unsold inventory is not too high; that is, $w - \widehat{\theta}r \leq \widehat{\lambda}\Delta\alpha/\beta$. If the baseline demand turns out to be high, then both the regular and safety stocks are cleared and the retailer is left without any unsold inventory. In contrast, if the baseline demand turns out to be low, which the retailer believes to occur with probability $\widehat{\lambda}^c$, then unsold inventory of an amount $\frac{1}{2}[\Delta\alpha - (\beta/\widehat{\lambda})(w - \widehat{\theta}r)]^+$ results. As such, the safety stock is proportional to the unsold inventory and can be regarded as the "expected" unsold inventory. As we see later, the retailer's regular stock and safety stock are instrumental for understanding the informational role of the buyback contract. We also note that the retailer's order quantity $s^R(w,r,\widehat{\theta},\widehat{\lambda})$ marks the volume of trade in the distribution channel and, hence, can serve as a measurement of the trade efficiency when comparing different signals in addition to the profit measurement.

4. Asymmetric Information About Returns Risk

In this section, we study the design of the buyback contract under asymmetric information about the manufacturer's returns risk, that is, when the retailer is uninformed about the manufacturer's likelihood of honoring the returns commitment $\theta \in \{\bar{\theta}, \underline{\theta}\}$ but is informed about the demand potential λ of the manufacturer's product.

According to Lemma 1, the retailer orders $s^R(w,r,\widehat{\theta},\lambda)$ up front and returns unsold inventory of amount $\frac{1}{2}[\Delta\alpha - (\beta/\lambda)(w - \widehat{\theta}r)]^+$ only if baseline demand is low, which occurs with probability λ^c. Therefore, given the retailer's belief $\widehat{\theta} \in [\underline{\theta}, \bar{\theta}]$ about the manufacturer's risk type, the expected profit of a manufacturer of type θ is

$$\prod\left(w,r\middle|\widehat{\theta},\theta\right) := ws^R\left(w,r,\widehat{\theta},\lambda\right) - \frac{1}{2}\lambda^c\theta r\left[\Delta\alpha - (\beta/\lambda)\left(w - \widehat{\theta}r\right)\right]^+, \tag{2}$$

where $\alpha := \lambda\alpha_h + \lambda^c\alpha_l$ denotes the mean baseline demand.

As a benchmark, we first establish the manufacturer's optimal buyback contract and the resulting outcomes under *symmetric information*, that is, when the manufacturer's returns risk is known to the retailer. We should note that the model analyzed by Gurnani et al. (2010) essentially corresponds to the symmetric information benchmark in our setup.[8] We next show how the less risky manufacturer can optimally leverage the buyback contract to credibly signal her lower returns risk when the retailer is uninformed about the manufacturer's returns risk. Finally, we elucidate the signaling mechanism further by comparing the equilibrium outcomes with those in the cases in which either the wholesale or returns price alone is used in isolation to signal the manufacturer's returns risk.

4.1. Symmetric Information Benchmark

Under symmetric information, the manufacturer's returns risk θ is known to the retailer; hence, $\widehat{\theta} = \theta$. Thus, the manufacturer of type θ solves the following profit maximization problem:

$$\pi^\circ(\theta) := \max_{w \geq \theta r \geq 0} \prod(w,r \mid \theta,\theta), \tag{3}$$

whose solution is denoted as $(w^\circ(\theta), r^\circ(\theta))$. The following lemma characterizes the symmetric information outcomes.

Lemma 2. *In the symmetric information benchmark, the manufacturer with returns risk θ offers a wholesale price $w^\circ(\theta) \equiv w^\circ := \alpha/(2\beta)$, independent of θ, and a returns price $r^\circ(\theta) = \alpha_l/(2\beta\theta)$, earning an expected profit of $\pi^\circ = [\lambda^c\lambda(\Delta\alpha)^2 + \alpha^2]/(8\beta)$. The retailer orders $s^\circ := \alpha_h/4$ and is left with unsold inventory $q^\circ := \Delta\alpha/4$ only if the baseline demand is low.*

We observe from Lemma 2 that, when the manufacturer's returns risk is known to the retailer, the less risky manufacturer offers the same wholesale price (w°) as the riskier manufacturer does and a lower returns price than the riskier manufacturer does, that is, $\overline{r}^\circ := r^\circ(\overline{\theta}) < \underline{r}^\circ := r^\circ(\underline{\theta})$. Essentially, because the retailer is risk neutral, his ordering and returns decisions depend on the manufacturer's risk type θ only through the expected returns price θr. Therefore, it suffices for the manufacturer, who is also risk neutral, to optimize her contract effectively in terms of the wholesale price w and the expected returns price θr. Consequently, both manufacturer types offer the same wholesale price w° and expected returns price $\theta r^\circ(\theta)$ in the optimum (which necessitates a lower returns price for the less risky manufacturer $\overline{r}^\circ = r^\circ(\overline{\theta}) < \underline{r}^\circ = r^\circ(\underline{\theta})$ because $\bar{\theta} > \underline{\theta}$), resulting in the same retailer's order quantity s°, unsold inventory q°, and the same manufacturer's expected profit π° for both manufacturer types.

4.2. Design of Buyback Contract to Signal Returns Risk

We now turn to the case in which the manufacturer is privately informed about her returns risk. In this case, the manufacturer's contract terms (i.e., the wholesale and returns prices) can convey information about her risk type, and subsequently, the retailer can update his belief ($\widehat{\theta}$) about the manufacturer's type before making ordering and returns decisions.

We first note that, if the two manufacturer types offered their respective symmetric information contracts, it is the riskier manufacturer who has the incentive to mimic the less risky manufacturer. Under the symmetric information contracts, the less risky and riskier manufacturers offer $(w^\circ, \overline{r}^\circ)$ and $(w^\circ, \underline{r}^\circ)$, respectively, with $\overline{r}^\circ < \underline{r}^\circ$. Consequently, the retailer would believe that the manufacturer is less risky (respectively, riskier) if the returns price is lower (higher). However, the risker manufacturer would then have an incentive to mimic the less risky manufacturer's lower returns price $\overline{r}^\circ$ because doing so induces the retailer to order the same quantity (s°) and leave the same unsold inventory (q°) as under her own symmetric information contract but with a lower expected returns price $\underline{\theta}\overline{r}^\circ < \underline{\theta}\underline{r}^\circ$. By the same argument, the less risky manufacturer would have no incentive to mimic the riskier manufacturer's higher returns price $\underline{r}^\circ$.

Therefore, it is the less risky manufacturer who has to bear the signaling burden of distinguishing herself from the riskier type. To understand how the buyback contract should be structured to signal lower returns risk, we solve for the *most efficient separating equilibrium* (e.g., Lariviere and Padmanabhan 1997, Kalra et al. 2003, Guda and Subramanian 2019), namely the separating equilibrium that maximizes the less risky manufacturer's profit. We also show in Lemma B.2 in Online Appendix B that the most efficient separating equilibrium is the unique PBE that survives Cho and Kreps's (1987) intuitive criterion. In this equilibrium, the riskier manufacturer offers her symmetric information contract $(w^\circ, \underline{r}^\circ)$, and the less risky manufacturer's contract, denoted as $(\overline{w}^\star, \overline{r}^\star)$, deviates from that under symmetric information. The retailer updates his belief to $\widehat{\theta} = \bar{\theta}$ upon being offered the contract $(\overline{w}^\star, \overline{r}^\star)$ and to $\widehat{\theta} = \underline{\theta}$ otherwise. To determine her most profitable separation, the less risky manufacturer solves the following problem:

$$\begin{aligned}\overline{\pi}^\star := \max_{\overline{w} \geq \overline{\theta}\overline{r} \geq 0} \; & \prod\left(\overline{w}, \overline{r} \middle| \overline{\theta}, \overline{\theta}\right) \\ \text{s.t.} \; & \prod\left(\overline{w}, \overline{r} \middle| \overline{\theta}, \underline{\theta}\right) \leq \pi^\circ \text{ and} \\ & \prod\left(\overline{w}, \overline{r} \middle| \overline{\theta}, \overline{\theta}\right) \geq \prod\left(w^\circ, \underline{r}^\circ \middle| \underline{\theta}, \overline{\theta}\right). \end{aligned} \tag{4}$$

The two constraints in (4) ensure that mimicry is not profitable for the riskier and the less risky manufacturer, respectively. (Recall that π°, given by Lemma 2, is the riskier manufacturer's profit of offering the symmetric information contract.) As is common in signaling games, only the first constraint (i.e., the nonmimicry condition for the riskier type) is binding at the optimum. To establish the existence of such a separating equilibrium, we also need to show that the less risky manufacturer does not have an incentive to deviate to any other off-equilibrium buyback contract (following which the retailer updates his belief to $\widehat{\theta} = \underline{\theta}$). The following proposition establishes that the most efficient separating equilibrium always exists, and characterizes the less risky manufacturer's buyback contract $(\overline{w}^\star, \overline{r}^\star)$ and retailer's quantity decisions in this equilibrium.

