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Value of Screening in Procurement Mechanism: An Experimental Study

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Abstract

Procurement mechanisms are widely employed and recommended for use in supply chain management practices. This study examines a retailer's decision to design a separating mechanism (as opposed to pooling mechanism) which is applied when buying from a supplier whose production cost information is private. The retailer's decision is based on the value of screening of the separating mechanism, as it allows the retailer to screen the supplier's private cost information, whereas the pooling mechanism does not. We conducted a laboratory experiment to investigate the retailer's decision-making behaviors, the supplier's decision behaviors, and the value of screening. We found that the observed value of screening is negligible and significantly lower than predicted given a large market size; however, it is substantially higher than predicted given a medium market size. According to the behavioral model analysis, this effect is mainly caused by the supplier's fairness concerns; the screening increases the supplier's fairness concern when operating in a large market, but decreases it when operating in a medium sized market. The results imply that a retailer should use a separating mechanism if the screening reduces the supplier's fairness concern; otherwise, a pooling mechanism suffices.

Keywords: behavioural OR, supply chain management; mechanism design; fairness; screening

1 Introduction

Procurement mechanisms are widely used by government to improve the efficiency of public utilities as they provide incentives for the public utilities to reduce costs. For example, Costello and Wilson (2006) report that most state regulators in the United States design incentive mechanisms for gas utility companies to reduce the procurement costs of natural gases. These mechanisms are also recommended for use in the supply chain; Plambeck and Denend (2011) suggest that private companies (e.g., Wal-Mart Stores, Inc.) must also have mechanisms to ensure that suppliers do not lie about their product information. Kelloway (2019) reports that Wal-Mart Stores, Inc. leverages its unprecedented size to dictate prices and quantities in transactions with suppliers. However, suppliers often keep private the information on their production costs (Çakanyıldırım et al., 2012). Given this information asymmetry, it is a challenge for companies to design optimal procurement mechanisms.

Furthermore, social preferences, such as fairness concerns, make the retailer's task of mechanism design more challenging as suppliers may reject the terms and conditions of the mechanism if they deem them to be unfair. In practice, fairness is a concern of supply chain parties. For example, O'Brien (2018) report that in October 2018, the European Union's Agriculture Committee drafted rules to improve the fairness of business transactions in agricultural supply chains. Through several experimental studies, Pavlov and Katok (2011) report that fairness considerations may induce a supply chain partner to reject a retailer's offer, which causes a failure in coordination. Kahneman et al. (1986) show that the impact of fairness concerns is not trivial, and it may help explain some anomalous market phenomena. They state that fairness concerns should not be ignored in analytical models.

This study considers a supply chain comprising a retailer and a supplier. The retailer dictates procurement terms; the supplier—with private production cost information—supplies products according to the retailer's terms. The retailer strives to maximize its profit by dictating the terms of wholesale prices and order quantities. The supplier chooses a supply quantity and the corresponding wholesale price to maximize its profit. The retailer faces a mechanism design problem, which can be formulated as a Stackelberg game with incomplete information between the retailer and supplier. The retailer may design either a separating or a pooling mechanism to work with the supplier. In the separating mechanism, multiple combinations of wholesale price and quantity are offered by the retailer corresponding to the supplier's different production costs. This mechanism allows the retailer to screen the supplier, that is, the retailer can infer the supplier's production cost based on a specific combination of wholesale price and quantity accepted by the supplier. Hence, the separating mechanism allows the retailer to screen the supplier's cost information. By contrast, in the pooling mechanism a single combination of whole sale price and quantity is offered regardless of the supplier's different production cost. Thus, the pooling mechanism does not screen the supplier's cost information. Assuming the decision-makers are profit maximizers, the separating mechanism is more beneficial to the retailer than the pooling mechanism because the former allows the retailer to screen the supplier's cost information, but the latter does not. Hence, the screening adds profit to the retailer and this added value is called the value of screening.

Extant studies assume a profit-maximizing supplier in above mechanism design problems (e.g., Laffont and Martimort 2009). However, in practice the suppliers are human decision makers, their decisions and the value of screening are affected by human social preferences such as fairness concerns. Hence, the main research questions are as follows: (1) What are the retailer's and supplier's decisions and supply chain performance under the separating and pooling mechanisms? (2) What is the value of screening to the retailer, and how do behavioral factors affect that value? (3) When should the retailer use a separating mechanism instead of a pooling mechanism? To answer these questions, we made theoretical predictions based on normative models and conducted experiments to examine the predictions.

Our study makes the following contributions to the existing literature on supply chain mechanism design under asymmetric information. First, the retailer's and supplier's behavioral decisions are affected by fairness concern preferences causing these decisions significantly different from normative models' predictions. Second, the value of screening to the retailer, i.e., the benefit of using a separating mechanism as opposed to a pooling mechanism, is negligible under a large market size, while it is significant under a medium market size. This is because the supplier's fairness concerns depend on both market sizes and mechanism types. These results imply that in practice a retailer should use the screening only when its effect on the supplier's fairness concern creates benefits, and that in theory the supply chain mechanism design must take into account social preferences such as fairness concerns.

2 Literature Review

In this section, we review relevant literature on supply chain contracting, theoretical and empirical fairness concern studies.

One stream of the literature concerning supply chain contracting addresses the double marginalization problem as well as supply chain coordination. Coordination contracts such as buyback contracts and revenue-sharing contracts do not help coordinate supply chains in experiments, because of individual decision biases; modified contracts remedy the negative impact of the decision biases (Becker-Peth et al., 2013; Becker-Peth and Thonemann, 2016). As per Katok and Pavlov (2013), fairness concerns affect the performance of wholesale price contracts, and privacy of the fairness concerns explains inferior supply chain performance. Subsequently, the wholesale price contract helps coordinate supply chains under certain fairness scenarios in the behavioral model by Katok et al. (2014). Katok and Wu (2009) compare these contracts and find that buyback contracts and revenue-sharing contracts slightly improve supply chain efficiency as compared to wholesale price contracts. Wu (2013) and Zhang et al. (2016) experimentally study buyback and revenue-sharing contracts in human-human and human-computer interactions, respectively; the former finds no statistical difference between them, while the latter finds that revenue-sharing contracts perform better in a high critical ratio environment. Kalkanci et al. (2011, 2014) study price-block contracts of different complexities designed by a supplier, where a retailer has private demand information and makes order quantity decisions. Their experimental studies find that a simpler contract (one- or two-part pricing) sometimes performs better than a complex contract (three-part pricing), and reinforcement and QRE are key factors that influence the decision. However, these highlighted contract studies do not consider adverse selection problems regarding private information such as private production costs.

The other stream of the supply chain contracting literature comprises mechanism studies that address the adverse selection problem and screening of private information in supply chains. Ha (2001) analyzes the optimal mechanism design problem of a retailer who designs a separating mechanism to screen private production cost. Corbett et al. (2004) study a supplier's problem of designing optimal mechanisms comprising a unit wholesale price and a lump-sum payment, and show that a two-part mechanism is more beneficial than a one-part mechanism in a supply chain. Supply chain mechanism design has been extended to various complex structures and contracts (see, e.g., Zhang, 2010; Çakanyıldırım et al., 2012). The above studies on these mechanisms assume supply chain parties are profit maximizers. Few studies consider behavioral preferences such as fairness concerns. Pavlov et al. (2021) theoretically study how to screen private fairness preference information under wholesale price contracts and find that pooling mechanisms are optimal; whereas we examine the private cost information and obtain different screening effects. Hoppe and Schmitz (2013, 2015) experimentally examine a modified ultimatum game and contract menu mechanism where a principal designs a single-wage mechanism to share total returns with an agent having private forecast information. Johnsen et al. (2019) experimentally study a buyer's ordering decision behavior when the buyer has private cost information and conducts transactions with a supplier who is utilizing a separating mechanism which comprises a reservation capacity and a fixed reservation fee. They explain the experimental results via the buyer's fairness concern even though human decision-makers play only the buyer role in the experiment. In this study, human decision-makers play both retailer and supplier roles. Furthermore, we compare the separating and pooling mechanisms and find that fairness concerns subtly impact the value of screening.

Fairness concerns, extensively studied in the empirical economics literature, are essential to explaining the experimental results. The seminal works by Fehr and Schmidt (1999) and Bolton and Ockenfels (2000), who conducted a theoretical analysis of several games, including an ultimatum game, proposed the fairness model to explain the disutility caused by inequity aversion. Cui et al. (2007) introduced the fairness model in supply chain management. Bellemare et al. (2008) and Andersen et al. (2011) conducted two-party experimental studies to examine the characteristics of the fairness concerns in ultimatum games. They found considerable fairness heterogeneity in the population; the former found that disadvantageous inequity aversion increased with profit allocation difference, and the latter adds that total profits or stakes affect the level of inequity aversion. Further, Ho and Su (2009) and Ho et al. (2014) conduct three-party experimental studies to explore different types of fairness concerns in ultimatum games and supply chains, respectively. The former finds that peer-induced fairness concern between followers is two times stronger than distributional fairness concern between a leader and follower, and the latter finds that distributional and peer-induced fairness are essential to describing supply chain behaviors. Our study extends the empirical fairness literature by showing that the levels of inequity aversion change with profit allocation under different mechanisms and markets sizes. The findings further provide new insights into the impact of fairness on value of screening and contract choices.

3 Benchmark Model and Theoretical Analysis

We develop a benchmark model to predict the value of screening in a supply chain comprising a supplier and a dominant retailer. The retailer orders the product from the supplier and sells it in a market. The market-clearing price $p = a - q$, where q is the quantity of product sold, p is the retail price, and a is the market size. We assume that the supplier's unit production cost is private to capture the information asymmetry between the supplier and retailer. The retailer only knows that there are two supplier types, those with low (c_l) and those with high (c_h) unit production costs and the corresponding probabilities. We assume $a > c_h > c_l$ to avoid a trivial solution. A supplier of type $t \in \{l, h\}$ has a unit production cost of c_t; the retailer knows the probability v of being a low-cost type (l) and $1 - v$ of being a high-cost type (h).

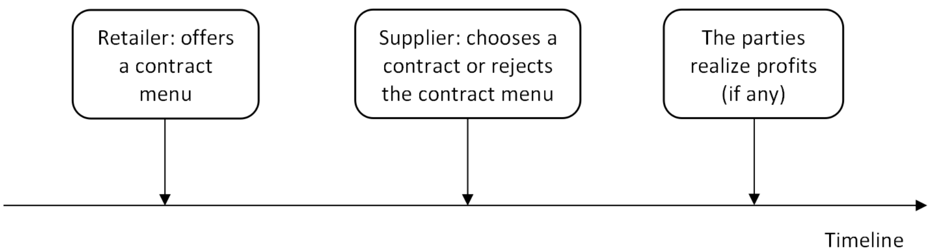

Figure 1: Sequence of Events in the Transaction.

Figure 1 illustrates the sequence of events in a typical transaction. First, knowing only the probability distribution of the supplier's production cost, the dominant retailer designs a separating or pooling mechanism and offers the corresponding contract menu to the supplier. Second, the supplier chooses a preferred contract from the menu or rejects the contract menu. Third, if a contract is chosen, the supplier delivers the product with the chosen quantity and receives payment from the retailer, and lastly, the retailer sells the product in the market to obtain revenue. If the supplier rejects the contract menu, neither party profits.

3.1 Separating Mechanism

We consider a benchmark in which the retailer and supplier are self-interested profit maximizers. The retailer designs the contract menu $\{(w_t, q_t)|t \in \{l, h\}\}$ using a separating mechanism. The menu contains two types of contracts corresponding to the two types of the supplier's production cost, each comprising a wholesale price and an order quantity. The market-clearing retail price is $p_t = a - q_t$, and the retailer's profit margin is $p_t - w_t = a - q_t - w_t$; hence, the retailer's profit is $(a - q_t - w_t)q_t$. To help explain the optimal separating mechanism under asymmetric information, we first present the optimal solutions in the case of complete information. The retailer with complete information sets the wholesale price and order quantity as follows.

Lemma 1 *The contract with complete information is* $q_t^{FB} = \frac{a-c_t}{2}, w_t^{FB} = c_t, \forall t = l, h.$

The superscript FB represents "first-best." The above contract reaches the first-best solution that maximizes the supply chain profit Hence, these contracts help explain the effects of asymmetric information in the subsequent analysis. Under these contracts, the retailer absorbs the entire supply chain profit.

In the case of asymmetric information, considering the distribution of the supplier's cost type t, the retailer maximizes the expected profit:

$$\max_{M \equiv \{(w_t, q_t)|t \in \{l,h\}\}} \Pi_R(M) = v(a - q_l - w_l)q_l + (1 - v)(a - q_h - w_h)q_h. \tag{1}$$

Given the separating mechanism M, if a type-t supplier chooses contract d—that is, (w_d, q_d)—then it results in profit as follows:

$$\Pi_S^t(d|M) = (w_d - c_t)q_d, \forall\ t, d \in \{l, h\}. \tag{2}$$

This profit function must satisfy the incentive compatibility (IC) and individual rationality (IR) constraints, according to the revelation principle in Laffont and Martimort (2009):

$$\Pi_S^t(d = t|M) \geq \Pi_S^t(d \neq t|M),\ \forall\ t, d \in \{l, h\}; \tag{3}$$

$$\Pi_S^t(d = t|M) \geq 0, \ \forall t \in \{l, h\}. \tag{4}$$

Equation (3) is the IC constraint, which states that the type-t supplier obtains higher profit by choosing the corresponding t rather than the non-corresponding $d \neq t$ contract. Thus, a separating mechanism satisfying the IC constraints can screen the supplier's private production cost information. Equation (4) is the IR constraint, in which the reserved profit on the right-hand side is generally assumed to be zero in standard mechanism design theory. The IR constraints ensure that each type of supplier earns a non-negative profit and participates in transactions. The retailer's mechanism design problem is completely specified by Equations (1) to (4). Its optimal solutions are as follows.

