Behaviors and Performance Improvement in a Vendor-Managed Inventory Program: An Experimental Study

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Behaviors and Performance Improvement in a Vendor-Managed Inventory Program: An Experimental Study

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Abstract

Although vendor-managed inventory (VMI) programs have gained popularity in practice, some empirical studies report that their implementations have not been successful. We conduct experiments to investigate behaviors in a supply chain where a supplier replenishes inventories for a retailer according to a VMI program under a revenue-sharing contract. The results show that subjects' decisions deviate significantly from the standard theoretical predictions because the retailer presents equality preference with adjustment, and the supplier exhibits fairness concern. Since the supplier bears not only the production cost, but also the risk of leftover inventory in the VMI program, we propose an approach that provides the retailer with an opportunity to voluntarily compensate the supplier with an additional percentage of revenue after demand realization. Experimental results based on this new operational procedure show that the retailer still presents equality preference with adjustment, but the supplier has a decision bias of ex-post inventory error regret. The supply chain can perform better under the proposed approach than under only a revenue-sharing contract. Interestingly, the proposed approach does not cause the retailer to share a higher percentage of revenue with the supplier, but it induces the supplier to replenish a higher stock quantity which leads to higher profits for both the retailer and the supplier.

Keywords. Vendor-Managed Inventory, Revenue Sharing, Behavior, Experiment, Stackelberg Game.

1 Introduction

In recent years, vendor-managed inventory (VMI) has attracted attention from both researchers and practitioners of supply chain management. Under a VMI program, a retailer does not place orders with its supplier; instead, the supplier takes responsibility for replenishment and inventory. Hausman (2004) states that Walmart and P&G are the leading companies to have adopted such a VMI program. A successfully implemented VMI supply chain can benefit both parties of a supplier and a retailer. However, it is also reported that many implementations of VMI programs are regarded as dissatisfactory by both parties, and the expected benefits are not fully realized (see Kaipia and Tanskanen (2003), Cooke (1998), and Fraza (1998)). Several factors may have led to the poor performance record of VMI programs. One factor is the inequality in VMI programs, whereby the retailer is loss-free and does not bear inventory costs but the supplier's profit is squeezed from having to bear full inventory costs. The behaviors associated with this inequality may play a significant role in such programs' failing to meet expectations of supply chain partners. The expected benefits of VMI programs are mostly predicted by equilibrium outcomes in a game, with rational decision-makers aiming to maximize their own profits. For example, Fry et al. (2001) find that VMI, through rational decision-making, reduces channel inventory, and both the retailer and the supplier are better off in most cases. However, if they are irrational due to social preferences and/or decision biases, the equilibrium may be difficult to reach. Consequently, the supply chain performance may be different from the equilibrium prediction.

Our study aims to understand the behaviors in a VMI program and their impact on supply chain performance. With this understanding, we further explore operational changes to address the negative impact of these behaviors. We consider a VMI program with a revenue sharing contract like the one in Gerchak and Wang (2004), where a retailer first sets up the contract and then the supplier determines the replenishment quantity. We analyze this VMI program and predict the equilibrium strategies of the retailer and supplier by standard model and behavioral model, respectively. We then conduct an experiment to test the equilibrium prediction. The experimental data show that the retailer's outcome is much worse off than the theoretical prediction because the supplier replenishes a significantly lower stock quantity than predicted. We find that the retailer shows equality preference with a recognition of the costs borne by the supplier, and the supplier exhibits fairness concern. These behaviors, particularly the supplier's fairness concern, cause the replenishment quantities to be much lower than predicted.

To address the supplier's concern, we propose an approach in which the retailer may voluntarily compensate the supplier after the demand is realized. This voluntary *ex post* compensation from the retailer is an extra step that is added to the benchmark operations of a VMI program. With the addition of the *ex post* compensation operation, we analyze equilibrium strategies by both standard and behavioral models. A new experiment is conducted under this proposed approach. The new results are significantly different from those predictions of standard model. Interestingly, the supplier replenishes more stock than the standard prediction, consequently, the supply chain profit is significantly increased. A deeper analysis finds that, surprisingly, most of this increased profit goes to the retailer. Hence, voluntary *ex post* compensation can be a valuable operational tool for a retailer who considers implementing a VMI program under a revenue-sharing contract.

Our paper is organized as follows. The next section reviews the literature. Section 3 introduces the setting of a VMI supply chain under a revenue-sharing contract, builds standard and behavioral models to characterize the decisions, and describes an experiment under this VMI setting. Section 4 adds voluntary compensation into VMI operations, and analyzes this new operational procedure in theory and in experiment. Section 5 compares the results between the two operational procedures to clarify the value of voluntary compensation. Finally, Section 6 concludes the paper.

2 Literature Review

Our research follows active studies of VMI programs in supply chains since the VMI increasingly becomes a popular way to improve supply chain performance in the last few decades. To clarify the contribution of our research, we review the literature in three streams: theoretical study of VMI programs with contracts, empirical study of VMI programs, and experimental study of behaviors in supply chains.

VMI programs have been studied theoretically under different contracts between suppliers and retailers. Early study focuses on the inventory replenishment decisions of suppliers under VMI programs with various service level contracts (Çetinkaya and Lee 2000, Fry et al. 2001). Then, Bernstein et al. (2006) study the performance of a VMI supply chain in which the supplier operates under a wholesale price contract, aiming to improve and/or coordinate the supply chain. A common contract in supply chain coordination (in non-VMI settings) is the revenue-sharing contract (Cachon and Lariviere 2005), which is analyzed and compared to a buyback contract (Cachon 2004). A VMI program under the revenue-sharing contract is studied by Gerchak and Wang (2004), in which a retailer sets a revenue-sharing contract with its multiple suppliers. All the above theoretical studies assume that the VMI partners are rational profit maximizers, and predict that VMI and/or a revenue-sharing contract improve supply chain performance. They provide analytical approaches that our study follows in our benchmark theoretical analysis.

Although the above standard theoretical analysis predicts that VMI programs can significantly improve supply chain performance, some empirical studies report that VMI programs are not successful because the VMI partners become unhappy and dissolve the partnership. For example, Kaipia and Tanskanen (2003) interviewed several supermarkets in Finland to evaluate supply chain performance under VMI programs. They show that those supermarkets under VMI do not perform as well as those that do not use VMI. There are many factors that can cause VMI programs to under-perform. Zammori et al. (2009) summarize several practical examples and studies of VMI operations. They point out that to guarantee satisfactory implementation, simply creating a contract is not enough; some non-contract issues are also important. These issues include how to penalize non-performing suppliers and how to reward good performers. One way to address them is to study the behaviors of suppliers and retailers in VMI programs and to suggest a better operational procedure accordingly.

Considering that human decision-makers may not behave as per standard theoretical predictions, several experiments are conducted based on various game settings to investigate behaviors in a supply chain. They mainly focus on non-VMI supply chains. Fairness preference is observed in Katok and Pavlov (2013) and Wu (2013) where a supplier replenishes products for a retailer under a wholesale price contract facing deterministic demand and stochastic demand, respectively, and in Ho et al. (2014) where one supplier replenishes for two retailers under a wholesale price contract in a deterministic demand case. Reciprocity preference is also reported in Wu (2013). Equality preference is implied in Keser and Paleologo (2004) where a supplier proposes a wholesale price to a retailer, equally splitting the supply chain profit. Believability of demand forecasting information is studied between a retailer and a manufacturer under a wholesale price contract in Özer et al. (2011) and Özer et al. (2014). In addition to the above-mentioned social preferences, several decision biases are observed in the literature. Loss aversion, anchoring, and ex-post inventory error regret are studied in Katok and Wu (2009). They compare three common supply chain contracts between a supplier and a retailer: wholesale price contract, buyback contract, and revenue-sharing contract. Demand-chasing, anchoring, forward-looking, and probabilistic choices are examined in Wu and Chen (2014), who compare different discounting schemes for wholesale price contracts between a supplier and a retailer. Reference-dependent valuation is reported in Becker-Peth and Thonemann (2016), who examine a supplier's transaction with a retailer under a revenue-sharing contract.

However, the operational procedure in a VMI supply chain is significantly different from a non-VMI supply chain. In a non-VMI supply chain, the first mover is generally considered to be the supplier (who proposes a contract based on, for example, the wholesale price scheme), and then the retailer places an order, whereas, under a VMI program, the first mover is usually the retailer (who proposes a contract based on the revenue-sharing scheme), and then the supplier replenishes the inventory. A relevant experimental study is pioneered by Davis et al. (2014), who consider three structures (push, pull, and advance purchase discount) to explore the behaviors of the supplier under a wholesale price contract. Our setting is close to their pull structure, but different in that they assume an expected profit-maximizing retailer. Furthermore, Davis (2015) theoretically and experimentally examines three types of contracts (wholesale price, buyback, and service-level agreement) under the pull-structure supply chain and investigates behaviors of the retailer against an automated best-response computer partner. Our research complements the studies in the literature by examining the behaviors of both an irrational supplier and an irrational retailer in the VMI program under a revenue-sharing contract. We find driving behaviors, including social preferences and decision biases, in a VMI program. Furthermore, we propose voluntary *ex post* compensation by the retailer to mitigate the supplier's concern of leftover inventory. Experimental studies of VMI programs are still lacking; hence, our research contributes to the understanding of VMI partners' behaviors.

3 Revenue-sharing Contract

The VMI partners consist of a single supplier (her) and a single retailer (him). The supplier produces products at a unit cost c, and the retailer sells them at a unit price $r(> c)$. Customer demand D for the products is stochastic and follows a cumulative distribution function $F(\cdot)$ with density function $f(\cdot)$. We assume that these system parameters are common knowledge. Specifically, probability distribution of demand D is known to both the supplier and the retailer. Information sharing is fundamental for implementing a VMI program and can be easily achieved by Internet technology (e.g., electronic data interchange (EDI) in the early stage of VMI).

3.1 Operational procedure

In line with many practical VMI supply chains, we consider the following procedure of operations. First, the retailer proposes the revenue-sharing contract with the percentage s of the revenue that he shares with the supplier. Second, after receiving the proposed value of s from the retailer, the supplier decides the replenishment quantity q with a total cost cq. Then the customer demand D is realized, and finally, the resultant revenue is distributed according to the contract plan s. The leftover inventory, owned by the supplier, is salvaged with zero value. We consider this operational procedure as *contract* mode, which is standard in VMI programs. For example, Gerchak and Wang (2004) state that VMI under a revenue-sharing contract is common, especially in retail businesses. Wang et al. (2004) document that consignment, similar to VMI with a revenue-sharing contract, is widely applied in many industries, especially in online marketplaces such as Amazon.com. Specifically, Amazon.com collects a fee only when a vendor's item is sold, which is consistent with the scheme of a revenue-sharing contract, and the vendor oversees inventory replenishment decisions (see "Sell on Amazon" and "Become an Amazon Vendor" at http://www.amazon.com). This revenue-sharing contract in VMI program is different from the traditional revenue-sharing contract (Cachon and Lariviere 2005), because it has only one parameter of the sharing percentage rather than two parameters of the sharing percentage and wholesale price in the latter case. Furthermore, this revenue-sharing contract in VMI program does not necessarily coordinate the supply chain, but the latter does.

On the other hand, in practical VMI programs, transactions between the supplier and the retailer are most likely conducted repeatedly over a long term. For example, Dong et al. (2007) show that VMI can realize benefits only in a fully long-term integrated supply chain. Dong and Xu (2002) emphasize that a long-term business transaction between partners is an important condition for efficient implementation of a VMI program. Marquès et al. (2010) also claim that long-term collaboration is a key factor for successful implementation of VMI.

3.2 Standard theory

With the above operational procedure, we define the standard theoretical benchmark to be a repeated finite-round game between the supplier and the retailer. In each round, they play a Stackelberg game. We assume that the players are perfectly rational and self-interested. Hence, the repeated game is played with complete information and with players' maximizing profits. Based on standard backward induction, the repeated finite game has a subgame perfect equilibrium that is a repetition of the equilibrium of the one-round game (Fudenberg and Tirole 1991).

Hence, we analyze the equilibrium in the one-round game. Since the supplier decides the replenishment quantity q after observing the sharing percentage s by the retailer, we derive the supplier's optimal decision first. The objective is to maximize her expected profit:

$$\pi_S = \max_{q\geq 0}\{sr\mathrm{E}_D \min(D, q) - cq\}. \tag{1}$$

Then, following the standard analysis, we obtain the optimal replenishment quantity:

$$q^*(s) = \begin{cases} 0, & \text{if } s < c/r, \\ F^{-1}(\frac{rs-c}{rs}), & \text{if } s \geq c/r. \end{cases} \tag{2}$$

When $s < c/r$, the supplier's revenue share is not enough to cover her production cost and guarantee a positive profit; hence, she replenishes nothing to the retailer. However, when $s \geq c/r$, the supplier gains a positive profit.

With the optimal replenishment quantity of the supplier $q^*(s)$ in (2), we proceed to analyze the retailer's optimization problem. The retailer chooses a sharing percentage s to maximize his expected profit:

$$\pi_R = \max_{s \geq c/r} \{(1-s)r\mathrm{E}_D \min(D, q^*(s))\}, \tag{3}$$

where the constraint $s \geq c/r$ avoids trivial cases in (2). The first order condition of objective function (3) with respect to s is

$$(q^*(s))' \frac{c}{rs} \times (1-s) - q^*(s) + \int_0^{q^*(s)} F(x)dx = 0. \tag{4}$$

Solving the above equation, we can obtain optimal s^*.

The equilibrium strategies $[s^*, q^*(s)]$ are specified by (2) and (4). With these strategies, we can evaluate the supply chain profit by

$$\pi = \pi_S + \pi_R. \tag{5}$$

According to Equation (2), the system-wide optimal replenishment quantity for maximizing π can be reached only if $s = 100\%$. In Equation (4), s^* is strictly less than 100%. Consequently, the revenue-sharing contract does not coordinate the supply chain.

3.3 Behavioral considerations

It is generally noted that human behavior in decision-making rarely conforms to the prediction of standard theory. We discuss the potential behaviors that are suggested in the existing literature. These behaviors affect both retailer and supplier decisions in our setting.

Equality preference:

In our VMI setting, the retailer proposes a sharing percentage, and the supplier responds by replenishing product quantity. Hence, their roles can be compared to a proposer and a responder, respectively, in an ultimatum game. According to the standard theoretical prediction for an ultimatum game, where all players are self-interested and perfectly rational, the Stackelberg equilibrium of the responder is to accept any plan, provided that her own share is positive. Thus, the proposer only needs to offer the responder the smallest share. However, the results of many experimental studies deviate from the standard theoretical prediction significantly. For example, Güth et al. (2000), Thaler (1988), and Roth and Erev (1995) find that the average distributed share of proposers is about 50 percent, that is, the proposer follows equality preference, and low distributed shares are rejected by responders with a high probability.