Proposition 1. *The most efficient separating equilibrium of the returns risk signaling game exists. In this equilibrium,*

i. *the riskier manufacturer offers her symmetric information contract $(w^\circ, \underline{r}^\circ)$;*

ii. *the less risky manufacturer offers contract $(\overline{w}^\star, \overline{r}^\star)$ with both wholesale and returns prices lower than their respective symmetric information counterparts, that is, $\overline{w}^\star < w^\circ$ and $\overline{r}^\star < \overline{r}^\circ < \underline{r}^\circ$.*

iii. *Under contract* $(\overline{w}^\star, \overline{r}^\star)$ *, the retailer's order quantity* $\overline{s}^\star$ *and unsold inventory* $\overline{q}^\star$ *in case of low baseline demand are both lower than their symmetric information counterparts, respectively, that is,* $\overline{s}^\star < s^\circ$ *and* $\overline{q}^\star < q^\circ$*; no unsold inventory results from high baseline demand realization.*

Proposition 1 shows that the optimal buyback contract to credibly signal low returns risk involves distorting both the wholesale and returns prices *downward* relative to those in the symmetric information contract. As can be seen from (2), given the retailer's belief $\widehat{\theta}$, the manufacturer's expected profit from selling to the retailer depends on her actual risk type θ only through the second term, which is her *expected* returns cost $\theta\lambda^c \cdot rc$, where $rc := r \cdot \frac{1}{2}[\Delta\alpha - (\beta/\lambda)(w - \widehat{\theta}r)]^+$ is the *returns cost* (i.e., the cost of repurchasing the retailer's unsold inventory $\frac{1}{2}[\Delta\alpha - (\beta/\lambda)(w - \widehat{\theta}r)]^+$) and $\theta\lambda^c$ is the probability that the manufacturer incurs this cost (i.e., returns occur and are honored). Thus, because $\underline{\theta} < \bar{\theta}$, lowering the returns cost generates lower expected cost savings for the risker manufacturer than for the less risky manufacturer. Consequently, to deter the riskier manufacturer's mimicry, the less risky manufacturer offers a buyback contract that distorts the returns cost downward from its symmetric information level. Proposition 1 shows that this distortion in returns cost is achieved most efficiently by distorting both the wholesale and returns prices downward. Determining the exact magnitude of these distortions requires solving a two-dimensional optimization problem, whose first-order conditions reduce to a system of bivariate quadratic equations that do not admit closed form solution in general. Nonetheless, Proposition 1 completely characterizes the qualitative nature of the equilibrium distortions.

To understand further how the most efficient separation distorts the contract terms, it is useful to express the less risky manufacturer's problem (4) in terms of the retailer's induced quantity decision, that is, his regular and safety stocks.[10] According to (1), a less risky manufacturer's contract $(\overline{w}, \overline{r})$ induces the retailer to order

$$\text{regular stock} \quad s_r(\overline{w}) := \frac{1}{2}\left(\alpha - \beta\overline{w}\right), \quad \text{and} \tag{5}$$

$$\text{safety stock} \quad \bar{s}_s(\overline{w}, \overline{r}) := \frac{\lambda^c}{2}\left[\Delta\alpha - \left(\beta/\lambda\right)\left(\overline{w} - \bar{\theta}\overline{r}\right)\right]. \tag{6}$$

We also note that the symmetric information regular stock and safety stock are given by

$$s_r^\circ := s_r(w^\circ) = \frac{\alpha}{4} \quad \text{and}$$
$$s_s^\circ := \bar{s}_s(w^\circ, \overline{r}^\circ) = \frac{\lambda^c\Delta\alpha}{4},$$

respectively.

Now, using (2), (5), and (6), we can express the less risky manufacturer's profit in terms of the deviations in the retailer's quantity decisions from their symmetric information levels as

$$\prod\left(\overline{w}, \overline{r} \,|\, \bar{\theta}, \bar{\theta}\right) = \pi^\circ - \underbrace{\frac{2}{\beta\lambda^c}\left\{\lambda^c\left[s_r^\circ - s_r(\overline{w})\right]^2 + \lambda\left[s_s^\circ - \bar{s}_s(\overline{w}, \overline{r})\right]^2\right\}}_{\text{signaling cost}}, \tag{7}$$

where π° is the symmetric information profit level and the second term is essentially the less risky manufacturer's *signaling cost* because it captures the profit reduction from π°.

Similarly, the riskier manufacturer's *gain from mimicry* (i.e., the difference between the two sides of the first constraint in (4)) can be rewritten as

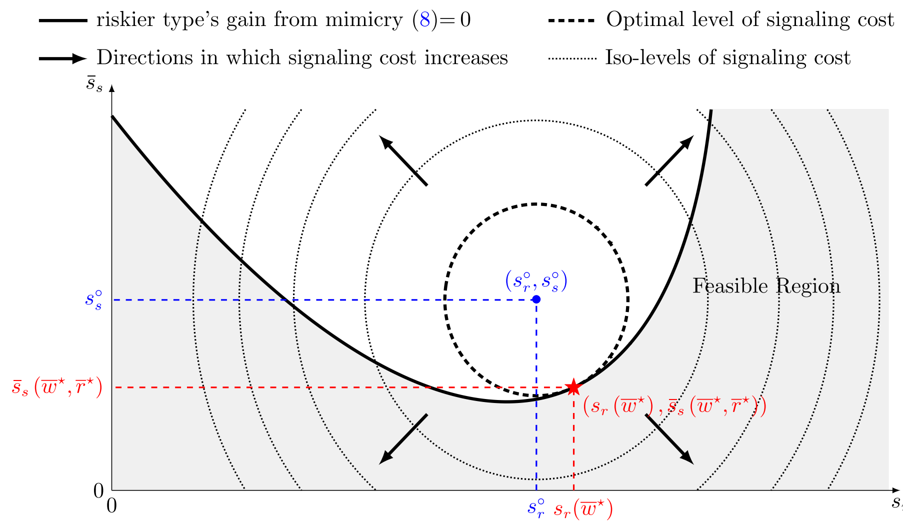
$$\begin{aligned}
&\prod\left(\overline{w}, \overline{r} \,|\, \bar{\theta}, \underline{\theta}\right) - \pi^\circ \\
&= \left\{\prod\left(\overline{w}, \overline{r} \,|\, \bar{\theta}, \underline{\theta}\right) - \prod\left(\overline{w}, \overline{r} \,|\, \bar{\theta}, \bar{\theta}\right)\right\} \\
&\quad + \left\{\prod\left(\overline{w}, \overline{r} \,|\, \bar{\theta}, \bar{\theta}\right) - \pi^\circ\right\} \\
&= \lambda^c\Delta\theta \cdot \underbrace{\frac{2}{\beta(\lambda^c)^2\bar{\theta}}\left[\frac{\lambda^c\alpha_l}{2} - \lambda^c s_r(\overline{w}) + \lambda\bar{s}_s(\overline{w}, \overline{r})\right]\bar{s}_s(\overline{w}, \overline{r})}_{\text{returns cost}} \\
&\quad - \underbrace{\frac{2}{\beta\lambda^c}\left\{\lambda^c\left[s_r^\circ - s_r(\overline{w})\right]^2 + \lambda\left[s_s^\circ - \bar{s}_s(\overline{w}, \overline{r})\right]^2\right\}}_{\text{signaling cost}},
\end{aligned} \tag{8}$$

where we express the returns cost in terms of the retailer's quantity decisions in (5) and (6).

From (8), we note that, for a given level of the less risky manufacturer's signaling cost, the riskier manufacturer's gain from mimicry can be minimized by minimizing the returns cost. This goal can be achieved by increasing the regular stock $s_r(\overline{w})$ and decreasing the safety stock $\bar{s}_s(\overline{w}, \overline{r})$. We note from (7) that the combinations of regular stock and safety stock that lead to a given level of the less risky manufacturer's signaling cost form an ellipse with the symmetric information stock levels (s_r°, s_s°) as the center as illustrated in Figure 2. Consequently, the regular stock needs to be distorted upward relative to the symmetric information level, that is, $s_r(\overline{w}^\star) > s_r^\circ$, and the safety stock needs to be distorted downward, that is, $\bar{s}_s(\overline{w}^\star, \overline{r}^\star) < s_s^\circ$; see Figure 2.

