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RESEARCH ARTICLE

Ex-ante versus ex-post buyback pricing: An experimental study

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ABSTRACT
We investigate behaviors and performance of a supply chain, in which a supplier uses buyback contracts to transact with a retailer under stochastic market demand. We compare ex-ante versus ex-post buyback pricing—the supplier decides the buyback price before demand realization in the former, but after demand realization in the latter. Theoretical analyses predict that the retailer order quantity and the supply chain efficiency are lower under ex-post buyback pricing. However, in experiments with human subjects playing both the supplier and retailer, we observe the opposite: the retailer order quantity and the supply chain efficiency are significantly higher under ex-post buyback pricing. Several behaviors are found significant. First, the supplier exhibits weaker advantageous fairness concern under ex-ante buyback pricing than under ex-post buyback pricing. Second, the supplier over-weights the buyback cost under the former, but under-weights (reciprocates) under the latter. Third, the retailer's fairness concern is weaker under the latter. Fourth, the retailer exhibits trust behavior with the supplier under the latter. These drivers lead to less rejection and higher order quantity under ex-post buyback pricing than under ex-ante buyback pricing. Our results shed light on how human behaviors change with the decision timing and benefit supply chain performance.

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Buyback contract; ex-ante pricing; ex-post pricing; fairness; mental accounting

1. Introduction

The buyback contract is popular in supply chain management, which specifies a wholesale price plus a buyback price between a supplier and a retailer (Cachon & Lariviere, 2005; Jokar & Hosseini-Motlagh, 2020; Yue & Raghunathan, 2007). The buyback price is implemented by the supplier to buy back the products that the retailer has ordered at the beginning of a selling season but has not sold at the end of it. When the market demand is stochastic, the buyback is of great value to the retailer in case of leftover inventory. As the retailer can always sell back the unsold products, the buyback reduces the retailer's cost of being stuck with too much leftover inventory. Hence, the retailer may order more from the supplier when the buyback is offered than when it is not offered. By offering the buyback, the supplier aligns the interest of the retailer with the supply chain, and by properly setting buyback prices, it can coordinate the supply chain.

The buyback price can be decided *ex ante*, namely, before the uncertain market demand is realized. When the ex-ante buyback price is set, the amount of leftover inventory is not known to both the supplier and the retailer because the uncertain demand has not been realized. The ex-ante buyback price has been used in the distribution of books, magazines, newspapers, music records, computers, greeting cards, and pharmaceuticals. For example, Viking Press was the first book publisher to use ex-ante buyback contract in 1932, and IBM Personal Computer Co. and Borland, Inc. were also reported to use the ex-ante buyback contracts (Padmanabhan & Png, 1995). This contract has been studied both theoretically and experimentally in existing literature (Cachon, 2003; Katok & Wu, 2009).

The buyback price can also be decided *ex post*, namely, after the uncertain demand is realized. When the ex-post buyback price decision is made, the amount of leftover inventory is known to both the supplier and the retailer. Thus, the buyback price decision is contingent on the realized demand and/or the realized leftover inventory. For example, Helper and Henderson (2014) reports that Toyota Inc. does not specify some payments explicitly to their long-term suppliers in the contract ex-ante, but clarify them ex-post to share the benefit of the result; this is called "governance by trust" and is one of the reasons that Toyota Inc. took market share away from General Motor Inc. Recently, it is also reported that many suppliers decide buyback price contingent on the retailers' severe overstocks that are caused by COVID-19 pandemic (Legal-Service-Network 2020). Contingent decisions are called "wait-and-see" solutions in the literature of

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stochastic decision-making (Birge & Louveaux, 2011).

We mainly focus on the long-term partnership between suppliers and retailers. Managing and maintaining long-terms supplier partnerships are of vital importance to supply chain management. In the automobile industry in Japan, companies prefer to enter into long-term relationships with suppliers, which are regarded as the reason for their success (Helper & Henderson, 2014). Syncee Inc. addresses that a long-term supplier relationship has many advantages for enterprises, such as lower purchase price and quality guarantee (Racz, 2018). Hence, we adopt fixed matching to explore the supply chain performance with a long-term partnership between suppliers and retailers. Moreover, the method of ex-post pricing can play a role under the long-term partnership rather than the short-term partnership. If random matching is adopted to simulate the short-term partnership, the advantage of ex-post decision-making may not be highlighted.

Decision-makers may be affected by individual biases and social preferences, resulting in decisions different from theoretical predictions (Kunc et al., 2016; White et al., 2020). In the long-term relationship, we mainly focus on social preferences such as fairness, trust, and reciprocity as they are most relevant to the decisions of suppliers and retailers under buyback contracts. Fairness is a social preference that negative affects a party's utility when it receives an unfair share of the benefits in a transaction with other parties. It has been shown to affect decisions in several supply chain settings (Cui et al., 2007; White et al., 2020). Trust behavior can be understood through the trust game (Berg et al., 1995), in which a first mover decides whether to send money for a second mover to investment, then the second mover decides how much money to send back to the first mover. It is an act of trust for the first mover to send money to the second mover in hope of getting a return because the second mover has no obligation to send any money back to the first mover. Reciprocity is the act of voluntarily repaying a trusting move at a later point in time (Gunnthorsdottir et al., 2002). If the second mover gives back money to the first mover, it exhibits reciprocal cooperation (Isoni & Sugden, 2019).

We can show that the ex-ante buyback contract performs better than the ex-post buyback contract in theory. However, in supply chain game settings, the experimental results usually deviate from the theoretical predictions because of human decision-making behaviors (Katok & Pavlov, 2013). Therefore, we conduct an experimental study to compare these two types of buyback prices in a supply chain game that is played between a supplier and a retailer with a long-term partnership. In the supply chain game with ex-ante buyback pricing, first the supplier decides a wholesale price and a buyback price, then the retailer decides an order quantity, and last market demand realizes. In the game with ex-post buyback pricing, the only difference is that the supplier decides a buyback price after observing the demand realization and the leftover inventory. Both parties are played by human subjects in the experiment. Our study aims to answer the following research questions: (1) How do the ex-ante and the ex-post buyback contracts perform in the supply chain game in a long-term partnership? (2) What are the partners' decision behaviors that drive the performance differences between these two buyback contracts?

The theoretical analysis predicts that the ex-ante buyback contract performs *better* than the ex-post buyback contract for the supply chain and the supplier, but worse for the retailer. However, our experimental results show that the ex-ante buyback contract performs *worse* than the ex-post buyback contract for both the retailer and the supplier, and thus for the supply chain. By developing behavioral models to fit the experimental data, we find that human behavioral preferences of reciprocity and advantageous fairness are the main drivers of the performance differences between these two buyback contracts. The ex-post buyback price induces trust of the retailer and higher reciprocity of the supplier, thus the ex-post buyback price better aligns the interest of the supply chain parties. Our results imply that in practice where most decisions are made by supply chain managers, the ex-post buyback pricing is a viable alternative to the ex-ante buyback pricing.

2. Literature review

Studies on supply chain contracts are vast. As we experimentally examine the supply chain performance of ex-ante and ex-post buyback pricing in buyback contracts, our research contributes to the studies of ex-ante buyback pricing in supply chain settings and the studies of ex-post decision-making in operations management. Besides, our study is also related to the experiments with fixed matching between supply chain parties.

After Pasternack (1985) takes the lead in research on buyback contracts, scholars conduct theoretical research on the assumption that retailers and manufacturers are not profit-maximizers; instead, they exhibit risk preference (Tran et al., 2018; Wang et al., 2021), mental accounting (Liu et al. 2020) and fairness concern (Qin et al., 2021). The buyback contracts are also studied by experiments under

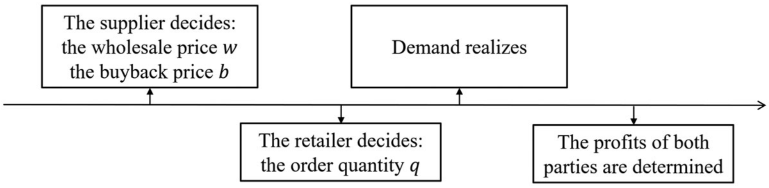


Figure 1. The sequences of events under the ex-ante buyback pricing.

ex-ante buyback pricing. Katok and Wu (2009) conduct experiments of the buyback contract in a supply chain game setting where either the supplier or the retailer, but not both, is played by a human subject and the other party is played by a computer. The results show that buyback contracts perform better than wholesale price contracts. Becker-Peth et al. (2013) investigate retailers' decision behaviors under a series of buyback contracts, and show that the retailer's order quantities deviate from the theoretical prediction, and the behavioral drivers of this result are mental accounting, loss aversion, and anchoring effect. The supplier's decision behaviors are studied by Zhang et al. (2016) under the buyback contract, and are compared with those under the revenue-sharing contract, in human-to-computer experiments (the human suppliers play with the computerized retailers). The result shows that due to the loss-aversion bias, the supplier is worse off with the buyback contract than with the revenue-sharing contract for high-profit margin products, but is indifferent between the two contracts for low-profit margin products.

Ex-post decision making is studied extensively in stochastic programming literature and is referred as "wait-and-see" strategy, by which capacity decisions (Birge & Louveaux, 2011), pricing decisions (Ku & Chang, 2012), and scheduling decisions (Hur et al., 2021) are made after random demand or other random parameters are realized. Ex-post decision making is also studied and practiced in supply chain management. The inventory replenishment decisions are made after observing early demand information on fashion products to reduce the mismatch cost between supply and demand in determining initial and replenishment order quantities (Fisher et al., 2001). Production decisions are made after observing demand realization to achieve mass customization (Zipkin, 2001). In an empirical study on general contract by Scott et al. (2020), some contract terms are better not explicitly specified ex-ante but determined ex-post because these explicit terms are not enforceable by law. Recent experimental studies of the supply chain contract focus on the supply chain performance and decision preferences. For example, Zhao et al. (2019) conduct fixed-matching experiments of a revenue-sharing contract under a VMI setting, in which the retailer has the option to decide another revenue-sharing percentage ex-post in addition to an ex-ante revenue-sharing percentage. They conduct human-to-human experiments and find that the supply chain performance is substantially improved because the ex-post revenue-sharing percentage effectively mitigates the supplier's fairness concerns.