The retailer in our setting is analogues to the proposer in an ultimatum game. Based on the principle of the equality-reciprocity-competition (ERC) model of related study by Bolton and Ockenfels (2000), the utility of the retailer can be formulated. The equality preference is measured by a weighting coefficient δ and a reference point $(50\% + \gamma)$, where γ is an adjustment, i.e., an extra share that the retailer pays the supplier for the inventory costs. If the sharing percentage is either higher or lower than the reference point $(50\% + \gamma)$, then disutility occurs. We express this disutility by an absolute value function to match its double-sided property. Then, the retailer utility for a decision s is given by

$$u_R(s) = r(1-s)\mathrm{E}_D \min(D, q(s)) - \delta[r|s-(0.5+\gamma)|\mathrm{E}_D \min(D, q(s))], \tag{6}$$

where $q(s)$ is the response of the supplier's replenishment quantity to the sharing percentage s of the retailer.

Fairness concern and ex-post inventory error regret:

The supplier is analogues to a responder in an ultimatum game. According to existing studies of the ultimatum game, the responder may penalize the proposer for an unfair sharing percentage; that is, she may reject the shares, and both parties would get nothing. Hence, we expect that the supplier exhibits fairness concern in replenishment quantity decisions.

Additionally, in our VMI setting, once the revenue-sharing percentage is given, the supplier faces a situation similar to the newsvendor problem. The ratio $\frac{rs-c}{rs}$ in (2) can be interpreted as the critical ratio in a standard newsvendor problem. In this problem, a scenario with a critical ratio larger than 0.5 is called a high profit margin while one with a critical ratio smaller than 0.5 is called a low profit margin. For the standard newsvendor problem, Schweitzer and Cachon (2000) conduct an experimental study and observe the well-known "pull-to-center effect" that a newsvendor orders too high a quantity in a low-profit margin scenario and orders too low a quantity in a high-profit margin scenario. They examine nine common utility functions, such as risk attitude, loss attitude, prospect theory, etc., for predicting the decision bias of newsvendors, and find only one of them, i.e., the "regret of ex-post inventory error", can predict the pull-to-center effect. (They also document that a behavior of non-utility type, i.e., anchoring and insufficient adjustment, can cause the pull-to-center effect. Moreover, in the recent literature, a few other decision biases are theoretically proved to be able to explain the pull-to-center effect, yet they need to be empirically justified.) Hence, under our game setting, the supplier likely exhibits ex-post inventory error regret in replenishment quantity decisions.

We propose a supplier's behavioral model to capture the behavioral preferences of fairness concern and the decision bias of ex-post inventory error regret. A general fairness-concern model is documented by Fehr and Schmidt (1999) and is used by Cui et al. (2007) and Wu and Niederhoff (2014) to study the decentralized supply chain. According to the model, the fairness concern is measured by a weighting coefficient ρ and a reference point θ. We use ϕ to represent the degree of regret for ex-post inventory error. Then, the supplier's utility function is

$$u_S(q) = sr\mathrm{E}_D \min(D, q) - cq - \rho[r(\theta - s)^+ \mathrm{E}_D \min(D, q)] - \phi \mathrm{E}_D|D-q|, \tag{7}$$

where $(\theta - s)^+$ models the single-sided disadvantageous fairness concern, that is, the supplier incurs disutility if the sharing percentage is smaller than the reference point. Such single-sided fairness-concern model is justified in the extant literature, e.g., Bolton (1991) and De Bruyn and Bolton (2008). We follow their approaches so that the behavioral model is parsimounious. For completeness, we also build and analyze the two-sided fairness-concern model in Appendix E, where the results show that the single-sided model is a better choice for our study.

Features of the retailer's decision:

The retailer's decision behavior is modeled by Equation (6), where the equality preference with adjustment is captured by the last term containing the weighting coefficient δ and the reference point $0.5 + \gamma$. If $\delta = 0$, the retailer has no equality preference. For this case, we use $\hat{s}$ to denote the optimal sharing percentage of the retailer with consideration of the supplier's behaviors. If $\delta > 0$, the retailer has the equality preference. We use $\widetilde{s}$ to denote the optimal sharing percentage for the retailer with the equality preference when considering the supplier's behaviors.

For a strictly positive δ, the last term of disutility in Equation (6) is smaller when the sharing percentage is closer to the reference point $0.5 + \gamma$. Hence, the retailer can increase utility by moving $\widetilde{s}$ closer to $0.5 + \gamma$. Therefore, we have either $\hat{s} \leq \widetilde{s} \leq 0.5 + \gamma$ if $\hat{s} \leq 0.5 + \gamma$ or $0.5 + \gamma \leq \widetilde{s} \leq \hat{s}$ if $\hat{s} \geq 0.5 + \gamma$. Furthermore, as δ becomes bigger, the equality preference with adjustment has stronger impact on the retailer's utility. Consequently, $\widetilde{s}$ gets closer to the reference point $0.5 + \gamma$. As we expect the human retailer has equality preference with adjustment, he is likely to offer a sharing percentage close to $50\% + \gamma$.

Features of the supplier's decision:

Let $\widetilde{q}(s)$ be the best response of the replenishment quantity that maximizes $u_S(q)$ in Equation (7). Assume the optimal decision of the self-interested supplier in Equation (1), $q^*(s)$, is unique. By comparing the first order optimality condition of Equation (7) with that of Equation (1), we have the following proposition.

Proposition 1: *If the parameter of the ex-post inventory error regret $\phi = 0$, it holds that $\widetilde{q}(s) < q^*(s)$ for $s < \theta$ and $\widetilde{q}(s) = q^*(s)$ for $s \geq \theta$.*

This proposition implies that if the human supplier has fairness concern but not the ex-post inventory error regret, her replenishment quantity decisions exhibit a "single-sided" understocking property. According to this proposition, we hypothesize the following:

Hypothesis 1: *The human supplier will replenish quantities that are lower than predicted by the standard theory.*

If the human supplier has the ex-post inventory error regret but no fairness concern, her replenishment decision is characterized by the following:

Proposition 2: *If the fairness concern parameter $\rho = 0$, and the probability density function f of demand D is symmetric about its mean μ, then $\mu \leq \widetilde{q}(s) \leq q^*(s)$ if $\frac{rs-c}{rs} \geq 0.5$ and $q^*(s) \leq \widetilde{q}(s) \leq \mu$ if $\frac{rs-c}{rs} \leq 0.5$.*

The proof of this proposition is similar to that of Theorem 5 in Schweitzer and Cachon (2000) who show the "pull-to-center effect". For completeness, we provide the details of the proof in Appendix A. This proposition leads to the following hypothesis.

Hypothesis 2: *The human supplier will replenish quantities that exhibit the pull-to-center effect.*

3.4 Experimental study

In the previous subsections, we make the standard theoretical prediction of the equilibrium strategies of the supplier and retailer in the VMI program, and propose potential behaviors. We further conduct an experiment to test these predictions and examine the behaviors of both parties.

3.4.1 Parameters

In our experimental setting, the percentage s is in $[0\%, 100\%]$. Demand D is uniformly distributed on [50, 200]. The unit selling price of the retailer is $r = 4$. The unit production cost of the supplier is $c = 1$.

After the retailer determines a sharing percentage s but before the demand is realized, the supplier produces, according to (2), the optimal replenishment quantity:

$$q^*(s) = \begin{cases} 0, & \text{if } s \leq 25\%, \\ 200 - \frac{150}{4 \times s}, & \text{if } s > 25\%. \end{cases} \tag{8}$$

Given the best response $q^*(s)$ in (8), the retailer solves Equation (4) for his optimal sharing percentage with the solution $s^* = 39\%$. Substituting it back to (8), we find the equilibrium replenishment quantity $q^*(s^*) = 104$. In summary, under our experimental setting for VMI with the revenue-sharing contract, the equilibrium is $[s^*, q^*(s^*)] = [39\%, 104]$. The expected profits of the retailer and supplier are $\pi_S = 43.03$ and $\pi_R = 230.04$, and the supply chain profit is $\pi = 273.07$.

In Figure 1, we draw the relationship between sharing percentage and replenishment quantity based on the standard theoretical prediction according to (8), as shown by the solid line. We also draw a vertical line pointed at $s = 50\%$. Then, from the critical ratio $\frac{rs-c}{rs}$, a case with a sharing percentage smaller than 50% belongs to a low profit margin scenario, whereas one with a sharing percentage larger than 50% belongs to a high profit margin scenario.

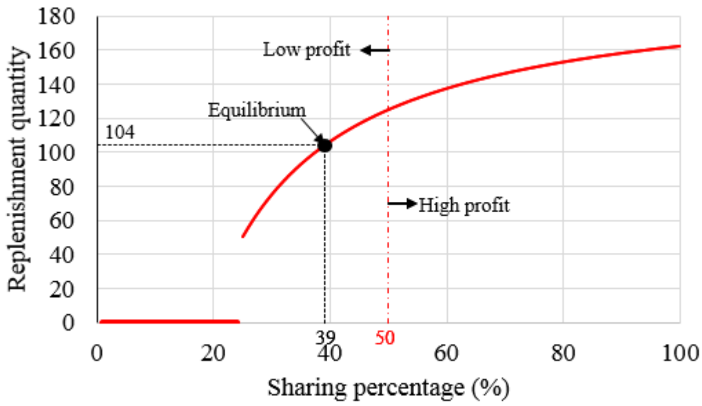

Figure 1: Replenishment quantity as the best response function of the sharing percentage

3.4.2 Process

We recruited 80 subjects, who are bachelor's and master's students from a university, to participate in our experiment. Before the experiment started, they were given a short introduction to inventory management and the VMI setting.

The experiment system was coded using Z-tree (Fischbacher 2007). In the experiment, a retailer subject first chose s between $[0\%, 100\%]$. Then, the partner supplier subject decided q between [0, 200].

The experiment was run for 50 rounds of repeated games without decision support for the subjects. 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. Their roles and partnership remained fixed over the 50 rounds. At the end of each round, both parties could observe each other's profits. The experiment lasted for about one hour.

At the end of the experiment, the subjects received performance-based payments. The performance was measured by a subject's total credit that consisted of a show-up fee of 10,000 points and the cumulative points earned over the 50 rounds. The monetary payment to a subject was his/her total credit divided by 250. Most subjects received payments that were triple to quadruple of the local standard hourly wage.

In this experiment, we used fixed matching instead of random matching because in VMI practice, fixed partners engage in repeated transactions over a long term (with finite rounds), as mentioned in the previous subsections.

3.5 Data analysis

We collect 2000 (40 pairs $\times$ 50 rounds) records of two decisions in the experiment, based on which we conduct statistical analysis to explore major behaviors of both the retailer and supplier, as well as some important findings.

First of all, the time trend of learning effect is studied and we find no learning effect for both the retailer and the supplier, as analyzed in Appendix B. In the followings, we report major observations.

Comparison with standard theoretical prediction:

With the parameters in the experiment, the standard theoretical prediction of the equilibrium is given as $(s^*, q^*(s^*)) = (39\%, 104)$, where $q^*(39\%)$ is obtained by (8). However, the experimental result of sharing percentage significantly deviates from the equilibrium 39%. Since the supplier's decision is made only after the retailer offers the sharing percentage of his revenue, we need to modify the standard theoretical prediction of replenishment quantity. For a given s offered by a retailer in our experiment, the supplier's best response for replenishment quantity is predicted in accordance with (8). As a result, the standard theoretical prediction of the suppliers' best responses is 126.59, which is the average of $q^*(s_{it})$ over s_{it} (the sharing percentage of subject i in round t in the experiment). These standard theoretical predictions and the observed results averaged over subjects are displayed in Table 1 with their standard errors.

Table 1: Decisions and profits under the contract mode

	s	q	π_R	π_S	π
Predicted	39%	126.59 [1.67]	230.04	43.03	273.07
Observed	55.68% [0.77%]**	105.89 [2.35]**	164.15 [0.68]	106.82 [2.55]	270.97

Note: ** denotes significance at $p < 0.001$.

The number in [ ] denotes the standard error.

Statistical analysis implies that the average sharing percentage of 55.68% is significantly greater than the standard theoretical prediction of 39% (single sample t-test, $t = 22.4$, $p < 0.001$), while the average replenishment quantity of 105.89 is significantly lower than the standard theoretical prediction of 126.59 (paired t-test, $t = 12.0$, $p < 0.001$). Given that both parties' decisions significantly deviate from the standard theoretical predictions, it is important to investigate the behaviors associated with their decisions.

Behavior of the retailer:

Under the contract mode, the operational procedure is similar to a ultimatum game. As the first mover, the retailer may have the equality preference when he determines the percentage of revenue to be shared with the supplier. Using the experimental data, we plot frequency histograms of decisions in Figure 2. The sharing percentage decision $s = 0\%$ means that the retailer is fully selfish, while $s = 100\%$ means that the retailer is fully altruistic. Then, all the decisions between 0% and 100% imply the equality preference of the retailer to some extent. In Figure 2, it is observed that most sharing percentage decisions fall between 50% and 65%, which has a "double-sided" property; that is, the retailer likes to share a percentage with the supplier that is neither too high nor too low. This result indicates that, under the contract

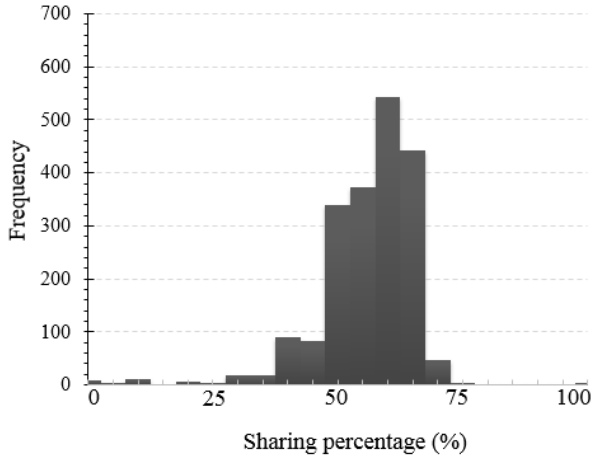

Figure 2: Sharing percentage distribution

mode, the retailer may exhibit equality preference and consideration for the costs borne by the supplier. A standard equality preference would have resulted in a 50%-50% split in sharing percentage. However, considering that the supplier bears the costs, the retailer adjusts the sharing percentage up about 5.68% to the observed average of 55.68%. The above observation is basically consistent with the discussion of the retailer's decision behavior in Subsection 3.3.

Behavior of the supplier:

Similar to Figure 1, we plot the pairs of sharing percentage decisions and replenishment quantity decisions from the experimental data, as shown by the dots in Figure 3, where each dot is the average replenishment quantity corresponding to a given sharing percentage. The results indicate that the replenishment quantity of the supplier subjects increases in the sharing percentage offered by the retailer subjects. When the sharing percentage is less than 65%, the replenishment quantity of the supplier subjects is significantly lower than the standard theoretical prediction (the solid line). This below-prediction replenishment quantity in our setting is consistent with the prediction due to the supplier's fairness concern. In contrast, when the sharing percentage is larger than 65%, the supplier's replenishment quantity is almost the same as that in the standard theoretical prediction; in this case, the supplier exhibits weak or even no fairness concern. In this sense, the fairness concern of the supplier presents a "single-sided" understocking property.