Proposition 1 *The optimal separating mechanism with asymmetric information is: If* $a \geq \frac{c_h - vc_l}{1-v}$,

$$q_l^{SB} = q_l^{FB}, \quad w_l^{SB} = c_l + \frac{(c_h - c_l)q_h^{SB}}{q_l^{SB}}, \quad q_h^{SB} = \frac{a - c_h - \frac{v}{1-v}(c_h - c_l)}{2}, \quad w_h^{SB} = c_h; \tag{5}$$

and the expected profits of the retailer and the supplier are

$$\Pi_R = v\{\frac{(a - c_l)^2}{4} - \frac{a - c_h - \frac{v}{1-v}(c_h - c_l)}{2}(c_h - c_l)\} + (1 - v)\{\frac{(a - c_h)^2}{4} - \frac{(\frac{v}{1-v}(c_h - c_l))^2}{4}\},$$
$$\Pi_S = v\frac{a - c_h - \frac{v}{1-v}(c_h - c_l)}{2}(c_h - c_l).$$

If $a < \frac{c_h - vc_l}{1-v}$, $q_l^{SB} = q_l^{FB}, w_l^{SB} = c_l, q_h^{SB} = 0$, *and* $w_h^{SB} = 0$; $\Pi_R = v\frac{(a-c_l)^2}{4}$, $\Pi_S = 0$.

The superscript SB stands for "second-best." The proof of Proposition 1 is given in Appendix A, along with the proofs for the other propositions in this paper.

The two cases of the optimal separating mechanism can be illustrated by Figure 2. If $a \geq \frac{c_h - vc_l}{1-v}$, the market size is sufficiently large for the retailer to sell with a high-profit margin. It is profitable for the retailer to order from both types of supplier, that is, the retailer always places a positive quantity order from the supplier, regardless of low-cost or high-cost. However, if the market size is small such that $a < \frac{c_h - vc_l}{1-v}$, the retailer is better off ordering from only the low-cost supplier. Nevertheless, in both cases, the quantity and wholesale price differ between the two types, effectively screening the supplier's private cost information.

3.2 Pooling Mechanism

Next, we consider the pooling mechanism. This mechanism is easier to implement than the separating mechanism and is also studied in academic research (Laffont and Martimort, 2009;

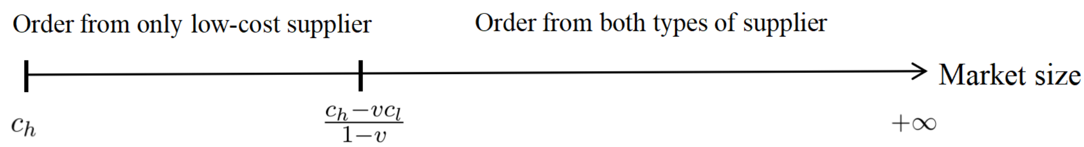

Figure 2: Optimal Separating Mechanism Design under Different Market Sizes.

Kalkanci et al., 2011). It provides a single contract $M \equiv (w, q)$ to the supplier of all cost types; hence, the retailer cannot use it to screen the supplier's private cost information. The supplier may accept this pooling mechanism depending on his profit gained from the transaction. The supplier's decision d takes the value of 1 for acceptance and 0 for rejection. If a supplier of type t accepts the pooling mechanism (i.e., $d = 1$), then his profit is

$$\Pi_S^t(d = 1|M) = (w - c_t)q, \forall t \in \{l, h\}. \tag{6}$$

Given that rejection results in zero profit to the supplier—that is, $\Pi_S^t(d = 0|M) = 0$ for all t—the supplier accepts the pooling mechanism if and only if the profit is greater than or equal to zero.

The retailer obtains profit $(a - q - w)q$ if the supplier participates in the contract and earns no profit if they do not, regardless of the supplier's production cost. Hence, the retailer maximizes the expected profit as follows:

$$\max_{M \equiv \{(w,q)\}} \quad \Pi_R(M) = (a - q - w)q[v\mathbb{1}(\Pi_S^l(d = 1|M)) + (1 - v)\mathbb{1}(\Pi_S^h(d = 1|M))], \tag{7}$$

where $\mathbb{1}$ is the indicator function; that is, its value equals 1 if $\Pi_S^t(d = 1|M) \geq 0$ and 0 otherwise for all $t \in \{l, h\}$. We solve the optimization problem for the optimal pooling mechanism by analyzing different cases and obtain the optimal contract.

Proposition 2 *The optimal pooling mechanism with asymmetric information is*

$$(q^*, w^*) = \begin{cases} (\frac{a-c_l}{2}, c_l), & \textit{if } a \leq \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}; \\ (\frac{a-c_h}{2}, c_h), & \textit{otherwise.} \end{cases} \tag{8}$$

The expected profits of the retailer and the supplier are

$$(\Pi_R, \Pi_S) = \begin{cases} (v\frac{(a-c_l)^2}{4}, 0), & \textit{if } a \leq \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}; \\ (\frac{(a-c_h)^2}{4}, v\frac{(c_h-c_l)(a-c_h)}{2}), & \textit{otherwise.} \end{cases}$$

Figure 3 illustrates Equation (8). If $a \leq \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}$, the optimal contract is only accepted by the low-cost supplier, because the high-cost supplier would make a loss if it accepted the contract. Consequently, the retailer only transacts with the low-cost supplier and excludes the high-cost supplier. If $a > \frac{c_h - \sqrt{v} c_l}{1 - \sqrt{v}}$, however, the optimal contract is set such that the retailer transacts with both supplier types, resulting in positive profit for the low-cost type and zero profit for the high cost type.

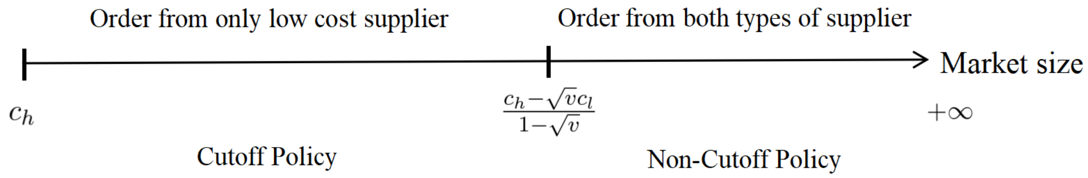

Figure 3: Optimal Pooling Mechanism Design under Different Market Sizes.

3.3 Screening Effect of Mechanism Design

The screening effect can be obtained by comparing the decisions under the separating and pooling mechanisms because the former sets different contracts for different cost types to screen private cost information, whereas the latter sets a single contract without differentiating between cost types.

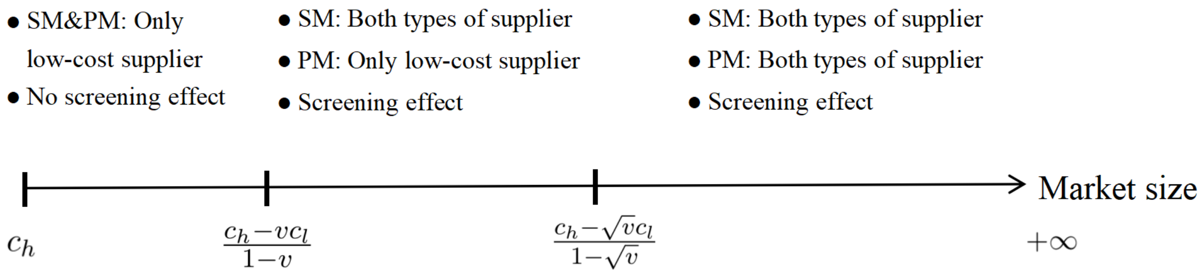

Figure 4: Structure of the Screening Effect.

Structure of the screening effect

We compare the optimal solution structure of the separating mechanism in Figure 2 with that of the pooling mechanism in Figure 3, which reveals the structure of the screening effect in Figure 4. We employ the notations SM and PM to represent the separating and pooling mechanisms, respectively. The screening effect is determined by two thresholds $\frac{c_h - v c_l}{1 - v}$ and $\frac{c_h - \sqrt{v} c_l}{1 - \sqrt{v}}$, with the first being smaller given the probability $v \in (0, 1)$. Three cases depend on the market-size value relative to the thresholds as follows. When the market size is smaller than the first threshold $\frac{c_h - v c_l}{1 - v}$, the separating and pooling mechanisms yield the same result. That is, under both mechanisms, the retailer effectively transacts with the low-cost supplier only; the screening makes no difference. When the market size is between the two thresholds (i.e., $\frac{c_h - v c_l}{1 - v} < a \leq \frac{c_h - \sqrt{v} c_l}{1 - \sqrt{v}}$), termed *medium market size*, the separating mechanism comprises two contracts and screens the two cost types. However, the pooling mechanism comprises a single contract to transact with the low-cost supplier and cuts off the high-cost supplier. When the market size is bigger than the second threshold $\frac{c_h-\sqrt{v}c_l}{1-\sqrt{v}}$, termed *large market size*, the separating mechanism comprises two contracts to screen the supplier's private cost information; the pooling mechanism comprises a single contract to transact with the low- and high-cost supplier. Note that the difference between the last two cases lies in the pooling mechanism, by which the hight-cost type of supplier is cutoff under the medium-sized market, but is kept in transaction under the large market.

Screening effect on the retailer

As the comparison between the two mechanisms has important implications for the retailer's contract design, we formally define the value of screening to the retailer as the difference in the retailer's expected profit between the two mechanisms.

Definition 1 *The value of screening to the retailer is* $\Delta_R = \Pi_R^{SM} - \Pi_R^{PM}$*, where* Π_R^{SM} *and* Π_R^{PM} *are the maximum profit in Equations* (1) *and* (7)*, respectively.*

The comparison between the two mechanisms shows that the screening makes a difference only when the market size is above the threshold $\frac{c_h-vc_l}{1-v}$. Using both mechanisms' optimal solutions in Propositions 1 and 2, we quantify the value of screening to the retailer under three different cases in Proposition 3.

Proposition 3 *The value of screening to the retailer is*

$$\Delta_R = \begin{cases} 0, & \text{if } c_h \le a \le \frac{c_h-vc_l}{1-v}; \\ -\frac{v(a-c_l)^2-(a-c_h)^2}{4} + \frac{v}{1-v}\frac{(c_h-c_l)^2}{4}, & \text{if } \frac{c_h-vc_l}{1-v} < a \le \frac{c_h-\sqrt{v}c_l}{1-\sqrt{v}}; \\ \frac{v}{1-v}\frac{(c_h-c_l)^2}{4}, & \text{if } a > \frac{c_h-\sqrt{v}c_l}{1-\sqrt{v}}. \end{cases} \tag{9}$$

As expected, the value of screening to the retailer is non-negative. If $\frac{c_h-vc_l}{1-v} < a \le \frac{c_h-\sqrt{v}c_l}{1-\sqrt{v}}$, the retailer transacts with a high-cost type supplier under the separating mechanism, but does not under the pooling mechanism. Hence, the value of screening comes from the transaction with the high-cost supplier; the value of this transaction increases in the market size a. If $a > \frac{c_h-\sqrt{v}c_l}{1-\sqrt{v}}$, the retailer transacts with both high- and low-cost supplier types under the two mechanisms. Hence, the value of screening comes from the discriminatory nature of the separating mechanism, which separates the supplier's cost types, whereas the pooling mechanism does not.

Screening effect on the supplier

In this section, we consider the impact of the screening effect on the ex-ante supplier and formally define the value of screening to the supplier as the difference in the supplier's expected profit between the two mechanisms.

Definition 2 *The value of screening to the supplier is* $\Delta_S = \Pi_S^{SM} - \Pi_S^{PM}$*, where* Π_S^{SM} *and* Π_S^{PM} *are the expected profit in Equations* (2) *and* (6) *under the optimal separating and pooling mechanisms, respectively.*

By comparing the supplier's expected profit under the two mechanisms, we can obtain the value of screening to the supplier under the three cases in Proposition 4. First, if $a \leq \frac{c_h - vc_l}{1-v}$, the screening makes no difference. Second, if $\frac{c_h - vc_l}{1-v} < a \leq \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}$, the screening results in a profit increase for the supplier. Third, if $a > \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}$, the screening results in a profit decrease to the supplier.

Proposition 4 *The value of screening to the supplier is*

$$\Delta_S = \begin{cases} 0, & \text{if } c_h \leq a \leq \frac{c_h - vc_l}{1-v}; \\ v\frac{a - c_h - \frac{v}{1-v}(c_h - c_l)}{2}(c_h - c_l), & \text{if } \frac{c_h - vc_l}{1-v} < a \leq \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}; \\ -\frac{v}{1-v}\frac{v(c_h - c_l)^2}{2}, & \text{if } a > \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}. \end{cases} \tag{10}$$

The above analysis implies that the screening effect is different in the case of $\frac{c_h - vc_l}{1-v} < a \leq \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}$ from it is in the case of $a > \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}$. In the former case, the screening benefits both the retailer and supplier, and this benefit increases with market size a. This is because the screening allows the transaction with high-cost suppliers to take place; the value of this transaction increases with market size a. However, in the latter case, the screening does not change the participation of the two types of suppliers, but makes the retailer more profitable at the cost of the supplier; hence, screening benefits only the retailer but harms the supplier.