There are relative few experimental studies that are based on fixed matching. Özer et al. (2011) study the demand information sharing game in a two-echelon supply chain under fixed and random matching. They find that fixed matching leads to higher channel efficiency than random matching. Hyndman et al. (2014) experimentally compare the outcome of the capacity selection game that two manufacturers simultaneously choose the capacity under fixed and random matching. They observe a "first-impressions" bias, which lowers the average profits under the fixed matching. Wu (2013) conducts fixed-matching experiments under the wholesale price, buyback and revenue-sharing contracts, with the retailer's ordering decisions limited to zero, minimum demand, or the optimal quantity. The results show that the retailer exhibits fairness and reciprocity.

In this study, we explore the contract of ex-ante and ex-post buyback pricing by an experimental study, examine behavioral preferences that are induced by these two buyback pricing strategies, and analyze how the preferences affect the efficiencies of supply chain performance. We provide experimental evidence to show the effectiveness of the ex-post buyback pricing. We identify social preferences of the supplier and the retailer under both contracts, and elaborate their impacts through behavioral models. Therefore, we provide valuable insights for the supply chain managers to make better use of buyback contracts in practice.

3. Standard theory

The supply chain in our study consists of a single retailer and a single supplier. The supplier produces products at a unit cost c, and the retailer sells them to the market at a unit price p. Market demand D is stochastic following a cumulative distribution function $F(\cdot)$. The supplier transacts with the retailer under a buyback contract in a Stackelberg game, where the information of cost, price, and market demand is assumed to be public and known to both parties. The buyback pricing can be determined by the supplier either ex-ante or ex-post, namely, before or after the stochastic demand realization.

3.1. Ex-ante buyback pricing

Under ex-ante buyback pricing, the sequence of events is shown in Figure 1 for the game between the supplier and the retailer. First, the supplier offers a wholesale price w and a buyback price b (naturally, $0 \le b \le w \le p$). Second, the retailer places an order of quantity q and pays the supplier wq. Third, market demand realizes; if the realized demand d is higher than q, all products are sold to the market; otherwise, the retailer has leftover inventory $(q-d)^+ \equiv \max(q-d, 0)$, and the supplier buys back it by paying the retailer $b(q-d)$.

We start with the retailer's optimal ordering decision. The retailer's profit is as follows:

$$\pi_R(q,d) = p\min(q,d) - wq + b(q-d)^+, \quad (1)$$

where the first term is the sales revenue from the market, the second is the ordering cost paying to the supplier, and the last is the buyback payment from the supplier. The retailer chooses a quantity to maximize the expected profit $\mathrm{E}_D[\pi_R(q,D)]$. The optimal order quantity is $F^{-1}\left(\frac{p-w}{p-b}\right)$ when $b < w \le p$. If $w \le b < p$, the retailer has an arbitrage opportunity to buy as many products as possible in order to return them for a profit. If $w = b = p$, the profit of the retailer is always 0, that is, it is indifference to the order quantity decision. The optimal order quantity is given by:

$$q_A^*(w,b) = \begin{cases} F^{-1}\left(\dfrac{p-w}{p-b}\right), & \text{if } b < w \le p; \\ +\infty, & \text{if } w = b < p; \\ \textit{arbitrary value}, & \text{if } w = b = p, \end{cases} \quad (2)$$

where the subscript A denotes ex-ante buyback pricing case.

We now proceed to solve the supplier's decision problem. Given a retailer's order quantity q, the supplier's profit is as follows:

$$\pi_S(w,b,q,d) = (w-c)q - b(q-d)^+, \quad (3)$$

where the first term is wholesale income, and the second term is leftover inventory buyback cost. By backward induction, the retailer use the optimal order quantity; hence, the supplier's expected profit is $\mathrm{E}_D[\pi_S(w,b,q_A^*(w,b),D)]$. Denote the optimal wholesale price by w_A^* and the optimal buyback price by b_A^*.

According to Pasternack (1985) and Lariviere (1999), the equilibrium is $w_A^* \to p$, $b_A^* \to p$ and $q_A^* = F^{-1}\left(\frac{p-c}{p}\right)$. The supplier, as the first mover in the game, sets both the wholesale price and the ex-ante buyback price close to the market price to obtain the largest proportion of the supply chain profit. This eliminates the double marginalization; hence, the retailer's order quantity is equal to the one that maximize the supply chain profit. However, at this equilibrium solution the retailer obtains the minimum proportion of the supply chain profit, i.e., zero.

3.2. Ex-post buyback pricing

Under ex-post buyback pricing, the sequence of events is the same as under ex-ante buyback pricing, except that the buyback price b is decided by the supplier after the market demand is realized and the leftover inventory is observed. Hence, the game consists of three decision stages in sequence: the supplier decides wholesale price w, the retailer decides order quantity q, and last, the supplier decides ex-post buyback price b. We solve the equilibrium of this game again by backward induction.

The decision problem in the third stage is for the supplier to decide the optimal ex-post price as follows:

$$\max_{b \ge 0} \{(w-c)q - b(q-d)^+\}, \quad (4)$$

where $(w-c)q$ is the wholesale income, and $b(q-d)^+$ is the buyback payment to the retailer after observing demand realization d. As $(q-d)^+$ is always nonegative, the optimal ex-post buyback price is

$$b_P^*(w,q,d) = 0, \quad (5)$$

that is, a profit maximizing supplier sets the ex-post buyback price to be zero, and the subscript P denotes ex-post buyback pricing case.

Moving one-step back, the decision problem in the second stage is for the retailer to decide the optimal order quantity maximizing its expected profit as follows:

$$\max_{q \ge 0} \{\mathrm{E}_D\left[p\min(q,D) - wq + b_P^*(w,q,D)(q-D)^+\right] = \mathrm{E}_D\left[p\min(q,D) - wq\right]\}, \quad (6)$$

where the last equality follows from $b_P^* = 0$. The optimal order quantity is given by

$$q_P^*(w) = F^{-1}\left(\frac{p-w}{p}\right). \quad (7)$$

We are back to solve the decision of w made by the supplier in the first stage as follows:

$$\max_{0 \le w \le p} \left\{\mathrm{E}_D\left[(w-c)q_P^*(w) - b_P^*(w,q^*(w),D)(q_P^*(w)-D)^+\right] = (w-c)F^{-1}\left(\frac{p-w}{p}\right)\right\}, \quad (8)$$

where the last equation is obtained by substituting q_P^* and b_P^* with their expressions. By first order condition, w_P^* satisfies the following equation

$$(w-c)\frac{dF^{-1}\left(\frac{p-w}{p}\right)}{dw}+F^{-1}\left(\frac{p-w}{p}\right)=0. \quad (9)$$

The equilibrium (w_P^*, b_P^*, q_P^*) means that when the supplier and the retailer maximize the profit, the ex-post buyback price is zero. Consequently, the game is similar to one under the wholesale price contract, which is studied in Davis et al. (2014). Under the equilibrium, the wholesale price w^* is greater than c and smaller than p. Hence, there is double marginalization in the supply chain. The order quantity in equilibrium is smaller than the quantity $F^{-1}\left(\frac{p-c}{p}\right)$ that maximizes the supply chain profit.

3.3. Comparison

Based on the assumption of profit maximization, the equilibrium analysis provides theoretical predictions. We compare them under the ex-ante and the ex-post buyback pricing.

First, we compare the order quantity and its implication on supply chain efficiency. The retailer's equilibrium order quantity is $q_A^* = F^{-1}\left(\frac{p-c}{p}\right)$ under the ex-ante buyback pricing and $q_P^* = F^{-1}\left(\frac{p-w_P^*}{p}\right)$ under the ex-post buyback pricing. Because the optimal wholesale price w_P^* is always larger than unit cost c, the order quantity q_P^* under the ex-post buyback pricing is smaller than q_A^* under the ex-ante buyback pricing. The supply chain profit is maximized when the order quantity is $F^{-1}\left(\frac{p-c}{p}\right)$, hence, a supply chain efficiency of 100% is achieved under the ex-ante buyback pricing. However, a supply chain efficiency of less than 100% is achieved under the ex-post buyback pricing because $q_P^* < q_A^*$.

Second, let's compare the supplier profit, which is determined by wholesale price and buyback price decisions. The equilibrium ex-post buyback price is 0, hence, the supplier's profit under ex-post buyback pricing is equivalent to its profit under ex-ante buyback pricing with contract $(w_P^*, 0)$. Under ex-ante buyback pricing, for every given $\hat{w}$, we can always find a contract $(\hat{w}, \hat{b}(\hat{w}))$ that maximizes the supplier profit. The buyback price $\hat{b}(\hat{w})$ is as follows (see the proof in Appendix A):

$$\hat{b}(\hat{w}) = \begin{cases} 0, & c < \hat{w} \le \frac{p+2c}{3}; \\ \frac{3\hat{w}-p-2c}{p+\hat{w}-2c}p, & \hat{w} > \frac{p+2c}{3}. \end{cases} \quad (10)$$

Because contract $(\hat{w} = w_P^*, \hat{b}(w_P^*))$ results in a supplier profit no smaller than contract $(w_P^*, 0)$ does, and the former contract is dominated by the contract (w_A^*, b_A^*), the supplier profit is higher under ex-ante buyback pricing than that under ex-post buyback pricing.

Lastly, we compare the retailer profit. It is almost 0 under ex-ante buyback pricing, but larger than zero under ex-post buyback pricing because $w_P^* < p$. Hence, the retailer profit is smaller under the former than that under the latter.

As a summary, in theory, the order quantity and the supplier chain efficiency are higher under ex-ante buyback pricing than those under ex-post buyback pricing, and so is the supplier profit; however, the retailer profit is lower under ex-ante buyback pricing.

4. Experimental implementation and data analysis

We design human-to-human experiments where human subjects play both the supplier and the retailer in the supply chain game under buyback contracts. We adopt a between-subjects experimental design: one group for ex-ante buyback pricing and the other for ex-post buyback pricing.