These distortions in quantities, in turn, uniquely determine how the wholesale and return prices are distorted. As can be seen from (5) and (6), the regular stock $s_r(\overline{w})$ is decreasing in the wholesale price and independent of the returns price, and the safety stock $\bar{s}_s(\overline{w}, \overline{r})$ is also decreasing in the wholesale price but increasing in the returns price. Hence, to increase the regular stock, the wholesale price needs to be distorted downward, and to lower the safety stock, the returns price needs to be distorted downward

Figure 2. (Color online) The Retailer's Regular and Safety Stocks Under the Less Risky Manufacturer's Most Efficient Separating Contract $(\overline{w}^{\star}, \overline{r}^{\star})$ ($\alpha_h = 10$, $\alpha_l = 4$, $\lambda = 0.5$, $\beta = 1$, $\bar{\theta} = 1$ and $\underline{\theta} = 0.3$)



(given that the wholesale price has been distorted downward).

Note that the decrease in the wholesale price counteracts the desired distortion in the safety stock. Thus, changing the wholesale price creates opposing effects on the regular and safety stocks relative to how they need to be distorted for efficient separation, whereas the returns price only affects the safety stock and, hence, does not create such opposing effects. In fact, the decrease in safety stock dominates the increase in regular stock, resulting in a net downward distortion of the retailer's order quantity (i.e., $s_r(\overline{w}^\star) + \bar{s}_s(\overline{w}^\star, \overline{r}^\star) = \bar{s}^\star < s^\circ$). Essentially, the returns price is used to lower the safety stock, and the wholesale price is used to mitigate the resulting downward distortion in the retailer's overall order quantity (by increasing the regular stock). These observations suggest that the returns price is a relatively more efficient signaling instrument than the wholesale price, a point we elaborate in the next subsection.

4.3. Importance of Returns Price to Signal Returns Risk

Prior literature has largely focused on the informational role of the wholesale price. Our analysis shows how the buyback arrangement and, in particular, the returns price can play an important role in signaling manufacturer's returns risk. In fact, as discussed at the end of Section 4.2, the returns price may even be the relatively more efficient signaling instrument than the wholesale price. To isolate and further elucidate the individual role of the wholesale price and the returns price, we now examine two (partial) signaling benchmarks, in which either only the wholesale price or only the returns price can be distorted from their respective symmetric information levels to signal the manufacturer's returns risk. We determine the efficient separating equilibrium in each of the two benchmarks and compare them with the most efficient separation.[11]

Signaling Returns Risk Only Through Wholesale Price. In this benchmark, we fix the less risky manufacturer's returns price at her symmetric information level $\overline{r}^\circ$ and only allow her to set her wholesale price to signal her lower returns risk in the most profitable manner. Thus, the less risky manufacturer's most efficient wholesale price, denoted as $\overline{w}^\ddagger$, is determined as the solution to

$$\begin{aligned} \overline{\pi}^\ddagger := \max_{\overline{w} \geq \bar{\theta}\overline{r}^\circ} \quad & \prod\left(\overline{w}, \overline{r}^\circ \,\middle|\, \overline{\theta}, \overline{\theta}\right) \\ \text{s.t.} \quad & \prod\left(\overline{w}, \overline{r}^\circ \,\middle|\, \overline{\theta}, \underline{\theta}\right) \leq \pi^\circ \text{ and} \\ & \prod\left(\overline{w}, \overline{r}^\circ \,\middle|\, \overline{\theta}, \overline{\theta}\right) \geq \prod\left(w^\circ, \underline{r}^\circ \,\middle|\, \underline{\theta}, \overline{\theta}\right). \end{aligned} \quad (9)$$

The retailer's order quantity under contract $(\overline{w}^\ddagger, \overline{r}^\circ)$ is denoted as $\bar{s}^\ddagger$. Proposition B.1 in Online Appendix B characterizes the equilibrium outcome in this case.

Signaling Returns Risk Only Through Returns Price. In this benchmark, we fix the less risky manufacturer's wholesale price at the symmetric information level w°, which is incidentally the same as that offered by the riskier manufacturer and only allow her to set her returns price to signal her lower returns risk in the most profitable manner. Thus, the less risky

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manufacturer's most efficient returns price, denoted as $\bar{r}^{\dagger}$, is determined as the solution to

$$\begin{aligned}\overline{\pi}^{\dagger} := \max_{w^\circ \ge \bar{\theta}\bar{r} \ge 0} \quad & \prod\left(w^\circ, \bar{r} \middle| \bar{\theta}, \bar{\theta}\right)\\ \text{s.t.} \quad & \prod\left(w^\circ, \bar{r} \middle| \bar{\theta}, \underline{\theta}\right) \le \pi^\circ \text{ and}\\ & \prod\left(w^\circ, \bar{r} \middle| \bar{\theta}, \bar{\theta}\right) \ge \prod\left(w^\circ, \underline{r}^\circ \middle| \underline{\theta}, \bar{\theta}\right). \end{aligned} \tag{10}$$

The retailer's order quantity under contract $(w^\circ, \bar{r}^{\dagger})$ is denoted as $\bar{s}^{\dagger}$. Proposition B.2 in Online Appendix B characterizes the equilibrium outcome in this case.

Comparison of Equilibria Outcomes. The following proposition summarizes our findings.

Proposition 2. *For the returns risk signaling game, the equilibria outcomes under symmetric information, the most efficient separation, and the partial signaling benchmarks are ranked as follows:*

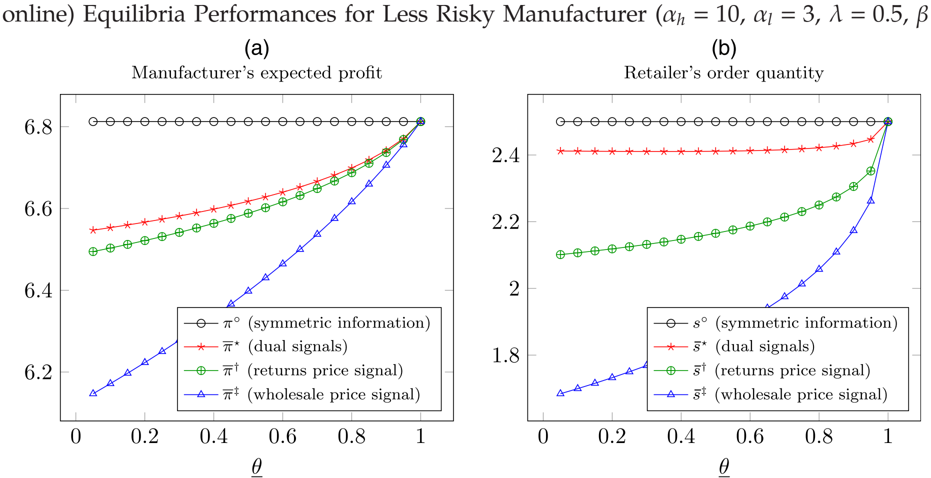
$$\begin{aligned}&\overline{w}^{\star} < w^\circ < \overline{w}^{\ddagger}, \quad \bar{r}^{\star} < \bar{r}^{\dagger} < \bar{r}^\circ < \underline{r}^\circ,\\ &\bar{s}^{\ddagger} < \bar{s}^{\dagger} < \bar{s}^{\star} < s^\circ, \text{ and } \overline{\pi}^{\ddagger} < \overline{\pi}^{\dagger} < \overline{\pi}^{\star} < \pi^\circ.\end{aligned} \tag{11}$$

Proposition 2 demonstrates the returns price as a more efficient signal of the returns risk than the wholesale price in three dimensions. First, signaling through the returns price alone generates *higher* profit (and, hence, closer to the profit under the most efficient separation) for the less risky manufacturer than signaling through the wholesale price alone does, that is, $\overline{\pi}^{\ddagger} < \overline{\pi}^{\dagger} < \overline{\pi}^{\star}$. Second, signaling through the returns price alone also yields *smaller* distortion to the retailer's order quantity (and, hence, closer to the order quantity under the most efficient separation), that is, $\bar{s}^{\ddagger} < \bar{s}^{\dagger} < \bar{s}^{\star}$. Finally, signaling through the returns price alone is always achievable (shown by Proposition B.2), whereas signaling through the wholesale price alone is not always feasible. As identified by Proposition B.1, the parameter range for which separation through the wholesale price alone is feasible corresponds to situations when the information asymmetry about the returns risk is not too severe (i.e., $\Delta\theta/\bar{\theta} \le (1 + \sqrt{\lambda^c})\Delta\alpha/\alpha_l$).

