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# Contract Preferences and Performance for the Loss-Averse Supplier: Buyback vs. Revenue Sharing

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Prior theory claims that buyback and revenue-sharing contracts achieve equivalent channel-coordinating solutions when applied in a dyadic supplier–retailer setting. This suggests that a supplier should be indifferent between the two contracts. However, the sequence and magnitude of costs and revenues (i.e., losses and gains) vary significantly between the contracts, suggesting the supplier's preference of contract type, and associated contract parameter values, may vary with the level of loss aversion. We investigate this phenomenon through two studies. The first is a preliminary study investigating whether human suppliers are indeed indifferent between these two contracts. Using a controlled laboratory experiment, with human subjects taking on the role of the supplier having to choose between contracts, we find that contract preferences change with the ratio of overage and underage costs for the channel (i.e., the newsvendor critical ratio). In particular, a buyback contract is preferred for products with low critical ratio, whereas revenue sharing is preferred for products with high critical ratio. We show these results are consistent with the behavioral tendency of loss aversion and are more significant for subjects who exhibit higher loss aversion tendencies in an out of context task. In the second (main) study, we examine differences in the performance of buyback and revenue-sharing contracts when suppliers have the authority to set contract parameters. We find that the contract frame influences the way parameters are set and the critical ratio again plays an important role. More specifically, revenue-sharing contracts are more profitable for the supplier than buyback contracts in a high critical ratio environment when accounting for the supplier's parameter-specification behavior. Also, there is little difference in performance between the two contracts in a low critical ratio environment. These results can help inform supply managers on what types of contracts to use in different critical ratio settings.

Data, as supplemental material, are available at http://dx.doi.org/10.1287/mnsc.2015.2182.

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## 1. Introduction

Suppliers frequently make decisions on the type and specifications of contracts they use with downstream business customers. Many considerations factor into these decisions, including the contract's financial return, ease of implementation, and fit with norms for the industry or type of business customer. In recent years, more companies have advocated the use of flexible supply contracts, such as buyback and revenue-sharing arrangements, as a tool to share risks among business partners. These flexible contracts often lead to higher profit for the supplier's company and their customers. As the number of companies adopting flexible contracts continues to grow (Doshi 2010), it is important to understand the relative performance of these contracts from the supplier's point of view.

Prior theory claims that buyback and revenue sharing, two of the most commonly used flexible contracts (Cachon 2003), achieve equivalent channel-coordinating solutions when applied in a single supplier–retailer setting (Cachon and Lariviere 2005). This suggests that a supplier in this setting should be indifferent in choosing between these two contracts. However, this result assumes that the decision of which contract to adopt, and how the associated contract parameters should be set, is made by a supplier focused only on maximizing her final expected profit. We know from prior research in behavioral economics that financial decisions often deviate from profit-maximizing predictions, especially when outcomes are determined by a sequence of financial transactions (Thaler 1999).

The sequence of financial transactions that result under buyback and revenue-sharing contracts is quite different, even though the overall profit achieved may be the same. A buyback contract provides the supplier with more money up front, but some portion must be given back after demand is realized if demand is less than supply. Revenue-sharing contracts provide less money up front, possibly resulting in an initial loss for the supplier if the initial payment does not cover the cost of production, but this lower up-front payment is offset by the possibility of a positive income stream once demand occurs. The two contracts thus differ in the relative magnitude of the expected loss and gain (even when the sum of the loss and gain is equivalent) and the sequence of the potential loss (before versus after demand is realized).

The goal of this paper is to determine how these unique framing differences may influence a supplier's decision of which contract to adopt, how contract parameters for each contract are set, and ultimately whether final expected profit actually differs between the contracts once these behavioral factors are incorporated. We focus our investigation on settings where the order behavior of the supplier's customer (i.e., retailer) is known. Specifically, the retailer's order quantity is set in accordance with a decision support system, such as SAP, and the supplier is informed about how the order quantity will change with contract decisions. Controlling the retailer's behavior in this way, besides being representative of decision making in many industries (Alpern 2010), allows us to focus on the supplier's intentions without introducing additional complexities related to how the supplier would or should predict the retailer's behavior when such behavior is unspecified.

Within this problem setting, we conduct two studies. The first is a preliminary study investigating whether human suppliers exhibit a preference between buyback and revenue-sharing contracts when the contracts are set optimally from the profit maximization point of view. Because the contracts are equivalent (i.e., profit outcomes are the same across the two contracts), this provides an authentic and controlled environment for testing whether suppliers' intentions deviate from typical profit maximization. This setting is also representative of situations where the supplier's company sets the contract terms to maximize firm profit (perhaps dictated by a decision support system), while leaving the choice of contract type to the managers. Using analytical models that incorporate loss aversion, we predict that a manager (i.e., human supplier) will exhibit a preference between the two contracts and that this preference will vary with the critical ratio defined by the underlying channel-level newsvendor problem. More specifically, we predict that a critical ratio threshold exists where the supplier's preferences will switch, with the supplier preferring a buyback contract when the critical ratio is below this threshold but preferring a revenue-sharing contract otherwise. We test these theoretical predictions using controlled laboratory experiments and find they are supported.

Having established that the human supplier's intentions deviate from profit maximization, and that this deviation is consistent with loss aversion, we advance to the second (main) study, which examines how these dynamics change when the supplier is free to set the contract parameters. More specifically, we investigate how human suppliers actually set the contract parameters and how this influences the company's realized profit. This question is important for companies wishing to choose contract types that are robust to the parameterization decisions of their managers. We again develop predictions by incorporating loss aversion into the supplier's objective function and solving for the supplier's optimal contract parameters. The analytical results suggest that framing differences also influence the way contract parameters are set, ultimately changing the contracts' associated profit levels. This leads to the prediction that revenue sharing will outperform buyback in high critical ratio environments, whereas neither contract dominates in low critical ratio environments. We test these predictions in a laboratory setting where the subjects now set contract parameter values for either revenue-sharing or buyback contracts. We consider two scenarios, one where the wholesale price is selected and the associated buyback or revenue-sharing parameters are set optimally and the other where both parameters are selected. The experimental results are consistent with our theoretical predictions in both cases.

## 2. Literature Review

Buyback and revenue-sharing contracts allow supply chain partners to share the risks associated with mismatches between supply and demand. These contracts have been studied extensively in the context of newsvendor-type settings, where the selling season is short compared with the acquisition lead time and demand uncertainty is high at the time order quantity decisions are made (see Cachon 2003 and Kaya and Özer 2012 for extensive reviews of recent developments in this area). The contracts are "channel coordinating" in the sense that the contract parameters can be set to align the retailer's incentives to match that of a centrally coordinated channel and thus allow a first-best solution. The contracts are also equivalent; that is, for any coordinating revenue-sharing contract, there exists a unique buyback contract that generates the same distribution of profit between the two supply chain parties for any given realization of demand (Cachon and Lariviere 2005).

Most of the research on supply chain contracts has been normative in nature, providing guidance on the form of optimal decisions under the assumption of expected profit maximization. Recently, there has been growing interest in understanding how different contracts perform when subjected to human decision-making errors and biases. Much of this behavioral research focuses on the retailer's problem of setting an order quantity in response to different contract structures, such as a simple wholesale price contract, i.e., the newsvendor problem (Bolton and Katok 2008, Bolton et al. 2012, Bostian et al. 2008, Ho et al. 2010, Ren and Croson 2013, Schweitzer and Cachon 2000, Su 2008), or a nonlinear wholesale price contract (Becker-Peth et al. 2013, Chen et al. 2013). We examine contract behavior from the supplier's perspective and focus on eliciting preferences as well as contract parameter decisions. Similar to prior retailer-based research, we find evidence that loss aversion contributes to supplier behavior as well. We also find the implications of this behavior play out differently depending on the operational environment (i.e., the underlying critical ratio).

Compared with research focused on retailer behavior, the quantity of research focused on supplier behavior is relatively sparse. Katok and Wu (2009) are the first to examine how suppliers set contract parameters in a flexible contract setting where the retailer faces uncertain demand. They find differences exist in the resulting order quantity outcomes across the two contracts and allude that these differences appear consistent with loss aversion. Kalkanci et al. (2011) study the supplier's behavior under the quantity discount contract and find that this more complex contract does not perform better compared with a simple wholesale price contract. Niederhoff and Kouvelis (2013) focus on how individual factors, such as risk preference, altruism, and rejection risk considerations influence supplier's behavior under a revenue-sharing contract and compare this with behavior under a noncoordinating wholesale price contract. Our research also tests the relative loss aversion levels of individuals by including an out-of-context test. Our work contributes to this stream by providing a rigorous theoretical grounding for how the presence of loss aversion influences the supplier's contract preference and the choice of contract parameters.

Our paper is also related to behavioral studies on supply chain coordination issues, including trust in information sharing (Özer et al. 2011, 2014), fairness perceptions (Cui et al. 2007, Katok and Pavlov 2013, Katok et al. 2014, Loch and Wu 2008), bargaining behavior (Leider and Lovejoy 2013), bullwhip effect (Croson and Donohue 2006, Croson et al. 2014), auction performance (Davis et al. 2011, 2014; Elmaghraby et al. 2012), and biases in demand forecasting tasks (Kremer et al. 2011). In addition, several papers in the marketing literature study contract behavior in a companion setting to the newsvendor environment, where the retailer faces deterministic demand and decides the retail price (Ho and Zhang 2008, Lim and Ho 2007). Our research is similar to this stream in that we also develop behavioral theory to explain how a behavioral regularity—in our case, loss aversion—might influence contract decisions, and then we test the behavioral theory in a laboratory setting.

Our model of loss aversion follows the definition used in prior newsvendor-based studies such as Schweitzer and Cachon (2000) and, more recently, Ho et al. (2010). This concept lies at the heart of prospect theory (Kahneman and Tversky 1979) and has been shown to exist in many decision contexts. Its effects are well studied in behavioral economics and other business fields such as finance and marketing (Camerer 2000). Loss aversion can explain many phenomena including the endowment effect (Kahneman et al. 1990), downward-sloping labor supply (Camerer et al. 1997), the disposition effect (Genesove and Mayer 2001, Shefrin and Statman 1985, Weber and Camerer 1998), the equity premium puzzle (Benartzi and Thaler 1995, Mehra and Prescott 1985), asymmetric price elasticities (Hardie et al. 1993, Putler 1992), and insensitivity to bad income news (Bowman et al. 1999, Shea 1995). Our study examines two payment structures that are equivalent in final outcome but differ in the sequence and magnitude of losses and gains, as well as whether the loss or gain is uncertain. This combination of framing differences has not been studied previously in the loss aversion literature, and so our results contribute to this literature by showing that loss aversion is also influential in this unique context that arises from a classic supply chain problem.

## 3. Model Setup and Preliminaries

Consider a two-echelon supply chain where a supplier offers contract terms to a retailer, who responds by setting an order quantity to cover demand over a single selling period. Under a buyback contract (BB), the supplier charges the retailer an initial wholesale price $w_b$ for each item ordered and provides a buyback credit $b$ for any items remaining at the end of the selling season. In the revenue-sharing contract (RS), the supplier again charges an initial wholesale price $w_r$ per unit ordered but now receives a portion of the retailer's revenue $r$ for each unit sold.

The retailer responds to either contract by choosing an order quantity $q$ with the intent to sell the items to the market at an exogenous price $p$. The supplier incurs a constant production cost $c$ in $(0, p)$ for each item produced. We assume the retailer incurs no additional selling cost and the product has no salvage value. The market demand $D$ is uncertain but drawn from a known distribution that is common knowledge to both parties. Let $F(\cdot)$ denote the distribution function for demand over this selling period, which we assume is characterized by an increasing generalized failure rate.[1]

Since our focus is on preferences and decision biases exhibited by the supplier, we hold the retailer's behavior fixed and thus control for possible additional behavioral factors introduced by the retailer. In other words, we focus our investigation on settings where the retailer's order behavior is known by the supplier. In particular, the retailer's order quantity is set in accordance with a decision support system, such as SAP, and the supplier is informed about how the order quantity will change with contract decisions. Although it is interesting to consider how the supplier would react to a retailer with uncertain ordering behavior or who is guided by a utility function that the supplier might learn over time, it is important to first understand how a supplier behaves when this additional uncertainty is controlled. Consequently, we assume the supplier knows the retailer's response function (operationally within our experiments, this means the supplier has access to a decision support tool that displays the order quantity response for any contract parameter values). Furthermore, we assume the retailer's response function is set to maximize his expected profit and the retailer only accepts contract terms when his expected profit is at least $M \geq 0$, where the reservation level $M$ is bounded above by the maximum expected profit of the channel as a whole.