We highlight the theoretical comparative study on separating and pooling mechanisms in view of the existing studies on mechanism design (Laffont and Martimort, 2009; Pavlov et al., 2021). First, the theoretical analysis provides an analytical solution concerning the value of screening to the retailer. The theory posits that the separating mechanism always benefits the mechanism designer (i.e., the retailer) and the value of screening to the retailer increases with the external market size. Second, the analytical study presents the value of screening to the agent (i.e., the supplier), which depends on different market-size conditions. Under a large market size, although screening is good for the retailer, it harms the supplier, while under the medium market size, screening improves the retailer, supplier, and supply chain channel. The quantification of the screening effect help us further understand mechanism choices in supply chain management.

4 Behavioral Experiments

In this section, we test the above analytical results about subjects' decisions and values of screening in behavioral experiments. We design experiments to explore possible behavioral preferences that may cause human decisions and values of screening to deviate from theoretical predictions.

4.1 Experimental Design

The system parameters are designed as follows: $c_l = 3$, $c_h = 9$, and $v = 0.5$. These values, together with market size values, are chosen to ensure integer optimal solutions to both separating and pooling mechanisms. The experiment employs a 2×2 factorial between-subject design, where the factors are mechanism type (separating vs. pooling) and market size (a). We focus on the large and medium market sizes as screening makes a difference in these two cases, including the large market size $a = 27 > \frac{c_h - \sqrt{v} c_l}{1 - \sqrt{v}}$ and medium market size $\frac{c_h - v c_l}{1 - v} < a = 21 \leq \frac{c_h - \sqrt{v} c_l}{1 - \sqrt{v}}$. The treatments are labeled using a combination of factor levels: SM27, PM27, SM21, PM21. Table 1 summarizes the optimal contract offer of the retailer and the optimal response of each supplier type according to Equations (5) and (8) for the separating and pooling mechanisms, respectively. Noted that in the most of cases, the wholesale price is equal to one of the production costs due to the assumption that the retailer decides the wholesale price. The table also shows the corresponding expected payoffs of the parties.

Table 1: Theoretical Benchmark for Each Treatment.

	SM27	PM27	SM21	PM21
Retailer's offer	$w_l = 6, q_l = 12$ $w_h = 9, q_h = 6$	$w = 9, q = 9$	$w_l = 5, q_l = 9$ $w_h = 9, q_h = 3$	$w = 3, q = 9$
Low-cost supplier choice	contract l	Accept	contract l	Accept
High-cost supplier choice	contract h	Accept	contract h	Reject
Retailer's expected profit	90	81	45	40.5
Supplier's expected profit	18	27	9	0
Expected channel profit	108	108	54	40.5

We conduct Human-Human (H-H) experiments under both mechanisms to examine human decision-making behavior and supply chain performance. We then compare the experimental results of the two mechanisms to investigate the value of screening.

Human decision-makers may not follow profit-maximization assumptions, due to various behavioral preferences. For instance, QRE can cause errors and heuristics in decision-making, and social preferences such as fairness concerns induce the behavioral utility function (Katok and Wu, 2009). Thus, to account for the multiple possible causes of anomalies, the experimental design empirically separates the effects of QRE and social preference by introducing controlled Human-Computer (H-C) experiments.

1. We first conduct H-H experiments under the separating and pooling mechanisms to examine the theoretical model prediction in the case of large market size and investigate whether screening benefits the retailer and harms the supplier.

2. We also conduct H-H experiments in the case of medium market size to check whether screening benefits both the retailer and supplier.

3. Given the H-H experiment results, we perform controlled H-C experiments to examine whether social preferences induce supply chain decision behaviors, where behaviors from social preferences (e.g., fairness concern) are weakened from the lack of human interactions.

In a bilateral monopoly setting, we conduct H-H and H-C experiments to mimic a sequential game under the supply chain contracting framework. In the H-H experiment with four cohorts, the retailer and supplier are both human subjects. They are matched randomly and anonymously in each round such that each round is a single-shot game. In the H-C experiment, the role of the retailer is assumed by a computer, and the contracts offered by the computerized retailer are controlled to be the same as those offered in the first two cohorts of the H-H treatment. The subjects play the role of the supplier, knowing that they play against computerized retailers.

4.2 Experimental Procedures

The experiments occurred in a major public university, where 280 subjects participated in the H-H experiments. Each treatment involved 70 subjects and included four cohorts of 10, 10, 6, and 9 pairs respectively. In each cohort, each subject's role (supplier or retailer) was randomly selected and revealed at the beginning of the game. These roles were fixed throughout the game. The experiments comprised 20 decision rounds. In each round, a human supplier is matched randomly and anonymously with a different human retailer. The experiment starts with a quiz that helps participants understand how the mechanism worked. All subjects go through six training rounds, as detailed in the Appendix D.

To control the social interaction, we ran the controlled H-C experiment in separate cohorts with 80 different subjects. Each treatment includes 20 human suppliers and 20 computerized retailers. The computerized retailers offered the same contracts that were offered in the first two H-H experiment cohorts. The human suppliers knew that the retailer role was being played by a computer.

Each subject made a decision in each round. In the first stage, the system generated the optimal quantity for the retailer, who inputed and then confirmed its decision of the wholesale price (note that for the H-C experiment, computers made the retailer decisions). In the second stage, the supplier decided which contract to accept or reject the menu. Finally, the profits were allocated according to the decisions made. At the end of each round, each subject received feedback regarding their role, current-round production costs, and both parties' decisions and profits.

Participation in the experiment was monetarily motivated. The payment to each subject included a fixed show-up fee equivalent to an hour of the local minimum wage, as the experiment lasted approximately one hour. A large part of the payment came from the additional amount proportional to the total profit earned from the experiment. The average total payment received by participants was three times the local hourly wage. The experimental software was programmed using z-Tree (Fischbacher, 2007). Appendix D lists detailed experimental instructions, decision support tools, and program interfaces.

5 Results

Based on the data collected in the experiment, we study the human subjects' behavior and supply chain performance and further develop the behavioral models to explore the inherent behavioral preferences in this mechanism design setting.

5.1 Data Analysis

We collected 700 records (35 pairs times 20 rounds) of experimental data for each of the four H-H treatments. Each record comprises two respective decisions by the retailer and supplier. The subjects were undergraduate and graduate students in a public university majoring in economics, engineering, computer science, social science, and mathematics. Their age ranges from 19 to 25. The ratio between male and female subjects was six over four.

Upon examining the actual decision-making time trends of retailers and suppliers over the rounds, we find that the decision behaviors of both parties do not exhibit the learning effect, as shown in Appendix B. We focusing on a few experimental observations regarding the subjects' decisions and supply chain performance.

Observation 1 *Human subjects' decisions and supply chain performance deviate from the benchmark predictions across all four experimental treatments.*

Table 2 presents the summary statistics of human subjects' decisions and supply chain performance across the four H-H experimental conditions, with standard deviation (clustered at cohort level) in the brackets. These observations are compared with the benchmark prediction in Table 1. The comparison shows that Observation 1 holds across all four treatment.

Table 2: Summary Statistics per Treatment Condition in the H-H Experiment.

	SM27	PM27	SM21	PM21
Retailer's offer	$w_l = 8.71[0.43]^{***}$ $w_h = 11.45[0.44]^{***}$	$w = 10.96[0.33]^{***}$	$w_l = 6.52[0.29]^{***}$ $w_h = 10.21[0.90]^{***}$	$w = 6.91[0.16]^{***}$
Low-cost supplier's choice	Contract l 82.6% Contract h 16.8% Reject 0.6%	Accept 98.0% Reject 2.0%	Contract l 74.6% Contract h 24.3% Reject 1.1%	Accept 90.6% Reject 9.4%
High-cost supplier's choice	Contract l 8.3% Contract h 59.4% Reject 32.3%	Accept 70.0% Reject 30.0%	Contract l 3.4% Contract h 58.9% Reject 37.3%	Accept 24.3% Reject 75.7%
Retailer's profit	$52.04[3.35]^{***}$	$52.02[4.70]^{***}$	$26.30[1.05]^{***}$	$22.52[1.73]^{***}$
Supplier's profit	$40.89[3.38]^{***}$	$42.48[2.41]^{***}$	$17.77[0.47]^{***}$	$17.44[1.49]^{***}$
Channel profit	$92.93[4.36]^{***}$	$94.50[3.39]^{***}$	$44.07[1.36]^{***}$	$39.96[3.13]^{***}$

Note: Statistical test result from comparing observation and benchmark prediction in Table 1. $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

First, we analyze the decision-making behavior of human retailers and suppliers. Experimental data show that the human retailer always offers wholesale prices higher than the analytical prediction. For example, in Treatment SM27, the wholesale price decisions ($w_l = 8.71, w_h = 11.45$) are significantly higher than the prediction in the benchmark ($w_l^* = 6, w_h^* = 9$) by the one-tailed t-test with $p < 0.001$, after passing the Shapiro-Wilk normality test and clustered at cohort level. The human supplier chooses the non-corresponding contract and the reject more than the benchmark predictions. The benchmark predicts that for a given retailer offer, the supplier accepts a contract item if and only if the item maximizes its profit and this maximum profit is nonnegative. For example, in Treatment SM27, the supplier's decision differs from that of a profit-maximizing supplier, under the contract offered in the experiment, by using Fisher's test with p =0.3. The results present experimental evidence that the decision-making behaviors of human retailers and suppliers in the H-H experiment deviate from the prediction results of the model.

Next, we discuss the supply chain performance of each party. Experimental results show that in Treatment SM27, the human retailer's profit of 52.04 is significantly lower than the benchmark prediction of 90, the human supplier's profit of 40.89 is significantly higher than the benchmark prediction of 18, and the channel profit of 92.93 is significantly lower than the benchmark prediction of 108. The statistical results pass the Shapiro-Wilk normality test via the one-tailed t-test at the $p < 0.001$ significance level. From the perspective of profit distribution, the profit distribution of the H-H experiment is fairer than the profit distribution predicted by the benchmark because a 50/50 split in profit is considered to be the fairest allocation. The observed profit of the retailer accounts for 57% (i.e., 52.04/92.03)of the total channel profit, which is far lower than the 83% (i.e., 90/108 in Table 1) predicted by the benchmark. From the perspective of the overall profit of the supply chain channel, due to the low-cost supplier's decision to choose the contract h and the high-cost supplier's decision to reject the contract, the channel profit decreases by approximately 14%.

The H-H experiment results show that the profit distribution between the retailer and supplier is biased toward a fairer outcome, which may be caused by fairness concern. We further analyze the supplier's decision-making behavior in the experiment, as in Figure 5. We observe that the lesser the supplier's profit share, the higher its rejection rate that is defined as the gray bar height divided by the total bar height. This results are evidence for a typical inequity aversion behavior of a decision-maker (Bolton, 1991; Fehr and Schmidt, 1999; Cui et al., 2007; Katok et al., 2014). Thus, inequity aversion is most likely the social preference that induces human decisions to deviate from theoretical results.

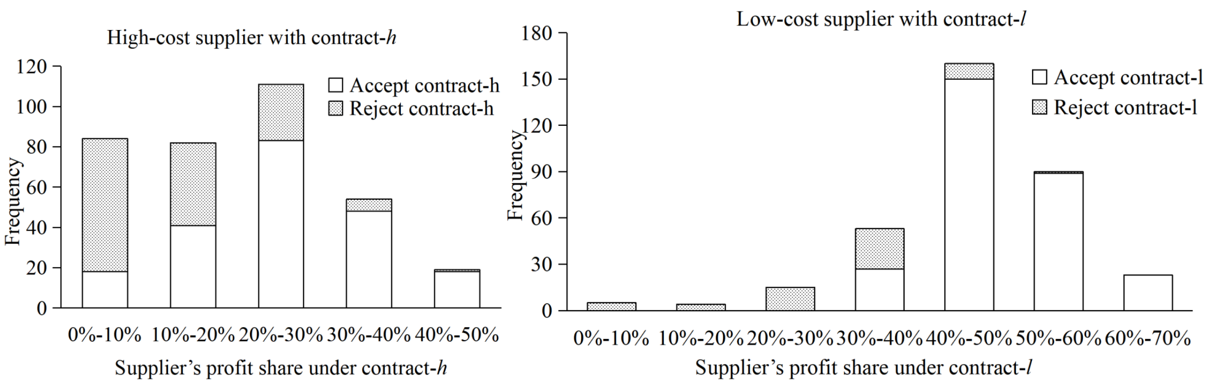

Figure 5: Supplier's behavior in the H-H Experiment of treatment SM27.

Observation 2 *Screening neither benefits the retailer nor harms the supplier under the large market size. However, screening benefits both the retailer and the supplier under the medium market size.*

Table 3 presents the summary statistics of the value of screening to each party in the H-H experiment against the theoretical prediction across the two market-size conditions. Overall, the value of screening to the retailer in the experiment is smaller than the theoretical prediction. Thus, the advantages of the separating mechanism over the pooling mechanism are not as great as theoretically predicted, especially when it comes to the retailer and supply chain profits.

Table 3: Values of Screening per Market-Size Condition.

	Large market size $a = 27$			Medium market size $a = 21$		
	Prediction	Observation	Change	Prediction	Observation	Change
Value to the retailer	9	0.02***	↓	4.5	3.78	↓
Value to the supplier	-9	-1.59***	↑	9	0.33***	↓
Value to the channel	0	-1.57	↓	13.5	4.11***	↓

Note. Comparing predictions and observations: $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

Specifically, under the large market size, the retailer's profit is not significant different between the separating and pooling mechanism ($p > 0.5$ by two-tailed t-test). This difference, i.e., the value of screening to the retailer, is 0.02, which is significantly smaller than the theoretical prediction of 9. In the case of medium market size, the retailer's profit is significantly different between the separating and pooling mechanism ($p < 0.02$ by two-tailed t-test). The value of screening to the retailer is 3.78, not significantly different from the theoretical prediction of 4.5 ($p > 0.5$ by two-tailed t-test). Hence, the value of screening to the retailer is significantly higher under the medium market size than under the large market size ($p < 0.01$ by one-tailed t-test). From the supplier's perspective, under the large market size, the theoretical model predicts that the value of screening to the supplier is negative 9; that is, the supplier's profit under the separating mechanism is significantly lower than it is under the pooling mechanism. However, experimental results show that the supplier's profit in the separating mechanism is slightly lower than that of the pooling mechanism. Under the medium market size, the value of screening to the supplier is 0.33, significantly lower than the theoretical model's prediction of 9. There is no significant difference in the supplier's profit under the two mechanisms. Consequently, the screening effect neither benefits the retailer nor harms the supplier under the large market size. Under the medium market size, screening benefits both the retailer and the supplier.