4.1. Experimental implementation

In our experiment setting, demand D is uniformly distributed on $[50, 150]$. The unit market price of the retailer is $p = 120$, while the unit cost of the supplier is $c = 30$. Under the ex-ante buyback pricing, the equilibrium is $w^* \to 120$, $b^* \to 120$, $q^* \to 125$. With this equilibrium, the supply chain efficiency is 100%. We employ this equilibrium as a benchmark in analysis, because it can be reached only when no behavioral factors exist in the game. Under ex-post buyback pricing, the equilibrium is $w^* = 105$, $q^* = 62.5$ and $b^* = 0$ (see proofs in Appendix B). With this equilibrium, the supply chain efficiency is 70.24%.

We recruited 134 subjects who study in the field of science and engineering in a major university, with 33 pairs for ex-ante buyback pricing and 34 pairs for ex-post buyback pricing in the experiments. One subject could only participate in one treatment. We coded the experimental program using oTree systems (Chen et al., 2016).

Before the experiment starts, subjects were given a ten-minute introduction to the newsvendor problem and the buyback contract. In the introduction, they were explained on value ranges of decisions, and they were also informed of all parameter values to ensure the information assumptions consistent with the theoretical model. To make sure that all

Table 1. Comparison between the ex-ante buyback pricing and the ex-post buyback pricing.

	Ex-ante buyback pricing	Ex-post buyback pricing
Sample size	33	34
Wholesale price	87.22[11.65]*	83.52[10.23]
Buyback price	43.61[28.42]	47.56[34.60]*
Order Quantity	81.14[36.63]	94.46[23.22]**
Normative order quantity	98.89[22.59]***	80.40[8.53]
Quantity = 0(%)	7.29	1.06
Leftover	11.74[20.53]	13.66[20.75]*
Stockout	30.40[36.07]***	19.00[25.13]
Supplier's profit	3895.00[1958.72]	4285.36[1441.26]*
Retailer's profit	1999.29[1587.33]	2577.20[1632.59]**
Efficiency	74.85[36.49]	87.14[30.16]***

*p-value < 0.1; **p-value < 0.01; ***p-value < 0.001.

subjects understand the basic setting, we asked them to do three exercises. After the exercises, a briefing of optimal solutions was given to further enhance understanding of the underlying problem. At the beginning of the experiment, each subject was randomly and anonymously paired with another to play the roles of a retailer or a supplier. The experiment ran 50 rounds of repeated games. Their roles and partnership remained fixed over all rounds. At the end of each round, both parties could observe each other's profits. The experiment lasted for about 75 min. At the end of the experiments, the subjects received performance-based payments. The performance was measured by the total credits, and monetary was the only incentive offered. Most subjects received a payment that was about three times the local standard hourly wage.

4.2. General results

We collect 3350 decisions (33 pairs × 50 rounds in ex-ante buyback pricing and 34 pairs × 50 rounds in ex-post buyback pricing) and analyze the decision behaviors of subjects. Because the data under the ex-ante buyback pricing exhibit time effect, we follow the approach in Zhang et al. (2019) to use the stable data of the last 25 rounds for analysis of stable decision behaviors. (Appendix C provides in detail the time effect analysis using all experimental data.) Table 1 provides descriptive statistics of both pricing schemes, including the supplier's decisions of the wholesale and buyback prices, the retailer's ordering decisions, and the supply chain efficiency. Before we test the statistical differences, we aggregated the data by pairs to arrive at independent observations. We applied the t-test to the observations of the wholesale price, order quantity, normative order quantity, the supplier's, and the retailer's profit, because they pass the Shapiro-Wilk normality test. Meanwhile, we applied Mann-Whitney test to the observations of the buyback price, leftover, stockout, and supply chain efficiency, for they do not pass the Shapiro-Wilk normality test.

By comparison, we first observe that the experimental results significantly deviate from the theoretical equilibrium under both contracts. Under ex-ante buyback pricing, because the retailer makes the order quantity decision after the supplier offers the wholesale price and the buyback price, we use the actual decisions of wholesale prices and buyback prices to predict the order quantity according to Eq. (2). For every pair of given experimental data (w, b), the predicted optimal order quantity on average is 98.89 (the standard deviation is 22.59). The experiment average order quantity 81.14 is significantly less than the prediction (single-sided t-test, $t = -3.29, p < 0.001$). The supply chain efficiency of 74.85% is significantly lower than the prediction of 100% (one-sample Mann-Whitney test, $V = 0, p < 0.001$).

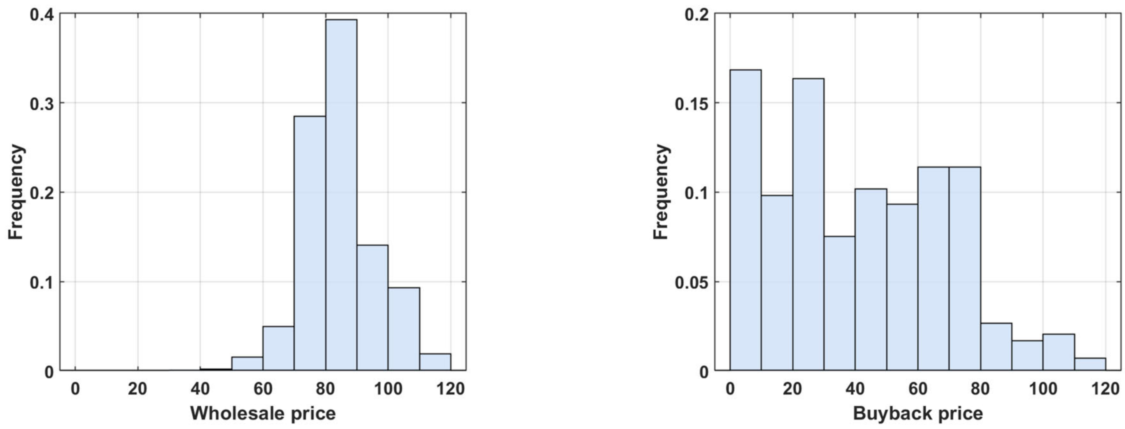
Under ex-post buyback pricing, the prediction of the optimal order quantity with experimental data according to Eq. (7) is 80.40 (the standard deviation is 8.53). The observed order quantity 93.53 is significantly larger than the prediction of 80.40 (single-sided t-test, $t = 4.99, p < 0.001$). The supply chain efficiency of 87.14% is significantly higher than the theoretical prediction of 70.24% (one-sample Mann-Whitney test, $V = 594, p < 0.001$).

We further compare the general performance under ex-ante buyback pricing with that under ex-post buyback pricing. The most remarkable result is as follows. The order quantity under ex-ante buyback pricing is significantly lower than that under ex-post buyback pricing (single-sided t-test, $t = -2.77, p < 0.01$), and so is the supply chain efficiency (Mann-Whitney test, $W = 299, p < 0.001$). This result is counter-intuitive. Moreover, the profits of both the supplier and the retailer are significantly higher under ex-post buyback pricing than those under ex-ante buyback pricing.

4.3. Behaviors under ex-ante buyback pricing

To better understand the decision biases and social preferences of the subjects under the ex-ante buyback pricing, we analyze the behaviors of suppliers and retailers respectively.

First, the suppliers' wholesale prices are mostly distributed between 70 and 110 (about 87.94%), as shown in Figure 2(a). Suppliers tend to offer a wholesale price that is not too high relative to the theoretically predicted value of 120. Two reasons may contribute to the deviation. The suppliers may exhibit advantageous fairness concern when they receive better outcomes than the retailers and decrease the wholesale price (Van Den Bos et al., 2006), or they may worry that high wholesale prices lead to retailers' non-cooperation behavior, namely, rejection. These



(a) Distribution of Wholesale Prices

(b) Distribution of Buyback Prices

Figure 2. Distribution of wholesale prices and buyback prices under ex-ante buyback pricing.

behaviors are examined later through behavior models. Figure 2(b) shows the distribution of the buyback price, which is simultaneously decided with the wholesale price. The distributions of the wholesale price and the buyback price indicate that the suppliers make noisy decisions.

Figure 3 shows the relationship between the wholesale price and the buyback price for each pair. The triangles represent the average value of the actual buyback prices with the corresponding wholesale price; the line represents the theoretical buyback price that maximizes the supplier's profit according to Eq. (10) with the assumption that the retailer acts as the optimal response. This theoretical buyback price is higher than most of the observed buyback price. This result can be explained by mental accounting effect that human decision-makers are sensitive to the sources of cash flow (Becker-Peth et al., 2013; Thaler, 1985). In our case, suppliers have two sources of cash flows, wholesale income and leftover inventory buyback cost. When they give a higher weightage to the buyback cost than that to the wholesale income, the buyback price is lower than that when they give equal weightage.

Second, the retailers' average order quantity decreases with the wholesale price, as shown in Figure 4(a). Note that the number of 0-quantity decisions increases when the wholesale price is above 75. The Pearson correlation coefficient between the ratio of 0-quantity and the wholesale price is 0.971 (Pearson correlation test, $p < 0.01$) when the wholesale price is discretized with a step-size of ten. This implies that observing a higher wholesale price, retailers more likely give up their profits and punish their partner suppliers. The decisions of 0-quantity indicate the retailers' fairness concern rather than other decision biases such as loss aversion or risk aversion because the retailers can order the minimum realized demand of 50 to make a certain profit. Figure 4(b) plots the observed order quantity versus the predicted optimal order quantity, showing that the retailer subjects mostly order less than the predicted. Moreover, the order quantity is scattered. The ordering decisions with a large variance result in more stockout and more leftover inventory costs, leading to a low supply chain efficiency. These decision-making fluctuations indicate that the retailers make noisy decisions.

4.4. Behaviors under ex-post buyback pricing

The suppliers' wholesale prices mostly fall between 70 and 100 (about 88.41%), as shown in Figure 5. The wholesale prices mainly determine the supply chain profit allocation, because buyback prices do not affect profit allocation except when there is leftover inventory. A higher wholesale price means a higher supplier profit share and a lower retailer profit share; hence, the suppliers avoid asking high wholesale prices that may result in retailers' noncooperation, i.e., rejection.