Furthermore, Proposition 2 shows that ignoring the informational role of the returns component in the buyback contract reverses the direction of distortion in the wholesale price, leading to qualitatively different insights regarding the design of buyback contracts when signaling only through the wholesale price. More specifically, when the wholesale price is used alone, it is distorted *upward* (i.e., $\overline{w}^{\ddagger} > w^\circ$), which is opposite to what we found when it is used in conjunction with the returns price in the most efficient separation. We note that in the most efficient separation as well as the partial signaling benchmarks, the distortions of equilibrium prices are driven by the less risky manufacturer's desire to reduce her returns cost. When signaling through the wholesale price alone (and fixing the returns price), the less risky manufacturer can only distort the safety stock (and, hence, the returns quantity) downward, which, in turn, necessitates an *upward* distortion of the wholesale price. When signaling through the returns price alone (and fixing the wholesale price), the less risky manufacturer distorts the returns price *downward* (i.e., $\bar{r}^{\star} < \bar{r}^{\dagger} < \bar{r}^\circ$) as in the most efficient separation (albeit with a smaller extent) because this reduces her returns cost by lowering both the returns price itself as well as the safety stock (and, hence, the returns quantity).

The superior efficiency of the returns price signal can also be illustrated by a numerical example depicted in Figure 3. As seen from Figure 3(a), the less risky manufacturer can, in fact, signal only using the returns price and appropriate most of her profit that she would earn in the most efficient separating equilibrium using both price intruments, whereas the

Figure 3. (Color online) Equilibria Performances for Less Risky Manufacturer ($\alpha_h = 10$, $\alpha_l = 3$, $\lambda = 0.5$, $\beta = 1$, and $\bar{\theta} = 1$)



profit from using only the wholesale price signal is considerably lower. From the order quantity perspective (see Figure 3(b)), the retailer's order quantity induced by the returns price signal, rather than by the wholesale price signal, is also closer to that of the most efficient equilibrium. In both figures, the gaps between each pair of equilibria profits or quantities shrink as the severity of information asymmetry diminishes (i.e., as $\underline{\theta}$ increases to $\bar{\theta} = 1$).

Our results, taken together, shed light on the optimal design of the buyback contract in practice when the retailer is uninformed about the manufacturer's returns risk. Buyback arrangements have been shown to be an effective means for a manufacturer to encourage a retailer to carry sufficient inventory of her product. However, a challenge for a small or less-established manufacturer is that a retailer may not adequately trust the manufacturer's buyback commitment. By explicitly incorporating the manufacturer's returns risk in the analysis of buyback arrangements, we are able to address this issue. Indeed, we find that, if the retailer is unsure of the manufacturer's returns risk, then the riskier manufacturer has an incentive to masquerade as the less risky manufacturer. We further find that, to credibly communicate her lower returns risk, the less risky manufacturer should offer a more competitive wholesale price and a lower returns price. Doing so gains the retailer's trust at the expense of some trade-efficiency (by distorting the order quantity downward). The retailer, on the other hand, should exercise caution against being lured by a manufacturer who offers an attractive returns price to offset a high upfront wholesale price. Adding to the price signaling literature that has mostly recognized high prices as a signal of superior quality or demand (see Section 2), our results show that lower wholesale and returns prices can signal lower returns risk. In particular, we find the returns price to be a more efficient signal than the wholesale price.

5. Asymmetric Information About Demand Potential

In this section, we study the design of the buyback contract under asymmetric information about the manufacturer's demand potential, that is, when the retailer is uninformed about the likelihood of the manufacturer's high baseline demand $\lambda \in \{\bar{\lambda}, \underline{\lambda}\}$ with $\Delta\lambda := \bar{\lambda} - \underline{\lambda}$. For expositional simplicity, we refer to $\bar{\lambda}$ as *high-demand* type and $\underline{\lambda}$ as *low-demand* type. Their expected baseline demands are denoted as $\bar{\alpha} := \bar{\lambda}\alpha_h + \bar{\lambda}^c\alpha_l$ and $\underline{\alpha} := \underline{\lambda}\alpha_h + \underline{\lambda}^c\alpha_l$, respectively. To focus on the asymmetric information about demand potential, we assume that the manufacturer is free of returns risk (i.e., $\theta \equiv 1$).[12]

Similar to (2), we can formulate the manufacturer's profit function according to the retailer's ordering strategy in Lemma 1. Given the retailer's belief $\widehat{\lambda} \in [\underline{\lambda}, \bar{\lambda}]$ about the manufacturer's demand potential, the manufacturer of type $\lambda \in \{\bar{\lambda}, \underline{\lambda}\}$, who offers a buyback contract (w, r), earns an expected profit of

$$\prod\left(w, r \,\middle|\, \widehat{\lambda}, \lambda\right) := ws^R\left(w, r, 1, \widehat{\lambda}\right) - \frac{1}{2}\lambda^c r\left[\Delta\alpha - \left(\beta/\widehat{\lambda}\right)(w - r)\right]^+. \quad (12)$$

Similar to Section 4, we first establish the symmetric information benchmark, in which the manufacturer's demand potential is known to the retailer.[13] We then characterize the equilibrium contract and outcomes when the retailer is uninformed about the manufacturer's demand potential. Finally, we further elucidate the signaling mechanism by comparing the equilibrium outcomes with those in the cases in which each individual price alone, wholesale or returns, is used to signal the manufacturer's demand potential.

5.1. Symmetric Information Benchmark

Under symmetric information, the manufacturer's demand potential λ is known to the retailer (i.e., $\widehat{\lambda} = \lambda$). The following lemma characterizes the manufacturer's optimal contract offer in this benchmark case.

Lemma 3. *In the symmetric information benchmark, the low- and high-demand manufacturer types offer the same returns price $r^\circ = \alpha_l/(2\beta)$ and offer wholesale prices*

$$\underline{w}^\circ := \frac{\underline{\alpha}}{2\beta} < \overline{w}^\circ := \frac{\bar{\alpha}}{2\beta}, \quad \textit{respectively}, \quad (13)$$

earning expected profits of

$$\underline{\pi}^\circ := \frac{\underline{\lambda}^c\underline{\lambda}(\Delta\alpha)^2 + \underline{\alpha}^2}{8\beta} < \overline{\pi}^\circ := \frac{\bar{\lambda}^c\bar{\lambda}(\Delta\alpha)^2 + \bar{\alpha}^2}{8\beta}, \textit{respectively}. \quad (14)$$

In response, the retailer orders $s^\circ := \alpha_h/4$, his unsold inventory in case of low baseline demand is $q^\circ := \Delta\alpha/4$, and no unsold inventory results from high baseline demand realization.

When the manufacturer's demand potential is known to the retailer, the manufacturer essentially optimizes the prices w and $w - r$ charged to the retailer for the regular stock and safety stock, respectively. We find that the high-demand manufacturer charges a higher wholesale price than the low-demand manufacturer does (i.e., $\overline{w}^\circ > \underline{w}^\circ$) although both types of manufacturer offer the same returns price r°. The retailer's order quantity s° and the unsold inventory in the case of low baseline demand q° are the same for both manufacturer types. Consequently, the high-demand manufacturer generates higher revenue because of the higher wholesale price (i.e., $\overline{w}^\circ s^\circ > \underline{w}^\circ s^\circ$) but incurs lower expected returns cost (i.e., $\bar{\lambda}^c r^\circ q^\circ < \underline{\lambda}^c r^\circ q^\circ$), thus earning higher expected profit than the low-demand manufacturer (i.e., $\overline{\pi}^\circ > \underline{\pi}^\circ$).

5.2. Design of Buyback Contract to Signal Demand Potential

We next turn to the focal case in which the manufacturer's demand potential is her private information, and hence, her buyback contract may signal this information. We find that it is the high-demand manufacturer that must bear the signaling burden in this case; in particular, under the symmetric information contracts, the higher wholesale price enjoyed by the high-demand manufacturer creates an incentive for the low-demand manufacturer to mimic as the induced order quantity and size of unsold inventory from the retailer would then remain unchanged (see Lemma 3). We again solve for the most efficient separating equilibrium, in which the low-demand manufacturer offers her symmetric information contract $(\underline{w}^\circ, r^\circ)$ and the high-demand manufacturer deviates from her symmetric information contract $(\overline{w}^\circ, r^\circ)$. We also show in Lemma C.1 in Online Appendix C that the most efficient separating equilibrium is the unique PBE that survives the intuitive criterion. Let $(\overline{w}^{\star\star}, \bar{r}^{\star\star})$ denote the high-demand manufacturer's contract. Then the retailer updates his belief to $\widehat{\lambda} = \bar{\lambda}$ upon being offered the contract $(\overline{w}^{\star\star}, \bar{r}^{\star\star})$ and to $\widehat{\lambda} = \underline{\lambda}$ otherwise. Therefore, the high-demand manufacturer's contract $(\overline{w}^{\star\star}, \bar{r}^{\star\star})$ is determined as the solution to

$$\begin{aligned} \overline{\pi}^{\star\star} := \max_{\overline{w} \geq \bar{r} \geq 0} \quad & \prod\left(\overline{w}, \bar{r} \,\middle|\, \bar{\lambda}, \bar{\lambda}\right) \\ \text{s.t.} \quad & \prod\left(\overline{w}, \bar{r} \,\middle|\, \bar{\lambda}, \underline{\lambda}\right) \leq \underline{\pi}^\circ \text{ and} \\ & \prod\left(\overline{w}, \bar{r} \,\middle|\, \bar{\lambda}, \bar{\lambda}\right) \geq \prod\left(\underline{w}^\circ, r^\circ \,\middle|\, \underline{\lambda}, \bar{\lambda}\right), \end{aligned} \quad (15)$$

where the nonmimicry constraints act to deter either demand type of manufacturer from pretending to be of the other type. We establish the feasibility of the most efficient separation and characterize it in the next proposition.