To create a normative benchmark, we first characterize the supplier's contract decisions when the objective is to maximize her expected profit. Let $S(q)$ denote the expected sales the retailer will achieve when ordering $q$ units, where

$$S(q) = E[\min(q, D)] = q - \int_0^q F(x)\,dx.$$

Under a buyback contract, the profit-maximizing supplier's problem is defined as Problem (BB):

$$\begin{aligned} \underset{w_b,\,b}{\text{Maximize}} \quad & \pi_{S_{BB}}(w_b, b) = (w_b - c)q - b(q - S(q)) \qquad \text{(BB)} \\ \text{s.t} \quad & \pi_{R_{BB}}(q \mid w_b, b) \geq M, \\ & \partial \pi_{R_{BB}}(q \mid w_b, b)/\partial q = 0, \end{aligned}$$

where $\pi_{R_{BB}}(q \mid w_b, b) = -w_b q + pS(q) + b(q - S(q))$. The first constraint guarantees the retailer achieves his reservation profit, and the second ensures the retailer chooses an order quantity, $q$, to maximize his own expected profit. The profit-maximizing supplier's problem under revenue sharing, Problem (RS), is similar:

$$\begin{aligned} \underset{w_r,\,r}{\text{Maximize}} \quad & \pi_{S_{RS}}(w_r, r) = (w_r - c)q + rS(q) \qquad \text{(RS)} \\ \text{s.t} \quad & \pi_{R_{RS}}(q \mid w_r, r) \geq M, \\ & \partial \pi_{R_{RS}}(q \mid w_r, r)/\partial q = 0, \end{aligned}$$

where $\pi_{R_{RS}}(q \mid w_r, r) = -w_r q + (p - r)S(q)$. The solution to these two problems is defined in Proposition 1, with proofs of all theoretical results included in Appendix A.

Proposition 1. *The supplier's expected profit is maximized by setting*

$$w_b^c = c + \lambda(p - c), \quad b^c = \lambda p \quad \textit{and} \tag{1}$$

$$w_r^c = (1 - \lambda)c, \quad r^c = \lambda p \tag{2}$$

*for a buyback and revenue-sharing contract, respectively, where $\lambda = 1 - M/\pi^c$ and $\pi^c$ is the optimal expected profit for the channel. Both solutions are efficient, and the resulting two contracts are equivalent in terms of profits realized by the supplier and retailer.*

The contract parameter values defined in Proposition 1 are similar to the efficient contract conditions provided by Pasternack (1985) and Cachon and Lariviere (2005) for buyback and revenue-sharing contracts, respectively. In our formulation, the existence of a reservation profit ($M$) for the retailer dictates a unique allocation of the channel profit, with the supplier extracting $1 - M/\pi^c$. Since the contracts are efficient, the resulting retailer's order quantity is $q^c = F^{-1}(Cr)$, where $Cr = (p - c)/p$ is the channel-optimal newsvendor critical ratio. An important implication of Proposition 1, and a major result in Cachon and Lariviere (2005), is that a profit-maximizing supplier should be indifferent between the two contracts since the contracts achieve identical outcomes. However, if the supplier's contract decisions are driven by a different utility function, this result may break down. The following example provides some insight into what factors, besides expected profit, might influence preferences between the two contracts.

Table 1 lists payment streams for four different pairs of buyback and revenue-sharing contracts, ordered by increasing production cost, $c$. Demand for this example is uniformly distributed between 0 and 9; i.e., $D \sim \mathrm{U}[0, 9]$. The contract parameters for each buyback and revenue-sharing contract are set according to conditions (1) and (2), implying that the final profit for a given buyback/revenue-sharing pair is equivalent for any demand realization. So, from a profit maximization perspective, the supplier should have no preference between the buyback and

[1] This is a common assumption in the supply chain literature and includes many of the most commonly used demand distributions, including the normal, gamma, and uniform distributions.

**Table 1** **Financial Transactions for the Two Contracts** ($p = \$80$, $\lambda = 3/4$, $D \sim U[0, 9]$)

| | | | Buyback | | Revenue sharing | |
|---|---|---|---|---|---|---|
| $Cr$ | c | $q^c$ | At order $(w_b - c)q$ | After demand $-b(q^c - D)^+$ | At order $(w_r - c)q$ | After demand $r\min(q^c, D)$ |
| 0.95 | \$4 | 9 | \$513 | $-\$60 \times (9 - D)^+$ | $-\$27$ | $\$60 \times \min(9, D)$ |
| 0.75 | \$20 | 7 | \$315 | $-\$60 \times (7 - D)^+$ | $-\$105$ | $\$60 \times \min(7, D)$ |
| 0.35 | \$52 | 3 | \$63 | $-\$60 \times (3 - D)^+$ | $-\$117$ | $\$60 \times \min(3, D)$ |
| 0.15 | \$68 | 1 | \$9 | $-\$60 \times (1 - D)^+$ | $-\$51$ | $\$60 \times \min(1, D)$ |

*Note*. Parameter values for $(w_b, b)$ and $(w_r, r)$ can be obtained using Equations (1) and (2).

revenue-sharing contracts within a given pair. However, if we compare the two contract columns, there are some clear framing differences.

The buyback contract begins with a certain gain, followed by an uncertain loss. By contrast, the revenue sharing contract starts with a certain loss followed by an uncertain gain. Take the case of $Cr = 0.95$ as an example. The buyback contract provides the supplier initially with a certain gain of \$513, but a portion of this gain must be given back after demand is realized. This reduction in the current wealth level (a common reference point), which has an expected value of $-\$270$ $(= E[-\$60 \times (9 - D)^+])$, may result in a feeling of loss. By contrast, the revenue sharing contract starts with a certain loss of $-\$27$, followed by an uncertain gain of \$270 $(= E[\$60 \times \min(9, D)])$. Although the sum of the loss and gain (i.e., the profit) is the same for the two contracts, a loss-averse supplier may now prefer the revenue-sharing contract since the loss is smaller. By contrast, for the case of $Cr = 0.15$, revenue sharing yields a sure loss of $-\$51$ followed by an expected gain of \$54 $(= E[\$60 \times \min(1, D)])$, but this initial loss is now much bigger than the expected loss of $-\$6$ $(= E[-\$60 \times (1 - D)^+])$ under the buyback contract, again with the sum of the loss and gain remaining the same. As a result, a loss-averse supplier may prefer a buyback contract. In general, as $Cr$ decreases, the optimal order quantity for the retailer decreases, impacting the initial revenue and the probability of a gain or loss after demand realization. Under a buyback contract, a smaller order quantity implies a lower chance of having leftover inventory, so the supplier's buyback loss is reduced. On the other hand, under a revenue-sharing contract, the supplier's initial loss, $w_r^c - c = -\lambda c$, becomes more salient with a higher $c$. This suggests that the attractiveness of revenue sharing over buyback may decrease with $Cr$.

This problem context differs from prior applications of loss aversion theory in that it is not only the relative magnitude of the gain and loss that changes across contracts but also the ordering of gains and losses and which one is uncertain. In most previous laboratory studies involving loss aversion (see Abdellaoui et al. 2007 for a review), decision makers are asked to choose between two options that are both either a sure outcome or a lottery with certain probability of achieving some stated value. For this reason, it is important to first establish, in a preliminary study, whether a supplier's preferences in this more complex problem context are consistent with loss aversion theory. Once behavioral tendencies are established, we will utilize this theory in the second (main) study to predict and test how suppliers actually set the corresponding contract parameters (i.e., solve problems BB and RS).

## 4. Study 1: Characterizing the Supplier's Contract Preferences

In this preliminary study, we examine the supplier's preferences between buyback and revenue-sharing contracts when contract terms are set optimally from the profit maximization perspective (i.e., according to conditions (1) and (2)), as in the scenarios outlined in Table 1. Because the contracts are equivalent in this case, this provides an authentic, controlled environment for testing whether suppliers' preferences are consistent with an expected profit utility function (in which case the preferences would appear random) or deviate in a systematic way.

### 4.1. Theory Development

Loss aversion is commonly modeled through a loss aversion coefficient $\gamma$, which represents the ratio of marginal utility of losses versus gains for the supplier (see Ho and Zhang 2008 and Schweitzer and Cachon 2000 for similar models). We adopt this convention and assume $\gamma \geq 1$, where $\gamma = 1$ implies no loss aversion. We also follow prior research in defining a loss as any reduction in current wealth (i.e., reduction in status quo rather than reduction relative to a fixed threshold).

With these conventions, a supplier's expected utility with loss aversion under a buyback contract is

$$U_{S_{BB}}(w_b, b) = (w_b - c)q - \gamma b(q - S(q)). \tag{3}$$

Here, the loss aversion coefficient only applies to the second term (i.e., buyback payment) since the first term is always a gain (recall that $w_b > c$ is required for a buyback contract). By contrast, under a revenue-sharing contract, the wholesale price $w_r$ could be set less than $c$, in which case the supplier will experience an initial loss. However, if $w_r \geq c$, then no initial loss occurs. This implies the following utility function under revenue sharing:

$$U_{S_{RS}}(w_r, r) = \begin{cases} \gamma(w_r - c)q + rS(q) & \text{if } w_r < c, \\ (w_r - c)q + rS(q) & \text{otherwise.} \end{cases} \tag{4}$$

To generalize the results alluded to in the discussion of Table 1, we compare the supplier's utility under each contract when the contracts are equivalent from an expected profit perspective (i.e., when contract parameters are set according to conditions (1) and (2)). Plugging in conditions (1) and (2) into Equations (3) and (4), respectively, as well as substituting in the retailer's optimal order quantity $q^c = F^{-1}(Cr)$, results in the following expression:

$$\begin{aligned} \Delta U_S &= U_{S_{BB}} - U_{S_{RS}} \\ &= -\lambda p(\gamma - 1)[F^{-1}(Cr)Cr - S(F^{-1}(Cr))], \end{aligned} \tag{5}$$

where $\Delta U_S$ denotes the relative utility of the buyback contract over the revenue-sharing contract. The sign of $\Delta U_S$, and thus the supplier's contract preference, is clearly dependent on $Cr$. Proposition 2 establishes that a critical ratio threshold exists that divides the supplier's preference space into three regions.

Proposition 2. *There exists a critical ratio threshold, $Cr^0$, such that a loss-averse supplier ($\gamma > 1$) will*

(a) *prefer a buyback contract when $0 < Cr < Cr^0$;*

(b) *prefer a revenue-sharing contract when $Cr^0 < Cr < 1$; or*

(c) *be indifferent between buyback and revenue sharing when $Cr = Cr^0$.*

*Furthermore, $Cr^0$ is the unique solution to the equation $F^{-1}(Cr)Cr - S(F^{-1}(Cr)) = 0$.*

This result leads to a pair of testable hypotheses.

Hypothesis 1A (H1A). *Revenue-sharing contracts are preferred by a higher percentage of human suppliers than buyback contracts in high critical ratio environments ($Cr > Cr^0$) when parameters are set according to (1) and (2).*

Hypothesis 1B (H1B). *Buyback contracts are preferred by a higher percentage of human suppliers than revenue-sharing contracts in low critical ratio environments ($Cr < Cr^0$) when parameters are set according to (1) and (2).*

### 4.2. Experimental Design and Implementation

We conducted a laboratory experiment to test these hypotheses using a computer-based interface consisting of two separate tasks. In the first task, each participant took part in a simulation designed to elicit his or her preference between buyback and revenue-sharing contracts. In the second, we measured each participant's loss aversion level using an out-of-context procedure. This second task allows us to group individuals by their loss aversion levels and examine whether contract preferences are consistent for suppliers with different levels of loss aversion.

The experiment was performed at the University of Minnesota, with participants recruited from the Carlson School of Management subject pool. A total of 193 students participated in this study across two sets of treatments. For brevity, we only report on the first set of treatments in the text (experiment 1a, consisting of 89 students and using parameters as shown in Table 1). The second set (experiment 1b) shows similar results, as summarized in Appendix C. The majority of the participants were undergraduate students (78.8%), with the rest being graduate students; 94.3% of the participants had completed at least one college-level business or economics course. Participants were paid based on the outcome of both tasks, in addition to a \$5 show-up fee. Final payments ranged from \$6 to \$22, with a median of \$14.

In the first task, participants witnessed financial transactions for the two contracts and then indicated which contract they preferred. The treatments varied by the order the contracts were presented (first BB or first RS) and the value of the critical ratio ($Cr = 0.15, 0.35, 0.75, 0.95$) used in the problem context, leading to $(2 \times 4) = 8$ treatments. We utilized a between-subject design, with each participant randomly assigned to only one treatment. The demand in all cases was drawn from a discrete U[0, 9] distribution, which implies a threshold critical ratio value of $Cr^0 = 0.65$. The four $Cr$ environments included two above (0.95 and 0.75) and two below (0.35 and 0.15) the threshold. The retailer's reservation profit $M$ in all treatments was set equal to the associated profit the retailer would achieve under a wholesale price contract, which resulted in the suppliers receiving a $\lambda = \frac{3}{4}$ share of the channel profit.[2] The resulting cash flows are as listed in Table 1.