The retailers decide order quantities after receiving the wholesale prices. In Figure 6, every dot represents actual order quantity, every triangle is the average order quantity with the corresponding wholesale price, and the solid line denotes the theoretical optimal order quantity according to Eq. (7). The number of 0-quantity decisions increases with the wholesale price. The Pearson correlation coefficient between the ratio of 0-quantity and the wholesale price is 0.780, but their correlation is not significant (Pearson correlation test, $p < 1$). Similar to the ex-ante buyback pricing, the existence of 0-quantity decisions indicates that retailers give up their profits and punish their partner suppliers who offer them unfair wholesale prices. It is also a sign of fairness concern.

Davis et al. (2014) conducted experiments to study the push contract, whose equilibrium is similar to the ex-post buyback pricing except $b^* = 0$.

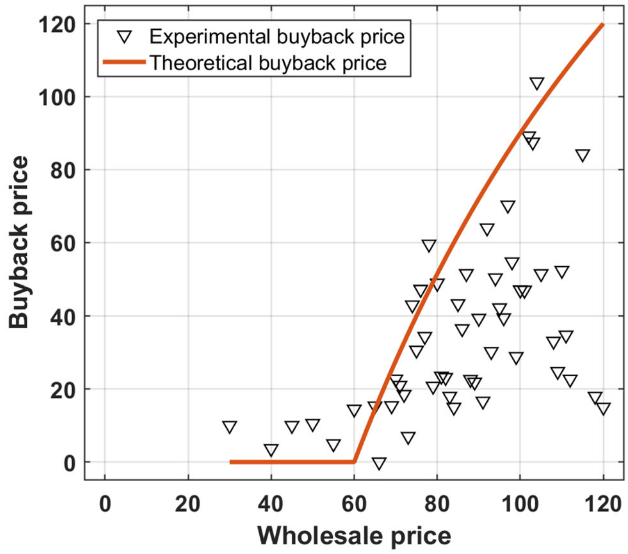


Figure 3. The relationship between wholesale prices and buyback prices under the ex-ante buyback pricing.

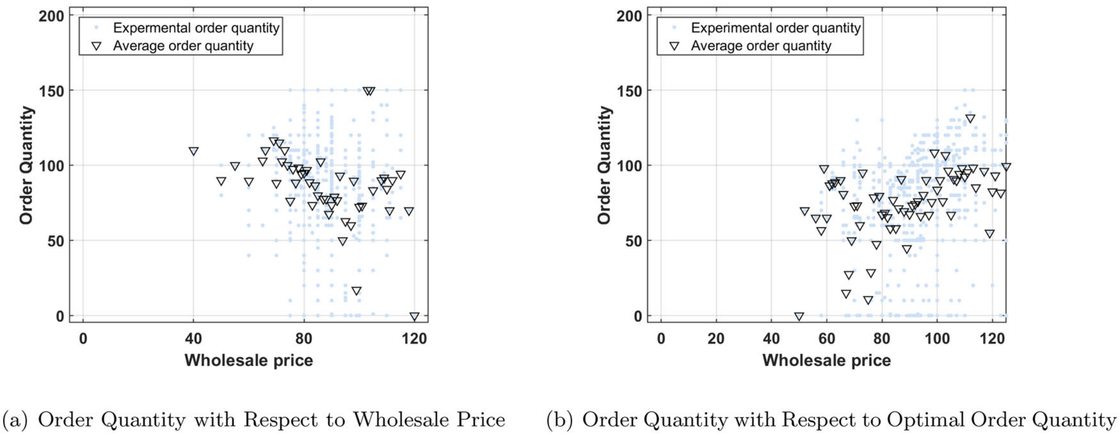


Figure 4. order quantity under ex-ante buyback pricing.

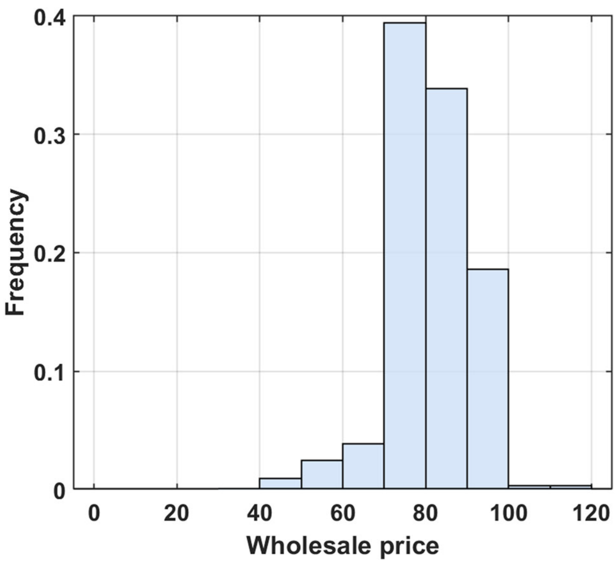


Figure 5. Distribution of the wholesale price under the ex-post buyback pricing.

Their observed quantity is lower than the theoretical prediction. However, in our experiment, we observe the opposite—the retailers' order quantities are higher than the theoretical prediction. This is because there is no inventory buyback in their case; but in our case, the retailers trust the suppliers to buyback the leftover inventory, and they form a belief of $\tilde{b}(>0)$ on the possible buyback price. Based on this belief, they order $q^* = F^{-1}\left(\frac{p-w}{p-\tilde{b}}\right)$, which is higher than the theoretical prediction of $q^* = F^{-1}\left(\frac{p-w}{p}\right)$.

Under the ex-post buyback contract, buyback pricing is meaningful only when there is leftover inventory. According to Table 1, the average ex-post buyback price is 46.76, which is significantly more generous than 0. It is analog to trust game (Cox, 2004). We analyze the impact of the wholesale price and the leftover inventory on the ex-post buyback price by the linear regression; Table 2 shows the results. There is a significant positive correlation between the ex-post buyback price and the wholesale price. The suppliers with a larger profit share offer higher buyback prices, which can be viewed as a reward to the retailers' trust in suppliers. Interestingly, the correlation coefficient between the buyback price and the leftover inventory is also

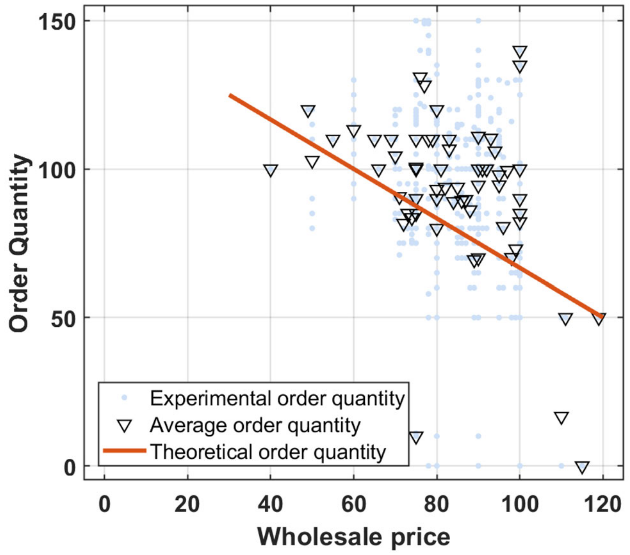


Figure 6. Order quantity under the ex-post buyback pricing.

Table 2. Regression results of the ex-post buyback price.

Variables	Wholesale price	Leftover	Intercept	R-square	F-statistic
Estimate	1.383***(0.157)	0.294***(0.077)	−75.053***(13.324)	0.192	44.45***

*p-value < 0.1; **p-value < 0.01; ***p-value < 0.001.

significantly positive. The more the leftover inventory is, the more the suppliers share the leftover inventory cost, which encourages the retailers to order more quantities.

Furthermore, we explore the dynamics of trust and reciprocity between the supplier and the retailer. First, for each pair we identify the round when the retailer first trusts the supplier (i.e., ordering more than normative prediction of quantity), and the round when the supplier first reciprocates the retailer (i.e., paying an ex-post buyback price higher than normative prediction of zero). We find that the retailer's trust happens in round one for 24 pairs out of 34, and the supplier's reciprocity happens also in round one for 23 pairs among the 24. Second, using the experimental data, we apply the Granger non-causality test (Dumitrescu & Hurlin, 2012) to relationship between the order quantity, a measure of trust, and the ex-post buyback price, a measure of reciprocity. The testing results show that the higher order quantity causes the higher ex-post buyback price and vice versa. Appendix D provides more details of the dynamics of the trust and the reciprocity. The positive reinforcement between these two behaviors leads to the result that the ex-post buyback pricing performs much better than the normative prediction and even better than the ex-ante buyback pricing.

4.5. Comparison of behaviors

To help understand the observation that the ex-ante buyback pricing performs worse than the ex-post buyback pricing, we compare the supply chain partners' behaviors.

4.5.1. Behavior of the supplier

The wholesale price is significantly higher under ex-ante buyback pricing than that under ex-post buyback pricing (single-sided t-test, $t = 1.64$, $p < 0.1$). The main difference lies in the proportion of wholesale prices above 110 between the two contracts, as shown in Figures 2(a) and 5. In the ex-ante buyback pricing, the proportion is 3.41% higher than that of the ex-post pricing (ex-ante: 4.12%, ex-post: 0.71%). Under the ex-ante buyback pricing, the wholesale price and the buyback price are proposed together; the suppliers view the buyback price as a compensation already committed to the retailers, thus, they ask a relatively high wholesale price. However, under the ex-post buyback pricing, the suppliers do not commit a buyback price, thus, they ask a relatively lower wholesale price.

The buyback price is significantly lower under the ex-ante buyback pricing than that under the ex-post buyback pricing (Mann-Whitney test, $W = 726$, $p < 0.05$). In the ex-ante case, when the suppliers decide the buyback price, they face the leftover inventory uncertain, and may view uncertain buyback costs as losses; they offer a low buyback price to control the losses. However, in the ex-post case, when the suppliers decide the buyback price, the leftover inventory is certain, and they may consider the buyback pricing as an opportunity to share the retailers' realized cost; thus they offer a high buyback price. The timing of buyback pricing decision changes the way that the suppliers account for the buyback cost; this behavior can be characterized by mental accounting effect.

4.5.2. Behavior of the retailer

In the retailers' decisions of order quantity, the proportion of 0-quantity is more significantly correlated with the wholesale price under ex-ante buyback pricing than under ex-post buyback pricing (Pearson correlation coefficient of 0.971 versus 0.780). This implies that more retailers choose rejection under ex-ante buyback pricing than under ex-post buyback pricing when they face high (unfair) wholesale prices.