Proposition 3. *The most efficient separating equilibrium of the demand potential signaling game exists. In this equilibrium,*

i. *the low-demand manufacturer offers her symmetric information contract $(\underline{w}^\circ, r^\circ)$;*

ii. *the high-demand manufacturer offers contract $(\overline{w}^{\star\star}, \bar{r}^{\star\star})$ with both wholesale and returns prices higher than their respective symmetric information counterparts, that is, $\overline{w}^{\star\star} > \overline{w}^\circ > \underline{w}^\circ$ and $\bar{r}^{\star\star} > r^\circ$.*

iii. *Under contract $(\overline{w}^{\star\star}, \bar{r}^{\star\star})$, the retailer's order quantity $\bar{s}^{\star\star}$ and unsold inventory $\bar{q}^{\star\star}$ in case of low baseline demand are both higher than their symmetric information counterparts, that is, $\bar{s}^{\star\star} > s^\circ$ and $\bar{q}^{\star\star} > q^\circ$; no unsold inventory results from high baseline demand realization.*

In contrast to the returns risk case (see Proposition 1), Proposition 3 shows that the optimal buyback contract to credibly signal high demand potential distorts both the wholesale and returns prices *upward* above their symmetric information levels. Similar to the way how the returns risk type enters the manufacturer's profit function, the manufacturer's demand type λ affects her profit only through her *expected* returns cost $\lambda^c \cdot rc$, where λ^c is the likelihood of low baseline demand realization (which results in the returns) and $rc := r \cdot \frac{1}{2}[\Delta\alpha - (\beta/\widehat{\lambda})(w - r)]^+$ is again her *returns cost* (i.e., the cost of repurchasing the retailer's unsold inventory given that it occurs); see (12). However, different from the returns risk case, because $\bar{\lambda}^c < \underline{\lambda}^c$, lowering the returns cost now generates lower benefit for the high-demand manufacturer than for the low-demand manufacturer. Consequently, a contract that induces a higher returns cost is now less attractive for the low-demand manufacturer to mimic, calling for the high-demand manufacturer to distort her returns cost *upward* from her symmetric information level. Proposition 3 finds that the most efficient way of doing so is to distort both the wholesale and returns prices upward.

Similar to the returns risk case, we can uncover the mechanism behind the aforementioned distortions by expressing the high-demand manufacturer's problem (15) via the retailer's quantity decision. According to (1), the retailer's order under the high-demand manufacturer's contract $(\overline{w}, \bar{r})$ consists of

$$\text{regular stock} \quad \bar{s}_r(\overline{w}) := \frac{1}{2}(\bar{\alpha} - \beta\overline{w}), \quad \text{and}$$

$$\text{safety stock} \quad \bar{s}_s(\overline{w}, \bar{r}) := \frac{\bar{\lambda}^c}{2}\left[\Delta\alpha - (\beta/\bar{\lambda})(\overline{w} - \bar{r})\right],$$

with the symmetric information regular stock and safety stock given by

$$\bar{s}_r^\circ := \bar{s}_r(\overline{w}^\circ) = \frac{\bar{\alpha}}{4} \quad \text{and} \quad \bar{s}_s^\circ := \bar{s}_s(\overline{w}^\circ, r^\circ) = \frac{\bar{\lambda}^c \Delta\alpha}{4},$$

respectively.

According to (12), the high-demand manufacturer's profit from offering contract $(\overline{w}, \bar{r})$ can be expressed as

$$\begin{aligned} &\prod\left(\overline{w}, \bar{r} \,\middle|\, \bar{\lambda}, \bar{\lambda}\right) \\ &= \overline{\pi}^\circ - \underbrace{\frac{2}{\beta\bar{\lambda}^c}\left\{\bar{\lambda}^c\left[\bar{s}_r^\circ - \bar{s}_r(\overline{w})\right]^2 + \bar{\lambda}\left[\bar{s}_s^\circ - \bar{s}_s(\overline{w}, \bar{r})\right]^2\right\}}_{\text{signaling cost}}, \end{aligned} \quad (16)$$

where the second term again is the high-demand manufacturer's *signaling cost*.

Now, the low-demand manufacturer's gain from mimicry (i.e., the difference between the two sides of the first constraint in (15)) can be similarly expressed as

$$\prod\left(\overline{w},\overline{r}\,\middle|\,\overline{\lambda},\underline{\lambda}\right)-\underline{\pi}^{\circ}$$
$$=\overline{\pi}^{\circ}-\underline{\pi}^{\circ}-\underbrace{\frac{2}{\beta\bar{\lambda}^{c}}\left\{\bar{\lambda}^{c}[\bar{s}_{r}^{\circ}-\bar{s}_{r}(\overline{w})]^{2}+\bar{\lambda}[\bar{s}_{s}^{\circ}-\bar{s}_{s}(\overline{w},\overline{r})]^{2}\right\}}_{\text{signaling cost}} \tag{17}$$
$$-\Delta\lambda\cdot\underbrace{\frac{2}{\beta(\bar{\lambda}^{c})^{2}}\left[\frac{\bar{\lambda}^{c}\alpha_{l}}{2}-\bar{\lambda}^{c}\bar{s}_{r}(\overline{w})+\bar{\lambda}\bar{s}_{s}(\overline{w},\overline{r})\right]\bar{s}_{s}(\overline{w},\overline{r})}_{\text{returns cost under contract }(\overline{w},\overline{r})}.$$

Now, for a given level of the high-demand manufacturer's signaling cost, reducing the low-demand manufacturer's gain from mimicry (so as to lower the signaling cost in turn) calls for raising the returns cost (i.e., decreasing the last term in (17)). Thus, the efficient deterrence of mimicry is achieved by distorting the regular stock downward (i.e., $\bar{s}_r(\overline{w}^{\star\star})<\bar{s}_r^{\circ}$) and the safety stock upward (i.e., $\bar{s}_s(\overline{w}^{\star\star},\overline{r}^{\star\star})>\bar{s}_s^{\circ}$). This is opposite to the returns risk case and consequently results in upward distortions of both the wholesale and returns prices when signaling the high demand potential. Nonetheless, akin to the returns risk case, the distortion in the wholesale prices exerts counteracting forces against the desired directions of distortion in the regular and safety stocks, whereas the returns price is able to focus on distorting the safety stock without affecting the regular stock. Again, the wholesale price is used to mitigate the distortion in the retailer's overall order quantity inflicted by the returns price. Therefore, the returns price should be a more efficient signal than the wholesale price as is verified in the next subsection.

5.3. Importance of Returns Price to Signal Demand Potential

Parallel to our analysis in the returns risk case, we demonstrate the higher efficiency of the returns price signal relative to the wholesale price signal by examining the following two partial signaling benchmarks and comparing their equilibrium outcomes with those in the most efficient separation.

Signaling Demand Potential Only Through Wholesale Price. In this benchmark, we fix the high-demand manufacturer's returns price at her symmetric information level r° and only allow her to set her wholesale price to signal her high demand potential in the most profitable manner. Thus, the high-demand manufacturer's most efficient wholesale price, denoted as $\overline{w}^{\#}$, is determined as the solution to

$$\begin{aligned}\overline{\pi}^{\#}:=\max_{\overline{w}\ge r^{\circ}}\quad&\prod\left(\overline{w},r^{\circ}\,\middle|\,\overline{\lambda},\overline{\lambda}\right)\\ \text{s.t.}\quad&\prod\left(\overline{w},r^{\circ}\,\middle|\,\overline{\lambda},\underline{\lambda}\right)\le\underline{\pi}^{\circ}\text{ and}\\ &\prod\left(\overline{w},r^{\circ}\,\middle|\,\overline{\lambda},\overline{\lambda}\right)\ge\prod\left(\underline{w}^{\circ},r^{\circ}\,\middle|\,\underline{\lambda},\overline{\lambda}\right).\end{aligned} \tag{18}$$

The retailer's order quantity under contract $(\overline{w}^{\#},r^{\circ})$ is denoted as $\bar{s}^{\#}$. Proposition C.1 in Online Appendix C characterizes the equilibrium outcome in this case.