We used the same set of 14 demand streams in all treatments to control for any potential demand realization effects between treatments (which would not have been possible if different demand streams were used for each treatment). Each demand stream was randomly generated and consisted of five numbers used for the five periods of the option 1 contract, followed by the same five numbers used for periods of the option 2 presented in a different sequence.[3] Within

[2] See §5 for details on the derivation of the retailer's profit level under a wholesale price contract.

[3] Using the same set of demand streams for both contract options ensured that the total profit outcomes were the same for both, and that any preference between the contracts would be due to factors other than total profit. We chose to randomize the order of the demand streams so that the participants' knowledge of the

a treatment, each participant was randomly assigned to one of these 14 demand streams.

The specifics of the first task were as follows. Each participant was initially told that he or she would be taking on the role of a cheesecake supplier for a local store and would have a chance to choose between two possible financial contracts to offer to the store. They were told the quantity of cheesecakes that the store would order and that this order would not vary across periods. They were also told that this order quantity was chosen by the retailer in order to maximize his own profit. The terms of each contract, labeled option 1 and option 2, were then explained. The participant next experienced five periods of the option 1 contract, followed by five periods of the option 2 contract. For the buyback contract, a period consisted of a first screen showing the order quantity $q$ received from the retailer along with the associated payment $\$(w-c)\times q$. A running account was also displayed near the bottom of the screen. After the participant clicked the "continue" button, a second screen then displayed the demand realization $D$ and the buyback payment the participant incurred, $\$b\times(q-D)^+$. The participants were told that market demand could be any integer from 0 to 9 with equal probability. There was no forced time delay between screens, and the running account was cleared after every period. The revenue-sharing contract periods were designed in a similar manner. Complete experimental instructions, along with screen shots, are provided in the online appendix (available as supplemental material at http://dx.doi.org/10.1287/mnsc.2015.2182).

After witnessing five periods of the two contracts, a summary screen was displayed listing two tables side by side. The first table contained a summary of the payments the participant observed in each period (before and after the demand realization) for all five periods of contract option 1. The second table provided similar information for contract option 2.[4] The participants indicated which option they prefer and were then paid based on one last period with the option selected.

After completing this preference task, the second task involved eliciting the relative loss aversion level of participants. We developed a simplified elicitation procedure for this purpose, drawing from the main ideas of the more involved procedure of Abdellaoui et al. (2008), which consisted of a series of 13 adaptive questions. Appendix B describes this procedure in more detail.

**Table 2** **Number of Participants and Percentage of Preferring BB ($P_{BB}$) for All Critical Ratio Treatments for Experiment 1a**

| | BB → RS | | RS → BB | | | | |
|---|---|---|---|---|---|---|---|
| *Cr* | Preferring BB | Total | Preferring BB | Total | Pooled (%) | Low $\gamma$ (%) | High $\gamma$ (%) |
| 0.95 | 2 | 13 | 1 | 12 | 12.0*** | 14.3** | 9.1** |
| 0.75 | 3 | 10 | 3 | 13 | 26.1* | 33.3 | 12.5* |
| 0.35 | 6 | 11 | 7 | 10 | 61.9 | 50.0 | 72.3 |
| 0.15 | 7 | 11 | 5 | 9 | 60.0 | 37.5 | 75.0† |

†$p<0.1$; *$p<0.05$; **$p<0.01$; ***$p<0.001$.

## 4.3. Results

We found no differences between the outcomes of the BB → RS versus RS → BB ordered treatments (using a likelihood ratio chi-square test) and so combined the data across presentation order for the remaining analysis. We computed the percentage of participants who prefer the buyback contract for each critical ratio, $P_{BB}$, and used a likelihood ratio test to examine whether this percentage is significantly smaller than 50% for high critical ratio treatments[5] ($Cr=0.95, 0.75$) and greater than 50% for low critical ratio treatments ($Cr=0.35, 0.15$). Table 2 lists the results (see the "Pooled" column). For the high critical ratio treatments, the percentages are significantly smaller than 50%, supporting H1A. However, for the low critical ratio treatments, the percentages are not significantly greater than 50%. Participant preferences appear random in this case, which fails to support H1B.

We next examine how the results vary based on the loss aversion tendencies of participants, revealed through their measured loss aversion coefficients $\gamma_i$ from the second task of the experiment. The solution to the critical ratio threshold (as shown in Proposition 2) shows that $Cr^0$ is a function of the demand distribution but not the loss aversion coefficient (for $\gamma>1$). However, Equation (5) shows that the absolute magnitude of $\Delta U_S$ decreases, eventually converging to 0, as $\gamma$ decreases to 1. This suggests that individuals with low loss aversion may find it more difficult to detect the sign of $\Delta U_S$ and be more susceptible to the influence of bounded rationality (Gigerenzer and Selten 2001 and Simon 1955). This claim is consistent with the quantal choice framework for modeling bounded rationality (e.g., Su 2008), which assumes that decision makers are more likely to make errors in choosing options that yield similar results than options that are clearly distinct. Low loss aversion

demand realizations was roughly the same between contracts (i.e., controlled for any behavioral differences resulting from knowledge of the next demand stream). However, we acknowledge that keeping the order of demand streams constant might be considered a "cleaner" test.

[4] The summary screen did not include a column listing the final profit for each trial, although this information could be easily computed by participants by adding the loss and gain.

[5] Testing $P_{BB}<50\%$ is equivalent to $P_{BB}<P_{RS}$ because $P_{RS}=100\%-P_{BB}$.

individuals may also have less incentive to distinguish between options since the relative utility gain is small (Eccles and Wigfield 2002). As a result, we expect preferences to appear more random for individuals with low levels of loss aversion.

Summary statistics of $\gamma_i$ across all participants are provided in Table B.2 in Appendix B. To test whether preferences of participants with high levels of loss aversion differ from participants with low levels of loss aversion, we partitioned the participants into either a low or high loss aversion group based on their measured loss aversion coefficients $\gamma_i$. We used the median from the combined data, 1.64, as the dividing line since the median was consistent across both experiments 1a and 1b (Mann–Whitney $U$ test of difference yields $p = 0.653$),[6] as well as consistent with the median reported in Abdellaoui et al. (2008).

The percentage of participants preferring the buyback contract across the four $Cr$ treatments for the low and high loss aversion groups are summarized in Table 2 under the columns labeled "Low $\gamma$" and "High $\gamma$," respectively. In the low loss aversion group, the percentages of participants preferring the buyback contract are indifferent from 50% for three of the four $Cr$ levels.[7] By contrast, the high loss aversion group continues to reveal strong preferences that are sensitive to the critical ratio level. The percentages of participants preferring the buyback contract are significantly less than 50% ($p < 0.001$) in the high critical ratio treatments. For the low critical ratio treatments, the magnitude of $P_{BB}$ has increased relative to the pooled analysis, and this percentage is now significantly greater than 50% in the $Cr = 0.15$ treatment. As a whole, these results suggest that loss aversion level influences contract choice, with more consistent preference trends for participants in the higher loss aversion group.

### 4.4. Robustness Test

To further test the predictions of H1A and H1B, we conducted a follow-up study in the form of a simple vignette-based survey administered to an independent subject pool consisting of 166 undergraduate students in multiple sections of an introductory operations management course. Participants were given a description of the two contract options, with parameters matching those of experiment 1a, and asked which contract they preferred. Each participant answered only one question (i.e., were assigned to only one critical ratio setting). The description did not include information about how the retailer would respond to either contract in terms of the order quantity ($q$) or provide an opportunity to experience the cash flows associated with each contract. In this sense, the experiment tested whether the contract frame alone triggered a preference, independent of making the cash flow explicit or guaranteeing how the retailer would respond to each contract. The results, summarized in Table 3, show a similar pattern of support for the hypotheses but at a reduced level of significance. The percentages of participants choosing buyback contracts are significantly lower than 50% in the high critical ratio settings but not in the low critical ratio settings (similar to the results of experiment 1 but at a weaker level). There also continues to be a significant decreasing trend of choosing buyback as the critical ratio grows ($\chi^2(3) = 6.624$, $p = 0.0849$).

**Table 3** **Survey Results**

| | BB → RS | | RS → BB | | |
|---|---|---|---|---|---|
| $Cr$ | Preferring BB | Total | Preferring BB | Total | Pooled $P_{BB}$ (%) |
| 0.95 | 9 | 22 | 6 | 22 | 34.09* |
| 0.75 | 8 | 18 | 6 | 19 | 37.84† |
| 0.35 | 11 | 20 | 8 | 19 | 48.72 |
| 0.15 | 12 | 24 | 15 | 22 | 58.70 |

† $p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

The survey results together with experiment 1 confirm that when human suppliers do exhibit significant preferences between financially equivalent buyback and revenue-sharing contracts, these preferences appear directionally consistent with loss aversion theory. These results also raise the possibility that if a supplier has the authority to set the contract parameters, her decisions may differ from a profit-maximizing supplier (i.e., Equations (1) and (2)) in a direction consistent with loss aversion.

## 5. Study 2: Optimizing Contract Parameters for a Loss-Averse Supplier

We now proceed to our main study, which explores how a supplier will set the contract parameters for buyback and revenue-sharing contracts, acknowledging that loss aversion may be a contributing behavioral factor. The study also examines how the expected profits resulting from these decisions compare across contracts. We are interested in understanding the impact on expected profit since this is important from the company point of view, even if it does not match the utility function of the supply manager who is making parameter decisions.

[6] We also tried two other cutoffs (1.3 and 1.7) as well as more than two groups. In all cases, we found similar results.

[7] The only exception is the $Cr = 0.95$ case. In this treatment, because of the large value of $p$, the magnitudes of the $\Delta U_S$ are very large even for individuals with a low to moderate level of loss aversion. As a result, individuals may be able to detect the difference between the two contracts and thus indicate a clear preference even at a lower loss aversion levels.

In our analysis, we continue to assume the reservation profit for the retailer, $M$, is equal to the expected profit the retailer would achieve under the supplier's associated optimal wholesale price contract (i.e., a contract with only one parameter, $w_p$). We also assume that market demand follows a $U[0, B]$ distribution. Applying the results from Lariviere and Porteus (2001), it is easy to show that the optimal wholesale price for an expected profit-maximizing supplier under a wholesale price contract is $w_p^* = (p+c)/2$, and the retailer's associated expected reservation profit is

$$M = \frac{(p-c)^2}{8p} B. \tag{6}$$

### 5.1. Theory and Hypothesis

Similar to Study 1, we start by developing a theory for how a loss averse supplier would perform this task. We do so by characterizing the monotonicity of the contract parameters over the loss aversion space and comparing them with a profit-maximizing supplier's decisions, ($w_b^c$, $b^c$) and ($w_r^c$, $r^c$), as defined in Proposition 1. Since ($w_b^c$, $b^c$) and ($w_r^c$, $r^c$) coincide with those of the centralized supply chain, we refer to them as the *channel-optimal* contract parameters.

Starting with the buyback contract, this requires solving problem (BB) with the the supplier's profit equation replaced by utility function (3). The solution is defined as follows.

Proposition 3. *The supplier's optimal wholesale price under a buyback contract, $w_b^*$, is nonincreasing in $\gamma$, with a lower bound of $w_p^*$. The optimal buyback price $b^*$ is also nonincreasing in $\gamma$, with a lower bound of 0. Furthermore, $w_b^* = w_p^*$ and $b^* = 0$ for $\gamma \geq 2$. The optimal buyback parameter $b^*$ for a given $w_b^*(\gamma)$ is*

$$b^*(w_b^*) = p - \frac{4p(p - w_b^*)^2}{(p-c)^2}. \tag{7}$$

Proposition 3 suggests that under the buyback contract, a loss-averse supplier will always set a lower wholesale price than a profit-maximizing supplier. Loss aversion makes the buyback loss more salient compared with the initial revenue, which leads the supplier to reduce the buyback price. This lower buyback price requires the supplier to also reduce her wholesale price to ensure the retailer's profit level is at least $M$. The wholesale and buyback prices both decrease with $\gamma$ as long as $\gamma < 2$. Once the level of loss aversion exceeds this threshold, the potential for higher profit is overcome by the disutility of a potential loss, leading the supplier to deactivate the buyback term and effectively offer a wholesale price contract.

In the case of revenue sharing, loss aversion influences the supplier's choice of parameter values ($w_r^*$ and $r^*$) in a different way. We show this below.