The order quantity under ex-ante buyback pricing has a larger variance than that under ex-post buyback pricing. The different variances may result in different leftover inventory and stock-out. The leftover inventory of 11.74 under ex-ante buyback pricing is less than that of 13.66 under ex-post buyback contract (Mann-Whitney test, $W = 445.5$, $p < 0.1$); while, the stock-out of 30.39 is significantly larger under the former than that of 19.00 under the latter (Mann-Whitney test, $W = 906.5$, $p < 0.05$). This significantly large stock-out contributes to the lower supply chain efficiency under ex-ante buyback pricing.

The decision behaviors result in different supply chain profit allocations and different profits for the suppliers and the retailers. The average suppliers' profit share of the supply chain is 66.08% under ex-ante buyback pricing but 62.45% under ex-post buyback pricing. However, due to a higher supply chain efficiency, we observe that both the suppliers' and the retailers' profits are higher under ex-post buyback pricing than those under ex-ante buyback pricing (suppliers' profit: single-sided t-test, $t = 1.50$, $p < 0.1$; retailers' profit: single-sided t-test, $t = 2.82$, $p < 0.01$). Therefore, the ex-post buyback pricing should be welcomed by both parties more than the ex-ante buyback pricing.

5. Behavioral model

Our experimental results show that mental accounting effect may explain the supplier's buyback price decision, and fairness concern may explain the retailer's 0-quantity decision. In this section, we use quantitative methods to explore how the mental accounting effect and fairness concern affect the supply chain efficiency. Furthermore, we make an in-depth analysis as to why the ex-post buyback pricing performs better than the ex-ante buyback pricing.

5.1. Model description

We incorporate the mental accounting effect and advantageous fairness concern in the supplier's utility, and the mental accounting effect and disadvantageous fairness concern in the retailer's. We also use the quantal response equilibrium (QRE) model (McKelvey & Palfrey, 1995) to capture humans' random choice that is shown by noisy decisions in the experimental data. As the decisions are random variables in QRE model, we use capital letter to denote them for their corresponding deterministic decisions: W for w, B for b, and Q for q.

5.1.1. Behavioral models of ex-ante buyback pricing

We first model the retailer's utility function and decision. Considering the mental accounting and fairness concern, the retailer has the following utility function:

$$U_R(q) = \mathrm{E}_D\left[p\min(q, D) - wq + \gamma_R b(q-D)^+ - \alpha(\pi_S-\pi_R)^+\right], \tag{11}$$

where γ_R denotes the retailer's mental accounting effect on buyback income. According to Chen et al. (2013), mental accounting describes that individuals mentally estimate the transactions based on factors such as time or an uncertain event before making evaluations. In our case, the retailer mentally estimates the income from inventory buyback, which is an uncertain event contingent on demand realization. The disutility of $\alpha(\pi_S-\pi_R)^+ \equiv \alpha\max(\pi_S-\pi_R, 0)$ is due to the retailer's fairness concerns (Cui et al., 2007), and π_S and π_R follow Eqs. (3) and (1), respectively. If the supplier's profit is higher than the retailer's, the retailer incurs disutility and reduces the order quantity. According to the QRE model, the order quantity decision—a function of the wholesale price and the buyback price—follows the probability distribution as below:

$$\mathrm{prob}(Q(w, b) = q_i) = \frac{\exp\left(U_R(q_i)/\beta_R\right)}{\sum_j \exp\left(U_R(q_j)/\beta_R\right)}, \tag{12}$$

where q_i and q_j are possible values of the order quantity, and parameter β_R characterizes the bounded rationality of the supplier (Su, 2008). A subject would be more rational with the decrease of β_R. If $\beta_R \to 0$, the subject exhibits perfect rationality, while if $\beta_R \to \infty$, the choice of the subject is completely random.

We proceed to model the supplier's utility function and decision. The supplier faces stochastic demand, as well as the stochastic quantity decision of the retailer. Its expected utility is as follows:

$$U_S(w, b) = \mathrm{E}_Q[\mathrm{E}_D[(w-c)Q(w, b) - \gamma_S b(Q(w, b)-D)^+ - \lambda(\pi_S-\pi_R)^+]], \tag{13}$$

where parameter γ_S characterizes the mental accounting effect of the retailer (Chen et al., 2013) and λ measures the advantageous fairness concern (Cui et al., 2007). Hence, the supplier may treat the buyback value differently. According to the QRE model, the supplier's decision is random and follows the distribution below:

$$\text{prob}(W = w_i, B = b_j) = \frac{\exp\left(U_S(w_i, b_j)/\beta_S\right)}{\sum_k \sum_l \exp\left(U_S(w_k, b_l)/\beta_S\right)}, \tag{14}$$

where (w_i, b_j) and (w_k, b_l) are possible decision values, and parameter β_S characterizes the bounded rationality of the supplier which has the same property as the retailer's β_R.

5.1.2. Behavioral models of ex-post buyback pricing

We start with the supplier's ex-post buyback price decision in the third stage. With the realized demand d and the leftover inventory, the supplier's utility function is as follows:

$$\begin{aligned} U_S(b) = {} & wq - cq - b(q-d)^+ \\ & + \sigma b(q-d)^+ - \lambda(\pi_S - \pi_R)^+, \end{aligned} \tag{15}$$

where parameter σ and λ characterizes the reciprocity and advantageous fairness concern, respectively. With a bigger σ value, the supplier's optimal ex-post buyback is higher, that is, more generous. This can be seen when we substitute the profits π_S and π_R by their expressions, Eq. (15) becomes the following:

$$\begin{aligned} U_S(b) = {} & (1-2\lambda)wq - (1-\lambda)cq + (\sigma + 2\lambda - 1)b(q-d)^+ \\ & + \lambda p \min(q, d). \end{aligned}$$

Moreover, we do not consider mental accounting here. According to Chen et al. (2013), the supplier's decision on the buyback price occurs immediately.

The buyback price decision is a function of the realized demand, the retailer's order quantity, and the supplier's wholesale price. By QRE model, it follows the distribution below:

$$\text{prob}(B(w, q, d) = b_i) = \frac{\exp\left(U_S(b_i)/\beta_S\right)}{\sum_j \exp\left(U_S(b_j)/\beta_S\right)}, \tag{16}$$

where b_i and b_j are possible values of the buyback price.

Then, we model the retailer's decision problem in the second stage. As the retailer faces stochastic demand, as well as the supplier's stochastic buyback price, its expected utility is as follows:

$$\begin{aligned} U_R(q) = {} & \mathrm{E}_D[\mathrm{E}_{B|D}[p \min(q, D) - wq \\ & + \gamma_R B(w, q, D)(q-D)^+ - \alpha(\pi_S - \pi_R)^+]], \end{aligned} \tag{17}$$

where $B|D$ denotes the distribution of buyback price conditional on demand. The buyback price $B(w, q, D)$ is the retailer's belief on the supplier's buyback price, and it characterizes the retailer's trust in the supplier. The retailer's decision is a function of the wholesale price and follows the distribution below:

$$\text{prob}(Q(w) = q_i) = \frac{\exp\left(U_R(q_i)/\beta_R\right)}{\sum_j \exp\left(U_R(q_j)/\beta_R\right)}. \tag{18}$$

Last, we model the supplier's wholesale price decision in the first stage. As the supplier faces stochastic demand, stochastic order quantity, and stochastic buyback price, its expected utility is given by

$$\begin{aligned} U_S(w) = {} & \mathrm{E}_D[\mathrm{E}_Q[\mathrm{E}_{B|(D,Q)}[(w-c)Q(w) \\ & - \gamma_S B(w, Q(w), D)(Q(w) - D)^+ \\ & - \lambda(\pi_S - \pi_R)^+]]], \end{aligned} \tag{19}$$

where $B|(D, Q)$ denotes the buyback price distribution conditional on the demand and order quantity; parameter γ_S again characterizes the mental accounting effect. Following the QRE model, the wholesale price follows the probability distribution below:

$$\text{prob}(W = w_i) = \frac{\exp\left(U_S(w_i)/\beta_S\right)}{\sum_j \exp\left(U_S(w_j)/\beta_S\right)}. \tag{20}$$

5.1.3. Maximum-likelihood estimation

We adopt the method of joint estimation (Davis et al., 2014; Zhao et al., 2019). We use the principle of maximum likelihood to obtain estimates of four parameters: the mental accounting γ, the fairness concern α, and the bounded rationality β_R and β_S. The likelihood function under ex-ante buyback pricing is as follows:

$$\begin{aligned} L(\gamma, \alpha, \beta_R, \beta_S | w, b, q) = \log \prod_{i=1}^{33} \prod_{t=1}^{50} \{ & \text{prob}(w_{it}, b_{it}) \\ & * \text{prob}(q_{it}(w_{it}, b_{it}))\}, \end{aligned} \tag{21}$$

where w_{it}, b_{it} and q_{it} are the experimental data of decisions of the ith subject in the tth round.

The likelihood function under ex-post buyback pricing is as follows:

$$\begin{aligned} L(\gamma, \alpha, \beta_R, \beta_S | w, q, d, \tilde{b}) = \log \prod_{i=1}^{34} \prod_{t=1}^{50} \{ & \text{prob}(w_{it}) \\ & * \text{prob}(q_{it}(w_{it})) \\ & * \text{prob}(\tilde{b}_{it}(w_{it}, q_{it}(w_{it}), d_{it}))\}, \end{aligned} \tag{22}$$

Table 3. Estimated result under ex-ante buyback pricing.

	γ_S	λ	β_S	γ_R	α	β_R	LL	BIC
Full	1.41	0.36	377.85	1.00	0.05	828.17	−5264.95	10,570.19
1	*(1)*	0.33	208.98	0.44	0.00	1286.27	−5380.87	10,795.32
2	1.68	*(0)*	724.46	1.07	0.27	767.19	−5358.50	10,750.57
3	1.41	0.36	377.82	*(1)*	0.05	828.13	−5264.95	10,563.48
4	1.37	0.39	340.69	0.96	*(0)*	820.32	−5268.26	10,570.09
0	*(1)*	*(0)*	1488.24	*(1)*	*(0)*	697.59	−5553.56	11,120.56

The italicized numbers in parentheses are the default values.

where w_{it}, q_{it} and $\tilde{b}_{it}$ are the experimental data of decisions of the ith subject in the tth round, and d_{it} is the realized demand.