Signaling Demand Potential Only Through Returns Price. In this benchmark, we fix the high-demand manufacturer's wholesale price at the symmetric information level $\overline{w}^{\circ}$ and only allow her to set her returns price to signal her high demand potential in the most profitable manner. Thus, the high-demand manufacturer's most efficient returns price, denoted as $\overline{r}^{\flat}$, is determined as the solution to

$$\begin{aligned}\overline{\pi}^{\flat}:=\max_{\overline{w}^{\circ}\ge\overline{r}\ge 0}\quad&\prod\left(\overline{w}^{\circ},\overline{r}\,\middle|\,\overline{\lambda},\overline{\lambda}\right)\\ \text{s.t.}\quad&\prod\left(\overline{w}^{\circ},\overline{r}\,\middle|\,\overline{\lambda},\underline{\lambda}\right)\le\underline{\pi}^{\circ}\text{ and}\\ &\prod\left(\overline{w}^{\circ},\overline{r}\,\middle|\,\overline{\lambda},\overline{\lambda}\right)\ge\prod\left(\underline{w}^{\circ},r^{\circ}\,\middle|\,\underline{\lambda},\overline{\lambda}\right).\end{aligned} \tag{19}$$

The retailer's order quantity under contract $(\overline{w}^{\circ},\overline{r}^{\flat})$ is denoted as $\bar{s}^{\flat}$. Proposition C.2 in Online Appendix C characterizes the equilibrium outcome in this case.

Comparison of Equilibria Outcomes. We now compare outcomes in different equilibria.

Proposition 4. *For the demand potential signaling game, the equilibria outcomes under symmetric information, the most efficient separation, and the partial signaling benchmarks are ranked as follows:*

$$\overline{w}^{\star\star}>\overline{w}^{\circ}>\underline{w}^{\circ}>\overline{w}^{\#},\quad \overline{r}^{\star\star}>\overline{r}^{\flat}>r^{\circ},$$
$$\bar{s}^{\#}>\bar{s}^{\flat}>\bar{s}^{\star\star}>s^{\circ},\quad\textit{and}\quad\overline{\pi}^{\#}<\overline{\pi}^{\flat}<\overline{\pi}^{\star\star}<\overline{\pi}^{\circ}. \tag{20}$$

Proposition 4 demonstrates the returns price as a more efficient signal of the demand potential than the wholesale price: relative to signaling through the wholesale price alone, signaling through the returns price alone generates *higher* profit (and, hence, closer to the profit under most efficient separation) and *smaller* distortion to the retailer's order quantity (and, hence, closer to the order quantity under the most efficient separation), that is, $\overline{\pi}^{\#}<\overline{\pi}^{\flat}<\overline{\pi}^{\star\star}$ and $\bar{s}^{\#}>\bar{s}^{\flat}>\bar{s}^{\star\star}$. Furthermore, we find that the returns price alone can always signal the high demand potential (as shown by Proposition C.2), whereas the wholesale price alone can do so for certain parameter range (specifically, for $\Delta\lambda/\underline{\lambda}[1+\bar{\lambda}/(4\underline{\lambda})]>4\alpha_h\Delta\alpha/\alpha_l^2$; see Proposition C.1). Finally, by enabling both the wholesale and returns price signals, the most efficient separation reverses the direction of distortion in the wholesale price from when the wholesale price alone is used to signal (i.e., $\overline{w}^{\star\star} > \overline{w}^{\circ} > \overline{w}^{\#}$) and enlarges the magnitude of distortion in the returns price when it acts alone (i.e., $\overline{r}^{\star\star} > \overline{r}^{\flat} > r^{\circ}$), albeit with the directions opposite to that in those in the returns risk case. Again, these distortions are driven by the high-demand manufacturer's desire to distort the retailer's induced regular and safety stocks in the directions that lead to a higher overall returns cost as required by mimicry deterrence.

Now, we illustrate in Figure 4 the superior efficiency of the returns price in conveying the manufacturer's demand information through a numerical example. Most notably, the use of returns price alone allows the manufacturer to capture most of the gains from the most efficient separation using both price instruments in terms of the manufacturer's profit (Figure 4(a)) as well as the retailer's order quantity (Figure 4(b)). As the information asymmetry diminishes (i.e., $\underline{\lambda}$ approaches to $\bar{\lambda}$), the profitability gap and trade inefficiency go down.

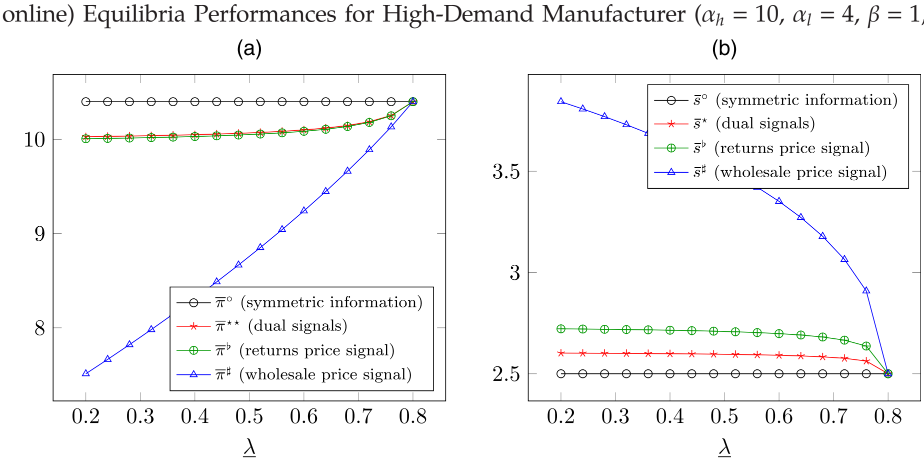
Our findings from Proposition 3 can be particularly relevant for large and established manufacturers who face the challenge of convincing retailers about the demand potential for their products. Prior research has examined how a manufacturer can structure the contract terms to credibly convey this information under deterministic demand (see Section 2). In the presence of stochastic demand and inventory considerations, however, the manufacturer may leverage a buyback arrangement to convey her demand information. Specifically, a high-demand manufacturer should offer a more generous returns price and a higher wholesale price than she would if her demand potential were known to the retailer. The retailer, on the other hand, should not be tempted by a lower wholesale price and should instead pay more attention to the returns price. Thus, signaling higher demand potential requires the manufacturer to design her buyback contract in the direction opposite to that when signaling lower returns risk. Nonetheless, a consistent finding is that the returns price constitutes a more efficient signal than the wholesale price.

6. Asymmetric Information About Both Returns Risk and Demand Potential

Our analysis in the previous sections sheds light on the optimal design and information role of buyback contracts in situations in which one type of manufacturer's inventory-related risk, either her returns risk or her demand risk, is the predominant source of unobservable information for the retailer. We find that the optimal buyback contracts to signal low returns risk and to signal high demand potential both involve distorting the manufacturer's corresponding returns cost, albeit in opposing directions. A natural question to ask then is how the buyback contract should be structured to signal the manufacturer's private information in the case in which the less risky manufacturer also has high demand potential and the retailer is uninformed about both types of inventory-related risks.[14] For example, this may represent situations in which a manufacturer having higher demand potential is also likely to be in better financial health and, hence, poses lower returns risk compared with other manufacturers who struggle with their sales and are, thus, plagued by liquidity problems.

To answer this question, we examine the most efficient separating contract when the manufacturer can be one of two types: a *low-risk high-demand* type with probability $\bar{\theta}$ of repurchasing the retailer's unsold inventory and probability $\bar{\lambda}$ of high baseline demand realization or a *high-risk low-demand* type with probability $\underline{\theta}$ of repurchasing the retailer's unsold inventory and probability $\underline{\lambda}$ of high baseline

Figure 4. (Color online) Equilibria Performances for High-Demand Manufacturer ($\alpha_h = 10$, $\alpha_l = 4$, $\beta = 1$, $\bar{\lambda} = 0.8$)



Manufacturer's expected profit.

Retailer's order quantity.

demand realization. That is, the manufacturer's private information consists of two dimensions that are perfectly correlated. The sequence of events is the same as specified in Section 3.