Proposition 4. *The supplier's optimal wholesale price under a revenue-sharing contract, $w_r^*$, is nondecreasing in $\gamma$, with an upper bound of $c$. The optimal revenue share $r^*$ is nonincreasing in $\gamma$, with a lower bound of $r_0$, where*

$$r_0 = (p-c) - \frac{(p-c) + \sqrt{(p-c)^2 + 16pc}}{8p}(p-c). \tag{8}$$

*Furthermore, there exists a loss aversion coefficient threshold $\gamma_0$, where $w_r^* = c$ and $r^* = r_0$ for $\gamma \geq \gamma_0$. This threshold is defined by*

$$\gamma_0 = \frac{2p - r_0 - ((p-c)/2)\sqrt{p/(p-r_0)}}{p - r_0 + c}. \tag{9}$$

*Finally, the optimal revenue-sharing parameter $r^*$ for a given $w_r^*(\gamma)$ is*

$$r^*(w_r^*) = (p - w_r^*) - \frac{(p-c) + \sqrt{(p-c)^2 + 16 w_r^* p}}{8p}(p-c). \tag{10}$$

Proposition 4 suggests that under the revenue-sharing contract, a loss-averse supplier will always set a higher wholesale price than a profit-maximizing supplier. When the level of loss aversion is relatively low, i.e., $\gamma < \gamma_0$, the optimal wholesale price $w_r^*$ is still below the production cost $c$. However, this wholesale price converges to $c$ as $\gamma$ increases. Once $\gamma$ exceeds the threshold $\gamma_0$, the supplier sets $w_r^* = c$ in order to avoid an initial loss. Unlike the buyback contract, where the loss aversion threshold is always 2, the threshold $\gamma_0$ varies with the critical ratio. It is never in the supplier's interest to set $w_r^*$ above $c$ since this would decrease her total profit while providing no benefit in terms of reducing the initial loss. Also unlike the buyback contract, the optimal revenue-sharing contract always has an active revenue-sharing term (i.e., the supplier never resorts to using a wholesale price contract).

Propositions 3 and 4 yield three sets of testable hypotheses. Hypothesis 2 compares the value of the wholesale price and associated buyback price or revenue share with the channel-optimal values. Hypotheses 3 and 4 examine how these contract parameters will change based on the supplier's loss aversion level.[8]

Hypothesis 2. *Compared with the associated channel-optimal contract parameter values, a human supplier will set* (a) *lower wholesale and buyback prices under a buyback contract and* (b) *a higher wholesale price but lower revenue share under the revenue-sharing contract.*

[8] Although the analytical results of Propositions 3 and 4 are limited to the $U[0, B]$ distribution because of the complexity of the supplier's problem structure, we did perform numerical experiments under the gamma distribution (which may be more representative of real market demand) and found the predictions implied by these propositions continue to hold.

Hypothesis 3. *Under a buyback contract, a human supplier's* (a) *wholesale price and* (b) *buyback price is nonincreasing in the individual's level of loss aversion.*

Hypothesis 4. *Under a revenue-sharing contract, a human supplier's* (a) *wholesale price is nondecreasing and* (b) *revenue share is nonincreasing in the individual's level of loss aversion.*

Having characterized the optimal buyback and revenue-sharing contract parameters and how they change with the supplier's level of loss aversion, we can use these solutions to compare the profits achieved by the two contracts and determine which contract yields a higher expected profit for the supplier's company. First, we establish how the loss aversion thresholds compare for the two contracts.

Lemma 1. *The revenue-sharing threshold* $\gamma_0$ *is smaller than the buyback threshold* 2.

This lemma suggests that the revenue-sharing contract parameters converge to constant values for a wider range of loss aversion levels than the buyback contract. This result helps establish how profits compare for suppliers whose loss aversion levels are relatively high.

Proposition 5. *A revenue-sharing contract yields higher profit than a buyback contract if the contract parameters are set by a sufficiently loss-averse supplier, i.e.,* $\gamma > \max(\gamma_0, \gamma_1)$, *where* $\gamma_0$ *is defined by* (9) *and* $\gamma_1$ *is the root of the following polynomial equation*:

$$(-\gamma^2+8\gamma-4)(p-c)^2-4\gamma^2 pr_0\left(1-\left(\frac{c}{p-r_0}\right)^2\right)=0. \quad (11)$$

*Furthermore*, $\max(\gamma_0, \gamma_1) < 2$.

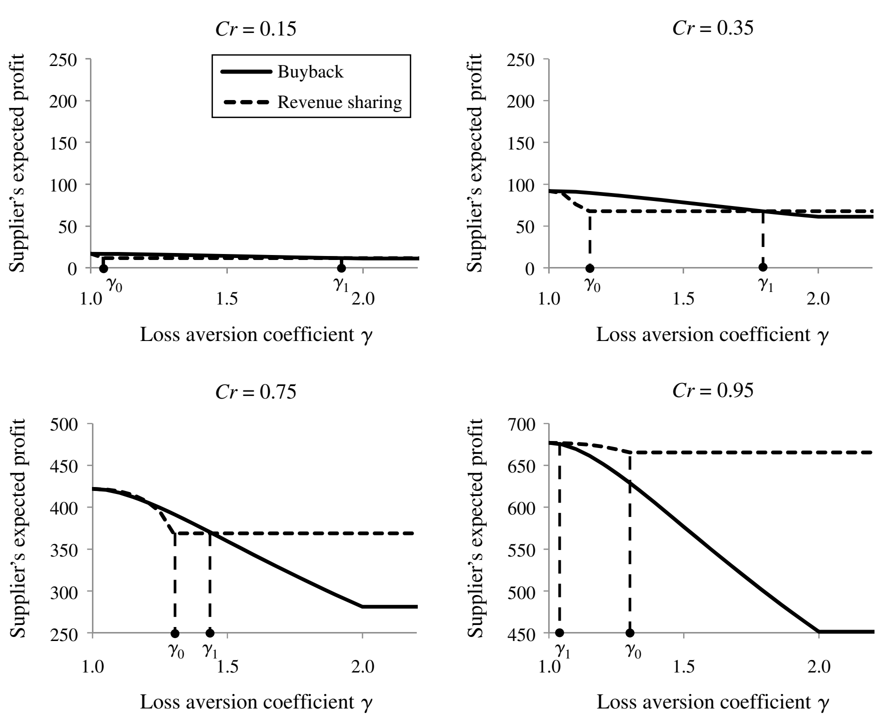
This result leads to a testable hypothesis.

Hypothesis 5. *Revenue sharing yields higher expected profit than buyback when contract parameters are set by a human supplier with high loss aversion* (*e.g.*, $\gamma > \max(\gamma_0, \gamma_1)$).

Proposition 5 provides a sufficient condition when revenue sharing dominates buyback. The threshold on $\gamma$ defines a relatively high level of loss aversion. For example, using the revenue and cost parameterizations used for experiment 1a (which we will also use later in experiments 2a and 2b), this threshold spans 1.29–1.92, which is near the median level (1.64) of the loss aversion coefficients we measured in the second task of the experiment. When loss aversion is below this threshold, it is unclear which contract dominates because a direct analytical comparison of the profit levels is no longer possible. However, to shed some light on how profits compare in this case, we performed a numerical study.

Figure 1 illustrates the main insights from the larger study, using the four revenue and cost parameterizations from experiment 1a. Here, we see that the

**Figure 1** **Impact of Contract Type on Supplier's Expected Profit**




*Note.* To illustrate the relative sensitivity of the supplier's expected profit in these examples, we scale the supplier's profit ($y$ axis) within the same range of 250 units (i.e., (0, 250) for $Cr = 0.15$ and 0.35, (250, 500) for $Cr = 0.75$, and (450, 700) for $Cr = 0.95$).

range of $\gamma$ levels where revenue sharing yields higher profit increases with the critical ratio. Also, its potential profit benefit over buyback grows with the critical ratio. Together, this suggests that a higher percentage of suppliers will benefit from adopting the revenue-sharing contract in a high $Cr$ environment compared with a low $Cr$ environment. Examining profit differences below the $\gamma$ threshold defined in Proposition 5 reveals no clear pattern. For example, in the low $Cr$ environments (0.15 and 0.35), the buyback contract seems to yield higher profit, whereas in the very high $Cr$ environment (0.95), revenue sharing becomes dominant. When $Cr = 0.75$, revenue sharing slightly outperforms buyback for very small $\gamma$ but becomes worse as $\gamma$ increases to a moderately low level. Altogether, this suggests that neither contract will consistently dominate for suppliers with low loss aversion levels.

### 5.2. Experimental Design

This experimental design followed a similar protocol to experiment 1, with two tasks performed on a computer. In the first task, participants take the role of a supplier facing an automated retailer and set contract parameters for one of the two contracts. Once again, to be consistent with our theory, the retailer's role is programed to choose $q^*$ to maximize his own expected profit.[9] In the second task, the participant's loss aversion level is assessed using the same procedure described in Appendix B. Ninety-six participants were recruited from the same subject pool described in §4.2 and spread between two experiments, 2a and 2b, explained in detail below. They were paid based on performance from both tasks, plus a $5 show-up fee. The final payment to all participants ranged from $7 to $25, with a median payment of $13.

For each experiment, the experimental design for the first task is a $2 \times 2$ between-subject design with two $Cr$ levels (0.35 or 0.75) and two contract types (BB or RS). Similar to experiment 1, we use the same set of 14 demand streams for all four treatments, with $D \sim U[0, 100]$. The market price $p$ is set to be $20, constant across all treatments. The corresponding production cost is thus $5 for the $Cr = 0.75$ treatment and $13 for $Cr = 0.35$. The participants took the role of a cheesecake supplier and had to set the contract terms for either a buyback or revenue-sharing contract, which was offered to the local store. They were told the store's ordering decisions would be automated and set to maximize the store's own profit. They were also told their decision screen would contain a support tool that displays the store's resulting order quantity decision for any possible contract parameter value. The specifics of the contract were then explained. Detailed experimental instructions, along with screen shots, are included in the online appendix. The experiment lasted 20 rounds with the first 5 rounds indicated as a warm-up period for participants to get familiar with the contract. They were paid based on the average profit earned in the last 15 rounds.

In experiment 2a, we limited the participants' decision to only choosing their desired wholesale price ($w$). Based on this inputted $w$, the program then provided the associated optimal $b$ or $r$ for each contract, as defined by Equation (7) or (10). In other words, for the chosen wholesale price $w$, we provided either a $b^*(w)$ or $r^*(w)$ that maximizes the supplier's expected profit while giving the retailer a profit of at least $M$.[10] The purpose of providing the optimal $b$ or $r$ was to simplify the task to control for potential decision errors resulting from the decision maker's bounded rationality or inability to optimize, allowing us to focus on examining how participants' contract decisions are influenced by their intention (i.e., utility function). In experiment 2b, we relaxed this assumption by allowing participants to set both contract parameters, which represents a more complex, but perhaps more natural, decision task. Our focus here is not to compare between the two experiments but rather test whether the hypotheses are robust to both types of tasks. In both experiments, we limit the choice of wholesale price by setting a lower and an upper bound (i.e., $w_b^{\text{lower}}$ and $w_b^{\text{upper}}$ for buyback; $w_r^{\text{lower}}$ and $w_r^{\text{upper}}$ for revenue sharing), as shown in Table 4. The lower bound for $w_b$ is the optimal wholesale price under a wholesale price contract, $w_p^*$, according to Proposition 3. The upper bound is the largest possible $w_b$ such that $w_b > b$.[11] As suggested by Proposition 4, the range of $w_r$ is between 0 and $c$, inclusive.[12]

Participants were aided by a decision tool that appeared on the first screen of each round. For example, in the buyback contract treatment, a scrollbar was used to choose the initial wholesale price. In experiment 2a, once a wholesale price was chosen, the associated optimal buyback price was then automatically

[9] Solving the second constraint from problems (BB) and (RS), the retailer's optimal order quantity for a given set of contract parameters, $(w_b, b)$ and $(w_r, r)$, is $q_b^*(w_b, b) = (p - w_b)B/(p - b)$ and $q_r^*(w_r, r) = (p - w_r - r)B/(p - r)$, respectively.

[10] In fact, for a given wholesale price, under the optimal value of $b^*(w)$ or $r^*(w)$, the retailer's profit is exactly equal to the reservation profit $M$.

[11] By definition, the buyback price $b$ must be less than the wholesale price $w_b$. Otherwise, the retailer could maximize profit by ordering infinity.

[12] It is feasible for $w_r$ to be greater than $c$, but we are interested in situations where the supplier experiences a loss up front since this is typically how revenue sharing contracts work in practice. Also from the results of the experiment, we only observed 0.82% of decisions at $w_r = c$.