The above observation and discussion suggest that Hypothesis 1 of the supplier's understocking is supported. On the other hand, clearly, no evidence supports Hypothesis 2 of the supplier's pull-to-center effect.

To end this subsection, we provide additional discussions. In Figure 2, it is shown that the retailer presents the equality preference. However, it seems that the average sharing percentage by the retailer, 55.68% in Table 1, is not enough to completely address the supplier's fairness concern because it can be addressed only by a 65% or higher sharing percentage, as reflected in

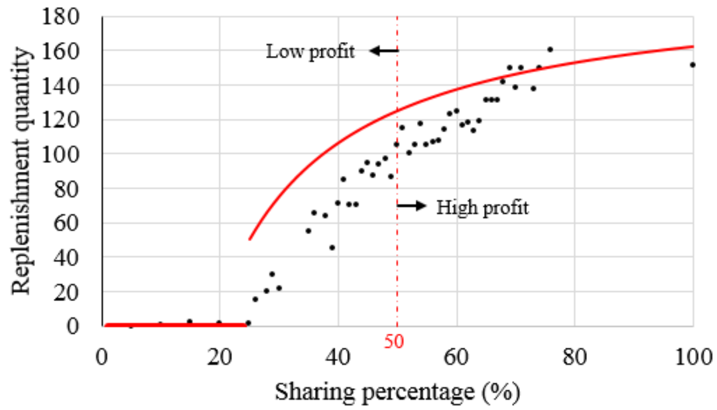

Figure 3: Observed quantity (dots) vs. theoretical quantity (solid line) as a function of the sharing percentage in the contract mode

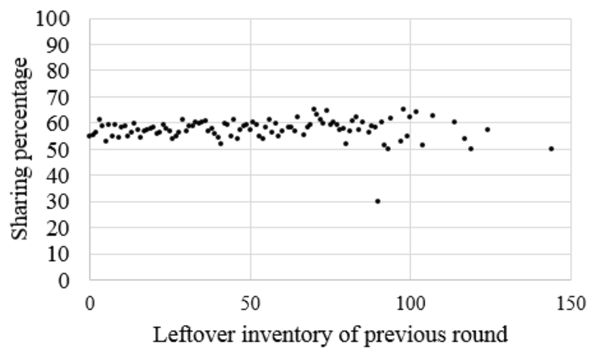

Figure 4: Relationship between retailer decision and the previous round's leftover inventory

Figure 3. Such a gap between the two parties may cause fairness concern for the supplier.

Regarding the stability of the sharing percentage decision over time (in Appendix B) by the retailer, this percentage consists of 50% due to the equality preference (obviously independent of time) and an adjustment amount to match his assessment of the cost borne by the supplier. His assessment seems to be mostly affected by the unit production cost c but little by the leftover inventory cost. This point is shown in Figure 4, where we find no significant correlation between the sharing percentage decision in the *current* round and the leftover inventory in the *previous* round. Consequently, the retailer's decision on the sharing percentage remains stable over rounds. Additionally, as the first mover, the retailer can take the first mover advantage in the setting, similar to existing observations in most ultimatum games. The first mover advantage at the retailer side, together with his little attention to the supplier's leftover inventory cost, leads to the "gap" described in the previous paragraph. Thus, it may be the major cause for the supplier's fairness concern.

3.6 Parameter estimation of the behavioral models

Based on observations from the experimental data, we further investigate the retailer's equality preference with adjustment and the supplier's fairness concern through parameter estimations of behavioral models. The utilities of the retailer and the supplier are developed in Subsection 3.3. Moreover, Figures 2, 9, and 10 show that the decisions of both the retailer and supplier exhibit random patterns. To capture the variations of the decisions, we use the quantum response equilibrium (QRE) model (McKelvey and Palfrey (1995)) for our game setting.

With QRE model, the retailer utility for a decision s is given by Equation (6) with the righthand side taking expectation on q. This is because the supplier follows a probability distribution when she responds according to QRE.

The retailer, according to the QRE model, chooses the sharing percentage s following a probability distribution that depends on the bounded rationality parameter β_R, with $\beta_R \to 0$ reflecting perfect rationality and $\beta_R \to \infty$ meaning complete randomization. Hence, the sharing percentage takes on a particular value s_i with the following probability:

$$\text{Prob}(s = s_i) = \frac{\exp^{u_R(s_i)/\beta_R}}{\sum_j \exp^{u_R(s_j)/\beta_R}}, \tag{9}$$

where $u_R(s_i)$ is in Equation (6) with its righthand taking expectation on q because of QRE.

We also use the QRE model to describe supplier behavior with a bounded rationality parameter β_S, which implies perfect rationality when it approaches to 0 and complete randomness when it goes to ∞. The probability that the supplier chooses a particular q_i in response to a sharing percentage s is then

$$\text{Prob}(q = q_i|s) = \frac{\exp^{u_S(q_i)/\beta_S}}{\sum_j \exp^{u_S(q_j)/\beta_S}}, \tag{10}$$

where the supplier's utility $u_S(q_i)$ is expressed in Equation (7).

The strategy of Equations (9) and (10) represents the equilibrium of one-round game, a repetition of which is also the equilibrium of the finitely repeated game.

Joint estimation of the behavioral parameters:

Using our experimental data, we jointly estimate the behavioral parameters β_R, δ and γ of the retailer and β_S, ρ, θ and ϕ of the supplier. Because the retailer and the supplier play different roles and make different decisions, their βs can be distinct. Specifically, given these parameters, the behavioral models from Equations (9) and (10) determine a joint probability distribution of s and q. Since we observe a q_{it} for each given sharing percentage s_{it} of subject i in round t, the behavioral parameters can be estimated by maximizing the following loglikelihood:

$$L(\beta_R, \delta, \gamma, \beta_S, \rho, \theta, \phi) = \sum_{i=1}^{n} \sum_{t=1}^{50} \log[\text{Prob}\{s = s_{it}, q = q_{it}|\beta_R, \delta, \gamma, \beta_S, \rho, \theta, \phi\}]. \tag{11}$$

We name the behavioral model of Equations (6), (7), (9) and (10) as full model R-SFE. For comparison, we also consider these other models: QRE – only the basic QRE model parameters; SFE – supplier fairness concern and ex-post inventory error regret (no retailer bias); R-SF – retailer equality preference with adjustment and supplier fairness (no ex-post inventory error regret); and R-SE – retailer equality preference with adjustment and supplier ex-post inventory error regret (no fairness). The results of the estimates are summarized in Table 2. The differences in LL values between full model R-SFE and the other models indicate that the influences of the supplier's fairness concern and the retailer's equality preference with adjustment are statistically significant, that is, R-SF model best fits the data. However, the degree of ex-post inventory error regret is statistically insignificant.

In model R-SF of Table 2 , there is a gap between the two reference points $50\%+\gamma = 57.4\%$ of the retailer and $\theta = 65.5\%$ of the supplier. They are basically consistent with the observations in the experimental data: The retailer shares an average of 55.68% (see Table 1); the supplier does not understock when the revenue sharing percentage is above 65% (see Figure 3). Therefore, the sharing percentage by the retailer has not completely addressed the supplier's fairness concern as she requires a higher sharing percentage. This gap could have caused the supplier's fairness concern. Other parameter estimates are generally within their normal scopes. Specifically, the two βs of the retailer and the supplier seem to have a little difference; however, their relative rationality parameters, which are defined as β divided by expected utility, are very close at 0.09 and 0.12, respectively.

Table 2: Joint estimate results under the contract mode

Models	QRE	SFE	R-SF	R-SE	R-SFE
δ			1.18	1.20	1.18
			[0.001]	[0.001]	[0.001]
γ			7.4%	8.4%	7.4%
			[0.11%]	[0.15%]	[0.11%]
$50\% + \gamma$			57.4%	58.4%	57.4%
β_R	26.7	25.6	11.4	12.5	11.4
	[1.81]	[1.53]	[1.26]	[1.33]	[1.26]
β_S	7.8	6.8	6.5	7.7	6.5
	[1.44]	[1.07]	[1.01]	[1.33]	[1.01]
ρ		1.11	1.06		1.06
		[0.02]	[0.01]		[0.01]
θ		65.6%	65.5%		65.5%
		[0.37%]	[0.35%]		[0.34%]
ϕ		0.02		0.02	0.02
		[0.01]		[0.01]	[0.01]
LL	-20421.1	-19472.1	-18355.2	-18982.6	-18355.1

Note: The number in [ ] denotes the standard error.

4 Revenue-sharing Contract plus Voluntary Compensation

From the analysis in the previous section, we find that, under contract mode, both the retailer and the supplier make decisions that significantly deviate from the standard theoretical predictions. Specifically, the retailer tends to have equality preference with adjustment in the sharing percentage of revenue, while the supplier is concerned with fairness in deciding replenishment quantity for a given sharing percentage. As described in Sections 1 and 2, many existing VMI supply chains are not operated successfully and end up as broken relationships. This calls for effective and efficient approaches to improve the performance of VMI supply chains.

4.1 Operational procedure

Under contract mode, the supplier owns the inventory and bears the risk and cost of leftover inventory, but the retailer does not pay attention to the supplier's leftover inventory cost and has no way to address her fairness concern. We suggest an approach in which the retailer makes a voluntary compensation decision after demand realization. This decision forces the retailer to pay attention to the supplier's leftover inventory cost and gives him an opportunity to address the supplier's fairness concern. Note that the leftover inventory is common knowledge to both the retailer and the supplier. Intuitively, such a compensation operation may reduce the extent of the supplier's fairness concern.

For the above purpose, we propose an operational procedure consisting of three decision stages with the first two being the same as those in Section 3. The third stage gives the retailer an opportunity to voluntarily compensate an additional sharing percentage to the supplier after demand is realized and the leftover inventory is salvaged. We call this three-stage operational procedure *voluntary compensation* mode.

The above setting may be justified from many existing studies. Doshi (2004) argues that a contract in practice should be flexible and asks the question: "Does the contract pricing and payment mechanism incentivize the type of supplier performance expected by the purchaser?" Our voluntary compensation can be interpreted as flexibility in the revenue-sharing contract, which incentivizes better performance from the supplier. Hauser et al. (1997) claim that side payments such as gainsharing and/or bribery are prevalent in marketing practices, and this is similar to our voluntary compensation. Moreover, in the spirit of a trust game, Berg et al. (1995) conduct an investment game and verify the existence of trust and trustworthiness, that is, the sender is willing to invest some money with the receiver, and the receiver voluntarily returns part of the amplified amount of money to the sender. Cox (2004) also reports that trust and trustworthiness both exist. Like a gift exchange, George (1982) indicates that some firms willingly pay workers more than the market clearing wage, and workers voluntarily supply more effort. Consequently, we consider that these existing observations are a potential means for improving supply chain performance in a VMI program. In fact, our voluntary compensation mode is similar in spirit to the advance purchase discount contract of Cachon (2004), where both parties share the risk of unsold inventory.

Voluntary compensation may be regarded as an implicit and informal term in the VMI contract and can be communicated orally between parties by handshakes. Such implicit and informal terms, e.g., "good husbandry" and "thorough and farmer-like," are prevalent in farmland contracts and are agreed on orally in Nebraska and South Dakota in the US (Allen and Lueck 1992). These informal terms are also typical in contracts between assemblers and subcontractors in Japan (Sako 1992). Kessler and Leider (2012) experimentally show that an informal agreement with a handshake is socially more beneficial than formally contracted terms.

4.2 Model analysis

The above operation procedure in voluntary compensation mode is a repeated game played between the retailer and the supplier. We first discuss the decision predicted by standard theory and then present behavioral considerations.

4.2.1 Standard theory

According to our discussion in Subsection 3.2, this finitely repeated game under complete information and profit maximization has an equilibrium that is a repetition of the equilibrium of the one-round game.

Let ε denote the revenue sharing percentage that is given to the supplier by the retailer in the third stage. In each round, they play a Stackelberg game. The equilibrium of this one-round game can be analyzed using backward induction when both the supplier and the retailer are self-interested and perfectly rational. In the third stage, the optimal decision of the retailer is to compensate nothing to his supplier, that is, $\varepsilon^* = 0$. As a result, in voluntary compensation mode, the equilibrium strategies of the second and first stages remain the same as those in contract mode.

Consequently, the equilibrium of one-round game in the voluntary compensation mode is $[s^*, q^*(s^*), 0\%]$, where s^* and $q^*(s^*)$ are given by Equations (4) and (2). Similar to contract mode, such an operational procedure does not coordinate the supply chain.

4.2.2 Behavioral considerations

As the third stage decision is voluntary, i.e., not contracted, in voluntary compensation mode, we hypothesize that the behavioral preferences of the players are also similar to those considered in Subsection 3.3.

The retailer may show equality preference with adjustment. Consequently, the retailer's first stage utility for a decision s is given by

$$u_R(s) = r(1-s-\varepsilon)\mathrm{E}_D \min(D, q(s)) - \delta[r|s+\varepsilon-(0.5+\gamma)|\mathrm{E}_D \min(D, q(s))], \tag{12}$$

where all parameters other than ε have the same meanings as in (6). In the third stage, the retailer's utility as a function of the voluntary compensation is

$$u_R(\varepsilon) = r(1-s-\varepsilon)\min(d,q) - \delta[r|s+\varepsilon-(0.5+\gamma)|\min(d,q)]. \tag{13}$$

We expect that the human retailer makes positive voluntary compensation ($\varepsilon > 0$) and offers total share more than 50%. Similar to the discussions in Subsection 3.3, the human retailer decisions are likely to be $\hat{s}+\hat{\varepsilon} \le \widetilde{s}+\widetilde{\varepsilon} \le 0.5+\gamma$ if $\hat{s}+\hat{\varepsilon} \le 0.5+\gamma$ and $0.5+\gamma \le \widetilde{s}+\widetilde{\varepsilon} \le \hat{s}+\hat{\varepsilon}$ if $\hat{s}+\hat{\varepsilon} \ge 0.5+\gamma$, where $\hat{s}$ and $\hat{\varepsilon}$ are the retailer's decisions for $\delta = 0$, and $\widetilde{s}$ and $\widetilde{\varepsilon}$ are those for $\delta > 0$.

The supplier may exhibit ex-post inventory error regret as she faces a newsvendor problem. The supplier may also present fairness concern as she plays a role similar to the responder in an ultimatum game. Hence, the supplier's utility is

$$u_S(q) = \mathrm{E}_D[(s+\varepsilon)r\min(D,q)] - cq - \rho[r(\theta - s)^+\mathrm{E}_D\min(D,q)] - \phi\mathrm{E}_D|D-q|. \tag{14}$$

Let $\widetilde{q}(s+\varepsilon)$ be the maximizer of the ex-post inventory error regret for the supplier in Equation (14), and $q^*(s+\varepsilon)$ be that of a self-interested supplier, in voluntary compensation mode. We can prove the same two propositions as those in Subsection 3.3 by replacing s with $s+\varepsilon$. Correspondingly, we make similar hypotheses for the supplier's decision in the voluntary compensation mode.