We start by examining the symmetric information benchmark, in which the retailer is informed about the manufacturer's type. In this case, the low-risk high-demand manufacturer offers contract

$$\overline{w}^\circ = \frac{\bar{\alpha}}{2\beta} \quad \text{and} \quad \overline{r}^\circ = \frac{\alpha_l}{2\beta\bar{\theta}},$$
$$\text{earning profit } \overline{\pi}^\circ = \frac{\bar{\lambda}^c\bar{\lambda}(\Delta\alpha)^2 + \bar{\alpha}^2}{8\beta}, \qquad (21)$$

and the high-risk low-demand manufacturer offers contract

$$\underline{w}^\circ = \frac{\underline{\alpha}}{2\beta} \quad \text{and} \quad \underline{r}^\circ = \frac{\alpha_l}{2\beta\underline{\theta}},$$
$$\text{earning profit } \underline{\pi}^\circ = \frac{\underline{\lambda}^c\underline{\lambda}(\Delta\alpha)^2 + \underline{\alpha}^2}{8\beta}. \qquad (22)$$

Under symmetric information, the low-risk high-demand manufacturer enjoys a higher wholesale price (i.e., $\overline{w}^\circ > \underline{w}^\circ$) and a higher expected profit (i.e., $\overline{\pi}^\circ > \underline{\pi}^\circ$) while offering a lower returns price (i.e., $\overline{r}^\circ < \underline{r}^\circ$) than the high-risk low-demand manufacturer. Consequently, under asymmetric information, the high-risk low-demand manufacturer (namely the *bad* type) would have an incentive to mimic the low-risk high-demand manufacturer (namely, the *good* type). Hence, the good type needs to distort her buyback contract from that under symmetric information so as to separate herself from the bad type. We now characterize the most-efficient separating equilibrium.

Proposition 5. *In the most efficient separating equilibrium of the returns risk and demand potential signaling game, if it exists, the high-risk low-demand manufacturer* $(\underline{\theta}, \underline{\lambda})$ *offers her symmetric information contract* $(\underline{w}^\circ, \underline{r}^\circ)$*, and the equilibrium contract offered by the low-risk high-demand manufacturer* $(\bar{\theta}, \bar{\lambda})$*, denoted as* $(\overline{w}^{\star\star\star}, \overline{r}^{\star\star\star})$*, demonstrates the following characteristics:*

1. *If* $\underline{\theta}\underline{\lambda}^c < \bar{\theta}\bar{\lambda}^c$*, then* $(\overline{w}^{\star\star\star}, \overline{r}^{\star\star\star})$ *either (i) satisfies* $\overline{w}^{\star\star\star} < \overline{w}^\circ$ *and* $0 \le \overline{r}^{\star\star\star} < \overline{r}^\circ$ *or (ii) induces the retailer to carry no safety stock (and, hence, make no returns).*
2. *If* $\underline{\theta}\underline{\lambda}^c > \bar{\theta}\bar{\lambda}^c$*, then* $\overline{w}^{\star\star\star} > \overline{w}^\circ$ *and* $\overline{r}^{\star\star\star} > \overline{r}^\circ$.
3. *If* $\underline{\theta}\underline{\lambda}^c = \bar{\theta}\bar{\lambda}^c$*, then there exist at least one contract such that* $\overline{w}^{\star\star\star} < \overline{w}^\circ$ *and* $\overline{r}^{\star\star\star} < \overline{r}^\circ$ *as well as one such that* $\overline{w}^{\star\star\star} > \overline{w}^\circ$ *and* $\overline{r}^{\star\star\star} > \overline{r}^\circ$.

As before, we find that efficient separation requires that the manufacturer distort the returns cost. For a manufacturer of type (θ, λ), the net probability of incurring the returns cost is given by $\theta\lambda^c$, which is the joint probability of a low baseline demand realization (which results in unsold inventory) and the manufacturer's acceptance of the retailer's returns. Proposition 5 shows that the direction of distortion depends on whether the net probability of incurring the returns cost is higher or lower for the good type than low type, leading to the following three cases.

- When $\underline{\theta}\underline{\lambda}^c < \bar{\theta}\bar{\lambda}^c$, the effect of the returns risk dominates that of the demand potential; hence, the good type should design her optimal buyback contract to distort the returns cost downward relative to the symmetric information benchmark as in the returns risk case. As a result, the safety stock is distorted downward. If the equilibrium safety stock is positive, then both the wholesale and returns prices are distorted *downward* (i.e., $\overline{w}^{\star\star\star} < \overline{w}^\circ$ and $\overline{r}^{\star\star\star} < \overline{r}^\circ$), the same as in the returns risk case. In particular, this case reduces to the returns risk case if $\underline{\lambda} = \bar{\lambda}$ (see Section 4). However, it is possible for the equilibrium safety stock to be distorted to zero, in which case the direction of distortion in the equilibrium prices is not uniquely determined.[15]
- Instead, when $\underline{\theta}\underline{\lambda}^c > \bar{\theta}\bar{\lambda}^c$, the effect of the demand potential dominates that of the returns risk; hence, the good type should design her optimal buyback contract to distort the returns cost upward. Subsequently, both the wholesale and returns prices are distorted *upward* (i.e., $\overline{w}^{\star\star\star} > \overline{w}^\circ$ and $\overline{r}^{\star\star\star} > \overline{r}^\circ$), the same as in the demand potential case. Indeed, this case reduces to the demand potential case if $\underline{\theta} = \bar{\theta} = 1$ (see Section 5).
- Finally, when $\underline{\theta}\underline{\lambda}^c = \bar{\theta}\bar{\lambda}^c$, the effects of the returns risk and the demand potential balance each other. Then, we find that the direction of distortion in the wholesale and returns prices is not uniquely determined. In particular, the wholesale and returns prices can both be distorted downward (i.e., $\overline{w}^{\star\star\star} < \overline{w}^\circ$ and $\overline{r}^{\star\star\star} < \overline{r}^\circ$) as in the returns risk case or both be distorted upward (i.e., $\overline{w}^{\star\star\star} > \overline{w}^\circ$ and $\overline{r}^{\star\star\star} > \overline{r}^\circ$) as in the demand potential case.

Thus, Proposition 5 generalizes our previous findings and allows us to identify a unified signaling mechanism across the different settings. This mechanism can be again uncovered by expressing the bad type's gain from mimicry in terms of the retailer's quantity decisions:

$$\begin{aligned}
&\text{bad type's gain from mimicry} \\
&= \overline{\pi}^\circ - \underline{\pi}^\circ - \underbrace{\frac{2}{\beta\bar{\lambda}^c}\left\{\bar{\lambda}^c\left[\bar{s}_r^\circ - \bar{s}_r(\overline{w})\right]^2 + \bar{\lambda}\left[\bar{s}_s^\circ - \bar{s}_s(\overline{w}, \overline{r})\right]^2\right\}}_{\text{good type's signaling cost}} \\
&\quad - \left(\underline{\theta}\underline{\lambda}^c - \bar{\theta}\bar{\lambda}^c\right) \\
&\quad \underbrace{\cdot \frac{2}{\beta\bar{\theta}\left(\bar{\lambda}^c\right)^2}\left[\frac{\bar{\lambda}^c\alpha_l}{2} - \bar{\lambda}^c\bar{s}_r(\overline{w}) + \bar{\lambda}\bar{s}_s(\overline{w}, \overline{r})\right]\bar{s}_s(\overline{w}, \overline{r})}_{\text{returns cost under contract } (\overline{w}, \overline{r})},
\end{aligned}$$

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where $\bar{s}_r(\overline{w}) := \frac{1}{2}(\bar{\alpha} - \beta\overline{w})$ and $\bar{s}_s(\overline{w},\overline{r}) := \frac{\bar{\lambda}^c}{2}[\Delta\alpha - (\beta/\bar{\lambda})(\overline{w} - \bar{\theta}\overline{r})]$ are the retailer's regular and safety stocks, respectively, with $\bar{s}_r^\circ$ and $\bar{s}_s^\circ$ being their symmetric information levels. As before, for a given level of signaling cost, efficient separation aims to reduce the bad type's gain from mimicry by distorting the returns cost in the last term. The direction of distortion, however, critically depends on the sign of the difference in the net probability of incurring the returns cost, $\underline{\theta\lambda}^c - \bar{\theta}\bar{\lambda}^c$, between the bad and good types as characterized by Proposition 5.

We find that the most efficient separating equilibrium may not always exist because, under two-dimensional private information, mimicking the good type entails the benefit of being perceived to be of both low returns risk and high demand potential, resulting in higher gain from mimicry for the bad type than that under a single-dimensional case. Establishing the exact condition for the existence of the most-efficient separating equilibrium is analytically intractable. The following corollary provides sufficient conditions under which we are able to establish the existence of the most efficient separating equilibrium analytically.