**Table 4** **Parameter Values for Both Experiments 2a and 2b ($p = \$20$ for all $Cr$ Treatments)**

| | | Buyback | | | | Revenue sharing | | | |
|---|---|---|---|---|---|---|---|---|---|
| $Cr$ | $c$ | $w_b^{\text{lower}}$ | $w_b^{\text{upper}}$ | $n$ (2a) | $n$ (2b) | $w_r^{\text{lower}}$ | $w_r^{\text{upper}}$ | $n$ (2a) | $n$ (2b) |
| 0.35 | 13 | 16.5 | 19.2 | 10 | 10 | 0.0 | 13.0 | 11 | 13 |
| 0.75 | 5 | 12.5 | 17.1 | 14 | 13 | 0.0 | 5.0 | 13 | 12 |

displayed. By contrast, for experiment 2b, a second scrollbar was used to set the buyback price $b$. To match our theory that the supplier must provide a minimum level of profit to the retailer, we showed the participants the lowest possible value for the buyback parameter, $b_{\min}$, for their inputted $w$, which is calculated using (7). If a participant sets $b$ below this value, his or her order quantity and profit default to 0.

For a given set of contract parameters, the computer also displayed the store's associated order quantity, the supplier's resulting initial revenue at the beginning of the week, and the possible buyback cost at the end. Since the buyback cost is dependent on the realized customer demand, which is not known at the decision stage, the screen displays the highest and lowest possible buyback costs (i.e., $b \times q$ and 0, respectively). This provides knowledge of the range of possible buyback cost outcomes at the end of the week while not overemphasizing the second period by listing the full distribution of possible outcomes. All the feedback information is presented in words to make sure the format is consistent across the two periods (i.e., the beginning and end of the week).

After confirming the contract parameters, participants then clicked on the "ok" button and advanced to a second screen showing the initial revenue, followed by a third screen showing the demand realization and total buyback cost. A history of contract parameters, store order quantities, demand, earnings before and after the demand realization, and round profit was displayed on the bottom of each screen. The revenue-sharing contract treatment was designed similarly.

### 5.3. Results

**5.3.1. Influence of Loss Aversion on Contract Parameters.** We start by examining whether the contract parameters set by human decision makers are different from the channel-optimal contract parameters (i.e., a profit-maximizing supplier's decision). Figure 2 plots the decisions made by the participants in each round, together with the channel-optimal values, $(w_b^c, b^c)$ and $(w_r^c, r^c)$. From the figure, we observe that under the buyback contract (top two panels), both the wholesale price and the buyback price are below the channel-optimal values. This suggests that human suppliers tend to avoid the buyback loss and thus choose a lower buyback price. This lowered buyback price requires them to reduce the wholesale price in order to maintain a minimum profit level for the retailer. Under the revenue-sharing contract (bottom two panels), we observe higher wholesale prices and lower revenue shares compared with the channel-optimal values, suggesting that human suppliers have the tendency to reduce the initial loss at the expenses of future revenue. We formally test these results by comparing the experimental data against the channel-optimal values using the one-tailed Wilcoxon signed-rank test. The analysis in Table 5 confirms the results, indicating full support for H2.

To test Hypotheses 3 and 4, we fit a regression model to characterize the influence of the loss aversion coefficient and critical ratio level on the contract parameters, $(w_b, b)$ and $(w_r, r)$, chosen by the supplier. We present below the regression model for the wholesale price. The regression equations for the buyback price and revenue share have a similar structure:

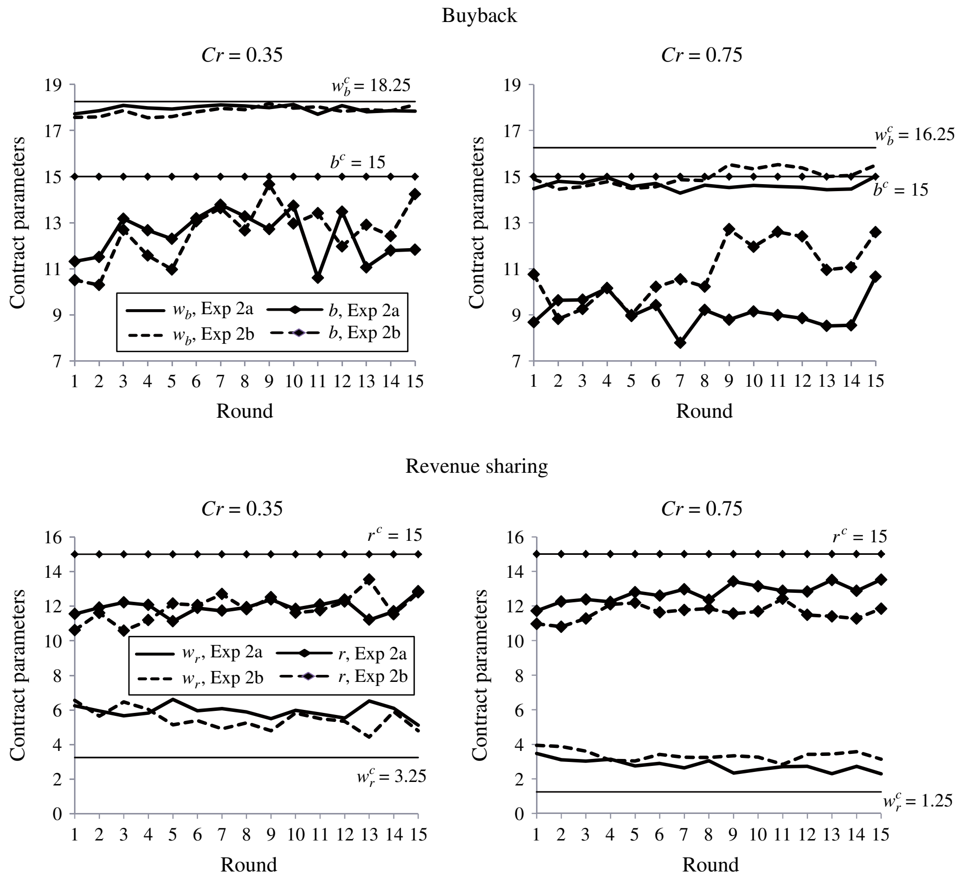
$$w_{i,t} = \mathit{Intercept} + \beta_{Cr} \times Cr + \beta_{\gamma_i} \times \gamma_i + \beta_{Cr\times\gamma_i} \times (Cr \times \gamma_i) + \mu_i + \varepsilon_{i,t}. \tag{12}$$

The dependent variable $w_{i,t}$ is subject $i$'s wholesale price in round $t$. The variable $Cr$ is a dummy variable for the critical ratio level, with the value set to 1 for the $Cr = 0.75$ treatment, and $\gamma_i$ is the measured loss aversion coefficient from the second task. We also include an interaction term $(Cr \times \gamma_i)$ to capture possible interaction effects.[13] We use a random effect model to control for unobserved heterogeneity across individuals, which is captured by the individual-specific error term $\mu_i$.[14] Both $\mu_i$ and $\varepsilon_{i,t}$ are assumed to be normally distributed with mean zero and standard deviation $\sigma_\mu$ and $\sigma_\varepsilon$, respectively. Note that for experiment 2a we only fit the regression model for the

[13] We ran a set of regressions that also included round index $t$ and its interaction terms with $Cr$ and $\gamma_i$. None of these terms was significant, suggesting that the learning effect is minimal. This lack of a learning effect could be because the experiment contained five unpaid "warm-up" rounds.

[14] This error term can capture the potential correlation among contract decisions, $w_{i,t}$, in different rounds $t$ for a given individual $i$. Moreover, $\mu_i$ accounts for the differences in the demand series each subject might see. Similar regression models have been used in prior research to analyze experimental data involving contract decisions (e.g., Kalkanci et al. 2011, 2013; Becker-Peth et al. 2013).

**Figure 2** **Average Contract Parameter Decisions in Each Round for Experiment 2a (Solid) and Experiment 2b (Dashed)**




wholesale price since this is the only decision variable. For experiment 2b, we fit a separate regression model for all contract parameters. We use the feasible generalized least square (FGLS) procedure to estimate our model with the regression estimates shown in Table 6.

The coefficient $\beta_{\gamma_i}$ measures the marginal changes in the contract parameters as the individual's level of loss aversion increases in the $Cr = 0.35$ treatment, and $(\beta_{\gamma_i} + \beta_{Cr\times\gamma_i})$ measure this change for the $Cr = 0.75$ treatment. We use the Wald test for linear restrictions to examine whether these two linear restrictions are significantly different from zero. Since we already predicted the direction (both linear restrictions are hypothesized to be less than zero for $w_b$ and $b$ (H3) and $r$ (H4), and greater than zero for $w_r$ (H4)), we perform a one-tailed test with the results summarized in Table 7.

Under the buyback treatment, both linear restrictions for the wholesale price $w_b$ are significantly smaller than zero, which is true in both experiments 2a and 2b. This implies that wholesale price decreases with participant's level of loss aversion, supporting Hypothesis 3(a). Similarly, under the revenue-sharing contract, the linear restrictions are significantly positive, suggesting that wholesale price increases with loss aversion level, supporting Hypothesis 4(a). Following the

**Table 5** **Comparison of Mean Contract Parameters for Experiments 2a and 2b vs. Channel Optimal**

| | Buyback contract | | | | | | Revenue-sharing contract | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Wholesale price ($w_b$) | | | Buyback price ($b$) | | | Wholesale price ($w_r$) | | | Revenue share ($r$) | | |
| *Cr* | 2a | 2b | vs. $w_b^c$ | 2a | 2b | vs. $b^c$ | 2a | 2b | vs. $w_r^c$ | 2a | 2b | vs. $r^c$ |
| 0.35 | 17.95 | 17.84 | 18.25 | 12.43 | 12.53 | 15 | 5.91 | 5.46 | 3.25 | 11.92 | 11.91 | 15 |
| | (17.90) | (17.80) | Lower | (12.80) | (12.80) | Lower | (5.20) | (5.00) | Higher | (12.70) | (12.40) | Lower |
| | [0.67] | [0.57] | $p < 0.001$ | 4.82 | 3.77 | $p < 0.001$ | [3.16] | [3.08] | $p < 0.001$ | [3.66] | [3.88] | $p < 0.001$ |
| 0.75 | 14.62 | 14.98 | 16.25 | 9.13 | 10.88 | 15 | 2.78 | 3.36 | 1.25 | 12.76 | 11.62 | 15 |
| | (14.50) | (14.70) | Lower | (9.30) | (10.40) | Lower | (2.80) | (3.30) | Higher | (12.60) | (11.70) | Lower |
| | [1.32] | [1.12] | $p < 0.001$ | [4.88] | [4.00] | $p < 0.001$ | [1.48] | [1.15] | $p < 0.001$ | [2.19] | [1.67] | $p < 0.001$ |

*Note.* Medians are listed in parenthesis and standard deviations in brackets.

**Table 6** FGLS Estimation for Participants' Contract Parameters

| | Experiment 2a | | Experiment 2b | | | |
|---|---|---|---|---|---|---|
| | $w_b$ | $w_r$ | $w_b$ | $w_r$ | $b$ | $r$ |
| *Intercept* | 19.11*** | 0.23 | 18.20*** | 2.38** | 14.16*** | 15.25*** |
| | (0.37) | (1.24) | (0.16) | (0.78) | (1.10) | (1.07) |
| $Cr$ | −2.24** | 1.42 | −2.08*** | 0.39 | 0.10 | −2.92* |
| | (0.83) | (1.32) | (0.47) | (0.82) | (1.81) | (1.14) |
| $\gamma_i$ | −0.70*** | 2.91*** | −0.19** | 1.72** | −1.13** | −1.86** |
| | (0.20) | (0.70) | (0.06) | (0.52) | (0.42) | (0.68) |
| $Cr \times \gamma_i$ | −0.69 | −2.29** | −0.56** | −1.43** | −1.45† | 1.52* |
| | (0.44) | (0.74) | (0.21) | (0.52) | (0.80) | (0.68) |
| $\sigma_\mu$ | 0.68*** | 1.19*** | 0.49*** | 1.62*** | 1.95*** | 2.17*** |

*Note.* Robust standard deviations are reported in parentheses.
†$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

**Table 7** Wald Test for the Changes in Contract Parameters

| | Experiment 2a | | Experiment 2b | | | |
|---|---|---|---|---|---|---|
| | $w_b$ | $w_r$ | $w_b$ | $w_r$ | $b$ | $r$ |
| $Cr = 0.35$ (value of $\beta_{\gamma_i}$) | −0.70*** | 2.91*** | −0.19** | 1.72** | −1.13** | −1.86** |
| $Cr = 0.75$ (value of $\beta_{\gamma_i} + \beta_{Cr\times\gamma_i}$) | −1.39** | 0.62* | −0.75*** | 0.29** | −2.58*** | −0.34*** |

†$p < 0.1$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

same procedure, we examine the linear restrictions for the buyback price $b$ and revenue share $r$ using data from experiment 2b. Since they are all significantly negative, both buyback price and revenue share are decreasing with loss aversion, which shows support for Hypotheses 3(b) and 4(b). Interestingly, the estimated changes in $w_b$ and $w_r$ in experiment 2b are smaller than those in experiment 2a, suggesting that the influence of loss aversion on wholesale prices is reduced when participants set the two contract parameters simultaneously.