Hypothesis $1'$: *The human supplier will replenish quantities that are lower than predicted by the standard theory.*

Hypothesis $2'$: *The human supplier will replenish quantities that exhibit the pull-to-center effect.*

4.3 Experimental study

Based on analyzing the model-predicted impact of the voluntary compensation mode on the equilibrium strategies as well as behavioral hypotheses, we conduct an experiment to understand how human decision-makers behave in such an operational procedure.

4.3.1 Parameters and process

All the parameters remain the same as those in contract mode in Section 3. Demand D is uniformly distributed on [50, 200], the unit selling price of the retailer r is 4, and the unit production cost of the supplier c is 1. The percentage s of revenue sharing is a number in [0%, 100%]. The resultant equilibrium is then $[s^*, q^*(s^*), \varepsilon^*] = [39\%, 104, 0\%]$, with expected profits $\pi_S = 43.03$, $\pi_R = 230.04$, and $\pi = 273.07$.

The whole experimental process (the experimenter, the rounds, the number of participants, and the payment scheme) stayed the same as that in the contract mode experiment. The sequence of random demand over 50 rounds was also the same. We recruited new subjects (80 for 40 pairs) to participate. In the experiment, two decisions in the first and second stages were implemented in the same way as those in contract mode. The third decision was new and was implemented by retailer subjects' voluntarily providing an additional share of the revenue after the demand was realized. Subjects received average payments about three to four times of the local standard hourly wage.

4.3.2 Data analysis

Using the experimental data of 2000 (40 pairs $\times$ 50 rounds) records of three decisions, we investigate the major behaviors of both the retailer and the supplier in making their decisions in the three-stage operational procedure.

First of all, we also study the time trend of learning effect, and find no learning effect either for both the retailer and the supplier, as analyzed in Appendix B. In the following, we report major observations.

Comparison with standard theoretical predictions:

For replenishment quantity, like the data analysis of contract mode, we can calculate the corresponding modified standard theoretical prediction $q^*(s)$ for a given observed s offered by a retailer in the experiment. The resultant standard theoretical predictions are $(s^*, q^*(s), \varepsilon^*) = (39\%, 110.64, 0\%)$, which are displayed in Table 3. In the table, the averages of sharing percentage, replenishment quantity, and voluntary compensation from the experimental data are also displayed with their standard errors.

Table 3: Results under voluntary compensation mode

	Predicted	Observed
s	39%	46.50% [1.15%]**
q	110.64 [2.98]	118.88 [1.97]**
ε	0%	8.51% **
π_R	230.04	184.72 [1.72]
π_S	43.03	112.10 [2.24]
π	270.07	296.82
$s + \varepsilon$	39%	55.01% [0.88%]**

Note: ** denotes significance at $p < 0.001$.
The number in [ ] is the standard error.

Statistical analysis shows that the average sharing percentage of 46.50% in the first stage is significantly greater than the standard theoretical prediction of 39% (single sample t-test, $t = 6.8$, $p < 0.001$), while the average replenishment quantity of 118.88 is significantly greater than the standard theoretical prediction of 110.64 (paired t-test, $t = 5.6$, $p < 0.001$). Importantly, the average sharing percentage of voluntary compensation in the third stage is 8.51%, which is significantly greater than the standard theoretical prediction of 0% (tested by Wilcoxon signed rank test with $p < 0.001$ instead of by t-test, because the error does not follow normal distribution). These results may have been caused by the behavioral preferences and decision biases of the supplier and retailer.

Behavior of the retailer:

Under voluntary compensation mode, because the retailer can share his revenue in the first and third stages, it is appropriate to evaluate his behavior by the total sharing percentage $(s+\varepsilon)$ in these two stages. Using the experimental data, we plot in Figure 5 the frequency histograms of the retailer's decisions in the first and third stages, as well as his total sharing percentage.

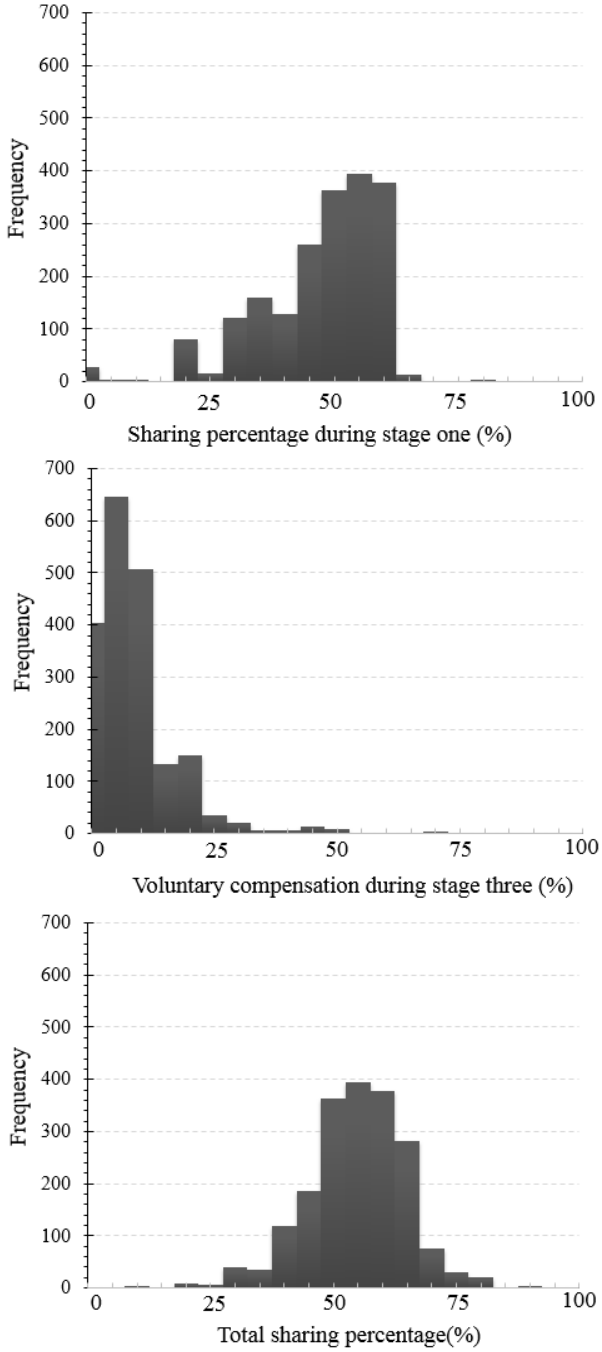

Figure 5: Revenue-sharing percentage distributions

As in contract mode, the sharing percentage decision of 0% means fully selfish, while the sharing percentage decision of 100% means fully altruistic. All decisions between 0% and 100% imply the equality preference of the retailer to some extent. Figure 5 indicates that all sharing percentage decisions in the first stage and total sharing percentage decisions of two stages fall between 0% and 100%, which supports the existence of equality preference. The total sharing percentage presents the "double-sided" property. Additionally, like in contract mode, the average total sharing percentage of 55.01% is different from the standard 50%-50% of equality preference due to the costs borne by the supplier alone. Therefore, under voluntary compensation mode, again, the retailer exhibits equality preference and consideration of the cost borne by the supplier, that is, he adjusts the sharing percentage up by 5.01% from the standard 50%, to the observed average of 55.01%.

Behavior of the supplier:

We first investigate whether the supplier's fairness concern still presents in voluntary compensation mode. Like in Figure 3, we plot the pairs of the replenishment quantity decision and the corresponding first stage sharing percentage decision in Figure 6. In this figure, each dot represents the average replenishment quantity and the corresponding sharing percentage from the experimental data. Had the supplier cared about fairness, the experimental data would be less than the corresponding values calculated by (8). However, most dots in Figure 6 are above the curve of the standard theoretical predictions. Even in the interval $s \in [0\%, 25\%]$ on which the replenishment quantity should be zero because the shared percentage is not enough to cover the supplier's production cost, the corresponding replenishment quantities are significantly larger than zero. These observations imply that the supplier may have little fairness concern when she makes the replenishment quantity decision.

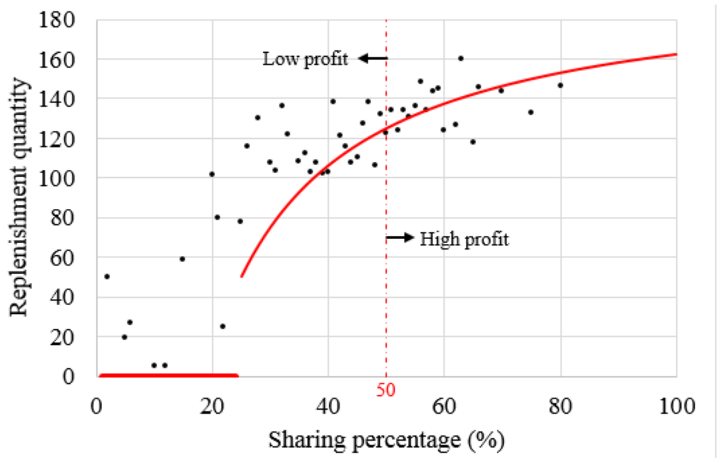

Figure 6: Observed quantity (dots) vs. theoretical optimal quantity (solid line) as a function of sharing percentage in the first stage of voluntary compensation mode

This result of little fairness concern is surprising, but it can be explained. Voluntary compensation relieves the supplier's worry of excessive leftover inventory, and the data indeed show that the retailer voluntarily compensates more when the supplier has higher leftover inventory, as shown in Figure 7. Statistical analysis shows that voluntary compensation and leftover inventory are positively correlated ($p < 0.001$). The supplier's trust in the retailer's voluntary compensation can be the driver that reduces the supplier's fairness concern, although the average total sharing percentage of 55.01% in Table 3 is slightly lower than the average sharing percentage of 55.68% in Table 1. Instead, the supplier may exhibit other decision behaviors.

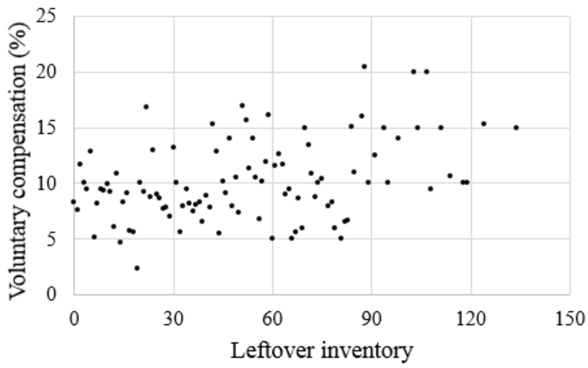

Figure 7: Voluntary compensation as a function of leftover inventory

We further plot the replenishment quantity versus the total sharing percentage of the first and third stages in Figure 8. It shows that the replenishment quantity is above the standard theoretical prediction for the sharing percentage smaller than 50%, but is below for the sharing percentage larger than 50%. From the critical ratio $\frac{r(s+\varepsilon)-c}{r(s+\varepsilon)}$, it is known that the scenarios for a sharing percentage smaller than 50% belong to the low profit margin, whereas, those for a sharing percentage larger than 50% belong to the high profit margin. Then, our observation is consistent with the pull-to-center effect reported in the existing experimental studies of standard newsvendor decisions, such as Schweitzer and Cachon (2000). This observation supports Hypothesis 2′. However, clearly, no evidence supports Hypothesis 1′ of the supplier's fairness concern.

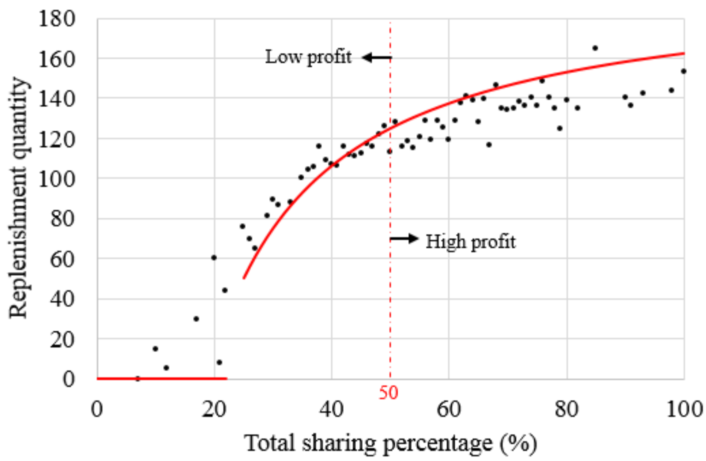

Figure 8: Observed quantity (dots) vs. theoretical optimal quantity (solid line) as a function of total sharing percentage in voluntary compensation mode

To quantify the impact of the behavioral preferences, we develop behavioral models and conduct statistical significance tests in the next subsection.

4.4 Parameter estimation of the behavioral models

To capture the variations of the decisions, like in contract mode, we again use the QRE model for the game setting. The retailer is modeled using the QRE model, but unlike in contract mode, the retailer utility now needs to account for the uncertainty in the compensation of the third stage. Then, the sharing percentage probability distribution is

$$\text{Prob}(s = s_i) = \frac{\exp^{u_R(s_i)/\beta_R}}{\sum_j \exp^{u_R(s_j)/\beta_R}}, \tag{15}$$

where $u_R(s)$ is in Equation (12) with the right hand side taking expectation on q and ε due to QRE.

In the third stage, given the sharing percentage s, the replenishment quantity q, and the realized demand d, the distribution of the retailer's voluntary compensation decision follows a probability distribution by QRE

$$\text{Prob}(\varepsilon = \varepsilon_i | s, q, d) = \frac{\exp^{u_R(\varepsilon_i)/\beta_R}}{\sum_j \exp^{u_R(\varepsilon_j)/\beta_R}}, \tag{16}$$

where u_R is in Equation (13).

Using QRE to model the supplier's replenishment quantity decision, we obtain its probability distribution as follows:

$$\text{Prob}(q = q_i | s) = \frac{\exp^{u_S(q_i)/\beta_S}}{\sum_j \exp^{u_S(q_j)/\beta_S}}, \tag{17}$$

where $u_S(q)$ is in Equation (14) with its right hand side taking expectation on ε because of QRE.

The strategy of Equations (15), (16), and (17) represents the equilibrium of a one-round game and its repetition is also the equilibrium of the repeated game.