For optimal mechanism design, we focus on the impact of the value of screening on the retailer and overall channel. Under the large market size, the theoretical model predicts that there is no difference between the overall channel profit under the two mechanisms, and the separating mechanism can benefit the retailer to obtain more income by the screening private cost information. However, the experimental results indicate that the screening does not improve the retailer's profit under the large market size, as shown in Table 3 that the observed value of screening to the retailer is 0.02. Under the medium market size, the theoretical model predicts that the separating mechanism can improve the profit of the retailer, supplier, and channel. The experimental results support this point, but the value of screening is not as high as theoretically expected.

We further explore the distortion of the value of screening from the perspective of human subjects' behavioral decision-making in the experiment. Regarding Observation 1, behavioral preferences such as fairness concern may affect the subjects' decision-making. Next, through the controlled H-C experiment to eliminate the impact of fairness concern, we empirically discuss behavioral preferences in this mechanism design.

Observation 3 *Human subjects' decisions and supply chain performance are inconsistent in the H-H and H-C treatments.*

Table 4 presents the summary statistics of the human subjects' decisions and supply chain performance in the H-C experiment versus the H-H experiment across the four treatments, with standard deviation (clustered by cohort) in brackets. The contract provided by the retailer in the H-C experiment is the same as that in the H-H experiment. The H-C experiment focuses on the difference between the supplier's decision-making when facing the computerized and human retailers.

Table 4: Summary Statistics per Treatment Condition in the H-C Experiment.

	SM27	PM27	SM21	PM21
Retailer's offer	Controlled	Controlled	Controlled	Controlled
Low-cost supplier's choice	Contract l 88.5% Contract h 11.5% Reject 0.0%	Accept 100.0% Reject 0.0%	Contract l 90.0% Contract h 10.0% Reject 0.0%	Accept 98.5% Reject 1.5%
High-cost supplier's choice	Contract l 8.0% Contract h 88.5% Reject 3.5%	Accept 93.5% Reject 6.5%	Contract l 8.5% Contract h 83.0% Reject 8.5%	Accept 21.5% Reject 78.5%
Retailer's profit	62.62[3.42]**	59.83[4.32]**	32.53[1.18]***	25.60[2.18]**
Supplier's profit	41.51[3.14]	45.54[2.55]*	18.53[0.96]	17.19[1.78]
Channel profit	104.13[4.79]**	105.37[4.58]***	51.06[1.51]***	42.79[3.62]*

Note. "Controlled" indicates that the retailer's offer is computerized, derived from the data sample of the H-H experiment. $^{***}p < 0.001$, $^{**}p < 0.01$, $^{*}p < 0.05$.

Considering the instance of Treatment SM27, we find that 88.5% of the choices made by low-cost suppliers are contract l in the H-C experiment, higher than 82.6% in the H-H experiment by Fisher's test at the $p = 0.5$; Only 3.5% of high-cost supplier decisions reject the contract in the H-C experiment, which is lower than the 32.3% in the H-H experiment. These observations imply a significant difference in the decision-making behavior of the human suppliers between the H-C and H-H experiments. Regarding the supply chain performance, the profits of the retailer and the supply chain in the H-H experiment are significantly lower than those in the H-C experiment by the one-tailed t-test after passing the Shapiro-Wilk normality test. The profit of the supplier is not significantly different under the two experiments. These evidences show that the profit distribution of the H-H experiment is fairer than that of the H-C experiment, supporting Observation 3 .

The observed differences between the H-C experiment and the H-H experiment can be explained by the fairness concern of human suppliers among the reported social behaviors in literature. Figure 6 shows the individual supplier's behavioral decision distribution in the H-H and H-C experiments, respectively, for each treatment. Each box plot shows the maximum, 25th percentile, median, 75th percentile, and minimum of the percentages of the profit-maximizing choices. The percentages of human suppliers who choose the profit-maximizing decision in H-H experiments are 82.9% for SM27, 84.6% for PM27, 81.0% for SM21, and 86.4% for PM21, lower than the percentages in H-C experiments: 97.8% for SM27-C, 97.5% for PM27-C, 97.3% for SM21-C, and 96.0% for PM21-C. However, the human suppliers' decisions in H-C experiments are not significantly different from the theoretical benchmark (100%). The statistical analysis indicates that the lack of human-to-human interaction effectively eliminates suppliers' fairness concerns and enables human suppliers to make profit-maximizing decisions, further demonstrating that fairness concern significantly affects human decision-making behavior and supply chain performance in the H-H experiment. Additionally, human suppliers' fairness concerns may show heterogeneity. There is a clear difference in the profit-maximization decision percentage for individual suppliers in the H-H experiment. Existing studies also report the heterogeneity of fairness concern (Bellemare et al., 2008; Katok et al., 2014).

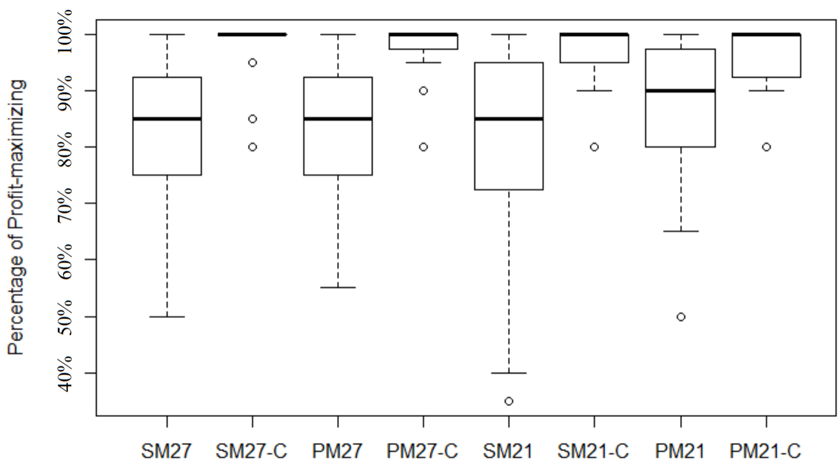

Figure 6: Behavior of Suppliers in the H-H and H-C Experiments.

We conducted a robust-check experiment by providing profit share information to the retailer after decision input but before decision confirmation. Our power analysis based on the H-H experiment data indicates that a sample size of 5 supplier decisions of each type and 5 retailer decisions can achieve 95% power and type-I error below 5% for each treatment. Hence, we recruited 20 subjects for each treatment (a total of 80 subjects for four treatments) in this new H-H experiment. The new experiment results are not significantly different from the original one. They support all three observations, particularly, the one regarding the value of screening.

5.2 Behavioral Model and Structural Estimation

To further understand why experimental results deviate from the prediction of benchmark model, we explore the decision biases by developing behavioral models and making a structural estimation. These behavioral models allow us to predict the impact of inequity aversion on the value of screening.

From the supplier's decision-making behavior perspective, the experimental results show that the human supplier shows a significant fairness concern, which manifests as inequity aversion. Following prior studies on fairness concern (Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000; Katok et al., 2014), we define the utility function of the supplier, depending on not only its own profit, but also the retailer's profit, as follows:

$$U_S^t(d|M,\alpha) = \Pi_S^t(d|M) - \alpha[\Pi_R(d|M) - \Pi_S^t(d|M)]^+, \tag{11}$$

where $\Pi_R(d|M)$ indicates the retailer's profit $(a - q_d - w_d)q_d$, the parameter $\alpha(\geq 0)$ measures the supplier's degree of inequity aversion, and $x^+ \equiv \max\{x, 0\}$. The second term with α is the supplier's disutility caused by the disadvantageous inequity aversion of earning less than the retailer's profit. There is no disutility caused by advantageous inequity aversion because the supplier was not in an advantageous situation in the experiment.

Considering the heterogeneity of the fairness concern, we define the fairness parameter α_i for supplier $i = 1, ..., I$, where I is the total number of suppliers. Regarding the separating mechanism, supplier i obtains utility $U_S^t(d|M, \alpha_i)$ when it is of cost type $t \in \{l, h\}$ and chooses decision $d \in \{l, h, 0\}$ for a given separating mechanism M from the retailer, where 0 refers to rejection. The supplier's utility is zero when it chooses rejection. Regarding his decision behavior, we use quantal response equilibrium (QRE) model with the parameter λ_S to describe the decision noise (Song et al., 2019; Xue et al., 2022). If $\lambda_S \to \infty$, the supplier is fully rational—his decision maximizes utility. At the other extreme, if $\lambda_S \to 0$, the supplier is completely random (i.e., fully irrational) in his choices. Supplier i of cost type t chooses d with the following probability:

$$\text{Prob}^t(d|M,\alpha_i) = \frac{\exp(\lambda_S U_S^t(d|M,\alpha_i))}{\exp(\lambda_S U_S^t(l|M,\alpha_i)) + \exp(\lambda_S U_S^t(h|M,\alpha_i)) + \exp(0)},\ d \in \{l,h,0\}. \tag{12}$$

For the retailer's decision model, we assume that the retailer perceives the average fairness concern $\bar{\alpha} = \sum_{i=1}^{I} \alpha_i/I$ but not individual suppliers' private fairness concern, because the retailer is randomly matched with different suppliers. When the retailer offers mechanism M, the supplier is predicted to choose contract $d \in \{l,h\}$ with an expected probability of $v\text{Prob}^l(d|M,\bar{\alpha}) + (1-v)\text{Prob}^h(d|M,\bar{\alpha})$, resulting in a profit of $\Pi_R(d|M)$. Hence, given an average fairness concern, the retailer's expected profit is

$$U_R(M|\bar{\alpha}) = \sum_{d\in\{l,h\}} (v\text{Prob}^l(d|M,\bar{\alpha}) + (1-v)\text{Prob}^h(d|M,\bar{\alpha}))\Pi_R(d|M). \tag{13}$$

The above summation does not include $d = 0$ (rejection) because $\Pi_R(d|M)$ is 0 when the contract is rejected. Using the QRE model, the retailer offers contract menu M with the following probability:

$$\text{Prob}(M|\bar{\alpha}) = \frac{\exp(\lambda_R U_R(M|\bar{\alpha}))}{\sum_{M_j\in M_N} \exp(\lambda_R U_R(M_j|\bar{\alpha}))}, \tag{14}$$

where M_N is the set of all feasible contract menus and λ_R captures the retailer's QRE parameter. The behavioral decisions form quantal response equilibrium that is completely specified by Equations (2), (11), (12), (13), and (14) for the supplier and retailer under the separating mechanism.

Regarding the pooling mechanism, supplier i of cost type $t \in \{l,h\}$ and decision $d \in \{1,0\}$ obtains utility $U_S^t(d|M,\alpha)$ on accepting the pooling mechanism $M = (w,q)$ per Equation (6) and the retailer's profit $\Pi_R(d|M)$. The supplier obtains zero utility on choosing rejection. Using the QRE model, supplier i of cost type t chooses option d with the following probability:

$$\text{Prob}^t(d|M,\alpha_i) = \frac{\exp(\lambda_S U_S^t(d|M,\alpha_i))}{\exp(\lambda_S U_S^t(1|M,\alpha_i)) + \exp(0)},\ d \in \{1,0\}. \tag{15}$$

The retailer's QRE model is the same as in Equation (14), but with the following redefined profit function:

$$U_R(M|\bar{\alpha}) = \big(v\text{Prob}^l(d=1|M,\bar{\alpha}) + (1-v)\text{Prob}^h(d=1|M,\bar{\alpha})\big) \cdot q(a-q-w), \tag{16}$$

where $q(a-q-w)$ is the retailer's profit if either the supplier of type-l or the supplier of type-h

accepts the contract. Under the pooling mechanism, the supplier and retailer's quantal response equilibrium is completely specified by Equations (6), (11), (14), (15), and (16).

When λ_R and λ_S go to infinity, the quantal response equilibrium converges to the optimal decisions of the fully rational supplier and retailer. A theoretical analysis of fully rational supplier and retailer is presented in Appendix E to investigate the impact of inequity aversion.

Based on the behavioral models in this section, we jointly estimate the parameters by maximizing the observed decision likelihood. In round j, let $\hat{d}_{ij}$ be supplier i's decision and $\hat{M}_{ij}$ be the decision of the retailer paired with supplier i. We obtain the following log-likelihood function:

$$LL(\alpha_1, ..., \alpha_I, \lambda_S, \lambda_R) = \sum_{i=1}^{I} \sum_{j=1}^{J} \left\{ \log(\text{Prob}^t(\hat{d}_{ij}|\hat{M}_{ij}, \alpha_i)) + \log(\text{Prob}(\hat{M}_{ij}|\bar{\alpha})) \right\}, \tag{17}$$

where $\bar{\alpha} = \frac{\sum_{i=1}^{I} \alpha_i}{I}$. $I = 35$ and $J = 20$ are the number of participant pairs and total rounds, respectively.