**5.3.2. Influence of Loss Aversion on Expected Profit.** We apply the following regression model to compare expected profit under the buyback and revenue-sharing contracts for each of the $Cr$ treatments:[15]

$$E(\Pi)_{i,t} = Intercept + \beta_{\gamma_i} \times \gamma_i + \beta_{BB} \times BB + \beta_{\gamma_{i\times BB}} \times (\gamma_i \times BB) + \mu_i + \varepsilon_{i,t}, \qquad (13)$$

where $BB$ takes a value of 1 for buyback and 0 for revenue sharing. We fit the regression model for experiments 2a and 2b separately, with the results summarized in Table 8.

[15] Note that the actual payout earned is a linear transformation of the "points" cumulated during the experiment. As is typical in previous newsvendor studies (e.g., Kalkanci et al. 2011, 2013), we use *points* as the dependent variable in our regressions. Using the actual payout instead of experimental points as the dependent variable changes the magnitude of the regression coefficients (i.e., the $\beta$'s) but not the significant level.

**Table 8** FGLS Estimation for $E(\pi)_{i,t}$

| | Experiment 2a | | Experiment 2b | |
|---|---|---|---|---|
| | $Cr = 0.35$ | $Cr = 0.75$ | $Cr = 0.35$ | $Cr = 0.75$ |
| *Intercept* | 93.61*** | 404.64*** | 34.16 | 390.67*** |
| | (3.10) | (6.21) | (32.52) | (7.08) |
| $\gamma_i$ | −4.95** | −3.54 | 15.12 | −2.10* |
| | (1.66) | (3.03) | (13.49) | (1.05) |
| $BB$ | −48.93 | 7.20 | 45.16 | 18.86 |
| | (31.01) | (18.57) | (34.55) | (14.37) |
| $\gamma_i \times BB$ | 10.93 | −29.41** | −19.31 | −21.22*** |
| | (14.57) | (11.36) | (14.56) | (6.04) |
| $\sigma_\mu$ | 13.09*** | 19.55*** | 22.11*** | 15.57*** |

*Note.* Robust standard deviations are reported in parentheses.
†$p < 0.1$; *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Combining regression terms, $(\beta_{BB} + \beta_{\gamma_{i\times BB}} \times \gamma_i)$ measures the difference in the supplier's expected profit, $\Delta E(\pi_i)$, between buyback and revenue-sharing contracts. Neither of the coefficients ($\beta_{BB}$ or $\beta_{\gamma_{i\times BB}}$) is significant for the $Cr = 0.35$ case, indicating that there is not a significant difference in expected profit in this low critical ratio environment. By contrast, for the $Cr = 0.75$ treatment, the slope $\beta_{\gamma_{i\times BB}}$ is significantly negative, implying that $\Delta E(\pi_i)$ is decreasing in $\gamma_i$. This suggests that the revenue-sharing contract begins to dominate buyback for the supplier as the loss aversion level increases. To test whether revenue sharing indeed yields higher profit for suppliers with a relatively high level of loss aversion, as predicted in H5, we compare differences in expected profit (i.e., the value of $\beta_{BB} + \beta_{\gamma_{i\times BB}} \times \gamma_i$) for several percentiles of $\gamma_i$ (one-tailed Wald test). The results are summarized in Table 9.

The results reveal an interesting interplay between the impact of loss aversion and critical ratio level, as alluded to earlier in our discussion of Figure 2. In experiment 2a, $\Delta E(\pi_i)$ is significantly negative for $Cr = 0.75$ across all loss aversion percentiles and marginally significant when $Cr = 0.35$. This provides partial support for H5 (which predicted revenue sharing would dominate for all critical ratio levels, but only for relatively high loss-averse suppliers). However, the result is consistent with the more informal prediction (inspired by our numerical study) that revenue sharing will dominate for a larger percentage of suppliers when the critical ratio is high versus low. In experiment 2b, where the participants set both contract parameters, similar trends apply but at less significant levels. For example, $\Delta E(\pi_i)$ is now significantly negative for $Cr = 0.75$ only across high aversion percentiles of 50% or higher, and it is no longer marginally significant for any percentiles when $Cr = 0.35$. Together, these results suggest that revenue sharing becomes more attractive for the supplier's firm as the supplier's loss aversion level or the product's $Cr$

**Table 9** Wald test for $\Delta E(\pi_i) = \beta_{BB} + \beta_{\gamma_i \times BB} \times \gamma_i$

| | | $Cr = 0.35$ | | $Cr = 0.75$ | |
|---|---|---|---|---|---|
| Percentile | $\gamma_i$ | Experiment 2a | Experiment 2b | Experiment 2a | Experiment 2b |
| 5th | 1.03 | −37.67<br>($p = 0.092$) | 25.27<br>($p = 0.207$) | −23.10<br>($p = 0.006$) | −3.00<br>($p = 0.376$) |
| 25th | 1.27 | −35.05<br>($p = 0.080$) | 20.64<br>($p = 0.218$) | −30.16<br>($p = 0.000$) | −8.08<br>($p = 0.173$) |
| 50th (median) | 1.64 | −31.00<br>($p = 0.056$) | 13.50<br>($p = 0.257$) | −41.04<br>($p = 0.000$) | −15.94<br>($p = 0.018$) |
| 75th | 2.04 | −36.63<br>($p = 0.057$) | 5.78<br>($p = 0.448$) | −52.80<br>($p = 0.000$) | −24.43<br>($p = 0.001$) |
| 95th | 3.44 | −11.33<br>($p = 0.133$) | −21.25<br>($p = 0.221$) | −93.98<br>($p = 0.000$) | −54.13<br>($p = 0.000$) |

level increases, but these differences weaken in significance as the number of contract parameter decisions increases.

## 6. Discussion and Conclusion

The goal of this study was to determine how framing differences between buyback and revenue-sharing contracts influence a supplier's decisions on which contract to adopt, how contract parameters for each contract are set, and ultimately which contract results in higher final expected profit (after accounting for the supplier's parameter-specification behavior). Whereas profit maximization is a common goal at the firm level, the execution of contract terms is often conducted at the individual level, by human decision makers (supply managers) who may exhibit behavioral tendencies such as loss aversion. This study has uncovered how the performance of the two contracts may differ once such behavioral tendencies are factored in.

The context of our analysis has been a single period demand setting, where the supplier interacts with a retailer whose ordering behavior is dictated by a decision support system that is predictable and known by the supplier. When human suppliers are asked in this context to choose between buyback and revenue-sharing contracts whose parameters are preset to be optimal from an expected profit perspective, we find that their preference is dependent on the underlying critical ratio, with revenue sharing preferred in high critical ratio environments and buyback preferred in low critical ratio environments (particularly for high loss-averse individuals). We also find differences in performance of the two contracts when suppliers have the authority to set contract parameters. Once supplier behavior is incorporated, revenue sharing is more profitable for the supply firm in high critical ratio environments, whereas the contracts perform equally well in low critical ratio environments. These insights appear to be driven by, or at least are consistent with, the presence of loss aversion.

However, the main contribution of the paper is not the identification of loss aversion as a contributing factor. Rather, it is showing how the product environments, specifically the critical ratio level, influence contract preferences and performance in light of this psychological factor. These results can help guide supply firms in mapping contract options to environments where they perform best. When framing effects exist, contract managers should consider the impact of the underlying critical ratio on their contract decisions. Our research indicates that revenue-sharing contracts may yield higher expected profit than buyback when the supplier is free to set the contract terms and service requirements are high. Revenue sharing should be more seriously considered as a contract option in such situations. For instance, the most cited use of revenue sharing is in the movie rental industry, which is arguably a high critical ratio environment. The flow of transactions in revenue sharing is also similar to consignment or vendor-managed inventory schemes where the supplier incurs an initial loss but holds out for the possibility of a significant future gain. These schemes are usually offered with a high service-level guarantee, which implies a high critical ratio environment. It is important to note that consignment and vendor-managed inventory schemes differ from our setting in that they often require the supplier to take over the inventory quantity decision in addition to setting the contract parameters. However, even in such cases, inventory decisions are often made automatically using decision support systems, and so the supplier's ordering behavior may follow a similar pattern to our automated retailer model, whereas the supplier's choice of contract type and parameter values is still subject to human judgment.

It is important to emphasize that our research focused on contexts where the retail order decision is controlled in the sense that it followed a prespecified (profit-maximizing) decision rule known to the supplier. Whether the relevant performance of these contracts changes in settings where the retailer introduces his own set of behavioral tendencies is an open question. However, preliminary analysis (Zhang 2013) suggests that many previously identified behavioral tendencies of human newsvendors (i.e., retailers), such as bounded rationality, rejection risk, or preference toward minimizing ex post inventory error, have no influence on the relative benefit of buyback versus revenue-sharing contracts from the supplier's perspective. However, the presence of loss aversion may cause the retailer to order differently under the two contracts and could cause the relative benefits of the two contracts to change from the supplier's point of view.

Although our research suggests that supply firms should consider increasing the use of revenue-sharing over buyback contracts in some settings, more research is needed to determine the boundary conditions of this and other key findings. This requires extending the model setting in several important ways. The most obvious is to incorporate a more general characterization of the retailer's ordering behavior to capture settings where orders are not set automatically through a decision support system (and thus are prone to the behavioral tendencies of individual retailers). For example, future research could establish theoretical results for how buyback and revenue-sharing contracts compare from the retailer's point of view with carefully designed experiments to test the associated theoretical predictions. This direction includes investigating the retailer's preference over equivalent contracts and how the retailers set order quantities. Having a full understanding of the retailer's problem could help establish a utility function that better describes the retailer's contract behavior.

After understanding how a supplier and retailer make decisions individually, future research is required to study how social preferences, such as fairness concerns, influence contract performance for both players. Previous studies have already shown that social preferences influence supply chain transactions and the resulting profit allocation (Cui et al. 2007, Loch and Wu 2008). However, it is unclear whether social preferences reveal further differences between buyback and revenue-sharing contracts, including how the supplier sets contract terms and which terms are accepted by the retailer. For example, our analysis suggests that the supplier may retain higher profit under the revenue-sharing contract, which leads to an uneven profit allocation between supply chain members. As a result, revenue- sharing contracts may be more likely rejected by the retailer because of fairness concerns, which reduces the supplier's overall expected profit, making revenue sharing less attractive. Other structural differences between the contracts, including implementation cost, time value of money, and ability to audit, may further impact their relative benefits and should be considered before choosing to implement either contract in an industrial setting.

Finally, our model can be extended to consider other flexible contracts such as quantity flexibility contracts, option contracts, and sale-rebate contracts. Framing differences between these contracts may suggest the influence of other behavioral factors in addition to loss aversion. This will provide a more comprehensive understanding of why certain contracts are more commonly adopted in specific industries.

### Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/mnsc.2015.2182.

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## Appendix A. Proofs

### Proof of Proposition 1

We use proof by contradiction to show that $\{b^c = \lambda p, w_b^c = c + \lambda(p-c)\}$ and $\{r^c = \lambda p, w_r^c = (1-\lambda)c\}$ are optimal solutions to the supplier's problem. Focusing first on the buyback contract, we can plug in contract conditions (1) into the supplier and buyer profit functions to reveal $\pi_{S_{BB}}(w_b^c, b^c) = \pi^c - M$ and $\pi_{R_{BB}}(w_b^c, b^c) = M$. Suppose there exists a different pair of parameters, $(\bar{w}_b, \bar{b})$, which achieves a higher profit level for the supplier, i.e., $\pi_{S_{BB}}(\bar{w}_b, \bar{b}) > \pi^c - M$. By definition, the sum of the supplier's and retailer's profits cannot exceed the maximum channel profit; i.e., $\pi_{S_{BB}}(\bar{w}_b, \bar{b}) + \pi_{R_{BB}}(\bar{w}_b, \bar{b}) \le \pi^c$. This implies $\pi_{R_{BB}}(\bar{w}_b, \bar{b}) \le \pi^c - \pi_{S_{BB}}(\bar{w}_b, \bar{b}) < M$, which violates the first condition in problem BB. The proof for revenue sharing follows the same logic. The proof of equivalency and efficiency follows the arguments for Theorems 1 and 2 in Cachon and Lariviere (2005). Q.E.D.