Corollary 1. *The most efficient separating equilibrium of the returns risk and demand potential signaling game always exists under any one of the following conditions:*

1. $\Delta\theta/\bar{\theta} \geq 1 - \frac{\bar{\lambda}^c}{(1+\sqrt{\underline{\lambda}})^2}$ *or* $\Delta\theta/\bar{\theta} > \Delta\lambda/\underline{\lambda}^c \geq \frac{\bar{\lambda}^c \min\{\alpha_l^2, \bar{\lambda}(\Delta\alpha)^2\}}{\underline{\lambda}^c \Delta\alpha(\alpha_l+\alpha_h)}$, *which both imply* $\underline{\theta\lambda}^c < \bar{\theta}\bar{\lambda}^c$.
2. $\Delta\theta/\bar{\theta} \leq \min\{\frac{(\underline{\lambda}^c\bar{\lambda} - \bar{\lambda}^c\Delta\lambda)\Delta\alpha}{2\underline{\lambda}^c\bar{\alpha}}, 1 - \frac{\bar{\lambda}^c}{(1-\sqrt{\underline{\lambda}})^2}\}$, *which implies* $\underline{\theta\lambda}^c > \bar{\theta}\bar{\lambda}^c$.
3. $\underline{\theta\lambda}^c = \bar{\theta}\bar{\lambda}^c$.

Numerical analysis shows that the separating equilibrium can exist even beyond these sufficient conditions. In cases in which the separating equilibrium does not exist, the manufacturer types may pool on the buyback contract (i.e., offer the same contract), eliminating the informational role of the buyback contract.

7. Conclusion

Retailers often face the challenge of managing their inventory to match supply with uncertain demand. Past research has extensively examined the use of buyback arrangements by manufacturers to share inventory risk with their retailers under the assumption that the buyback commitment will be honored and that manufacturers and retailers are equally informed about the product's demand potential. In practice, however, not all manufacturers may be able to honor their buyback commitment, thus making retailers wary of buyback offers. Or retailers may be less informed about market conditions than the manufacturers and, thus, be unconvinced about a product's demand potential, leading to lower order quantities. We seek to shed light on the use and design of buyback arrangements in such situations.

Overall, our findings highlight the strategic and informational role of buyback contracts over and above their oft-studied transactional role in the literature. In the presence of stochastic demand and inventory considerations, efficient signaling of manufacturer's returns risk or demand potential necessitates distorting its *returns cost* (i.e., the cost of repurchasing the retailer's unsold inventory) away from the symmetric-information level. The direction of distortion depends on whether the separating type has a higher or lower *net probability of incurring the returns cost* (i.e., probability that returns occur and is honored by the manufacturer) than the mimicking manufacturer type. The signaling distortion in returns cost uniquely determines how the retailer's induced regular stock and safety stock are distorted and, in turn, how the underlying contractual prices are adjusted. In fact, changing the wholesale price creates opposing effects on the regular and safety stocks relative to how they need to be distorted for efficient separation, whereas the returns price only affects the safety stock without creating such opposing effects. As a result, we find the returns price to be a relatively more efficient signaling instrument than the wholesale price. In particular, the returns price reverses the direction of distortion in the wholesale price from what is necessary for the wholesale price alone to distort the returns cost, and the wholesale price is used to mitigate the signaling distortion in the retailer's overall order quantity.

This novel signaling mechanism results in contrasting design of the buyback contracts between signaling the manufacturer's returns risk and signaling her demand potential. Efficient signaling of low returns risk entails *downward* distortion of both the wholesale and returns prices below their symmetric-information counterparts, whereas efficient signaling of high demand potential entails *upward* distortion of both prices. If the manufacturer needs to signal both low returns risk and high demand potential, then the direction of the price distortions depends on the manufacturer's net probability of incurring the returns cost. When this net probability is higher for the "good" manufacturer (who is better on both dimensions), then the direction of distortion is the same as that in the case of signaling low returns risk alone. Instead, when the net probability is higher for the "bad" manufacturer (who is worse on both dimensions), then the direction of distortion is the same as that in the case of signaling high demand potential alone.

Our research speaks to manufacturers who manage their distribution channels plagued with asymmetric information about inventory-related risks. In a market with small and less-established manufacturers, a more competitive wholesale price together with a lower returns price can help the less risky manufacturers to distinguish themselves and assure the downstream retailers of their reliability to fulfill their returns commitment. For markets dominated by large and well-established manufacturers (e.g., national brands), returns risk may not be an issue. Yet, manufacturers typically have the incentive to acquire proprietary information about the downstream demand potential. In this situation, a higher wholesale price together with a more generous returns price can signal to the downstream retailers the confidence of manufacturers with high demand potential.

We regard our work as a first attempt to examine the informational role of buyback arrangements with a number of directions for future exploration. For instance, we assumed no salvage value for retailer's unsold inventory. A positive salvage value should not affect our results if it is lower than the equilibrium returns price. We further expect that our results continue to hold qualitatively if the salvage value is not too high. However, if the salvage value is sufficiently high, it lowers the retailer's reliance on the manufacturer's returns price, and it becomes more onerous for the manufacturer to signal through the returns price. We defer the analysis for this case as future research. Another interesting avenue is to examine the role of manufacturer's trade credit.[16] Trade credit refers to short-term financing offered by a supplier to a downstream buyer to facilitate the purchase of supplies without immediate payment. Although offering trade credit can potentially mitigate the retailer's returns risk, it poses significant costs for the manufacturer (e.g., Woodruff 2019). In particular, small and less-established manufacturers who typically pose returns risk for the retailer may not be able to offer trade credit. Moreover, trade credit may also be used by manufacturers to screen buyers with private default risk (e.g., Smith 1987). This context is different from ours as manufacturers in our setting have private information. It would be interesting for future research to study the interaction and trade-off between offering trade credit and signaling returns risk through the buyback contract. Finally, we assume that both manufacturer and retailer are risk-neutral in our setting. Future research could examine the implication of relaxing the risk-neutrality of one or both channel members (e.g., Jiang et al. 2016).

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Endnotes

[1] As pointed out by practitioners (e.g., Rosenfeld 2015), it is an insurmountable challenge for American companies to anticipate all contingencies and include them in upfront contracts when dealing with foreign suppliers.

[2] The comment was made by Paul Pierce, who was VP of Fresh Sales at 7-Eleven, in a private interview by the authors.

[3] Later, in Section 6, we study the case when *both* risks are the manufacturer's private information.

[4] Wang (2004) showed that Padmanabhan and Png's (1997) conclusions in the retail competition model no longer hold for the case of deterministic demand once the equilibrium is solved by correctly accounting for the retailers' inventory constraints.

[5] The qualitative nature of our results is not affected when the marginal production cost becomes positive (see details in Online Appendix E).

[6] In practice, buyback contracts typically allow the retailer to make returns only after sufficient time has passed in the selling season, for example, to ensure that that the retailer has made sufficient efforts to sell the product before attempting to return unsold units. Consequently, the retailer does not know whether the manufacturer will accept returns till the end of the selling season. The sequence of events in our model captures this situation parsimoniously. We thank an anonymous reviewer for this suggestion.

[7] The results in Lemma 1 differ from the analysis in Gurnani et al. (2010) by explicitly incorporating the retailer's beliefs about the manufacturer's type.

[8] Lemma 2 essentially restates the results of Gurnani et al. (2010) in our context. The results in Lemma 2 can be obtained by replacing the returns price in their results with the expected returns price θr.

[9] This notion of regular and safety stocks is commonly used in the inventory management literature (e.g., Zipkin 2000).

[10] We thank the associate editor for suggesting this approach.

[11] We note that any separating equilibrium within these two benchmarks is also a separating equilibrium of the original signaling game supported by suitable off-equilibrium beliefs. Thus, they are well-defined equilibria of the original game, albeit (by construction) not the most efficient ones.

[12] This is without loss of generality because, as a result of the risk neutrality of the manufacturer and the retailer, θ simply appears as a scaling factor for the returns price r in all subsequent analysis. We further note that large and well-established manufacturers who typically have the resources and means to acquire proprietary demand information also tend to have enough financial assets or reputation at stake that they honor the buyback returns for sure.

[13] As before, the model analyzed by Gurnani et al. (2010) corresponds to the symmetric information benchmark. Our results in Lemma 3 below can be obtained by applying their results to each demand type.

[14] We thank the department editor, the associate editor, and an anonymous reviewer for suggesting this investigation.

[15] This situation may emerge only for sufficiently large $\Delta\lambda$ (i.e., $\Delta\lambda \geq \bar{\lambda}^c \min\{\alpha_l^2, \bar{\lambda}(\Delta\alpha)^2\}/[\Delta\alpha(\alpha_l + \alpha_h)]$) as shown by Lemma D.5.

[16] We thank an anonymous reviewer for this suggestion.

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