Table 5 exhibits the maximum likelihood estimation results for the supplier's average fairness parameter $\bar{\alpha}$, the supplier's QRE parameter λ_s, and the retailer's QRE parameter λ_r in all four treatments. The standard deviations are obtained by bootstrap method: we randomly draw 400 records of decisions and use them to estimate parameters; this is repeated 400 times. All the parameters are significantly different from their default values (0 for $\bar{\alpha}$ and $+\infty$ for λ_r and λ_s) in the rational benchmark case ($p < 0.001$), confirming the supplier and retailer behavioral models. In addition, Appendix C presents the estimate of each supplier's individual fairness parameter. The estimates of the behavioral parameters lead to several important remarks when compared across treatments.

Table 5: Estimated Individual Preferences for the Different Treatments

	Large market size (a = 27)		Medium market size (a = 21)	
	SM27	PM27	SM21	PM21
$\bar{\alpha}$	0.248***	0.203***	0.079***	0.146***
	[0.015]	[0.015]	[0.005]	[0.012]
λ_s	0.094***	0.106***	0.674***	0.164***
	[0.006]	[0.008]	[0.068]	[0.037]
λ_r	0.338***	0.364***	0.239***	0.064***
	[0.018]	[0.036]	[0.011]	[0.008]
LL	-2861.46	-1095.18	-2777.99	-1529.28

Note. Standard deviations in brackets. ***$p < 0.001$.

Table 5 shows that the estimate of the fairness parameter at 0.248 is larger in the separating mechanism than the estimate of 0.203 in the pooling mechanism under the large market size.

However, this estimate of 0.079 is smaller in the separating mechanism than that of 0.146 in the pooling mechanism under a medium market size. Both differences are significant ($p < 0.001$) using the Wilcoxon rank-sum test. Nevertheless, these seemingly inconsistent results can be explained by a consistent phenomenon, that the fairness parameter increases in payoff difference between two parties. Bellemare et al. (2008) report the phenomenon where the responder has a stronger fairness concern when the payoff difference of the proposer's offer is larger. The payoff differences are the major reason for the discrepancy in the fairness parameters between the separating and pooling mechanisms. We analyze the retailer's contract offers in our experiment and find that because screening increases the retailer's profit but decreases the supplier's profit, the payoff differences (the retailer's expected profit minus the supplier's expected profit given the contract offered by the retailer and accepted by the supplier) are 33.8 and 18.6 in the separating and pooling mechanisms, respectively, under a large market size. That is, the payoff difference is larger in the former than in the latter ($p < 0.01$ from one-sided t-test clustered by cohort); hence, the fairness concern estimate is larger in the separating than pooling mechanism under the large market size. However, under the medium market size, because the screening effect increases both parties' profits, the payoff differences are 27.7 and 37.6 in the separating and pooling mechanisms respectively. Hence, the payoff difference is smaller in the former than the latter ($p < 0.01$ from one-sided t-test clustered by cohort); the fairness parameter estimate is smaller in the separating than the pooling mechanism under the medium market size.

Then, the fairness parameter estimates of 0.248 and 0.203 under the large market size ($a = 27$) are significantly higher than those of 0.079 and 0.146 under the medium market size ($a = 21$) ($p < 0.001$ from one-sided t-test). The major reason for this discrepancy is the overall profit difference in the supply chain. A similar result is also reported by Andersen et al. (2011), who observe that the responder has a higher rejection rate when the overall profit is higher (16 hours of work versus 1.6 hours of work) under the same proposed profit allocation ratio. This observation implies that the fairness parameter increases with the overall profit under the same hourly wage. In our experiment, the large market size has a larger overall profit than the medium market size, which results in a larger fairness parameter estimate.

That the model parameters are different rather than the same across treatments is supported by likelihood ratio test comparing the above model and a common parameter model. Log-likelihood of the former is -8263.91 by summing up the LL values in Table 5. Log-likelihood of the common parameter model is found to be -8955.79. Thus, the likelihood ratio test statistics is 1383.76 and the degree of freedom is 9 because the former model has 9 more model parameters. This results in $p < 0.01$ supporting that the former model is significantly better. These results and the behavioral models enable us to further explore the sensitivity of the value of screening on the model parameters.

6 Extended Discussions

We examine how the value of screening changes with the behavioral parameters based on the structural estimation results, focusing on the impact of fairness concerns. We also apply a more flexible model by Bellemare et al. (2008) to examine nonlinear effect of fairness concerns on the supplier's utility.

6.1 Sensitivity Study of the Value of Screening

The experimental result shows that the value of screening is negligible under the large market size but substantial under the medium market size. The contrast is more striking if we evaluate the relative value of screening as defined by the percentage improvement of the retailer's profit due to screening: From the retailer's profit in Table 2, it is 0.00% ((52.04-52.02)/52.02) under the large market size versus 16.79% ((26.30-22.52)/22.52)) under the medium market size. However, according to the normative prediction in Table 1 without the behavioral factors, the relative value of screening is 11.11% under both market sizes, which is derived by (90-81)/81 and (45-40.5)/40.5, respectively. We predict the behavioral factors' contributions to the value of screening by using the behavioral models and the estimated behavioral parameters to numerically simulate the retailer's and supplier's decision.

We start with the prediction of the normative benchmark and evaluate the behavioral parameters to arrive at their contributions to the unexpected value of screening. Specifically, we consider three behavioral models with incrementally more behavioral preferences: MI of fairness only, MII of fairness and the supplier's QRE, and MIII of fairness and both parties' QRE. We compute the relative value of screening, namely, the percentage improvement of the retailer's profit under the separating mechanism over that under the pooling mechanism, in the three models. As the observed decisions are fitted best by the behavioral parameter estimates in Table 5, we use them to evaluate the incremental impact of behavioral parameters for both the large and medium market sizes. Figure 7 shows the computational results along with the benchmark and experimental result.

Under the large market size, behavioral factors incrementally reduce the screening benefit to below zero, as shown in the left part of the figure. First, compared with the benchmark, inequity aversion contributes a 6.11% (11.11%-5.00%) reduction of the screening benefit. This observation is because the separating mechanism results in a larger profit difference between the

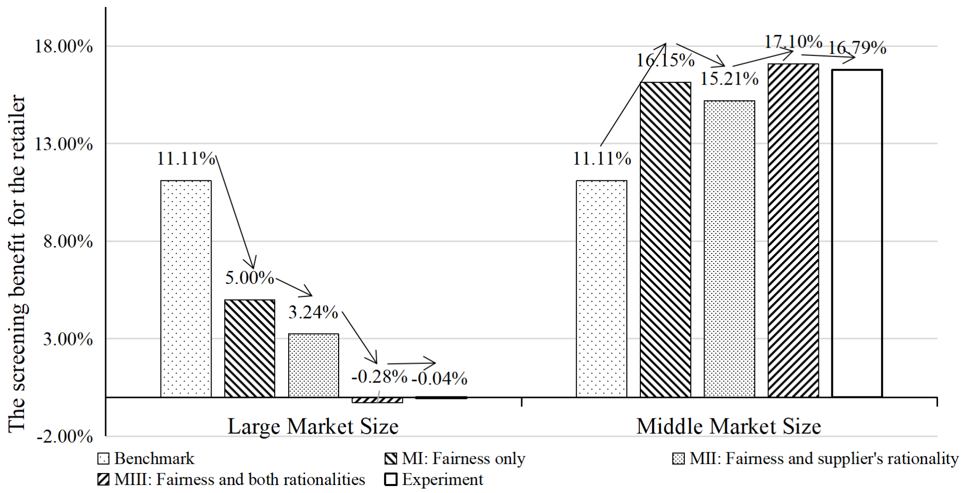

Figure 7: Screening Benefit as a Function of Behavioral Preferences under the Large and Medium Market Sizes

two parties, eliciting stronger fairness than the pooling mechanism. Consequently, the retailer makes less profit. Then, comparing Models I, II, III and Experiment reveals that the two QRE parameters contribute to a 5.04% (5.00%+0.04%) reduction. The computational study reveals that under the large market size, all behavioral preferences reduce the screening-value benefit. Nevertheless, fairness concern reduces it by the largest share.

By contrast, under the medium market size, the impacts of the behavioral preferences are dramatically different, shown by the right part of Figure 7. Comparing the benchmark with Model I, we observe that inequity aversion contributes to a 5.04% (16.15%-11.11%) increase in the value of screening. As screening increases both parties' profits, the payoff difference is smaller in the separating mechanism than in the pooling mechanism, eliciting lower fairness concern in the former. This relatively low fairness concern of the supplier increases the screening benefit for the retailer. Next, the two QRE parameters increase the benefit by 0.64% (16.79%-16.15%) (see the comparison among Models I, II and III). The above computational analysis shows that under the medium market size, fairness concern increases the value of screening by the largest share, and the QRE parameters have little effect.

Fairness concern has the largest influence on the retailer's value of screening under both the medium and large market sizes. However, the influence is negative under the former but positive under the latter. QRE parameters have a weak influence. Thus, using the behavioral models and behavioral parameter estimates, we quantify the impact of the behavioral preferences and pinpoint the reasons why the value of screening to the retailer is significantly lower than the prediction under the large market size but significantly higher than the prediction under the medium market size.

6.2 Nonlinear Effect of Inequity Aversion

We observe that the effects of inequity aversion vary among the four treatment in Table 5, and so are the parties' profit differences among them. Bellemare et al. (2008) provide a nonlinear model that links the effects of inequity aversion on utility and the parties' profit differences. According to their model, the supplier's utility in Equation (11) changes to the following:

$$U_S^t(d|M,\alpha,\beta) = \Pi_S^t(d|M) - \alpha[\Pi_R(d|M) - \Pi_S^t(d|M)]^+ - \beta\{[\Pi_R(d|M) - \Pi_S^t(d|M)]^+\}^2, \quad (18)$$

where the last term with the nonlinear coefficient β captures nonlinear effect of inequity aversion. Correspondingly, Equations (12) - (16) are changed to include β because they all depend on Equation (18) in the mechanism design game. Using this new behavioral model, we make maximum likelihood estimation similar to Section 5.2 and obtain the following results.

Table 6: Estimated Individual Preferences with Nonlinear Inequity Aversion

	Large market size (a = 27)		Medium market size (a = 21)	
	SM27	PM27	SM21	PM21
$\bar{\alpha}$	0.170	0.203	0.062	0.238
β	0.001	0.000	0.000	-0.002
λ_s	0.100	0.106	0.649	0.190
λ_r	0.319	0.364	0.242	0.059
LL	-2842.57***	-1095.18	-2773.47	-1520.31***

Note. ***$p < 0.001$ by likelihood ratio test with respect to linear inequity aversion models in Table 5.

The likelihood ratio test shows that the nonlinear inequity aversion model fits the data significantly better than the linear model for treatments SM27 and PM21, but not for PM27 and SM21. This result implies that the parties' profit difference may have a second order effect on supplier's utility. Nevertheless, the linear inequity aversion model is a good approximation of the nonlinear inequity aversion model for our study because it explains well why screening value is significantly higher than the prediction under market size 21, but not under market size 27.

7 Conclusion

This study examines the problem of a retailer's optimal mechanism design given a supplier with private production cost information. We consider a separating mechanism in which the retailer offers multiple contracts to screen the supplier's private cost information, and a pooling mechanism in which the retailer offers a single contract, which does not screen the private information.

The theoretical models predict that screening always benefits the retailer. Screening harms the supplier if the market size is large but benefits the supplier if the market size is medium.

The human-to-human experiment results indicate that the subjects' decision and supply chain performance significantly deviate from the prediction. The controlled human-to-computer experiment shows that the lack of human-to-human interaction effectively eliminates suppliers' fairness concern and enables human suppliers to make profit-maximizing decisions. This empirical evidence supports the idea that fairness concern significantly affects decision-making behavior and supply chain performance in the supply chain setting. while the fairness concern effect depends on the market size, its impact on the value of screening depends on a market threshold that defines medium-sized and large markets.

Some interesting observations on value of screening emerge from comparing the separating and pooling mechanisms. In large markets, the value of screening is negligible to the retailer and significantly less than what was predicted. This happens because the separating mechanism induces a stronger fairness concern from the supplier than the pooling mechanism. By contrast, in medium-sized markets, the value of screening is substantially higher to the retailer because the separating mechanism induces a weaker fairness concern from the supplier than the pooling mechanism.

These results imply that the parties in the supply chain should use mechanisms selectively based on concerns regarding fairness. In general, the mechanism designer in supply chain management should pay attention to the fairness-concern levels induced by the mechanisms' screening effects. If the screening reduces the parties' profit differences, the value of screening is substantially enhanced by the reduced fairness-concern levels. Thus, the screening (i.e., separating) mechanism should be preferred over the non-screening (i.e., pooling) mechanism. We observe this in the medium market-size case. If the screening increases the parties' profit differences, the value of screening substantially diminishes due to increased fairness concern. In this case, the screening mechanism may hold little advantage over the non-screening mechanism; this is what we observed in the large market case. Hence, the screening mechanism is less preferred than the non-screening mechanism due to the latter's simpler mechanism structure.

Being one of few studies of the screening through behavioral mechanism design in supply chain contracting, our paper has a few limitations and addressing them may lead to a fruitful future research agenda. First, our study assumes a deterministic demand, but uncertain demands are common in practice; thus, it will be interesting to study whether the lessons of our study hold under uncertain demands. Second, the retailer decides both wholesale price and order quantity in our paper, but in practice some retailers set only order quantity and the screening effect in this case is unknown. Finally, we study only wholesale price contract, but many other types of contract are commonly used in practice such as revenue-sharing, buyback, and profit-sharing contracts (Li et al., 2015; Çakanyıldırım et al., 2012); the screening effects and its interaction with social preferences are not trivial and worthy of study under these types of contract. This future research agenda helps yield management techniques and theories to improve procurement via screening.