### Proof of Proposition 2

To prove the existence of a unique threshold value, $Cr^0 \in (0,1)$, we need to show that the sign of $\Delta U_S$ switches only once as $Cr$ increases. To show this, we first rewrite $\Delta U_S$ as

$\Delta U_S = -\lambda p(\gamma-1)(qF(q)-S(q))$, where $q = F^{-1}(Cr)$. Since $q$ is a monotonically increasing function of $Cr$, we can shift our focus to determining whether $\Delta U_S$ only changes sign once with $q$. The first factor of $\Delta U_S$, $-\lambda p(\gamma-1)$ is strictly negative, so we can further shift our attention to the second factor, $qF(q)-S(q)$.

To establish that $qF(q)-S(q)$ has a unique zero point, we need to show that the function $\phi(q) = qF(q)-S(q)$ crosses the horizontal axis once and only once. Let $[\underline{q}, +\infty)$ for $\underline{q} \ge 0$ be the support of $F$, and let $\bar{q} \le +\infty$ be the supremum (the least upper bound) of the set that contains all elements satisfying $F(q) < 1$. We can then state that $0 < Cr < 1$ (equivalently, $0 < F(q) < 1$) implies $\underline{q} < q < \bar{q}$, and expected sales $S(q)$ can be rewritten as

$$S(q) = q - \int_{\underline{q}}^{q} F(x)\,dx.$$

We first consider the limit of the two ending points of $\phi(q)$:

$$\lim_{q\downarrow \underline{q}} \phi(q) = -S(\underline{q}) \le 0 \quad \text{and} \quad \lim_{q\uparrow \bar{q}} \phi(q) = \bar{q} - S(\bar{q}) > 0.$$

The upper limit is always strictly greater than zero, and so the behavior of $\phi(q)$ depends on whether $\underline{q}$ is equal to or strictly greater than zero. We examine each case in turn.

*Case* 1: $\underline{q} = 0$. In this case, we need to determine whether $\phi(q)$ crosses the horizontal axis at all (and if so, whether it crosses it only one time). Taking the first derivative of $\phi(q)$, we have

$$\begin{aligned}\phi'(q) &= 2F(q) - 1 + qf(q)\\ &= (1-F(q))\left(g(q) + \frac{1}{1-F(q)} - 2\right),\end{aligned} \tag{A1}$$

where $g(q) = qf(q)/(1-F(q))$ is the generalized failure rate of $F(q)$, which is assumed to be increasing in $q$. As a result, $g(q) + 1/(1-F(q)) - 2$ is increasing in $q$ and thus can be equal to 0 at only one point. Also, the upper limit of $\phi'(q)$, $\lim_{q\uparrow\bar{q}} \phi'(q) = 1 + \bar{q}f(\bar{q})$, is strictly positive, whereas the lower limit, $\lim_{q\downarrow 0} \phi'(q) = -1$, is strictly negative. This implies that $\phi'(q) < 0$ when $q$ is small and switches to $\phi'(q) > 0$ as $q$ increases. Thus, the function $\phi(q)$ is quasiconvex, which first decreases and then increases in $q$. Since we also know that the lower limit of $\phi(q)$ is zero and the upper limit is greater than zero, this implies that $\phi(q)$ crosses the horizontal axis once and only once, and therefore it has a unique zero point.

*Case* 2: $\underline{q} > 0$. In this case, it is easy to see that the lower limit of $\phi(q)$ is smaller than zero, so $\phi(q)$ will cross the horizontal axis at least once. Turning to the first derivative of $\phi(q)$ defined in (A1), we now find that the lower limit of $\phi'(q)$, $\lim_{q\downarrow\underline{q}} \phi'(q) = -1 + \underline{q}f(\underline{q})$, could be negative or positive. This implies that $\phi(q)$ is either a quasiconvex or increasing function of $q$ and, in either case, so crosses the horizontal axis once and only once, implying a unique zero point.

Combining the results of Cases 1 and 2, $\phi(q)$ has a unique zero point $q^0$ that solves $\phi(q^0) = 0$ and a corresponding $Cr^0$ that solves $F^{-1}(Cr^0)Cr^0 - S(F^{-1}(Cr^0)) = 0$. This leads to the following:

a. For $0 < Cr < Cr^0$ (or equivalently, $\underline{q} < q < q^0$), $\phi(q) < 0$ and $\Delta U_S > 0$, which implies that suppliers prefer the buyback contract.

b. For $Cr^0 < Cr < 1$ (or equivalently, $q^0 < q < \bar{q}$), $\phi(q) > 0$ and $\Delta U_S < 0$, which implies suppliers prefer a revenue-sharing contract.

c. For $Cr = Cr^0$ (or equivalently, $q = q^0$), $\phi(q) = 0$ and $\Delta U_S = 0$, which implies that suppliers are indifferent between a buyback and a revenue-sharing contract. Q.E.D.

**Proof of Proposition 3**

Proving this proposition requires characterizing the optimal contract parameters that solve problem (BB) when the supplier's objective function is replaced by utility function (3). Substituting the optimal order quantity for the retailer, $q^*(w_b, b)$, into this optimization problem yields the following modified formulation:

$$\begin{aligned}\max_{w_b,\, b}\ U_{S_{BB}}(w_b, b) = \max_{w_b,\, b}((w_b - c)q^*(w_b, b)\\ - \gamma b(q - S(q^*(w_b, b))))\end{aligned} \tag{BB-L}$$

$$\text{s.t.}\quad \pi_{R_{BB}}(w_b, b) \ge M,$$

where $q^*(w_b, b) = ((p-w_b)/(p-b))B$, $M = ((p-c)^2/(8p))B$, and $\pi_{R_{BB}}(w_b, b) = -w_b q^*(w_b, b) + pS(q^*(w_b, b)) + b(q^*(w_b, b) - S(q^*(w_b, b)))$.

We can construct the Lagrangean of problem (BB-L) as follows:

$$\begin{aligned}L(w_b, b; l) &= (w_b - c)q^*(w_b, b) - \gamma b(q^*(w_b, b) - S(q^*(w_b, b)))\\ &\quad + l(\pi_{R_{BB}}(w_b, b) - M),\end{aligned} \tag{A2}$$

where $l$ is a Kuhn–Tucker multiplier. The optimal solution to (BB-L) must satisfy the following conditions:

$$\frac{\partial L(w_b, b; l)}{\partial w_b} = 0, \tag{A3}$$

$$\frac{\partial L(w_b, b; l)}{\partial b} = 0, \tag{A4}$$

$$\frac{\partial L(w_b, b; l)}{\partial l} \ge 0, \tag{A5}$$

$$l \ge 0, \quad \text{and} \tag{A6}$$

$$l\frac{\partial L(w_b, b; l)}{\partial l} = 0. \tag{A7}$$

Equation (A7) implies that either $l = 0$ or $\partial L(w_b, b; l)/\partial l = 0$. We examine both cases.

*Case* 1: $l = 0$. In this case, we need to solve the system of equations consisting of (A3) and (A4) and check whether these solutions satisfy the condition (A5). Solving (A3) and (A4), we obtain one solution at $w^* = p$ and $b^* = p$. This solution cannot be the optimal contract parameters for the supplier since she extracts the entire channel profit and leaves zero profit for the retailer, which clearly violates condition (A5). Therefore, the optimal contract parameters cannot be obtained in this case.

*Case* 2: $\partial L(w_b, b; l)/\partial l = 0$. In this case, we need to solve the system of equations consisting of (A3), (A4), to identify any critical points and then check whether the solution satisfies condition (A6). Solving the problem, we obtain the following solution:

$$w_b^* = p - \frac{p-c}{4}\gamma, \quad b^* = \frac{4-\gamma^2}{4}p, \quad \text{and} \quad l^* = -\gamma + 2. \tag{A8}$$

When $l^* \geq 0$ or $\gamma \leq 2$, the supplier's optimal contract parameters are defined in (A8). When $l^* < 0$ or $\gamma > 2$, the optimal solution is obtained at the boundary where $b^* = 0$ and $w_b^* = (p+c)/2 = w_p^*$. It is easy to show that the optimal prices $w_b^*$ and $b^*$ both first decrease with $\gamma$ and then stay at $w_p^*$ and 0, respectively, when $\gamma > 2$, implying a nonincreasing function of $\gamma$. Furthermore, solving $\partial L(w_b, b; l)/\partial l = 0$, we obtain a relationship between the two optimal contract parameters:

$$b^* = p - \frac{4p(p - w_b^*)^2}{(p-c)^2}. \quad \text{Q.E.D.} \tag{A9}$$

**Proof of Proposition 4**

The proof of Proposition 4 is similar to the proof of Proposition 3. In the interest of brevity, we will only highlight major differences in the proof. Since the retailer is now offered a revenue-sharing contract, his optimal order quantity is given by the new expression:

$$q^*(w_r, r) = \frac{p - w_r - r}{p - r} B. \tag{A10}$$

The supplier's objective function is now dependent on whether $w_r$ is greater or less than $c$, and so we discuss the two cases separately.

*Case* 1: $w_r < c$. By constructing a Lagrangean function and solving the Kuhn–Tucker conditions, we can show that the optimal $r^*$ is given by the root of a polynomial equation:

$$(p - (\gamma - 1)(p - r^*) - \gamma c)^2 (p - r^*) = \frac{(p-c)^2 p}{4}, \tag{A11}$$

and the optimal wholesale price is

$$w_r^* = \frac{(\gamma - 1)(p - r^*)^2 + \gamma c (p - r^*)}{p}. \tag{A12}$$

The direct relationship between the two optimal contract parameters is

$$r^* = (p - w_r^*) - \frac{(p-c) + \sqrt{(p-c)^2 + 16 w_r^* p}}{8p}(p - c). \tag{A13}$$

Further, we can rewrite the Equation (A11) to obtain $\gamma$ as a function of $r^*$, which is[16]

$$\gamma = \frac{2p - r^* - ((p-c)/2)\sqrt{p/(p - r^*)}}{p - r^* + c}. \tag{A14}$$

Define $r_0$ to be the value of $r^*$ when $w^* = c$ and $\gamma_0$ be the value of $\gamma$ when $r^* = r_0$. Plugging these values into (A13) and (A14), we get

$$r_0 = (p-c) - \frac{(p-c) + \sqrt{(p-c)^2 + 16pc}}{8p}(p-c) \quad \text{and} \tag{A15}$$

$$\gamma_0 = \frac{2p - r_0 - ((p-c)/2)\sqrt{p/(p - r_0)}}{p - r_0 + c}. \tag{A16}$$

Lemma A1 (included after the proof of Proposition 4) suggests that $\gamma$ strictly decreases with $r^*$ for $r^* > r_0$. This is equivalent to saying that $r^*$ strictly decreases with $\gamma$, for $\gamma < \gamma_0$. Furthermore, from (A13) we can easily show that $r^*$ strictly decreases with $w_r^*$ by examining the first derivation. Therefore, $w_r^*$ strictly increases with $\gamma$ for $\gamma < \gamma_0$. For $\gamma \geq \gamma_0$, the optimal wholesale price can only be obtained when $w_r \geq c$, which leads to the second case.

*Case* 2: $w_r \geq c$. Solving the Kuhn–Tucker conditions, we obtain $w_{r1} = c/4$, and $r_1 = 3p/4$. This solution violates condition $w_r \geq c$ and thus cannot be the optimal solution to the supplier's problem. Therefore, the optimal solution is obtained at the boundary where $w_r^* = c$ and $r^* = r_0$.

Combining the results from Cases 1 and 2, it is clear that (1) the optimal wholesale price $w_r^*$ first increases with $\gamma$ for $\gamma < \gamma_0$ and then equals $c$ when $\gamma \geq \gamma_0$, implying a nondecreasing function of $\gamma$, and (2) the optimal revenue sharing $r^*$ first decreases with $\gamma$ for $\gamma < \gamma_0$ and then equals $r_0$ when $\gamma \geq \gamma_0$, implying a nonincreasing function of $\gamma$. The relationship between $w_r^*$ and $r^*$ is defined by (A13). Q.E.D.

Lemma A1. *The value of* $\gamma$ *is strictly decreasing in* $r^*$ *for* $r^* > r_0$.

Proof. From (A14), taking the first derivative of $\gamma$ with respect to $r^*$, we get

$$\frac{d\gamma}{dr^*} = \varphi(r^*) \frac{p - c}{(p - r^* + c)^2} \sqrt{\frac{p}{p - r^*}}, \tag{A17}$$

where

$$\varphi(r^*) = -\frac{c}{4(p - r^*)} + \sqrt{\frac{p - r^*}{p}} - \frac{3}{4}. \tag{A18}$$

We need to prove $d\gamma/dr^*$ is negative, or equivalently, $\varphi(r^*) < 0$ for $r^* > r_0$. Define $\tilde{r} = (p - c)/2$. We can easily check that $\tilde{r} < r_0$ and $\varphi(\tilde{r}) < 0$. From (A18) we see that $\varphi(r^*)$ decreases with $r^*$, and thus $\tilde{r} < r_0 < r^*$ implies that $\varphi(r^*) < \varphi(r_0) < \varphi(\tilde{r}) < 0$. Q.E.D.