Joint estimation of the behavioral parameters:

Given the behavioral parameters of the retailer and supplier, we can obtain the joint probability distribution of their decisions from the conditional distributions in Equations (15), (16), and (17). Since we observe for each pair i in each round t the three decisions s_{it}, q_{it}, and ε_{it}, and demand realization d_t, we estimate the behavioral parameters jointly by maximizing the loglikelihood of these observed data as follows:

$$L(\beta_R, \delta, \gamma, \beta_S, \rho, \theta, \phi) = \sum_{i=1}^{n} \sum_{t=1}^{50} \log[\text{Prob}\{s = s_{it}, q = q_{it}, d = d_t, \varepsilon = \varepsilon_{it} | \beta_R, \delta, \gamma, \beta_S, \rho, \theta, \phi\}]. \tag{18}$$

We name the above behavioral model as full model R-SFE. For comparison, we name other behavioral models the same as those in contract mode. The results of the estimates are shown in Table 4, from which both the equality preference with adjustment and the ex-post inventory error regret bias in R-SE are statistically significant in voluntary compensation mode. Specifically, the value of parameter $\phi = 0.96$ is significantly larger than zero, reflecting that the ex-post inventory error regret bias influences the decision of the supplier under voluntary compensation mode. Contrarily, the degree of fairness concern is statistically insignificant. Thus, these results further suggest support of hypothesis $2'$ and rejection of Hypothesis $1'$.

Table 4: Joint estimate results under voluntary compensation mode

Models	QRE	SFE	R-SF	R-SE	R-SFE
δ			0.94	0.92	0.91
			[0.001]	[0.001]	[0.001]
γ			7.2%	6.7%	6.6%
			[0.19%]	[0.15%]	[0.14%]
$50\% + \gamma$			57.2%	56.7%	56.6%
β_R	28.2	27.1	12.4	11.7	11.4
	[1.74]	[1.68]	[1.21]	[1.05]	[1.04]
β_S	7.9	6.7	7.7	6.9	6.9
	[1.36]	[0.97]	[1.29]	[0.90]	[0.90]
ρ		0.02	0.02		0.02
		[0.01]	[0.01]		[0.01]
θ		66.7%	66.4%		66.4
		[0.20%]	[0.19%]		[0.18%]
ϕ		0.99		0.96	0.97
		[0.04]		[0.02]	[0.01]
LL	−25829.6	−24814.1	−25829.4	−23177.2	−23177.1

Note: The number in [ ] denotes the standard error.

From model R-SE in Table 4, the estimate of parameter $\gamma = 6.7\%$. Hence, the reference point 56.7% (50%+γ) is consistent with the experimental observation 55.01% in Table 3. Additionally, we may wonder whether the reference point $50\% + \gamma = 56.7\%$ of the retailer can address the supplier's fairness concern. We provide further discussion about this issue in Subsection 5.1. The values for other parameters are generally within their normal scopes. Specifically, as in contract mode, the relative rationality parameters (β divided by expected utility) of the retailer and the supplier are very close with values 0.10 and 0.12, respectively.

5 Comparisons and Discussions

We compare the experimental observations and the results of the behavioral models between contract mode and voluntary compensation mode. Understanding the operational procedure and behavioral factors leads to important implications for improving the performance of VMI supply chains.

5.1 Behavioral factor comparison between the modes

We have identified three major behavioral factors through experimental data analyses and behavioral model analyses. They are summarized in Table 5. These factors show distinct features and exert different influences on decisions and supply chain performance.

Table 5: Summary of behaviors under two modes

	Retailer	Supplier
Contract	Equality preference with adjustment	Fairness concern
Voluntary compensation	Equality preference with adjustment	Ex-post inventory error regret

Behavior of the retailer:

In the previous sections, we demonstrated the existence of the retailer's equality preference with adjustment under both operational modes. Under contract mode, the reference point for sharing percentage is $50\% + \gamma = 57.4\%$ in Table 2 (Model R-SF). In contrast, under voluntary compensation mode, it is $50\% + \gamma = 56.7\%$ in Table 4 (Model R-SE). These are consistent with the observation that the retailer subjects offered revenue sharing percentages with little difference between the two modes (55.68% in Table 1 versus 55.01% in Table 3). The results show that sharing percentages are very similar between the two operational modes. The difference is statistically insignificant (independent sample t-test, $t = 0.675$, $p = 0.501$). The above observation seems to support the robustness of the retailer's behavior even though the operational procedures are significantly different across the two modes. Therefore, the retailer's behavior is robust not only over rounds (no learning effect over time) but also across operational procedures to some degree.

However, this stable sharing percentage has different impacts on supplier decision behavior under the two modes. In contract mode, as analyzed in Section 3, this implies that the supplier has persistent fairness concern over rounds because her leftover inventory cost is not addressed by the retailer. In voluntary compensation mode, as analyzed in Section 4, this implies that the supplier has less fairness concern because she *psychologically* feels that the leftover inventory cost is mostly addressed by the retailer's voluntary compensation within each round.

Behaviors of the supplier:

Under contract mode, the supplier's fairness concern causes her to be averse to a low sharing percentage, which induces her to replenish a lower quantity than the best response.

However, the supplier is not as concerned with fairness under voluntary compensation mode. In other words, the supplier does not care strongly about the gap between the reference point $50\%+\gamma$ of sharing percentage and the reference point θ of fairness concern. Instead, the supplier exhibits the decision bias of ex-post inventory error regret.

It is interesting that voluntary compensation shifts the supplier's attention from fairness concern to ex-post inventory error regret bias, but the total sharing percentage changes little. Recall that in the second stage of voluntary compensation mode, the replenishment quantity is significantly higher than the standard theoretical prediction, as shown in Figure 6, implying that the supplier trusts the retailer to voluntarily compensate her in the third stage. From our results, we observe that when the supplier trusts the retailer, she cares less about fairness. In fact, the compensation ε in the behavioral model of voluntary compensation mode can be regarded as trustworthiness behavior.

Comparison with other possible behaviors:

In our setting, the behavior of the retailer is relatively simple and focused. Conversely, the situation of the supplier is much more complex.

In the existing studies in the literature, many behavioral factors such as risk attitude, loss aversion, reference point, mental accounting, and overconfidence in inventory and supply chain management have been discussed. Nevertheless, for voluntary compensation mode, we have examined the ex-post inventory error regret bias of the supplier, which is the only one that can explain the pull-to-center effect (Schweitzer and Cachon 2000), as described in Subsection 3.3; hence, we may not need to compare other decision biases.

In contract mode, three existing behavioral factors other than fairness concern have the potential to explain the understocking phenomena of the supplier: risk aversion, loss aversion, and leftover inventory aversion (Schweitzer and Cachon 2000). To examine the significance of these factors, we build a full model of supplier behavior with the following utility:

$$\begin{aligned} u_S(q) =& \mathrm{E}_D[((sr\min(D,q)-cq)^+)^\alpha - (sr\min(D,q)-cq)^-] - \rho[r|\theta - s|\mathrm{E}_D\min(D,q)] \\ &- \lambda \mathrm{E}_D[sr\min(D,q)-cq]^- - \eta \mathrm{E}_D(q-D)^+, \end{aligned} \tag{19}$$

where $0 < \alpha \leq 1$ is the coefficient of the risk aversion with $\alpha = 1$ being risk-neutral, $\lambda \geq 0$ the loss aversion with $\lambda = 0$ being no loss aversion, and $\eta \geq 0$ the leftover inventory aversion with $\eta = 0$ being no leftover inventory aversion.

We compare the fairness concern model with the other three models of different behavior factors and with the full model, using our experimental data. Table 6 displays the statistical result of model selection. The Vuong test result shows that the fairness concern model fits the data better than the other three models. Furthermore, the values ($\chi^2 = 5.4$ and $p > 0.05$) of the loglikelihood ratio between the fairness model and the full mode indicate that the three behavioral factors of risk aversion, loss aversion, and leftover inventory aversion are not significant. Hence, we may rule out these three behavioral biases. This result makes sense because the other decision biases would have caused understocking for all sharing percentages; only the fairness concern causes "single-sided" understocking according to Proposition 1. This "single-sided" phenomena is a unique feature of our experimental data. Therefore, among those behaviors considered in inventory and supply chain management, fairness concern is the only significant behavioral factor that explains the experimental data in our setting of VMI under contract mode.

Table 6: Comparison between the supplier's behaviors under contract mode

Parameter	Fairness	Risk	Loss	Leftover inventory	Full
δ	1.19	1.27	1.25	1.28	1.19
γ	7.2%	9.3%	9.6%	9.7%	7.2%
β_R	11.4	13.1	12.1	11.9	11.3
β_S	6.5	8.2	7.5	7.1	6.5
ρ	1.08				1.08
θ	65.3%				65.1%
α		0.87			0.98
λ			0.21		0.01
η				0.16	0.02
LL	-18354.8	-18815.3	-18621.2	-18597.9	-18352.1
Vuong test		164.2	104.1	95.7	
LLR					$\chi^2 = 5.4$, $p > 0.05$

In the literature, Davis et al. (2014) find that the leftover inventory aversion best explains their experiment data in pull structure. Even though their pull structure is equivalent to our revenue-sharing contract in theory, we consider that the behavior is different possibly due to *framing effect*. In our setting, the retailer proposes a revenue-sharing percentage, which easily causes the supplier's fairness concern.

5.2 Value of voluntary compensation

The behavioral differences lead to performance differences between contract mode and voluntary compensation mode. We first discuss these performance differences and show that voluntary compensation significantly improves supply chain performance. We list the performance of the two operational modes in terms of averages over subjects in Table 7, where the values of $\widetilde{\pi}_R$, $\widetilde{\pi}_S$, $\widetilde{\pi}$ and $\widetilde{q}$ are the corresponding profits and replenishment quantity in the experiments.

Table 7: Profits and replenishment quantities

Mode	$\widetilde{\pi}_R$	$\widetilde{\pi}_S$	$\widetilde{\pi}$	$\widetilde{q}$
Contract	164.15 [0.68]	106.82 [2.55]	270.97 [1.72]	105.89 [2.35]
Voluntary compensation	184.72 [1.72]	112.10 [2.24]	296.82 [1.84]	118.88 [1.97]

Note: The number in [ ] is the standard error.

This table shows that the supply chain profit under voluntary compensation mode is about 9.5% better than that under contract mode (independent-samples t-test, $t = 3.6$, $p < 0.001$).

This difference is attributed to the shift in supplier attention from fairness concern in contract mode to ex-post inventory error regret bias in voluntary compensation mode. As a result, the replenishment quantity under voluntary compensation mode is significantly higher than that under contract mode, which leads to improvement in supply chain performance.

More interestingly, it is observed that the retailer's profit under voluntary compensation mode is 12.5% higher than that under contract mode (independent-samples t-test, $t = 3.4$, $p < 0.001$), and the supplier's profit is about 5% higher (independent-samples t-test, $t = 2.4$, $p = 0.016$). In a VMI program with a revenue-sharing contract, the retailer always benefits from a higher replenishment quantity for a given total sharing percentage. Intuitively, adding a voluntary compensation stage should benefit the supplier and reduce profit for the retailer because in the third stage, the retailer gives up a portion of his profit to (hopefully) improve the supply chain performance. The supply chain is indeed improved, but about 80% of the increased profit goes to the retailer. As a result, the retailer's profit is higher in voluntary compensation mode even though the average total sharing percentage (55.01% in Table 3) is a little smaller than that (55.68% in Table 1) in contract mode. The increased profit for the retailer would not have been surprising if the retailer was a trusted party in a typical trust game. This is because existing studies show that the trusted party usually takes in a higher share of the increase in efficiency, but trusting behavior seldom pays off for the trusting party such as the supplier. However, our observation is slightly counter-intuitive in a VMI supply chain setting that is not a typical trust game.

To clarify contributions of the voluntary compensation, we did two robustness checks. First, we design and conduct an experiment on a contingent compensation that coordinates the supply chain. We find that the contingent compensation mode does not necessarily improve supply chain performance in the presence of social preferences. Therefore, the voluntariness of the compensation is the reason for the improved performance of voluntary compensation mode in our VMI setting. Appendix C contains the detailed results of the theoretical analysis and the experimental study of this contingent compensation mode. Second, we conduct random matching experiments for both contract mode and voluntary compensation mode. We find that in random matching, the supply chain performance is statistically significantly worse than in fixed matching for both contract mode and voluntary compensation mode. We report the details of these experiments and their results in Appendix D.

We further discuss the implications of the voluntary compensation mode. In the parameter combination in the experiments, the system-wide optimal replenishment quantity is $q = F^{-1}(\frac{r-c}{r}) = F^{-1}(0.75) = 162.5$. Recall that, in general, the system-wide optimal replenishment quantity is reached only if $s = 100\%$ for the VMI setting with a revenue-sharing contract. Therefore, to improve the supply chain performance under the VMI program with a revenue-sharing contract, one way is to encourage the supplier to replenish a larger quantity. As analyzed and discussed previously, the sharing percentage decision of the retailer is consistent across the two modes. However, the replenishment quantity of the supplier in voluntary compensation mode is significantly higher than that in contract mode (independent-sample t-test, $t = 3.375$, $p < 0.001$). Consequently, the profits of both parties as well as the profit of the supply chain are all improved.

The supplier's fairness concern causes the single-sided understocking in contract mode, and the supplier's ex-post inventory error regret bias leads to pull-to-center effect (i.e., overstock when facing low profit margin and understock when facing high profit margin) in voluntary compensation mode. In our experiments, the supplier's reference point for fairness concern is larger than the retailer's reference point for sharing percentage, and both references are larger than 50%. In our study, the value of $s = 50\%$ corresponds to the critical ratio $\frac{rs-c}{rs} = 0.5$, at which low and high profit margins are divided. Then, for a given sharing percentage $s \leq 50\%$, the supplier under contract mode replenishes less than the best response quantity, whereas the supplier under voluntary compensation mode replenishes more than the best response quantity. Indeed, our experimental data support that, for all $s \leq 50\%$, the replenishment quantities in voluntary compensation mode are significantly larger than those in contract mode (Mann-Whitney test, $p < 0.001$). For a given sharing percentage $s > 50\%$, the supplier's fairness concern in contract mode becomes weak, whereas the supplier in voluntary compensation mode faces a decision with a high profit margin. Hence, the outcome of the comparison between the two modes may be mixed. Nevertheless, from our experimental data, for all $s > 50\%$, the replenishment quantities in voluntary compensation mode are still significantly larger than those in contract mode (Mann-Whitney test, $p < 0.001$). However, such an outcome may not be always guaranteed.

In general, according to the standard newsvendor problem, systems with $\frac{r-c}{r} \leq 0.5$ are categorized into low profit margin systems, whereas systems with $\frac{r-c}{r} \geq 0.5$ are categorized into high profit margin systems. Then, for low profit margin systems, it holds that $\frac{rs-c}{rs} \leq 0.5$ for all $s \leq 100\%$. In such a system, the supplier always faces decisions in a low profit margin for any sharing percentage s. In this case, our observations imply that voluntary compensation mode can certainly perform better than contract mode. On the other hand, for high profit margin systems, $\frac{rs-c}{rs}$ can be either larger or smaller than 0.5, which depends on sharing percentage s. In such a system, the supplier can possibly face decisions in either a low profit or high profit margin. Our observations in this case imply that voluntary compensation may still be beneficial.