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Appendices

Appendix A Proofs of Proposition

Proof of Proposition 1:

The retailer maximizes the expected profit function in Eq. (1), and the optimal separating mechanism satisfies the incentive compatibility and individual rationality constraints in (3)-(4):

$$
\begin{aligned}
&(IC1) \quad q_l(w_l - c_l) \geq q_h(w_h - c_l) = q_h(w_h - c_h) + q_h(c_h - c_l) \\
&(IC2) \quad q_h(w_h - c_h) \geq q_l(w_l - c_h) = q_l(w_l - c_l) - q_l(c_h - c_l) \\
&(IR1) \quad q_l(w_l - c_l) \geq 0 \\
&(IR2) \quad q_h(w_h - c_h) \geq 0
\end{aligned}
$$

First, IR1 is redundant because it is implied by IC1 and IR2. Second, according to standard mechanism design, we impose the *monotonicity condition* $q_l \geq q_h$; this condition and IC1 implies IC2 redundant. Finally, under the monotonicity condition, IC1 and IR2 are binding because the objective function decreases in w_h and w_l. Therefore,

$$q_l(w_l - c_l) = q_h(c_h - c_l), \; q_h(w_h - c_h) = 0.$$

This implies

$$w_l = c_l + \frac{(c_h - c_l)q_h}{q_l}, \; w_h^{SB} = c_h.$$

Now we can replace w_l and w_h in the retailer's profit function,

$$\Pi_R(M) = v(a - q_l - c_l)q_l + (1 - v)(a - q_h - c_h)q_h - v(c_h - c_l)q_h.$$

The retailer's profit function $\Pi_R(M)$ is concave in q_l and q_h. Hence, the optimal quantities are

$$
\begin{aligned}
q_l^{SB} &= (a - c_l)/2, \\
q_h^{SB} &= \max\{\frac{a - c_h - \frac{v}{1-v}(c_h - c_l)}{2}, 0\}.
\end{aligned}
$$

Hence, q_h^{SB} is $\frac{a-c_h-\frac{v}{1-v}(c_h-c_l)}{2}$ if $a \geq \frac{c_h - vc_l}{1-v}$, but zero otherwise. w_l^{SB} is obtained by substituting q_l^{SB} and q_h^{SB}. Finally, we check that this solution satisfies the monotonicity condition. ■

Proof of Proposition 2: We derive the optimal pooling mechanism. Recall the retailer's problem of pooling mechanism design is defined by Equation (7). The supplier profit functions are

$$\Pi_S^l(d = 1|M) = (w - c_l)q,$$
$$\Pi_S^h(d = 1|M) = (w - c_h)q.$$

Because $c_h > c_l$,

$$\Pi_S^l(d = 1|M) - \Pi_S^h(d = 1|M) = (c_h - c_l)q \geq 0.$$

That is, if the high cost supplier accepts the contract, the low cost supply must accept the contract. Hence, there are only two cases to consider: (1) the retailer purchases from both types of suppliers, and (2) the retailer purchases from only the low cost suppler. We compare the profits obtained from both cases to determine the retailer's optimal contract.

Case (1): Both types of supplier participate; the participation constraint binds for the high cost supplier. Solving $\Pi_S^h(d = 1|M) = 0$ allows us to express w in terms of q,

$$w^* = c_h$$

Maximizing the retailer's profit $q(a - q - w)$ with $w^* = c_h$ results in the optimal $q^* = \frac{a-c_h}{2}$. Thus, the retailer optimal standard pooling contract in Case (1) is as follows

$$\left(w^* = c_h, q^* = \frac{a - c_h}{2}\right), \quad \Pi_R(M) = \frac{(a - c_h)^2}{4}.$$

Case (2): The high cost supplier is excluded from the trade, i.e., $\Pi_S^h(d = 1|M) < 0$. Thus, the low cost supplier's participation constraint is binding, i.e., $\Pi_S^l(d = 1|M) = 0$. Thus, we have

$$\left(w^* = c_l, q^* = \frac{a - c_l}{2}\right), \quad \Pi_R(M) = \frac{(a - c_l)^2}{4}v.$$

As the optimal retailer profit is lower in Case (1) than in Case (2) if $v \geq (\frac{a-c_h}{a-c_h})^2$, i.e, $a \leq \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}$, the retailer's optimal pooling contract is expressed by Equation (8). ■

Proof of Proposition 3: The value of screening to the retailer is the retailer's profit difference by Definition 1. Based on the optimal separating contract in Proposition 1 and the optimal pooling contract in Proposition 2, we can obtain the value of screening in three scenarios.

Case (1): When the market size satisfies $c_h \leq a \leq \frac{c_h - vc_l}{1-v}$, the expected profit of the retailer in the separating contract equals that in the pooling contract, thus the value of screening $\Delta = 0$.

Case (2): When the market size satisfies $\frac{c_h - vc_l}{1-v} < a \leq \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}$, the expected profit of the retailer in the pooling contract equals $v\frac{(a-c_l)^2}{4}$. We derive the expected profits of retailer according to the optimal separating mechanisms specified in Proposition 1 as follows:

$$\Pi_R^{SM} = v\{\frac{(a-c_l)^2}{4} - \frac{a - c_h - \frac{v}{1-v}(c_h - c_l)}{2}(c_h - c_l)\} + (1-v)\{\frac{(a-c_h)^2}{4} - \frac{(\frac{v}{1-v}(c_h - c_l))^2}{4}\}.$$

The screening value $\Pi_R^{SM} - \Pi_R^{PM}$ is

$$-\frac{v(a-c_l)^2 - (a-c_h)^2}{4} + \frac{v}{1-v}\frac{(c_h - c_l)^2}{4}.$$

Case (3): When the market size satisfies $a > \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}$, the expected profit of the retailer in the pooling contract equals $\frac{(a-c_h)^2}{4}$. The expected profits of retailer in optimal separating mechanism is the same as the above expression of Π_R^{SM}, thus the value of screening is as follows:

$$\frac{v}{1-v}\frac{(c_h - c_l)^2}{4}.$$

Hence, the value of screening to the retailer in standard benchmark is Equation (9). ■

Proof of Proposition 4: The value of screening to the supplier is the supplier's profit difference by Definition 2. Based on the optimal separating contract in Proposition 1 and the optimal pooling contract in Proposition 2, we can obtain the value of screening in three scenarios.

Case (1): When the market size satisfies $c_h \leq a \leq \frac{c_h - vc_l}{1-v}$, the expected profit of the supplier in the separating contract equals that in the pooling contract, thus the value of screening $\Delta = 0$.

Case (2): When the market size satisfies $\frac{c_h - vc_l}{1-v} < a \leq \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}$, the expected profit of the supplier in the pooling contract equals 0. We derive the value of screening, which equals the expected profits of supplier according to the optimal separating mechanisms specified as follows:

$$\Pi_S^{SM} = v\frac{a - c_h - \frac{v}{1-v}(c_h - c_l)}{2}(c_h - c_l).$$

Case (3): When the market size satisfies $a > \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}$, the expected profit of the supplier in the pooling contract equals $v(c_h - c_l)\frac{(a-c_h)}{2}$. The expected profits of supplier in optimal separating mechanism is the same as the above expression of U_R^{SM}, thus the value of screening is as follows:

$$-\frac{v}{1-v}\frac{v(c_h-c_l)^2}{2}.$$

Hence, the value of screening to the supplier in standard benchmark is Equation (10). ■

Appendix B Learning Effect

We use regression analysis and panel data to test if the decisions of the retailer and the supplier have time trends. For the retailer, we use a regression model with each subject's decision w as a dependent variable and the period as an independent variable. A panel data regression model takes into account of the subject-specific effect that is time-invariant and the time-varying component, as follow:

$$w_{it} = intercept + period_{it}\beta_i + u_i + \epsilon_{it}, \quad i \in \{1, 2, ...35\}; t \in \{1, 2, ...20\}; \tag{C.1}$$

where *intercept* is the constant item, β_i is the time trend coefficient, $u_i \sim N(0, \sigma_u^2)$ indicates the subject-specific random effect i and $\epsilon_{it} \sim N(0, \sigma_e^2)$ the time-varying effect.

To test the learning effect of the supplier subjects, we use a logistic regression model because the supplier makes discrete choices between rejection or acceptance in the pooling mechanism, and among rejection, contract l, or contract h in the separating mechanism. Each supplier's decision $Choice$ as a dependent variable, the period and the retailer's offer w as an independent variable. A panel data regression model takes into account of the subject-specific effect that is time-invariant and the time-varying component, as follow:

$$Choice_{it} = Logit[intercept + w_{it}\theta_i + period_{it}\beta_i + u_i + \epsilon_{it}], i \in \{1, 2, ..., 35\}; t \in \{1, 2, ..., 20\}; \tag{C.2}$$

where *Logit* indicates the logistic regression model (binary in pooling mechanism and multiple in separating mechanism), *intercept* is the constant item, θ_i is the wholesale price related coefficient, β_i is the time trend coefficient, $u_i \sim N(0, \sigma_u^2)$ indicates the subject-specific random effect i and $\epsilon_{it} \sim N(0, \sigma_e^2)$ the time-varying effect.

The regression results of the retailer and both types of suppliers are summarized in Tables B.1–B.3 for all four treatments. The results show that the supplier's behavior is significantly affected by the wholesale price. However, in all treatments, the time trend coefficient is statistically insignificant from 0 in all treatments for all players in all treatments under significance level of 0.01. Under significance level of 0.05, only the retailer in treatment SM21 in Table B.1 shows a time trend. Overall, the subjects of the retailer and the supplier have little learning effects over time.

Table B.1: Learning effect in the retailers' behavior under each treatment.

	PM21	PM27	SM21(w_l)	SM21(w_h)	SM27(w_l)	SM27(w_h)
time trend coefficient	-0.019	0.0082	0.026*	0.027*	-0.0059	0.018
intercept	7.11***	10.88***	6.25***	9.92***	8.77***	11.26***

Note. ***$p < .001$,**$p < .01$, *$p < .05$. The parentheses indicate different contract offers under different treatments.

Table B.2: Learning effect in the suppliers' behavior under pooling mechanism.

	PM21(type-l)	PM21(type-h)	PM27 (type-l)	PM27 (type-h)
w	1.60***	1.74***	1.96***	1.76***
time trend coefficient	-0.0092	0.075	-0.27	-0.06
intercept	-6.08***	-16.06***	-12.27***	-17.50***

Note. ***$p < .001$,**$p < .01$, *$p < .05$. The parentheses indicate different types of suppliers under different treatments.

Table B.3: Learning effect in the suppliers' behavior under separating mechanism.

		SM21(type-l)	SM21(type-h)	SM27 (type-l)	SM27 (type-h)
Contract l	w_l	6.74*	10.69*	4.12**	2.84***
	w_h	-0.42	-0.23	-0.26	-0.12
	time trend coefficient	-0.44	-0.27	-0.049	-0.51
	intercept	-22.15**	-96.69*	-22.75***	-27.31***
Contract h	w_l	2.12	-0.086	-1.25	-0.30*
	w_h	0.81	2.07***	2.06*	1.28***
	period	-0.42	-0.035	-0.017	-0.016
	intercept	-8.31	-19.97***	-9.88***	-11.13***

Note. ***$p < .001$,**$p < .01$, *$p < .05$. Multinomial logistic regression model setting rejection as a baseline. The parentheses indicate different types of suppliers under different treatments.

Appendix C Individual-Level Fairness Analysis

Using the behavioral model in Subsection 4.2, we estimated individual supplier's fairness parameters α_i for $i \in \{1, \cdots, 35\}$. Table C.1 shows the estimation results of individual subject's fairness concern. We observe first the fairness concern varies significantly among different suppliers in all four treatments, supporting the observation that the suppliers have heterogenous fairness concern at the aggregate level. Second, using the estimated individual subject's fairness parameter, we can check the individual subject's decision consistence. Given the estimates of the fairness parameter, the percentage of the supplier subjects' decisions that maximize their utility is 95.2% in total of all treatments, 96.3% in PM21, 92.0% in SM21, 94.4% in PM27, and 92.1% in SM27, respectively. These results support the observation that each supplier has consistent fairness concern at individual level.

Table C.1: Estimated Individual Fairness Concern for Different Treatments.

	Large Market Size (a = 27)		Medium Market Size (a = 21)	
	SM27	PM27	SM21	PM21
α_1	0.000	0.049	0.010	0.017
α_2	0.011	0.112	0.256	0.243
α_3	0.001	0.435	0.000	0.786
α_4	0.166	0.077	0.335	0.642
α_5	0.172	0.364	0.002	0.258
α_6	0.120	0.128	0.055	0.008
α_7	0.229	0.000	0.045	0.069
α_8	0.509	0.000	0.000	0.600
α_9	0.283	0.000	0.028	0.000
α_{10}	0.505	0.190	0.037	0.000
α_{11}	0.260	0.461	0.109	0.000
α_{12}	0.001	0.044	0.194	0.000
α_{13}	0.737	0.057	0.003	0.208
α_{14}	0.000	0.122	0.084	0.109
α_{15}	0.085	0.000	0.000	0.080
α_{16}	0.001	0.144	0.262	0.005
α_{17}	0.217	0.061	0.000	0.090
α_{18}	0.088	0.245	0.065	0.001
α_{19}	0.033	0.113	0.079	0.395
α_{20}	0.001	0.000	0.161	0.004
α_{21}	0.272	0.000	0.009	0.016
α_{22}	0.348	0.728	0.000	0.140
α_{23}	0.119	0.178	0.065	0.001
α_{24}	0.036	0.659	0.000	0.142
α_{25}	0.923	0.147	0.080	0.001
α_{26}	0.078	0.027	0.000	0.111
α_{27}	0.229	0.025	0.000	0.013
α_{28}	0.000	0.423	0.485	0.005
α_{29}	0.064	0.761	0.233	0.493
α_{30}	0.830	0.003	0.017	0.086
α_{31}	0.383	0.000	0.000	0.000
α_{32}	0.407	1.174	0.062	0.000
α_{33}	0.005	0.400	0.007	0.000
α_{34}	0.529	0.000	0.079	0.102
α_{35}	0.861	0.024	0.206	0.388

Appendix D Experimental Materials

D.1 Separating: instruction

The original instructions were in Chinese. The following instructions are for market size a=27 (those for a=21 are analogous). The human-to-computer experiment uses the same instructions except the human subject knows the other player being a computer.