**Proof of Lemma 1**

From Proposition 4 we know when $\gamma = \gamma_0$, $w_r^* = c$. Thus Equation (A12) implies that

$$\gamma_0 = \frac{pc + (p - r_0)^2}{(p - r_0)^2 + c(p - r_0)}, \tag{A19}$$

and

$$\gamma_0 - 2 = \frac{2cr_0 - cp - (p - r_0)^2}{(p - r_0)^2 + c(p - r_0)}. \tag{A20}$$

Since the denominator of Equation (A20) is positive, to prove that $\gamma_0 < 2$, we need to show that $\theta(r_0) = 2cr_0 - cp - (p - r_0)^2 < 0$. The first derivative of $\theta(r_0)$ is $\theta'(r_0) = 2c + 2(p - r_0) > 0$, so $\theta(r_0)$ is increasing with $r_0$. Define $\hat{r} = (6p - c)(p - c)/(8p)$. It is easy to check that $r_0 < \tilde{r}$ and $\theta(\hat{r}) < 0$. Thus $\theta(r_0) < \theta(\tilde{r}) < 0$. Q.E.D.

**Proof of Proposition 5**

To prove Proposition 5 we need to examine two separate cases: (1) $\gamma \geq 2$ and (2) $\gamma_0 < \gamma < 2$.

*Case* 1: $\gamma \geq 2$. According to Proposition 3, the buyback contract reduces to a wholesale price contract with $w_b^* = w_p^*$ and $b^* = 0$. Proposition 4 suggests that revenue-sharing contract always outperforms the wholesale price contract. Therefore, the supplier's profit under revenue sharing is greater than buyback.

[16] For the retailer to make positive profit, the optimal contract parameters $w_r^*$ and $r^*$ must satisfy $p - w_r^* - r^* > 0$. This implies that $p - (\gamma - 1)(p - r^*) - \gamma c > 0$. Therefore, only one solution for $\gamma$, as a function or $r^*$, can be obtained.

*Case* 2: $\gamma_0 < \gamma < 2$. Since the optimal buyback contract parameters are defined in (A8), the supplier's profit is then

$$\pi^*_{S_{BB}}(\gamma) = (w^*_b - c)q^*_b - b^*(q^*_b - S(q^*_b)) = \frac{-\gamma^2 + 8\gamma - 4}{8\gamma p}(p-c)^2 B. \tag{A21}$$

It is easy to show that $\pi^*_{S_{BB}}(\gamma)$ strictly deceases with $\gamma$.

The optimal parameters for the revenue-sharing contract are $w^*_r = c$ and $r^* = r_0$, where $r_0$ is defined by (A15), so the supplier's profit for revenue sharing is

$$\pi^*_{S_{RS}} = (w^*_r - c)q^*_r + r^* S(q^*_b) = \frac{1}{2} r_0 \left[1 - \left(\frac{c}{p - r_0}\right)^2\right]. \tag{A22}$$

Note that $\pi^*_{S_{RS}}$ is a constant and does not change with $\gamma$.

Now we can determine the condition when $\pi^*_{S_{RS}} > \pi^*_{S_{BB}}(\gamma)$. We know that at the upper bound of $\gamma$ (i.e., $\gamma = 2$), $\pi^*_{S_{RS}} > \pi^*_{S_{BB}}(2)$. Therefore, the comparison between $\pi^*_{S_{RS}}$ and $\pi^*_{S_{BB}}(\gamma)$ for the entire range $\gamma_0 < \gamma < 2$ depends on the values at the lower bound $\gamma = \gamma_0$. When $\pi^*_{S_{RS}} \geq \pi^*_{S_{BB}}(\gamma_0)$, since $\pi^*_{S_{BB}}(\gamma)$ strictly deceases with $\gamma$, $\pi^*_{S_{RS}} > \pi^*_{S_{BB}}(\gamma)$ must follow for $\gamma_0 < \gamma < 2$. When $\pi^*_{S_{RS}} < \pi^*_{S_{BB}}(\gamma_0)$, there must exist a threshold $\gamma_1 > \gamma_0$ at which $\pi^*_{S_{RS}} = \pi^*_{S_{BB}}(\gamma_1)$, such that $\pi^*_{S_{RS}} > \pi^*_{S_{BB}}(\gamma)$ for $\gamma_1 < \gamma < 2$. The value of $\gamma_1$ can be obtained by solving the following condition:

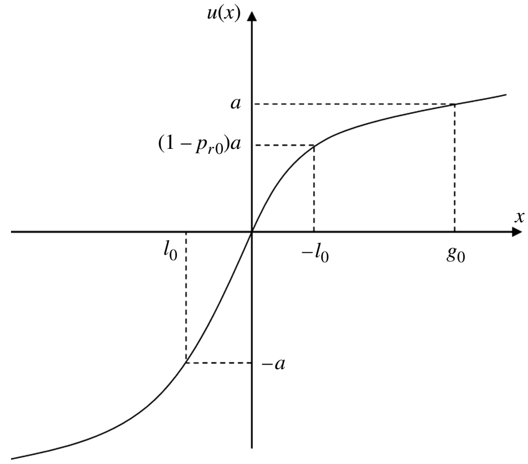
$$\pi^*_{S_{BB}}(\gamma_1) = \pi^*_{S_{RS}} \;\Leftrightarrow\; (-\gamma^2 + 8\gamma - 4)(p-c)^2 - 4\gamma^2 p r_0 \left(1 - \left(\frac{c}{p - r_0}\right)^2\right) = 0. \tag{A23}$$

Combining the results from Cases 1 and 2, it is clear that when $\gamma > \max(\gamma_0, \gamma_1)$, the revenue-sharing contract yields higher profit than the buyback. Because both $\gamma_0$ and $\gamma_1$ are smaller than 2, $\max(\gamma_0, \gamma_1) < 2$ must hold. Q.E.D.

## Appendix B. The Simplified Elicitation Procedure

Several approaches have been developed in the literature to calculate loss aversion coefficients at an individual level (e.g., Tversky and Kahneman 1992; Schmidt and Traub 2002; Abdellaoui et al. 2007, 2008) by precisely estimating the shape of the individual's utility function under prospect theory (Kahneman and Tversky 1979). These approaches require individuals to make a large number of choice decisions with many different combinations of monetary outcomes and probabilities, so that the utility on both loss and gain domains can be approximated. For the purposes of our study, we are interested in calibrating the participants' relative standing based on their attitude toward loss, rather than precisely calibrating the complete shape of their utility function. This allowed us to simplify the procedure described in Abdellaoui et al. (2008) by using only one combination of parameter values. Although this simplified approach provides a less precise measure of the loss aversion coefficient, it does provide a reasonable rank of the participants' attitude toward loss, which is exactly what we need for our study. The simplified procedure can also be administered fairly quickly (roughly five minutes versus roughly one hour for the full procedures), which was critical for our experiment.

**Figure B.1 Loss Aversion Elicitation Method**




The simplified elicitation procedure consists of two steps. Let $(x, p_r; y)$ denote a prospect in which outcome $x$ is received with probability $p_r$ and $y$ is received with probability $1 - p_r$. In the first step, for a given $g_0$, a loss $l_0$ is elicited such that a participant is indifferent between a sure payoff of 0 and a prospect $(g_0, 0.5; l_0)$; i.e., $(g_0, 0.5, l_0) \sim 0$. Suppose that $u(g_0) = a$. It follows, under expected utility theory, that

$$0.5u(g_0) + 0.5u(l_0) = 0 \;\Rightarrow\; u(l_0) = -u(g_0) = -a.$$

Figure B.1 illustrates this relation.

In the second step, the utility of $-l_0$ is determined by the elicitation of probability $p_{r0}$ such that a participant is indifferent between a sure payoff of $-l_0$ and a prospect $(g_0, p_{r0}, 0)$; i.e., $-l_0 \sim (g_0, p_0; 0)$. It follows that

$$u(-l_0) = p_{r0} u(g_0) + (1 - p_{r0}) u(0) = p_{r0} a.$$

**Table B.1 An Example of the Bisection Approach**

| Iteration | Choices in elicitation of $l_0$ | Choices in elicitation of $p_{r0}$ |
|---|---|---|
| 1 | **0** vs. (1,000, 0.5; −1,000) | **598** vs. (1,000, 0.5; 0) |
| 2 | 0 vs. **(1,000, 0.5; −500)** | 598 vs. **(1,000, 0.75; 0)** |
| 3 | **0** vs. (1,000, 0.5; −750) | 598 vs. **(1,000, 0.63; 0)** |
| 4 | **0** vs. (1,000, 0.5; −625) | **598** vs. (1,000, 0.57; 0) |
| 5 | 0 vs. **(1,000, 0.5; −563)** | **598** vs. (1,000, 0.60; 0) |
| 6 | 0 vs. **(1,000, 0.5; −594)** | — |
| 7 | **0** vs. (1,000, 0.5; −609) | — |
| 8 | **0** vs. (1,000, 0.5; −602) | — |
| Indifferent value | −598 | 0.615 |

**Table B.2 Basic Statistics of Measured Loss Aversion Coefficient ($\gamma_i$)**

| | Experiment 1 | | | Experiment 2 | | |
|---|---|---|---|---|---|---|
| | 1a | 1b | Pooled | 2a | 2b | Pooled |
| Mean | 2.38 | 1.82 | 2.08 | 1.76 | 1.85 | 1.81 |
| Median | 1.54 | 1.64 | 1.64 | 1.61 | 1.64 | 1.64 |
| Min | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 | 1.03 |
| Max | 33.33 | 11.11 | 33.33 | 4.00 | 7.69 | 7.69 |
| s.d. | 4.79 | 1.19 | 3.37 | 0.67 | 1.07 | 0.89 |

**Table C.1** Number of Participants and Percentage Preferring BB ($P_{BB}$) for All Critical Ratio Treatments for Experiment 1b

| | | | BB → RS | | RS → BB | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Cr* | *p* | *c* | Preferring BB | Total | Preferring BB | Total | Pooled (%) | Low $\gamma$ (%) | High $\gamma$ (%) |
| 0.95 | 26.67 | 1.33 | 4 | 14 | 3 | 13 | 25.9* | 50.0 | 6.7*** |
| 0.75 | 106.67 | 26.67 | 3 | 13 | 3 | 11 | 25.0* | 38.5 | 0.0*** |
| 0.35 | 80 | 52 | 7 | 13 | 7 | 12 | 56.0 | 37.5 | 64.7 |
| 0.15 | 144 | 122.67 | 9 | 14 | 9 | 14 | 64.3 | 41.7 | 81.2** |

$^{\dagger}p < 0.1$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

The loss aversion coefficient $\gamma$ is then computed as

$$\gamma = \frac{-u(l_0)}{u(-l_0)} = \frac{1}{p_{r0}}.$$

All indifferences are elicited using a bisection process (Abdellaoui et al. 2007, 2008), which consists of a series of binary choice questions. This process is illustrated in Table B.1 for $l_0$ and $p_{r0}$. The values of $l_0$ and $p_{r0}$ are elicited in eight and five iterations, respectively. The prospect chosen is shown in bold. The starting value of $l_0$ is $-g_0$ and the starting value of $p_{r0}$ is 1/2. For each iteration, depending on the choice made, the value is increased or decreased by half the size of change in the previous iteration. An interval is obtained after the final iteration where the true indifferent value should lie. The value is estimated by taking the midpoint of the resulting interval. For example, the value of $p_{r0}$ should lie between 0.60 and 0.63, and we take 0.615 as the final value of $p_{r0}$, which implies that the loss aversion coefficient for this participant $i$ is $\gamma_i = 1/0.615 = 1.63$.

We used this simplified approach to measure the loss aversion level of our participants in the second task of experiments 1 and 2, with the summary statistics provided in Table B.2. The median for all our participants is 1.64. This value is reasonably close to the median reported in Abdellaoui et al. (2008), suggesting that the simplified approach is not biased.

## Appendix C. Results of Experiment 1b

In choosing the parameter values $p$ and $c$ to support the four critical ratios, we considered two approaches: (a) fixing $p$ while varying $c$ for experiment 1a and (b) varying both simultaneously while keeping $|\Delta U_S|$ fixed for experiment 1b. Approach (b) is less straightforward but offers an important additional control for potential differences in the participants' ability to discern the sign of $\Delta U_S$ (and thus their ability to exhibit clear preferences between buyback or revenue-sharing contracts) across *Cr* levels. Parameter values and experimental results for experiment 1b are summarized in Table C.1. The statistical results are similar to experiment 1a.

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