5.2. Parameter estimation and value of ex-post buyback pricing

We name the model that contains all the behavior parameters as the full model. For comparison, we also consider sub-models where some parameters are fixed at their default values. We evaluate the significance of the parameters by comparing the likelihood values of the models using the default values and the full model.

5.2.1. Ex-ante buyback pricing

Table 3 shows the joint estimation results under the ex-ante buyback pricing. The retailer's mental accounting γ_R is not statistically significant, as shown by comparing the likelihood values of the full model and Model 3. All other parameters are statistically significant by comparing the likelihood values between the full model and sub-models. The Bayesian information criterion (BIC) value supports that Model 3 captures the decision behaviors. As it is difficult to obtain closed-form solutions to the behavioral models, we resort to numerical analysis of the behavioral decisions. We numerically study the sensitivity of the decisions to each statistically significant behavioral parameter using the estimation results and the behavioral models. In the study, the parameters are fixed at the estimation values of Model 3 in Table 3 (i.e., $\gamma_S = 1.41$, $\lambda = 0.36$, $\beta_S = 377.82$, $\alpha = 0.05$, and $\beta_R = 828.13$) except the one under sensitivity study.

The first sensitivity study is on the supplier's mental accounting parameter γ_S, as plotted in Figure 7. Figure 7(a) shows that an increase of γ_S has little impact on the wholesale price, and Figure 7(b) shows that it causes the buyback price to decrease. Conseqently, the order quantity in Figure 7(c) decreases in γ_S. At the estimated value of $\gamma_S = 1.41$, the supplier over-weights the inventory buyback costs, which is consistent with Zhang et al. (2016). This causes the supplier to offer a buyback price lower than the default case (i.e., $\gamma = 1$). Hence, the retailer orders less than the default case, which partly explains the supply chain efficiency lower than the normative prediction.

The second sensitivity study is on the supplier's advantageous fairness concern λ, as shown in Figure 8. Figure 8(a) and 8(b) shows the sensitivity of the wholesale and buyback prices, respectively; both prices decrease in λ. The resulted order quantity in Figure 8(c) increases in λ. As the estimated value $\lambda = 0.36$ is higher than the default value of zero, the advantageous fairness concern of the supplier should improve the order quantity.

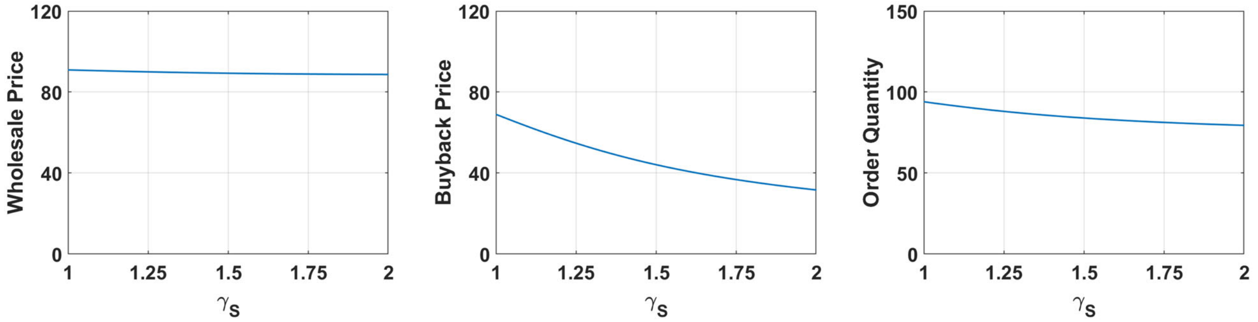
The third sensitivity study is on the retailer's disadvantageous fairness concern parameter α. Figure 9(a) shows that the wholesale price decreases in α, whereas Figure 9(b) shows that the buyback price is not sensitive to α. Fairness parameter α affects the order quantity in two ways. On one hand, the wholesale price decreases with α, which leads to the increase of the order quantity. On the other hand, α directly contributes to the decrease of order quantity according to the retailer's utility in Eq. (11). The combined effect of α on order quantity is shown in Figure 9(c). When α is small, it decreases the order quantity; however, when α is big, the order quantity increases slightly. Nevertheless, the variation range of order quantity is small because the supplier adjusts the wholesale price to counterbalance the retailer's fairness concern.

5.2.2. Ex-post buyback pricing

Table 4 shows the joint estimation results under the ex-post buyback pricing. Statistical testing shows that Model 6 fits the data best, hence, it captures the significant behaviors under the ex-post buyback pricing. The significant behaviors are the supplier' s reciprocity σ, advantageous fairness concern λ, and the retailer's mental accounting γ_R, but not the supplier' s mental accounting γ_S and the retailer' s fairness concern α. We numerically study the sensitivity of the decisions to each statistically significant behavioral parameter using the estimation results and the behavioral models. In the study, the parameters are fixed at the estimation values of Model 6 in Table 4 (i.e., $\sigma = 0.22$, $\lambda = 0.44$, $\beta_S = 328.05$, $\gamma_R = 0.89$, and $\beta_R = 321.98$) except the one under sensitivity study.

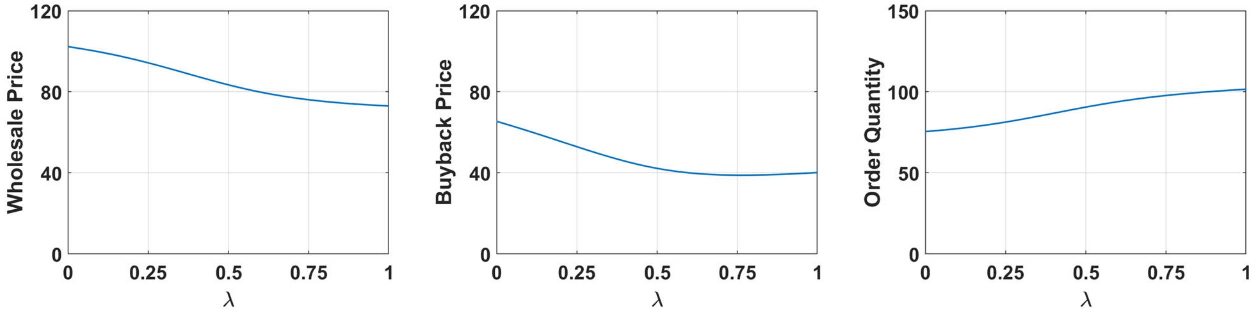
The supplier exhibits advantageous fairness concern; its effect on the decisions of the supplier and the retailer is plotted in Figure 10. The supplier's wholesale price decreases in λ, because this behavior motivates the supplier to reduce the profit difference between the retailer and itself. The ex-post buyback price also decreases in λ. The resulted retailer' s order quantity increases in λ.

The supplier also exhibits another social preference: reciprocity with its estimated parameter value



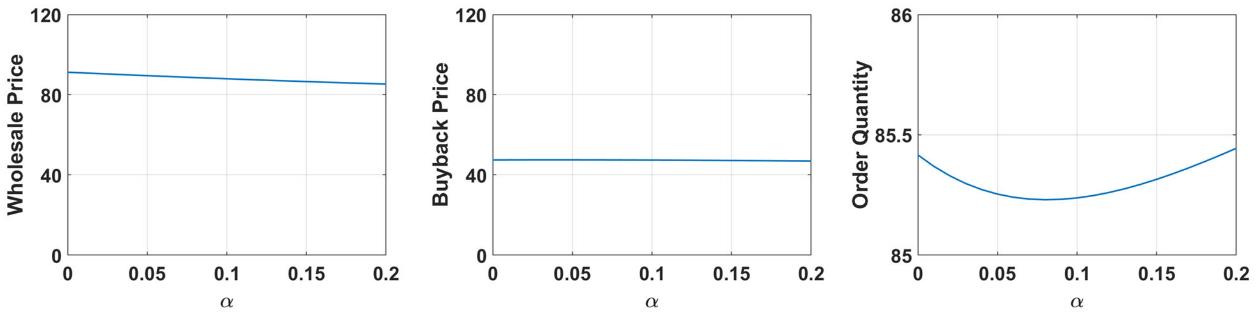
(a) Wholesale Prices (b) Buyback Prices (c) Order Quantities

Figure 7. Sensitivity of the decisions to γ_s under the ex-ante buyback pricing.



(a) Wholesale Prices (b) Buyback Prices (c) Order Quantities

Figure 8. Sensitivity of the decisions to λ under the ex-ante buyback pricing.



(a) Wholesale Prices (b) Buyback Prices (c) Order Quantities

Figure 9. Sensitivity of the decisions to α under the ex-ante buyback pricing.

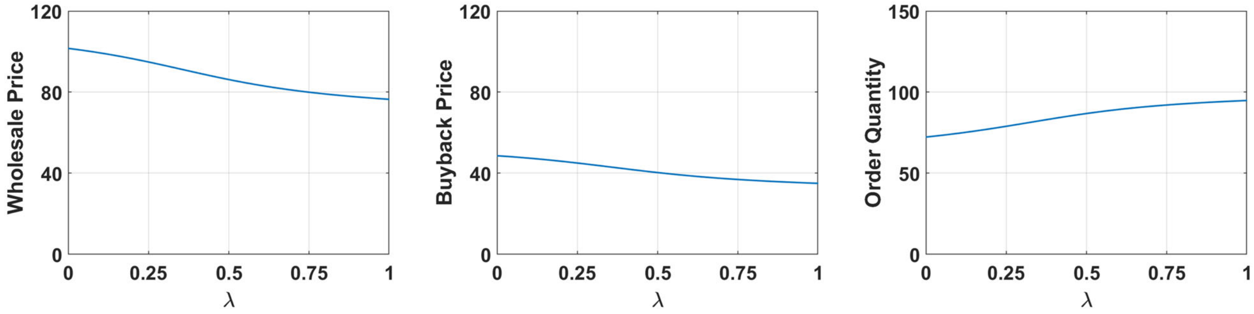
Table 4. Estimated result under ex-post buyback pricing.