General. Welcome and thank you for participating in this experiment. In this experiment you will earn money. From now on until the end of the experiment, please do not communicate with other participants. If you have any question, please raise your hand. An experimenter will come to your place and answer your question privately.

Overview

This is an experiment about decision making in supply chains. In the experiment, you will randomly play a supplier or a retailer. Your profit will be determined by your decisions and those of your partners. The final payment you receive consists of a show-up fee of 20 CNY, and a reward proportional to your performance in the experiment.

Decision Task

The supply chain consists of a supplier and a retailer. The retailer proposes two distinct contracts (each of which includes a wholesale price and a supply quantity) to the supplier, who can either accept one of them, or reject both. The unit cost of producing the requested goods is privately known to the supplier, and is considered by the retailer a random number being 3 with 50% chance, and being 9 with another 50% chance.

Profits of suppliers and retailers are determined in the following manner:

$$\begin{aligned}\text{Retail price} &= \text{Market size } a - \text{supply quantity},\\ \text{Supplier's profit} &= (\text{wholesale price} - \text{production cost}) \times \text{supply quantity},\\ \text{Retailer's profit} &= (\text{Retail price} - \text{wholesale price}) \times \text{supply quantity}.\end{aligned}$$

where the market size $a = 27$.

Experimental Procedure

There are 20 rounds of the experiment. Each round of the experiment consists of three stages:

Stage 1: The system gives the order quantity to the retailer, and then the retailer determines the wholesale prices for the two contracts, which have to lie between 3 and the retail price.

Stage 2: The supplier observes the production cost and the contracts offered by the retailer (each containing a wholesale price and a fixed supply quantity), and decides which contract to accept or rejects both.

Stage 3: If any contract is accepted, the chosen contract is executed according to its terms; and both supplier and retailer make the corresponding profits; if both contracts are rejected, both parties earn zero profit.

The timing of events in each single round of experiment is summarized in the diagram below:

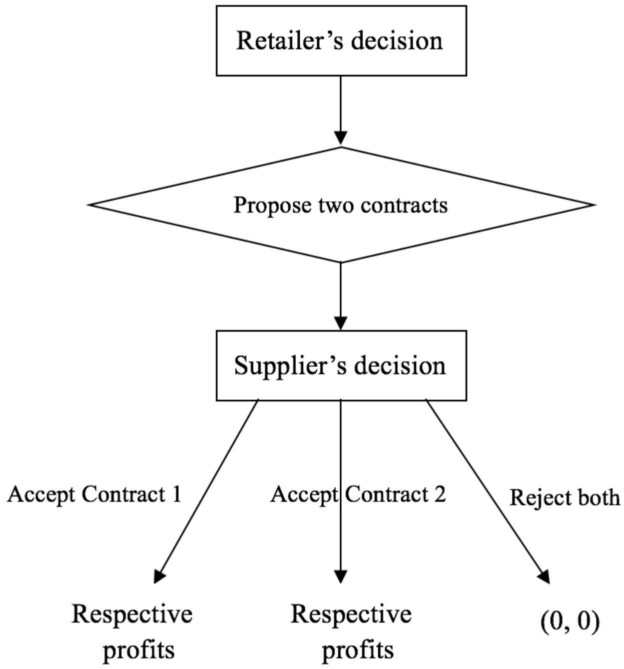

Figure D.1: The timing of events

Before the formal experiment begins, there will be 6 rounds of experiment for you to practice, with no earning accumulated to the game. In the practice experiment, you will be assigned with a random role as supplier or retailer and will be randomly matched with other participants. In the formal experiment that follows, your role is fixed (i.e., if you are assigned as a supplier [retailer] in one round, you will remain as a supplier [retailer] in all rounds of the formal experiment). You will not encounter a same partner in any two consecutive rounds of the experiment. Before the game starts, you are required to complete a quiz, which covers the important knowledge about the game. The quiz will be shown on your computer screen. You will start to play the game only after you correctly answer all the questions in the quiz.

At the end of each round, you will review the outcome of the game in the current round, including your role, the production cost, retailer's decision, supplier's decision, retailer's profit, supplier's profit.

Payment

Your earnings in the game totaled from all rounds of the formal experiment will be converted to Chinese Yuan at the rate of 1 experimental dollar = ¥0.05. The converted payment, added with your participation fee of ¥20, will be paid to you at the end of the session.

D.2 Separating: Decision Support

For the subject's convenience of calculation, we provide in each round both parties a decision support tool which graphically maps contract choices into profits if the supplier accepts the offered wholesale prices, under different production costs. In Figure D.2 and D.3, Contract 1[2] corresponds to the contract that involves a high [low] supply quantity. Note that in Figure D.3, the supplier's profit is negative if it accepts a retailer's wholesale price below the unit production cost of 9.