5.3 Extended remarks

We summarize the major implications. Equality preference with adjustment is the main behavior of the retailer in deciding the sharing percentage in both modes; for the supplier, however, fairness concern is the main behavior in deciding the replenishment quantity in contract mode, and ex-post inventory error regret bias is the main behavior in deciding replenishment quantity in voluntary compensation mode. We would also consider that these behaviors are robust over parameter combinations of c, r, and D. Different parameter combinations can impact the degrees of these behaviors, but their behaviors should be consistent. Specifically, in this study, we adopt a high profit margin system with $\frac{r-c}{r} = 0.75$. In the literature, a low profit margin system with, e.g., $\frac{r-c}{r} = 0.25$, is also common in experimental studies on the standard newsvendor problem. As discussed and analyzed just previously, the supplier always faces low profit margin decisions in low profit margin systems, which is a special case in high profit margin systems because the supplier can face either low or high profit margin decisions in high profit margin systems. Consequently, we do not adopt a low profit margin system in our experimental study but consider a high profit margin system to be sufficient for our motivation.

Additionally, the standard theoretical model predicts that the supply chain in our setting is not coordinated (i.e., system-wide optimal) unless the total sharing percentage is 100%, which is not likely in either theory or practice. Nevertheless, because of the behavioral preferences, it is possible that the supply chain may be coordinated in voluntary compensation mode. Specifically, for low profit margin systems, the pull-to-center effect increases the replenishment quantity for all sharing percentages below 100%, which makes it possible to coordinate the supply chain. On the other hand, the behavioral preferences may cause a theoretically coordinating contract not to achieve a centralized performance, as we observed in the experimental study of contingent compensation mode (as shown in Appendix C).

6 Conclusions

We conduct an experimental study based on a VMI program under a revenue-sharing contract. We examine two operational procedures: contract mode and voluntary compensation mode. The results show that the subjects' decisions deviate significantly from the standard theoretical predictions. The analyses of the experimental data and behavioral models suggest that some major social preferences and decision biases exist in both modes. Specifically, the retailer presents equality preference with adjustment when he determines the percentage of revenue to share with the supplier, and the supplier exhibits fairness concern when she determines the replenishment quantity under contract mode. However, in voluntary compensation mode, the supplier exhibits no significant fairness concern; instead, she has a decision bias of ex-post inventory error regret, which causes the pull-to-center effect of the replenishment quantity decisions.

Due to the existence of these behavioral factors, a VMI supply chain can perform better in voluntary compensation mode than in contract mode. Thus, managers in VMI programs need to pay attention to the effect of voluntary compensation. In other words, we encourage the retailer to voluntarily compensate the supply partner. In doing so, the retailer does not sacrifice his profit but, instead, increases profit by accruing most of the increased profit in the supply chain. The supplier is also slightly better off. Furthermore, due to better performance of fixed matching than random matching, the retailer and supplier are better off to build a long-term partnership for implementing a VMI program.

These observations are of importance for the successful and effective implementation of VMI programs. Especially, to date, the implementation of many VMI programs has paid significant attention to contract terms but little attention to voluntary compensation based on trust and trustworthiness. Our study shows that voluntary compensation can potentially bring significant benefit to VMI programs.

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Appendix

A. Proof of Proposition 2

A self-interested supplier chooses a replenishment quantity to maximize the objective $sr\mathrm{E}_D \min(D, q) - cq$.

Since the objective function of the self-interested supplier is concave in q, the optimal replenishment q^* satisfies the following first order condition:

$$rs\frac{\mathrm{dE}_D \min(D, q)}{\mathrm{d}q}|_{q=q^*} - c = 0.$$

We prove the case of high profit margin first. By definition of high profit margin, we have $\mu < q^*$. Then, the concavity of the objective function implies

$$rs\frac{\mathrm{dE}_D \min(D, q)}{\mathrm{d}q}|_{q=\mu} - c > 0.$$

As f is symmetric, it follows from the proof of Theorem 5 in Schweitzer and Cachon (2000) that

$$\phi\frac{\mathrm{dE}_D|D-q|}{\mathrm{d}q}\begin{cases} > 0, & \text{if } q > \mu; \\ = 0, & \text{if } q = \mu; \\ < 0, & \text{if } q < \mu. \end{cases}$$

Consequently, with $\rho = 0$, the first order derivative of Equation (14) has the following property:

$$\frac{\mathrm{d}u_S(q)}{\mathrm{d}q} = rs\frac{\mathrm{dE}_D \min(D, q)}{\mathrm{d}q} - c - \phi\frac{\mathrm{dE}_D|D-q|}{\mathrm{d}q}\begin{cases} > 0, & \text{if } q = \mu; \\ < 0, & \text{if } q = q^*. \end{cases}$$

As the first order derivative of $u_S(q)$ is continuous in q, there exists an optimal $\widehat{q} \geq \mu$ and $\widehat{q} \leq q^*$ such that $\frac{\mathrm{d}u_S(q)}{\mathrm{d}q}|_{q=\widehat{q}} = 0$. Similar steps can prove the case of low profit margin. ■

B. Learning effect over time

It is necessary to investigate dynamics such as reputation building in games with fixed matching and repeated interaction. In the literature, Wu (2013) finds a dynamic effect of the decisions between a supplier and a retailer in fixed matching under a non-VMI setting with a wholesale price contract. Hyndman et al. (2014) show a dynamic effect in a supply chain setting of two firms playing a capacity game under both fixed and random matches. Andreoni and Miller (1993), Cochard et al. (2004), and Slembeck (1999) observe the reputation building in prisoner's dilemma, ultimatum, and trust games with fixed matching players. We next discuss the learning effect in both contract mode and voluntary compensation mode.

Contract mode:

We first plot subject decisions over rounds in Figures 9 and 10 for the retailer and the supplier, respectively. In these figures, the black-dotted lines are the average decision values, while the gray dashed lines are the envelopes ($\pm$ 3 times of standard deviation) of decision values. We observe that both decisions are stable over rounds showing no significant learning effect over time. We also conduct a rigorous statistical regression analysis of these data, and find no significant learning effect over time because the p-values of time coefficient are higher than 0.05. In addition, we plot the sharing percentage decision in a *current* round against the replenishment quantity decision in its *previous* round in Figure 11. The statistical analysis shows no significant correlation either. Moreover, we do not observe any ending effect of last three rounds (for the retailer decision, the paired t-test $t = 1.443$, $p = 0.149$; and for the supplier decision, the paired t-test $t = 1.105$, $p = 0.301$), which is different from the predicted ending effect by the theoretical incomplete information model in Kreps et al. (1982).

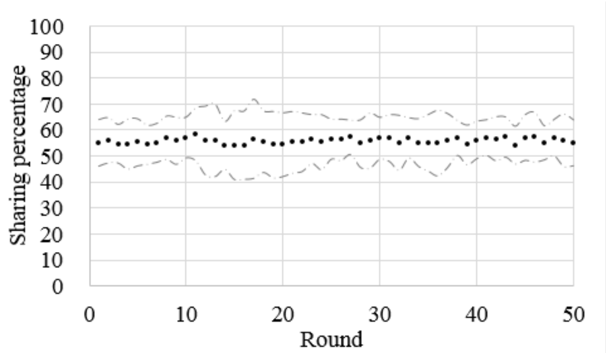

Figure 9: The decisions of retailer subjects over time in contract mode

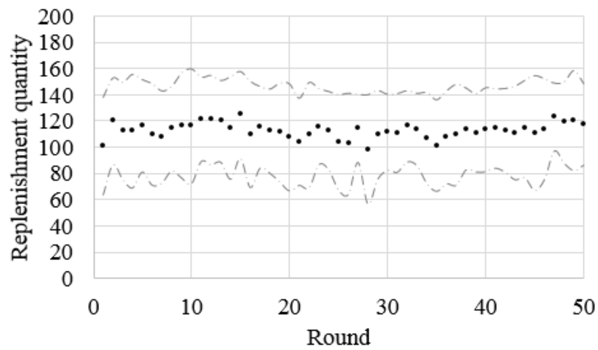

Figure 10: The decisions of supplier subjects over time in contract mode

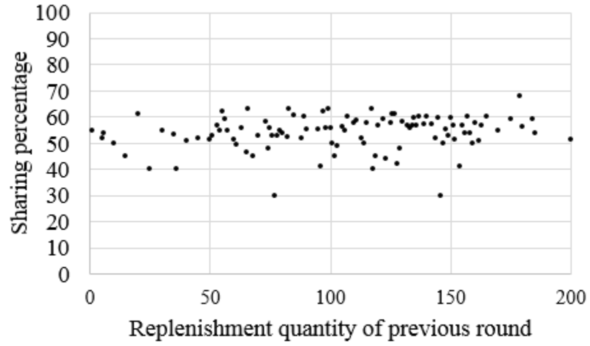

Figure 11: The decisions of retailer and of the previous round supplier in contract mode

As described previously, in our VMI setting, once the sharing percentage is given by the retailer, the supplier faces a situation like the newsvendor problem. The experimental study of the standard newsvendor setting by Schweitzer and Cachon (2000) shows that there is no significant learning effect when the newsvendor subjects make the ordering decisions. Bolton and Katok (2008) clarify a similar observation in this base setting and then conduct an experiment with different feedback information to improve the decision. Bostian et al. (2008) also study standard newsvendor behavior, the results of which are not in contradiction with Schweitzer and Cachon (2000), and they propose an adaptive dynamic model based on past demand chasing to explain individual subject behaviors. In our experiment, the retailer subjects offer a stable sharing percentage over rounds. Therefore, in our setting, it is not surprising that the supplier subjects do not exhibit learning effect nor ending effect, which is consistent with observations in existing experiments on the standard newsvendor setting.

Among the existing experimental studies on games with fixed matching method, the most relevant setting to ours may be the one in Wu (2013). While Wu (2013) observes the learning effect, this could have been caused by the dynamics of the supplier's reported unstable wholesale price decisions. But in our setting, the first mover is the retailer subject who offers a stable sharing percentage over rounds. Because our setting and the first mover decision are different from Wu (2013), the parties in our supply chain behave differently. The setting differences could have also explained our learning effect difference from other existing observations on fixed matching and multi-round repeated interactions.

Voluntary compensation mode:

Figures 12 and 13 display the decisions of retailer subjects in the first and the third stage respectively, and Figure 14 shows the decisions of supplier subjects, over rounds. In all these figures, the black-dotted lines are the average values of decisions, while the gray dashed lines are the envelopes of decision values (± 3 times of standard deviation). Over all, they show no noticeably time trend, similar to the observation of no learning effect in the contract mode.

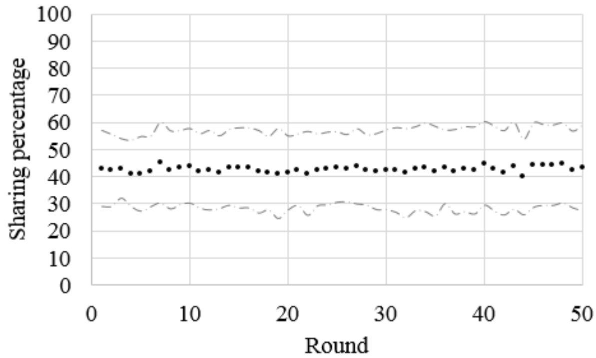

Figure 12: The first stage decisions of retailer subjects over time in voluntary compensation mode

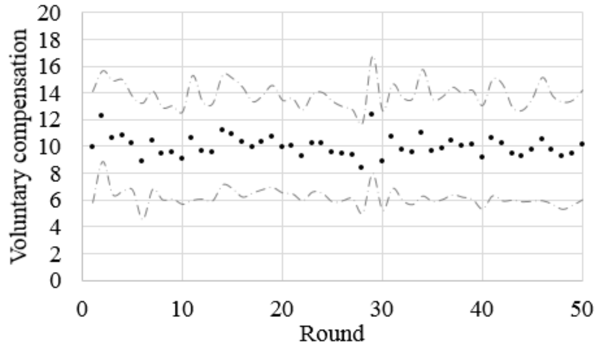

Figure 13: The third stage decisions of retailer subjects over time in voluntary compensation mode

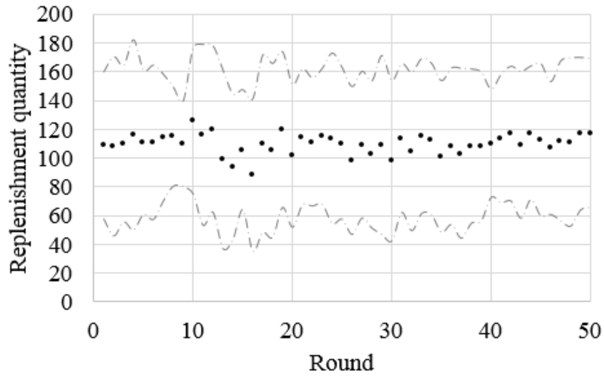

Figure 14: The decisions of supplier subjects over time in voluntary compensation mode

We also test the sharing percentage decisions of the retailer in stage one in a *current* round against the replenishment quantity decision of the supplier in its *previous* round in Figure 15. Similar figure is plotted for the replenishment quantity decisions of the supplier in a *current* round against the compensation decision of the retailer in stage three in its *previous* round in Figure 16. In both cases, we find no significant correlation.

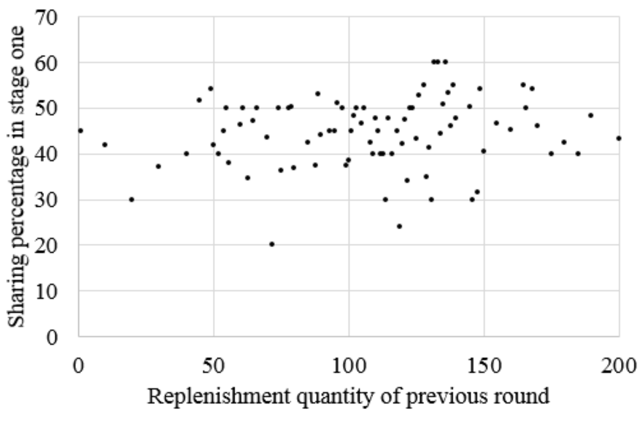

Figure 15: The decisions of retailer and of the previous round supplier in voluntary compensation mode

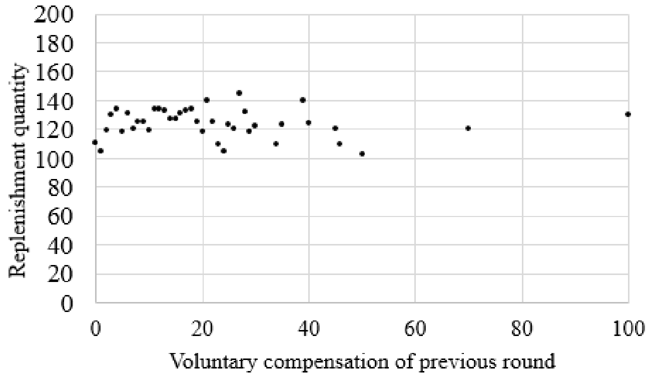

Figure 16: The decisions of supplier and of the previous round retailer in voluntary compensation mode

Additionally, we conduct a rigorous statistical regression analysis of the data presented in figures 12-16. The analysis indicates no significant learning effect over time because their p-values of time coefficient are higher than 0.05. We also plot the relationship between the retailer's decision and the previous round leftover inventory, similar to Figure 4, which shows no correlation. Moreover, we do not observe any ending effect of last three rounds (for the retailer decisions of stage one, the paired t-test $t = 1.505$, $p = 0.140$ and stage three, the paired t-test $t = 1.181$, $p = 0.245$, and for the supplier decision, Wilcoxon signed rank test $p = 0.121$).