	γ_S	σ	λ	β_S	γ_R	α	β_R	LL	BIC
Full	0.80	0.21	0.45	360.97	0.90	0.00	322.95	−3963.14	7973.49
1	*(1)*	0.22	0.44	328.05	0.89	0.00	321.98	−3964.15	7968.76
2	0.15	*(0)*	0.53	463.53	1.04	0.00	327.54	−3984.71	8009.89
3	0.00	0.91	*(0)*	577.96	1.08	0.09	435.00	−4123.39	8287.26
4	0.75	0.16	0.45	370.71	*(1)*	0.00	327.33	−3966.51	7973.50
5	0.80	0.21	0.45	360.97	0.90	*(0)*	322.95	−3963.14	7966.75
6	*(1)*	0.22	0.44	328.05	0.89	*(0)*	321.98	−3964.15	7962.02
7	*(1)*	0.17	0.44	330.52	*(1)*	*(0)*	326.59	−3968.02	7963.02
0	*(1)*	*(0)*	*(0)*	2683.61	*(1)*	*(0)*	439.85	−4443.19	8899.88

The italicized numbers in parentheses are the default values.

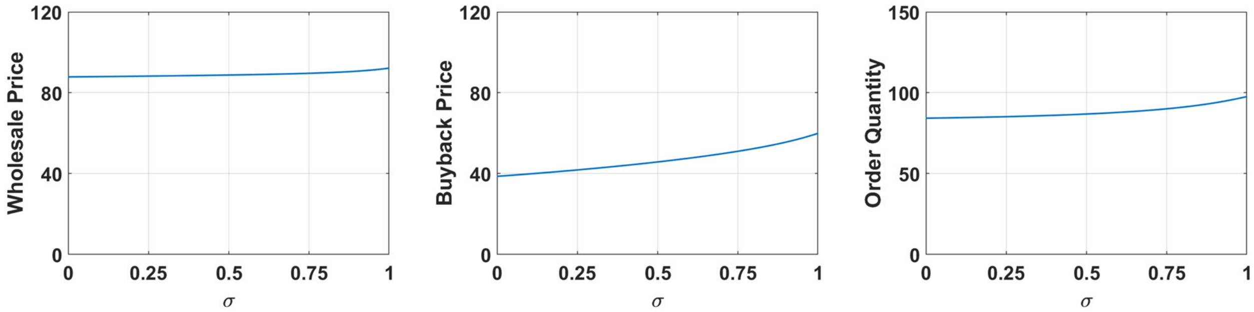
$\sigma = 0.22$. The last two stages under the ex-post buyback pricing are analogue to the trust game: The retailer decides order quantity without knowing the buyback price in stage two, the supplier decides buyback price to reward the retailer in stage three. A higher order quantity in stage two benefits the supplier, but puts the retailer at the risk of higher leftover inventory. In stage three, the supplier can voluntarily compensate the retailer by buying back the leftover inventory. As shown in Figure 11(a) and 11(b), reciprocity increases the buyback price, but has little impact on the wholesale price. As result, the reciprocity increases the retailer's order quantities, as shown in Figure 11(c).

The retailer exhibits significant mental accounting effect, that is, it weighs the buyback income differently from the sales income when it makes ordering decisions. Figure 12(a) and 12(b) shows the sensitivity of the wholesale and buyback prices, respectively. The wholesale price slightly increases, but the buyback price slightly decreases. The resulted order quantity slightly increases, as shown in Figure 12(c).



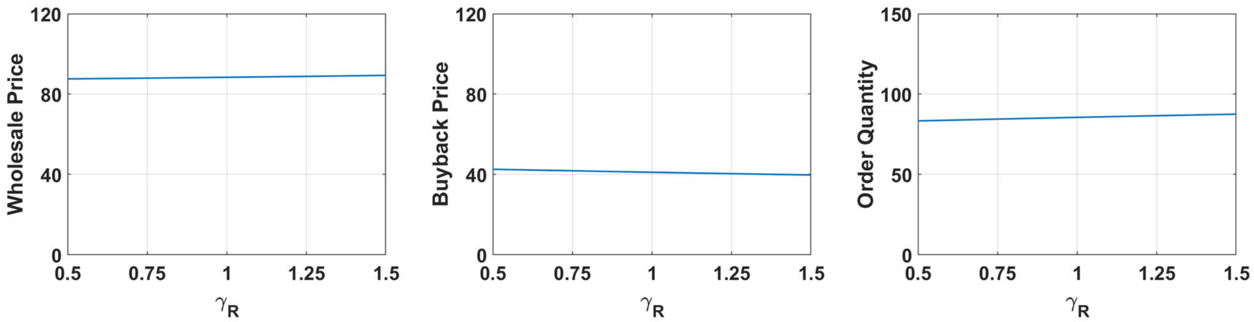
(a) Wholesale Prices (b) Buyback Prices (c) Order Quantities

Figure 10. Sensitivity of the decisions to λ under the ex-post buyback pricing.



(a) Wholesale Prices (b) Buyback Prices (c) Order Quantities

Figure 11. Sensitivity of the decisions to σ under the ex-post buyback pricing.



(a) Wholesale Prices (b) Buyback Prices (c) Order Quantities

Figure 12. Sensitivity of the decisions to γ_r under the ex-post buyback pricing.

Among the three significant behaviors, the advantageous fairness concern and the reciprocity are the main drivers of the retailer's order decision, and their combined effects explain why the ex-post buyback price is significantly larger than the theoretical prediction.

5.2.3. Comparison and value of ex-post buyback pricing

We compare the different impacts of supplier behaviors on decisions under the ex-ante and ex-post pricing. The advantageous fairness concern ($\lambda = 0.44$) is stronger under the ex-post buyback pricing than that ($\lambda = 0.36$) under the ex-ante buyback price; the supplier under former is more sensitive to profit difference, which leads to a smaller profit gap.

The supplier's over-weighting on the buyback cost lowers the buyback price under the ex-ante buyback pricing. Under the ex-post buyback pricing and because of its reciprocity behavior, the supplier offers a higher buyback price than that under the ex-ante buyback price. The reciprocity helps induce the retailer to order a larger quantity.

The retailer exhibits fairness concern under the ex-ante buyback pricing, but not under the ex-post buyback pricing. The ex-post buyback pricing shifts the retailer's attention from fairness into trust. Hence, the order quantity is higher under the ex-post buyback pricing than under the ex-ante buyback pricing.

Moreover, β_R of value 321.98 under the ex-post buyback pricing is smaller than that of 828.13 under the ex-ante buyback pricing, which might be due to the less complex setting under ex-post buyback pricing (i.e., only one wholesale price decision in the first stage of the game). This result implies that the retailer is more rational under ex-post buyback pricing, hence, its order quantity has a smaller variance. A larger order quantity with a smaller variance results in a significantly higher supplier chain efficiency under ex-post buyback pricing than under ex-ante buyback pricing, consequently both the supplier and the retailer profits are higher as well.

6. Concluding Remarks

We examine, by experimental study, the behaviors and performance of a supply chain operated under either ex-ante buyback pricing or ex-post buyback pricing in a long-term partnership. Under both pricing cases, the supplier exhibits advantageous fairness concern. However, the fairness concern is stronger under the ex-post buyback pricing, resulting in a lower wholesale price. The supplier exhibits mental accounting bias of over-weighting the uncertain buyback cost under ex-ante buyback pricing, but reciprocity under ex-post buyback pricing; hence, the buyback price is significantly higher under the latter. The lower wholesale price and the higher buyback price help induce the retailer to order a larger order quantity under ex-post buyback pricing. Furthermore, under ex-post buyback pricing, the retailer trusts the supplier more, is less concerned with fairness, and makes decisions more rationally with less rejection. As a result, comparing with ex-ante buyback pricing, the supply chain efficiency is significantly higher under ex-post buyback pricing, and so are the retailer' s and the supplier' s profits.

Due to social preferences and decision biases, most contracts cannot coordinate the supply chain in practice. This study demonstrates that ex-post buyback pricing performs better than ex-ante buyback pricing in the presence of behavioral preferences. For supply chain managers, the buyback contract based on ex-post buyback pricing is a viable alternative to the contract based on ex-ante buyback pricing as ex-post buyback pricing results in higher profit for both supply chain partners. But this approach may also have limitations. Our study points to a few future research directions. First, our experiment is based on fixed matching, a future study may investigate the ex-post buyback pricing based on random matching. Second, our contract parameters are not adjusted based on the behavioral preference, another future study may design preference-dependent contracts to improve the supply chain efficiency.

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Appendix A: Proofs: The equilibrium of the ex-ante buyback pricing for every given wholesale price $\bar{w}$

Supposing that demand follows a uniform distribution on $[\underline{D}, \bar{D}]$, we solve the retailer's decision problem firstly.

According to Lariviere (1999), the optimal solution of Eq. (1) is

$$q^* = \frac{p-w}{p-b} * (\bar{D}-\underline{D}) + \underline{D}. \quad (A.1)$$

Let $y = \frac{p-w}{p-b}$. Then we have $y \in [0, 1]$. That is, $w = p-(p-b)y = yb + (1-y)p$, $0 \le b \le p$. The supplier's decision function is as follows.

$$\begin{aligned} max_{\bar{w} \ge w \ge c, b \ge 0} \pi_S(w, b) &= \mathrm{E}_D\left[(w-c)q^*(w, b)-b(q-D)^+\right] \\ &= (\bar{D}-\underline{D})y(yb-(1-y)p-c) \\ &\quad + \underline{D}(p-(p-b)y-c)-\frac{1}{2}(\bar{D}-\underline{D})by^2 \end{aligned} \quad (A.2)$$

Because $w < \bar{w}$, we have $yb + (1-y)p \le \bar{w}$. Then,

$$b_y \le p-\frac{p-\bar{w}}{y}, \; y \in \left[\frac{p-\bar{w}}{p}, 1\right]. \quad (A.3)$$

$$\frac{\partial \pi_S(y, b_y)}{\partial b_y} = \frac{1}{2}(\bar{D}-\underline{D})y^2 + \underline{D}y \ge 0 \quad (A.4)$$

The optimal b^* will be achieved on the boundary. Hence,

$$b_y^* = p-\frac{p-\bar{w}}{y}. \quad (A.5)$$

Taking the derivative of y,

$$\begin{aligned} \frac{\partial \pi_S(y, b_y)}{\partial y} &= (\bar{D}-\underline{D})(\bar{w}-c)-(\bar{D}-\underline{D})py + \frac{1}{2}(\bar{D}-\underline{D})(p-\bar{w}) \\ &= \frac{1}{2}(\bar{D}-\underline{D})(\bar{w}-2c-2py + p) \end{aligned} \quad (A.6)$$

Making $\frac{\partial \pi_S(y, b_y)}{\partial y} = 0$, we have $y^* = \frac{p+\bar{w}-2c}{2p}$.

If $y^* \ge \frac{p-\bar{w}}{p}$, we have

$$\bar{w} \ge \frac{p+2c}{3}, \; w^* = \bar{w}, \; y^* = \frac{p+\bar{w}-2c}{2p}, \; b^* = \frac{3\bar{w}-p-2c}{p+\bar{w}-2c}p. \quad (A.7)$$

If $y^* < \frac{p-\bar{w}}{p}$, we have

$$\bar{w} < \frac{p+2c}{3}, w^* = \bar{w}, \; y^* = \frac{p-\bar{w}}{p}, \; b^* = 0. \quad (A.8)$$

To sum up, the equilibrium is as follows.

If $\bar{w} \ge \frac{p+2c}{3}$, the equilibrium is $w^* = \bar{w}$, $b^* = \frac{3\bar{w}-p-2c}{p+\bar{w}-2c}p$, $q^* = \frac{(\bar{w}-2c)(\bar{D}-\underline{D})+p(\bar{D}+\underline{D})}{2p}$; If $c < \bar{w} \le \frac{p+2c}{3}$, the equilibrium is $w^* = \bar{w}$, $b^* = 0$, $q^* = \frac{(p-\bar{w})\bar{D}+\bar{w}\underline{D}}{p}$.

Appendix B: Proofs: The equilibrium of the ex-post buyback pricing

Supposing that demand follows a uniform distribution on $[\underline{D}, \bar{D}]$, we solve the retailer's decision problem firstly.

According to Sec. 3.2, $b^* = 0$ and $q^* = F^{-1}\left(\frac{p-w}{p}\right)$. Thus, $q^* = \frac{p-w}{p}(\bar{D}-\underline{D}) + \underline{D}$.

The supplier's decision problem is transformed as follows.

$$\begin{aligned} max_{\bar{w} \ge w \ge c} \pi_S(w) &= E_D\left[(w-c)q^*\right] \\ &= (w-c)(\frac{p-w}{p}(\bar{D}-\underline{D}) + \underline{D}). \end{aligned} \quad (B.1)$$

Taking the derivative of w,

$$\frac{\partial \pi_S(w)}{\partial w} = \frac{p-2w+c}{p}(\bar{D}-\underline{D}) + \underline{D}. \quad (B.2)$$

Making $\frac{\partial \pi_S(w)}{\partial w} = 0$, we have $w^* = \frac{(p+c)\bar{D}-c\underline{D}}{2(\bar{D}-\underline{D})}$.

If $\bar{w} \ge \frac{(p+c)\bar{D}-c\underline{D}}{2(\bar{D}-\underline{D})}$, we have

$$w^* = \frac{(p+c)\bar{D}-c\underline{D}}{2(\bar{D}-\underline{D})}, \; q^* = \frac{(p-c)\bar{D}+c\underline{D}}{2p}, \; b^* = 0. \quad (B.3)$$

If $\bar{w} < \frac{(p+c)\bar{D}-c\underline{D}}{2(\bar{D}-\underline{D})}$, we have

$$w^* = \bar{w}, \; q^* = \frac{(p-\bar{w})\bar{D}+\bar{w}\underline{D}}{p}, \; b^* = 0. \quad (B.4)$$

Appendix C: Time effect

With all data, we test the time effect by using Pearson correlation analysis of the decisions and time (i.e., round), and the result is shown in Table C.1 below. Under ex-ante buyback pricing, wholesale price exhibits statistically significant time trend (i.e., p-value < 0.5), but buyback price and order quantity do not. Under ex-post buyback pricing, we observe the same result.

However, the time trend effect is not significant for all decisions in both buyback cases when we test the effect using the data of the last 25 rounds, as also shown in Table C.1. Because our research objective is to understand the stable decision behaviors in the one short game, we use the last 25 rounds of stable decisions to estimate the behavioral parameters; the estimation results and their

Table C.1. Pearson's production-moment correlation.

		Ex-ante buyback pricing			Ex-post buyback pricing		
		Wholesale price	Buyback price	Order quantity	Wholesale price	Buyback price	Order quantity
All the data	Coeffcient	−0.064	0.000	0.048	0.063	0.127	0.034
	p-value	0.009	0.146	0.050	0.009	0.057	0.157
Data of the last 25 round	Coeffcient	−0.066	0.052	0.056	−0.014	0.011	−0.015
	p-value	0.057	0.134	0.109	0.674	0.834	0.671

Table C.2. Comparison between the ex-ante buyback pricing and the ex-post buyback pricing.

	All data		Data in the last 25 round	
	Ex-ante buyback pricing	Ex-post buyback pricing	Ex-ante buyback pricing	Ex-post buyback pricing
n	1650	1700	825	850
Wholesale price	87.90[7.59]**	83.09[7.96]	87.22[11.65]***	83.52[10.23]
Buyback price	40.39[20.72]	46.76[28.91]***	43.61[28.42]	47.56[34.60]*
Order quantity	79.52[22.07]**	93.53[13.19]	81.14[36.63]	94.46[23.22]***
Normative order quantity	97.29[31.22]***	80.76[8.34]	98.89[22.59]***	80.40[8.53]
Quantity = 0(%)	8.18	1.29	7.29	1.06
Leftover	10.51[7.44]	12.03[19.12]	11.74[20.53]	13.66[20.75]*
Stockout	30.99[16.68]***	18.50[8.21]	30.40[36.07]***	19.00[25.13]
Supplier's profit	3904.63[1225.96]	4313.07[713.98]*	3895.00[1958.72]	4285.36[1441.26]***
Retailer's profit	1991.25[758.01]	2661.00[778.52]***	1999.29[1587.33]	2577.20[1632.59]***
Efficiency	74.87[17.44]	88.56[7.81]***	74.85[36.49]	87.14[30.16]***

*p-value < 0.1; **p-value < 0.01; ***p-value < 0.001.

implications are updated accordingly in Subsec. 5.2. The estimates are very close to those of using all the data in Table C.2, and their qualitative implications are not different from those obtained using all the data.

Appendix D: The causation between the order quantity and the ex-post buyback price

Using all experimental data, we analyze the development of trust and trustworthiness (i.e., reciprocity) behavior over time per pair, and then examine the causal relationship between the higher order quantity and higher ex-post buybacks in the ex-post buyback case.

First, we analyze when trust and reciprocity behaviors start per pair by comparing the observed decisions with the normative theory predictions. The retailer shows trust behavior if its order quantity is higher than prediction of the normative theory Eq. (7) in Sec. 3.2. The supplier shows trustworthiness behavior if its ex-post buyback price is higher than zero, which is the normative prediction. Table D.1 below shows the starting round of trust and reciprocity. In 24 pairs out of 34, the retailers start to trust suppliers in the first round, and among the 24 pairs, 23 suppliers show reciprocity. In the pairs without reciprocity, the retailers no longer trust suppliers in the next few rounds. In ten pairs, the suppliers first show trustworthiness, and then the retailers trust suppliers in the following rounds. In all other pairs except pair no. 24, the retailers start trust first, which is followed by the supplier's trustworthiness.

Second, we examine the causal relationship between the retailer's trust and the supplier's trustworthiness. We apply the concept of Granger causality (Granger, 1969), which is a statistical test of causality based on prediction. If X Granger-causes Y, then past values of X should contain information that helps predict Y above and beyond the information contained in past values of Y alone. We use the Granger non-causality test (Dumitrescu & Hurlin, 2012) to check the causal relationship between the order quantity and the ex-post buyback price. We choose the optimal number of period lags by Bayesian information criterion for the tests. Two hypotheses are tested using the experimental data. The first is that the ex-post buyback price does not Granger-cause the order quantity. This hypothesis is rejected because the testing shows $\bar{Z} = 10.842$ and a p-value less than 0.05; hence, the ex-post buyback price does Granger-cause the order quantity at least one group. The second hypothesis is that the order quantity does not Granger-cause the ex-post buyback price. It is also rejected because the testing shows $\bar{Z} = 3.062$ and a p-value less than 0.05; therefore, the data supports that the higher order quantity Granger-causes the high prior ex-post buyback price.

Table D.1. The start round of trust and reciprocity.

Group	1	2	3	4	5	6	7	8	9
When the trust starts	1	1	1	1	1	1	1	1	1
[a]The difference	8.33	16.67	25	40.83	16.67	26.67	20	25	16.67
When the reciprocity starts	1	1	1	1	1	1	1	1	1
Ex-post buyback price	20	80	20	50	15	30	20	10	30
Group	10	11	12	13	14	15	16	17	18
When the trust starts	1	1	1	1	1	1	1	1	1
The difference	5	8.3	12.5	6.67	12.5	30.83	16.67	25	75
When the reciprocity starts	8	1	1	1	1	1	1	1	1
Ex-post buyback price	60	10	20	13	10	25	5	20	80
Group	19	20	21	22	23	24	25	26	27
When the trust starts	1	1	1	1	1	1	2	2	2
The difference	12.5	16.67	32.5	15	12.5	25	18.33	25	25
When the reciprocity starts	1	1	1	1	1	49	1	8[b]	6[b]
Ex-post buyback price	10	40	60	15	5	1	10	10	1
Group	28	29	30	31	32	33	34		
When the trust starts	3	3	3	4	5	12	27		
The difference	2.5	28.33	16.67	2.5	2.5	2.5	8.33		
When the reciprocity starts	1	1	1	1	1	8[b]	1		
Ex-post buyback price	8	5	20	10	20	60	37		

[a]The difference between the experimental order quantity and the normative order quantity according to Eq. (7) in the round that the retailer first exhibits trust.
[b]The round number is also the first time when there is leftover inventory.