Again, we find no significant learning effect of all decisions over time as well as no ending effect. We consider the reason for no dynamics over rounds in voluntary compensation mode to be similar to those in contract mode. In voluntary compensation mode, we may regard the supplier's decision as a *modified* newsvendor decision. According to the experimental data, the retailer's decisions are stable over rounds. Hence, the replenishment quantity by the supplier is stable.

C. Contingent compensation

As the contract plus voluntary compensation significantly improves the performance of the retailer and the supply chain over the contract only, it is not clear whether this performance improvement comes from the voluntary effect of the retailer's goodwill or the extra compensation. To clarify this point, we design a bonus plan contingent on the replenishment quantity to compensate the supplier in the third stage. The operational mode with this bonus plan is called *contingent compensation mode*. This bonus plan is contracted at the same as the revenue sharing percentage is. Thus, it has no voluntary effect. We first develop a bonus plan that coordinates the supply chain in theory and then conduct an experiment to assess its performance.

Standard theory:

Recall that the revenue sharing contract is specified by a sharing percentage s of the revenue that is given to the supplier. If we add a bonus plan contingent on replenishment quantity q, it provides incentive for the supplier to replenish a higher quantity. One such bonus plan is to compensate the suppler $(1-s)cq$ by the retailer in the third stage. In theory, the bonus motivates the supplier to replenish a quantity that coordinates the supply chain because the supplier under the bonus plan faces an optimization problem, as follows:

$$\pi_S = \max_{q \geq 0} \{sr\mathrm{E}_D \min(D, q) - cq + (1-s)cq\}, \tag{20}$$

where the last term is the bonus plan contingent on the replenishment quantity. The optimal quantity of the supplier is then

$$q^*(s) = F^{-1}\left(\frac{r-c}{r}\right), \forall s \geq 0. \tag{21}$$

Note that q^* is independent of s. By backward induction, the retailer has a decision problem to decide s in stage one, as follows:

$$\pi_R = \max_{s \geq 0} \{(1-s)r\mathrm{E}_D \min(D, q^*) - (1-s)cq^*\}, \tag{22}$$

where the last term is the compensation paid out by the retailer according to the bonus plan. As the retailer profit decreases in s, the optimal sharing percentage is $s^* = 0$.

Note that by Equation (21), the optimal quantity of the supplier coordinates the supply chain for any sharing percentage s between zero and one. Hence, the total profit of the supply chain equals the system optimal and does not change with the sharing percentage s. However, by offering different s, the retailer divides the supply chain profits between the supplier and the retailer such that the supplier has s share of the total supply profit and the retailer has $1-s$ share.

To understand the behavioral preferences under the contract consisting of the revenue sharing and the contingent compensation of the bonus plan, we next design an experiment and collect data to test decision behaviors.

Experiment study and results:

For the experiment, we use the same set of parameters as those in Subsection 3.4.1. Consequently, under contingent compensation mode, the theoretical predictions of decisions are $(s^* = 0, q^* = 162.5)$ and the profits are 318.75 and 0 for the retailer and the supplier, respectively. Furthermore, for any given s, the best replenishment quantity of the supplier is $q^*(s) = 162.5$. That is, a rational profit-maximizing supplier always replenishes a quantity to coordinate supply chain, no matter what is the retailer's offer of revenue sharing percentage. This experiment has 78 subjects and follows the same process as those in Subsection 3.4.2.

First, we observe no learning effect because there is no time trend in the decisions of the retailer and supplier as a function of rounds, as shown in Figures 17 and 18, respectively. These results are consistent with those in voluntary compensation mode in Figures 12 and 14.

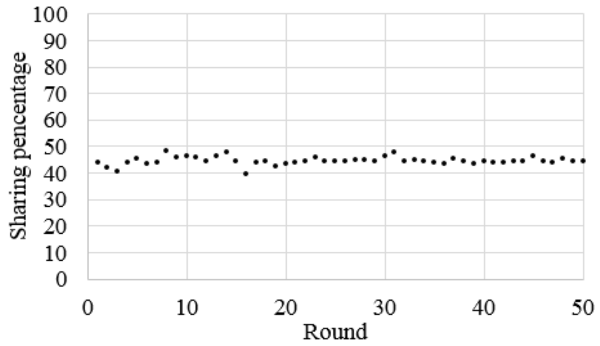

Figure 17: The decisions of retailer subjects over time in contingent compensation mode

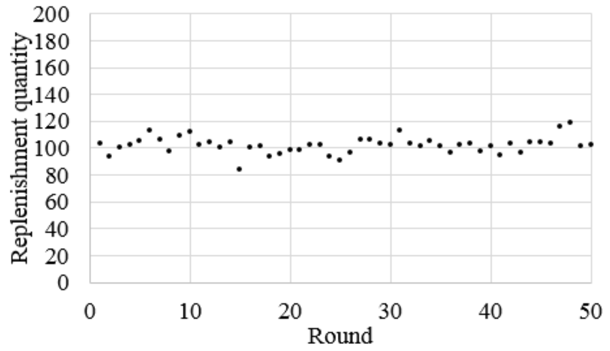

Figure 18: The decisions of supplier subjects over time in contingent compensation mode

Second, Figure 19 shows that the retailer still exhibits equality preference like those in contract mode and voluntary compensation mode. Nevertheless, the sharing percentages offered by the retailer are about 45%, smaller than those offered in contract mode and voluntary compensation mode, as shown in Figures 2 and 5, respectively.

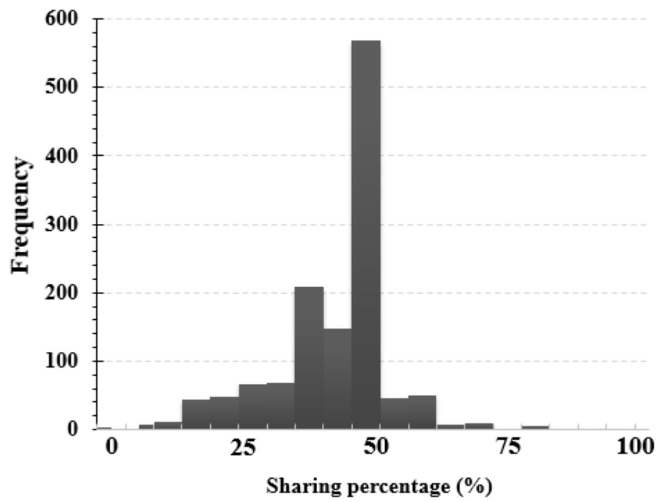

Figure 19: The decisions of retailer in contingent compensation mode

Finally, Figure 20 shows the supplier decision as a function of sharing percentage. We observe that the supplier exhibits both fairness concern and ex-post inventory error regret.

Fairness concern can be inferred because the supplier replenishes much lower quantity than expected when sharing percentage is below 50%. Ex-post inventory error regret exists because the replenishment quantity is pulled down towards mean demand for high profit margin case when sharing percentage is above 50%, for which there is no reason for fairness concern. Overall, the joint impact of these two behaviorial preferences causes much lower replenishment quantity than predicted, resulting in poorer supply chain performance for both the retailer and the supplier.

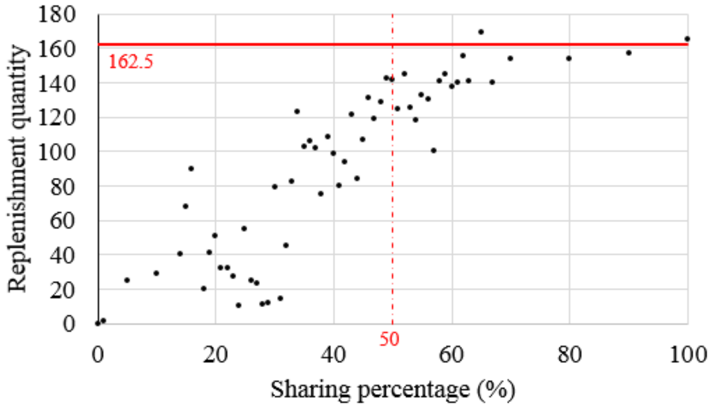

Figure 20: Results of sharing percentage and replenishment quantity

Voluntary compensation versus contingent compensation:

Table 8 shows the experiment performance of contingent compensation mode. Compared to Table 7, this performance is slightly worse than but not statistically significantly different from that of contract mode. However, it is significantly worse than that of voluntary compensation mode. Analysis of the experiment data shows that the retailer subjects exhibit equality preference, and the supplier subjects show both fairness concern and ex-post inventory error regret. When the sharing percentage is smaller than 50%, the supplier replenishes less than the predicted quantity due to fairness concern. When the sharing percentage is above 50%, the supplier also replenishes less than the predicted quantity because of ex-post inventory error regret. This explains why the coordination bonus plan performs slightly worse than contract mode, and why it performs significantly worse than voluntary compensation mode. Contingent compensation mode does not necessarily improve supply chain performance in the presence of social preferences. Therefore, the voluntariness of the compensation is the reason for the improved performance of voluntary compensation mode in our VMI setting.

Table 8: Profits and replenishment quantities under contingent compensation

$\widetilde{\pi}_R$	$\widetilde{\pi}_S$	$\widetilde{\pi}$	$\widetilde{q}$
122.62 [3.98]	145.32 [4.32]	267.94 [4.12]	102.31 [3.41]

Note: The number in [ ] is the standard error.

D. Random matching

We conduct random matching experiment for both contract mode and voluntary compensation mode, and compare the experiment results with those in fixed matching.

Experiment under contract mode:

We conduct an experiment of a random matching method for contract mode by recruiting 58 subjects to play the game for 50 rounds in four cohorts with two sessions. Roles are fixed with half subjects playing the supplier and the other half the retailer, and they are matched randomly in each round.

First, we find no significant learning effect of both decisions over time as shown in Figures 21 and 22. We consider that the reason for no learning effect in random matching method is similar to that in fixed matching method. We may also regard the supplier's decision as a newsvendor decision. Given the stable sharing percentage by the retailer, the replenishment quantity by the supplier is stable.

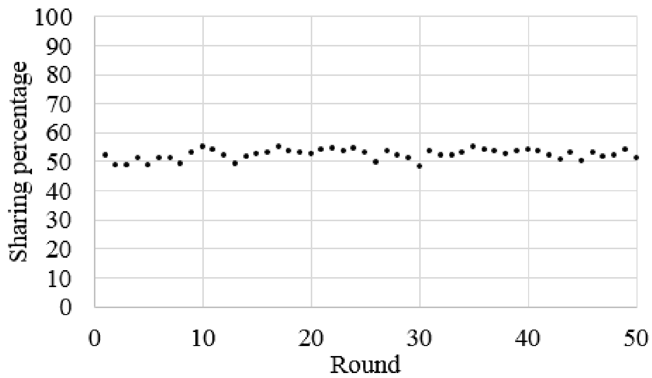

Figure 21: The retailer decisions over rounds in contract mode with random matching

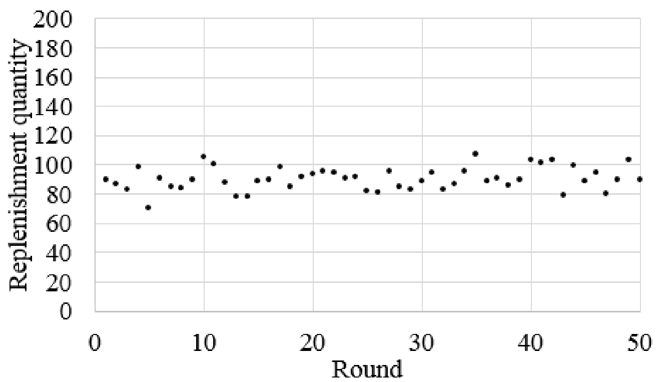

Figure 22: The supplier decisions over rounds in contract mode with random matching

Next, we explore the behavioral preferences of retailer and supplier in random matching method. Equality preference with adjustment of retailer is also supported by Figure 23. For supplier under random matching method, Figure 24 shows that she has single-sided fairness concern, which is consistent with Figure 3 for fixed matching.

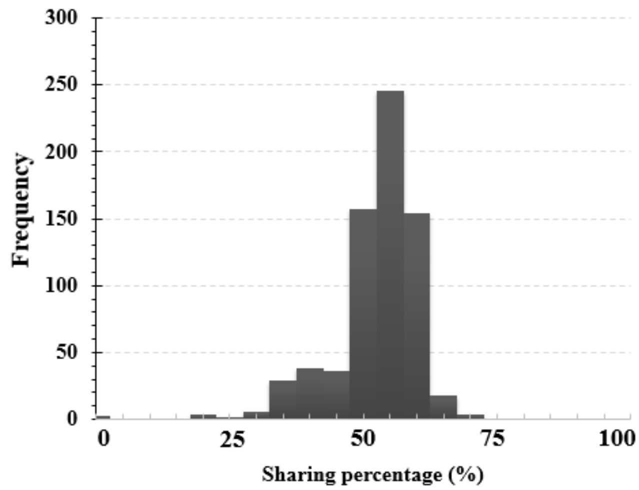

Figure 23: The decisions of retailer in contract mode with random matching

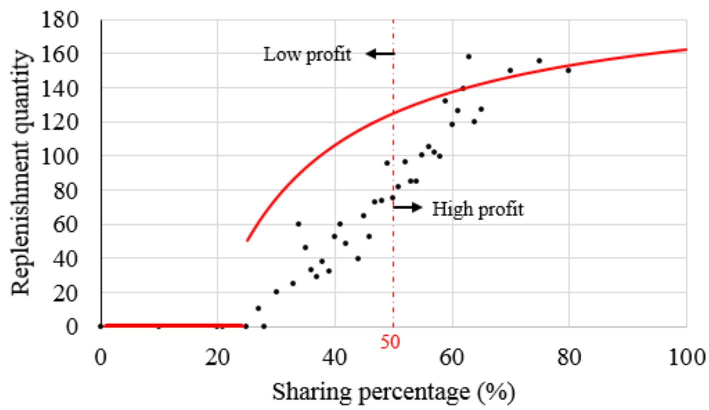

Figure 24: Actual quantity vs. theoretical optimal quantity in the contract mode with random matching

Furthermore, Table 9 shows that the fairness concern fits experimental data better than the leftover inventory aversion. This finding is different from the result of Davis et al. (2014), who also use random matching and report that leftover inventory aversion explain their supplier's decisions well. This difference could have been caused by the different setting. In our setting, the first mover is the retailer subject who offers a sharing percentage, which is similar to a proposer in ultimatum game. In a ultimatum game, the receiver exhibits significant fairness concern when the proposer decides the distribution plan. In Davis et al. (2014), the first mover (the retailer subject) offers a wholesale price, which may induce less fairness concern than a sharing percentage.

Table 9: Comparison between the supplier's behaviors in random matching treatment

	Fairness concern	Leftover inventory
δ	1.25	1.31
γ	4.4%	6.2%
$50\% + \gamma$	54.4%	56.2%
β_R	11.1	11.9
β_S	6.4	7.7
ρ	1.15	
θ	60.2%	
λ		0.34
LL	-13032.4	-13997.2
Vuong test		121.3

However, the random matching method causes subtle behavioral differences from the fixed matching method when we compare statistical estimates in Table 9 with those in Table 2. The fairness weighting coefficients of both the retailer and supplier are bigger under random matching than those under fixed matching, $\delta = 1.25$ versus 1.19 and $\rho = 1.15$ versus 1.08, respectively. However, the reference points of sharing percentage of the partners are smaller under random matching than those under fixed matching, $50\% + \gamma = 54.4\%$ versus 57% and $\theta = 60.2$ versus 65.3%, respectively. In other words, random matching causes both the retailer and supplier to be more sensitive to fairness than fixed matching, but to have weaker requirements on the reference points of sharing percentage for fairness.

Experiment under voluntary compensation mode:

We conduct an experiment of a random matching method for voluntary compensation mode by recruiting 54 subjects to play the game for 50 rounds in four cohorts with two sessions. Roles are fixed with half subjects playing the supplier and the other half the retailer, and they are randomly matched in each round.

First, we find no significant learning effect of all decisions over time as shown in Figures 25, 26, and 27. We may also regard the supplier's decision as a newsvendor decision. Given the stable sharing percentage by the retailer, the replenishment quantity by the supplier is stable.

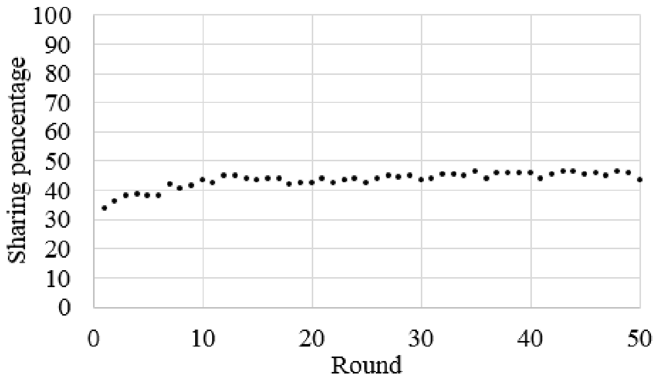

Figure 25: The retailer decisions of first stage over rounds in voluntary compensation mode with random matching

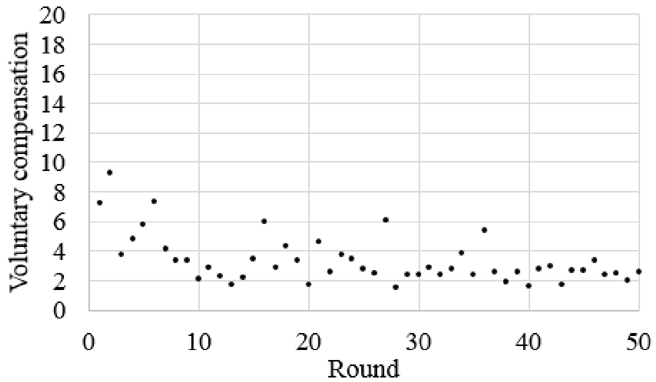

Figure 26: The retailer decisions of third stage over rounds in voluntary compensation mode with random matching

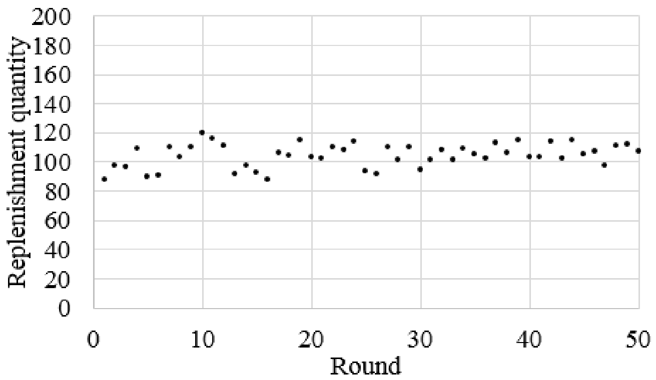

Figure 27: The supplier decisions over rounds in voluntary compensation mode with random matching

Next, we explore the behavioral preferences of retailer and supplier in random matching method. Equality preference with adjustment of retailer is supported by Figure 28, 29, and 30.

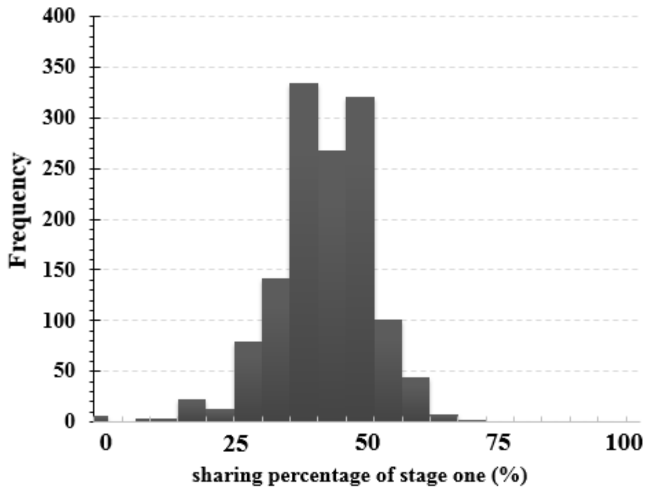

Figure 28: The decisions of retailer in first stage in voluntary compensation mode with random matching

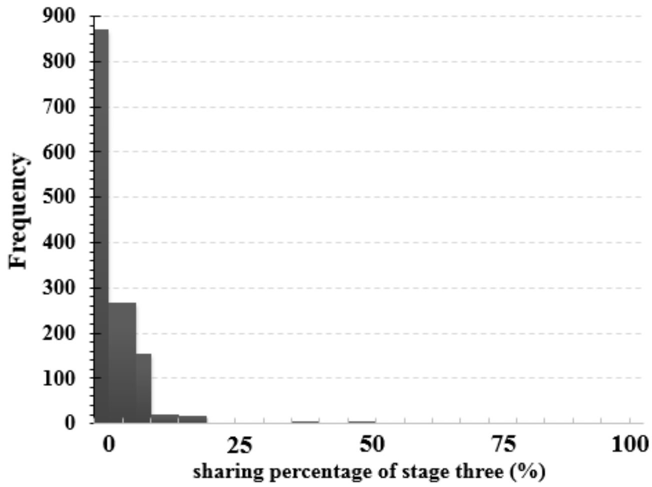

Figure 29: The decisions of retailer in third stage in voluntary compensation mode with random matching

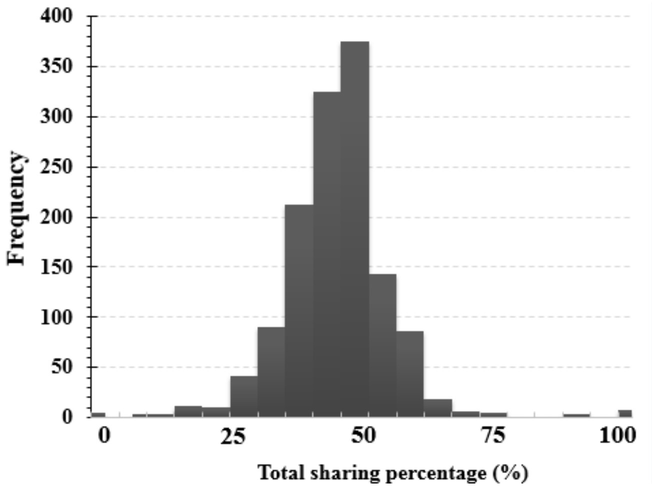

Figure 30: Total sharing percentage of retailer in voluntary compensation mode with random matching

For supplier, Figures 31 and 32 show that the replenishment quantities are smaller and have a bigger variance than those results in Figures 6 and 8 with fixed matching. The behavioral preferences seem to be a convolution of fairness concern and ex-post inventory error regret. It is more difficult to disentangle these behaviors in random matching than in fixed matching. This explains the higher variance and worse performance under random matching than under fixed matching.

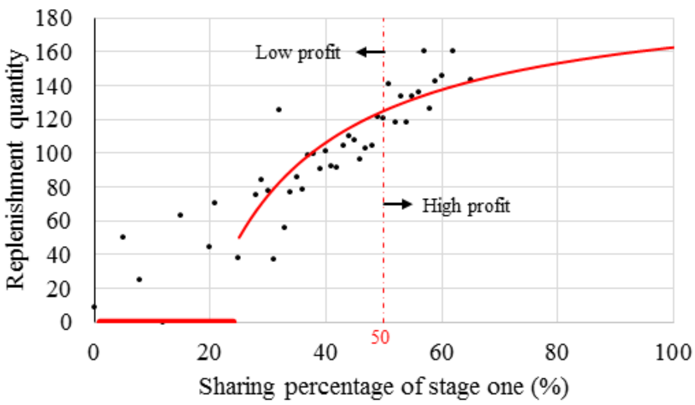

Figure 31: Actual quantity as a function of the sharing percentage in first stage in the voluntary compensation mode with random matching

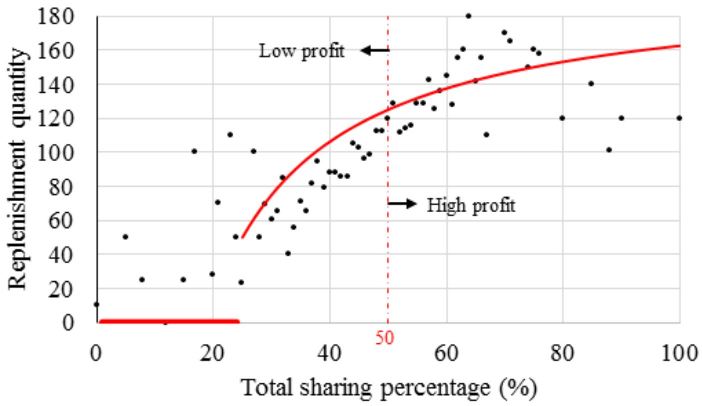

Figure 32: Actual quantity as a function of total sharing percentage in the voluntary compensation mode with random matching

Fixed matching versus random matching:

In random matching, the supply chain performance is statistically significantly worse than in fixed matching for both contract and voluntary compensation modes, as shown in Table 10.

Table 10: Profits and replenishment quantities under random matching

Mode	$\widetilde{\pi}_R$	$\widetilde{\pi}_S$	$\widetilde{\pi}$	$\widetilde{q}$
Contract	154.62 [3.79]	82.02 [4.56]	236.64 [9.77]	91.97 [5.00]
Voluntary compensation	186.16 [2.57]	68.74 [2.11]	254.90 [8.21]	100.39 [4.54]

Note: The number in [ ] is the standard error.

Under contract mode, the random matching method also causes subtle behavioral differences from the fixed matching method. Random matching causes both the retailer and supplier to be more sensitive to fairness than fixed matching. From the perspective of the reference point, the fairness concern effect in random matching is weaker than that in fixed matching. Under voluntary compensation mode, random matching has behavioral preferences that seem to be a convolution of fairness concern and ex-post inventory error regret. It is more difficult to disentangle these behaviors in random matching than in fixed matching. This is why we observe a more variable and worse performance in random matching, as shown in the comparison between Tables 10 and 7.

E. Two-sided fairness model and analysis of the supplier behavior

We consider both disadvantageous fairness concern and advantageous fairness concern in our behavioral models by weighting coefficient ρ_1 and ρ_2, respectively. Hence, the supplier's utility changes from Equation (7) to the following:

$$u_S(q) = sr\mathrm{E}_D \min(D, q) - cq - [\rho_1(\theta - s)^+ + \rho_2(s - \theta)^+]r\mathrm{E}_D \min(D, q) - \phi\mathrm{E}_D|D - q|. \quad (23)$$

We make parameter estimates as shown in tables 11 and 12 below for contract mode and voluntary compensation mode, respectively. The results show that the advantageous fairness concern parameter ρ_2 is small and statistically insignificant in contract mode, and both disadvantage and advantageous parameters ρ_1 and ρ_2 are insignificant in voluntary compensation mode.

Table 11: Estimates of double-sided behavioral parameters in contract mode

	SF	R-SF	R-SFE
δ		1.18[0.001]	1.18[0.001]
γ		7.4% [0.11%]	7.4% [0.11%]
$50\% + \gamma$		57.4%	57.4%
β_R	25.2[1.77]	11.4[1.26]	11.4[1.26]
β_S	6.6[1.06]	6.5[1.01]	6.5[1.01]
ρ_1	1.03[0.02]	1.06[0.02]	1.07[0.01]
ρ_2	0.01[0.01]	0.01[0.01]	0.01[0.01]
θ	65.7%[0.50%]	65.7%[0.34%]	65.6% [0.34%]
ϕ			0.02[0.01]
LL	-19472.0	-18355.0	-18354.9

Note: The number in [ ] denotes the standard error.

Table 12: Estimates of double-sided behavioral parameters in voluntary compensation mode

	SF	R-SF	R-SFE
δ		0.94[0.001]	0.91[0.001]
γ		7.2% [0.19%]	6.6% [0.14%]
$50\% + \gamma$		57.2%	56.6%
β_R	27.7[1.69]	12.4[1.20]	11.4[1.04]
β_S	7.4[1.28]	7.7[1.29]	6.9[0.90]
ρ_1	0.02[0.02]	0.02[0.01]	0.02[0.01]
ρ_2	0.01[0.01]	0.01[0.01]	0.01[0.01]
θ	66.5%[0.22%]	66.4%[0.20%]	66.4% [0.22%]
ϕ			0.97[0.01]
LL	-25829.2	-25829.1	-23177.0

Note: The number in [ ] denotes the standard error.

Furthermore, our experiment data show that 13% of the data records have a sharing percentage greater than 65% the fairness reference point of the supplier. Note that the dots in Figure

3 for sharing percentage greater than 65% are the averages of multiple sharing percentage for a given replenishment quantity. These data points are dots around the best response curve; that is, overall data show “one-sided” effect. Therefore, the experiment data suggest that it is more reasonable to use one-sided fairness concern model than double-sided one.

Finally, even though the standard fairness model is double-sided with both disadvantageous fairness and advantageous fairness, empirical studies show that the former has much stronger effect on the decision behavior than the latter in relevant settings, e.g., De Bruyn and Bolton (2008). Hence, the behavioral model considers disadvantageous fairness alone in existing studies, e.g., Ho et al. (2014).