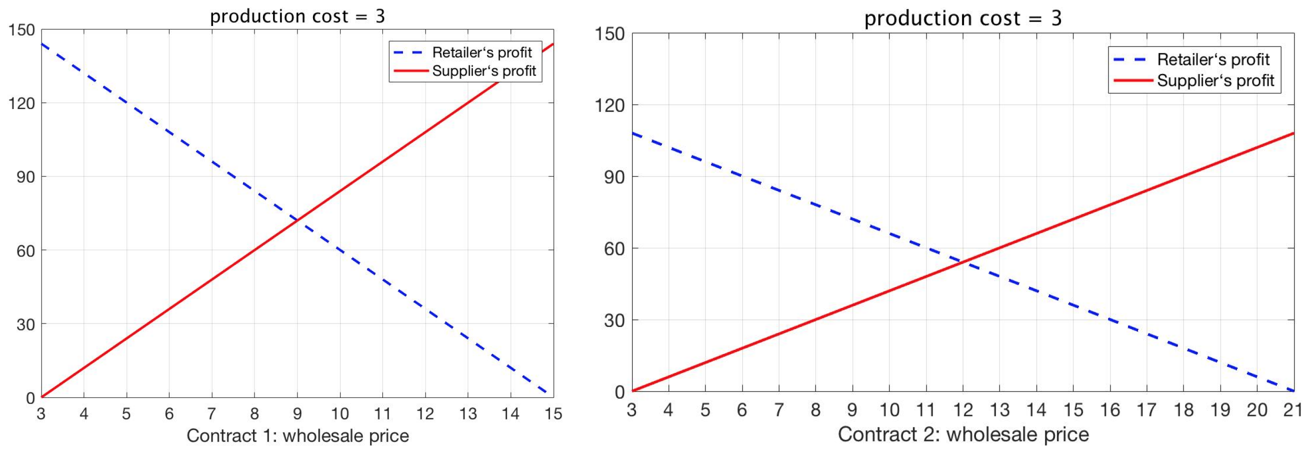

Figure D.2: Decision support when the supplier type is low-cost

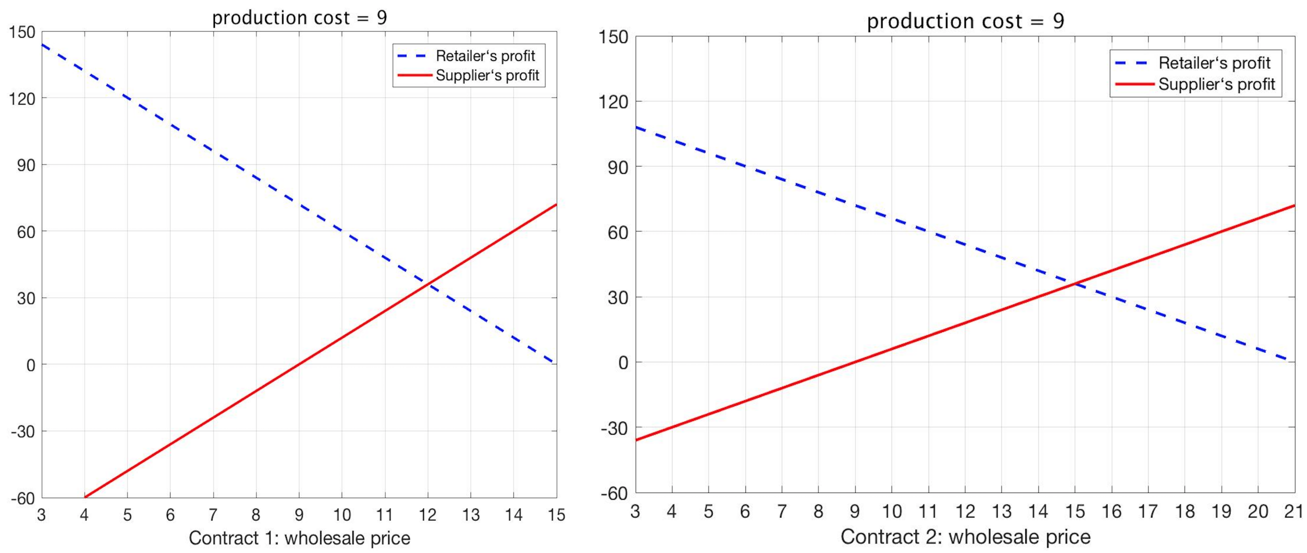

Figure D.3: Decision support when the supplier type is high-cost

D.3 Separating: Screen shots for SM27 treatment

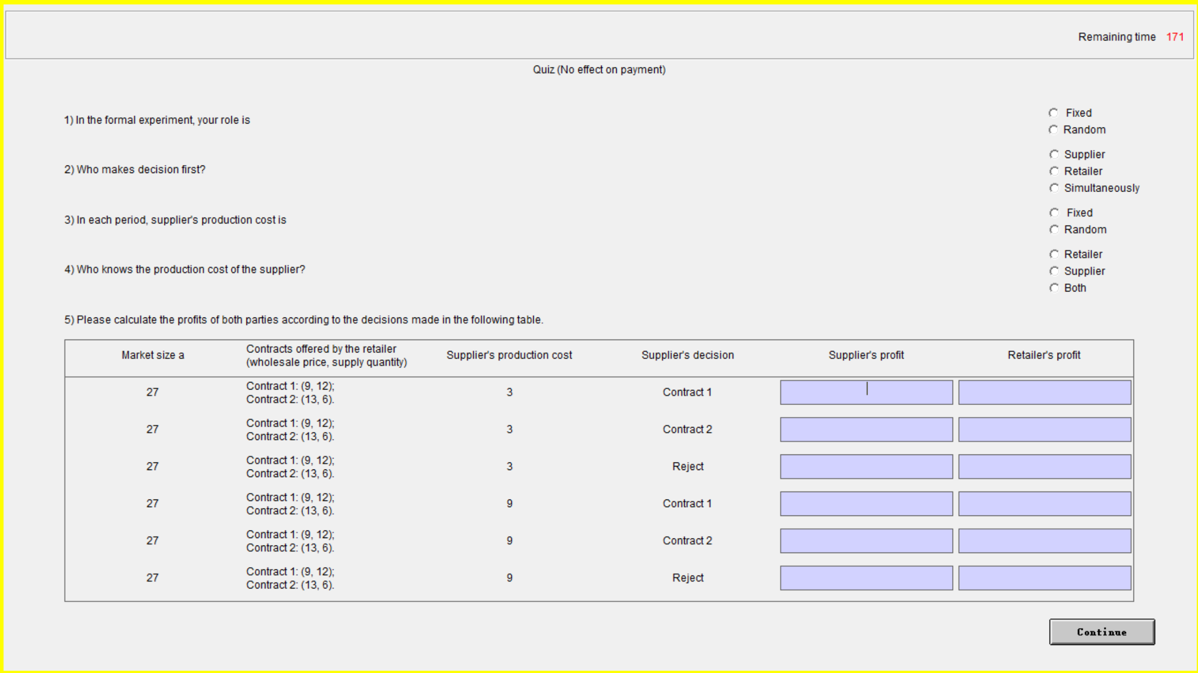

Figure D.4: The quiz screen

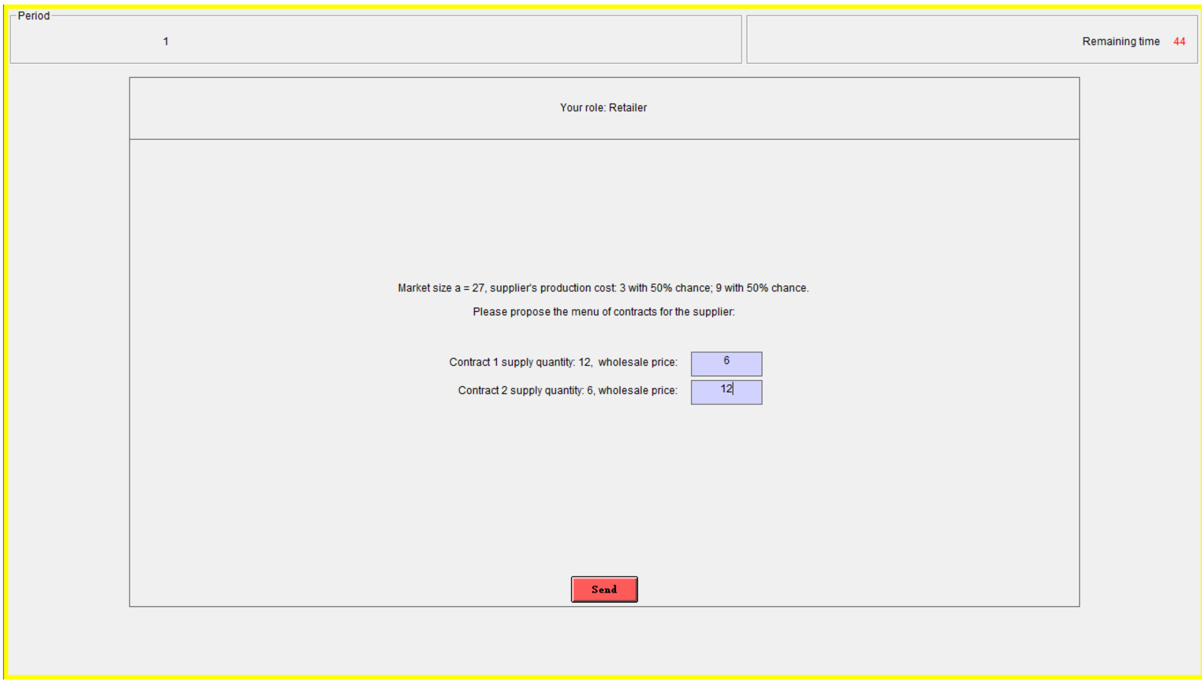

Figure D.5: The retailer's decision screen

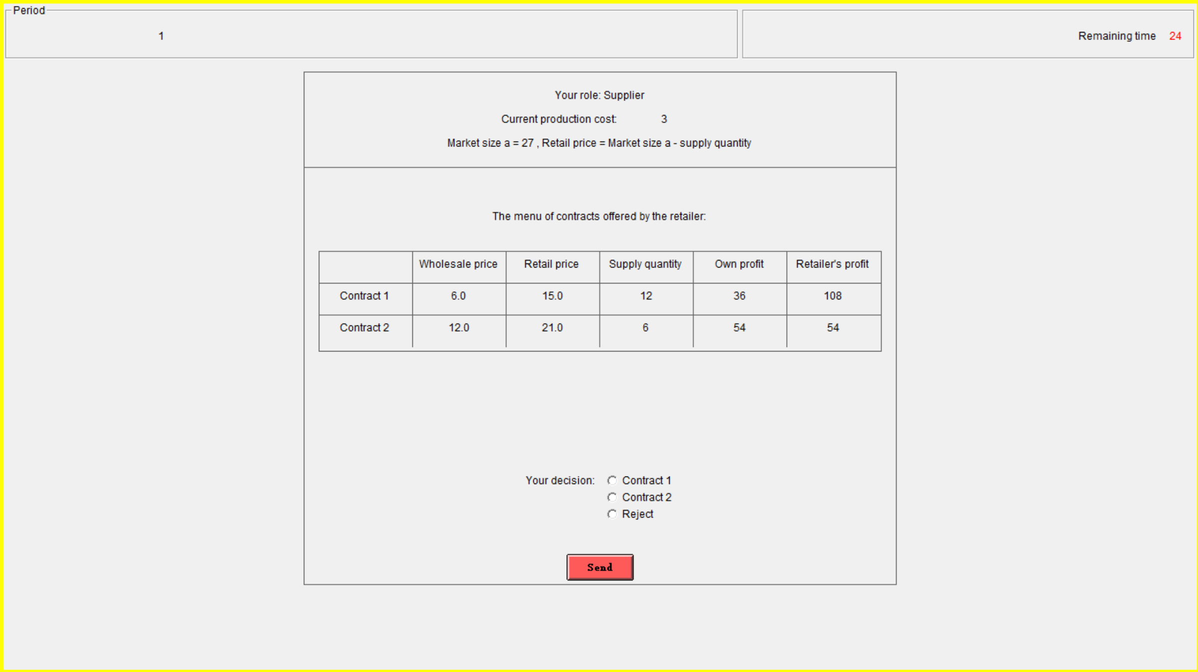

Figure D.6: The supplier's decision screen

D.4 Pooling: instruction

The original instructions were in Chinese. The following instructions are for market size a=27 (those for a=21 are analogous).

General. Welcome and thank you for participating in this experiment. In this experiment you will earn money. From now on until the end of the experiment, please do not communicate with other participants. If you have any question, please raise your hand. An experimenter will come to your place and answer your question privately.

Overview

This is an experiment about decision making in supply chains. In the experiment, you will randomly play a supplier or a retailer. Your profit will be determined by your decisions and those of your partners. The final payment you receive consists of a show-up fee of 20 CNY, and a reward proportional to your performance in the experiment.

Decision Task

The supply chain consists of a supplier and a retailer. The retailer proposes a contract (including a wholesale price and a supply quantity) to the supplier, who then chooses to accept or reject it. The unit cost of producing the requested goods is privately known to the supplier, and is considered by the retailer a random number being 3 with 50% chance, and being 9 with another 50% chance.

Profits of suppliers and retailers are determined in the following manner:

$$\text{Retail price} = \text{Market size } a - \text{supply quantity},$$

$$\text{Supplier's profit} = (\text{wholesale price} - \text{production cost}) \times \text{supply quantity},$$

$$\text{Retailer's profit} = (\text{Retail price} - \text{wholesale price}) \times \text{supply quantity}.$$

where the market size $a = 27$.

Experimental Procedure

There are 20 rounds of formal experiment. Each round of the experiment consists of three stages:

Stage 1: The system gives the order quantity to the retailer, and then the retailer determines the wholesale price, which has to lie between 3 and the retail price.

Stage 2: The supplier observes the production cost and the contract offered by the retailer (containing a wholesale price and a fixed supply quantity), and decides whether to accept the contract, or reject it.

Stage 3: If accepted, the contract is executed according to its terms; and both supplier and retailer make the corresponding profits; if the contract is rejected, both parties earn zero profit.

The timing of events in each single round of experiment is summarized in the diagram below:

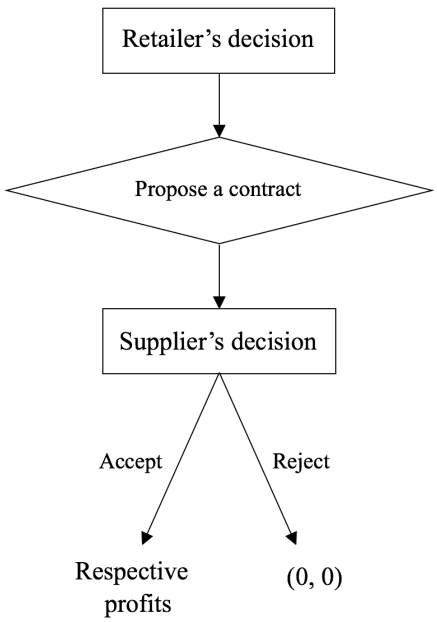

Figure D.7: The timing of events

Before the formal experiment begins, there will be 6 rounds of experiment for you to practice, with no earning accumulated to the game. In the practice experiment, you will be assigned with a random role as supplier or retailer and will be randomly matched with other participants. In the formal experiment that follows, your role is fixed (i.e., if you are assigned as a supplier [retailer] in one round, you will remain as a supplier [retailer] in all rounds of the formal experiment). You will not encounter a same partner in any two consecutive rounds of the experiment. Before the game starts, you are required to complete a quiz, which covers the important knowledge about the game. The quiz will be shown on your computer screen. You will start to play the game only after you correctly answer all the questions in the quiz.

At the end of each round, you will review the outcome of the game in the current round, including your role, the production cost, retailer's decision, supplier's decision, retailer's profit, supplier's profit.

Payment

Your earnings in the game totaled from all rounds of the formal experiment will be converted to Chinese Yuan at the rate of 1 experimental dollar = ¥0.05. The converted payment, added with your participation fee of ¥20, will be paid to you at the end of the session.

D.5 Pooling: Decision Support

For the subject's convenience of calculation, we provide both parties a decision support tool which graphically maps contract choices into profits, under different production costs. Note that the decision support is not provided during the quiz.

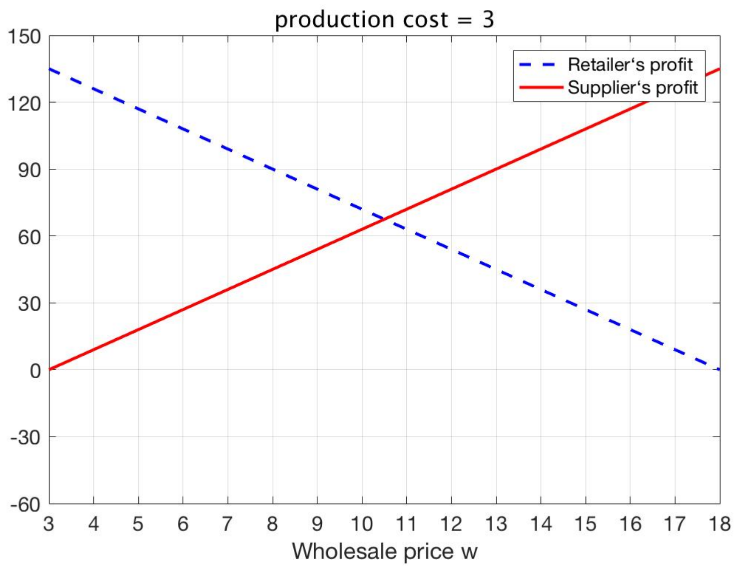

Figure D.8: Decision support when the supplier type is low-cost

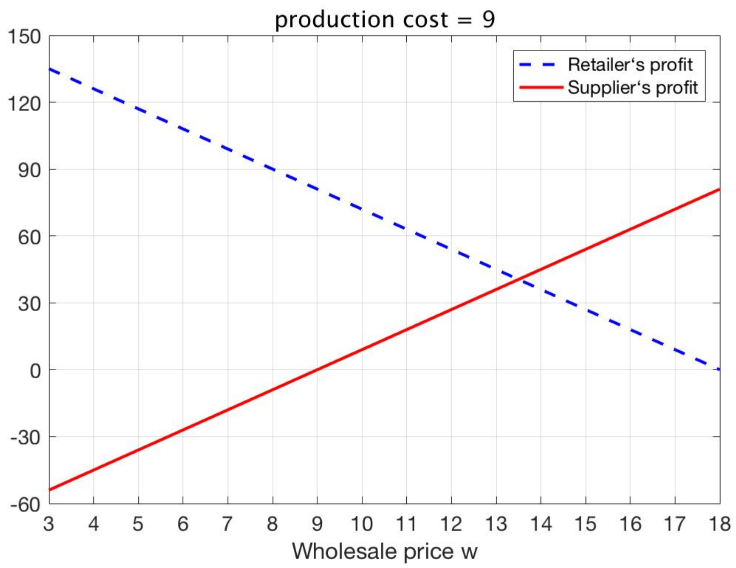

Figure D.9: Decision support when the supplier type is high-cost

D.6 Pooling: Screenshot for PM27 treatment

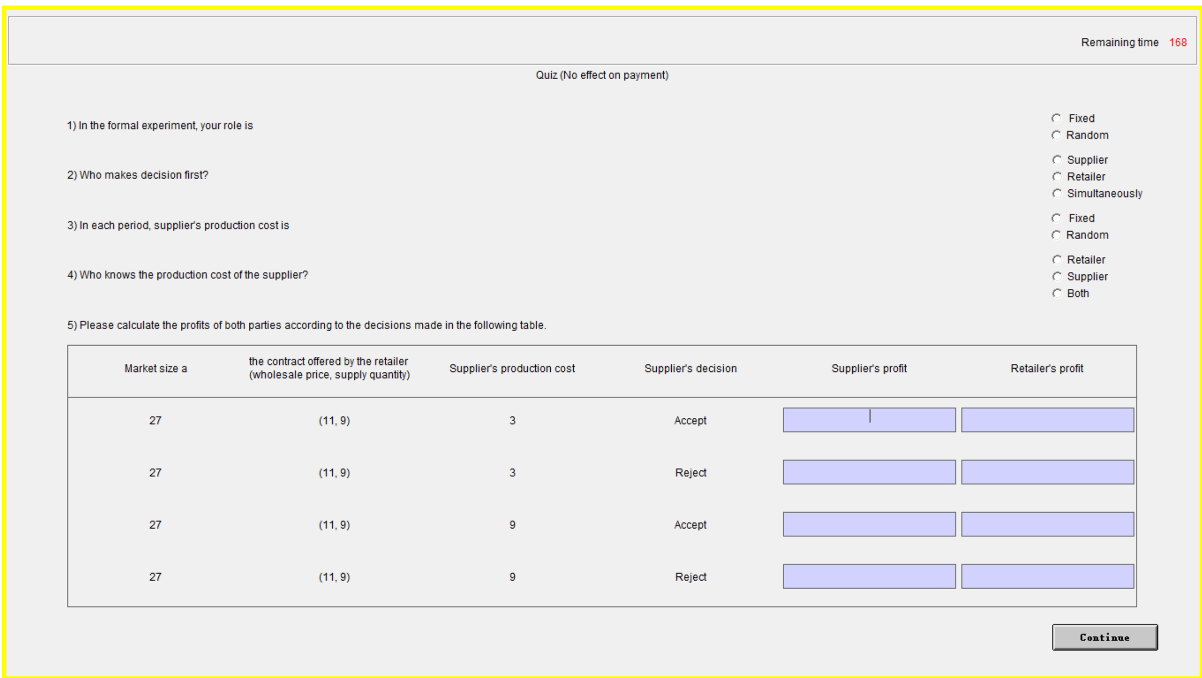

Figure D.10: The quiz screen

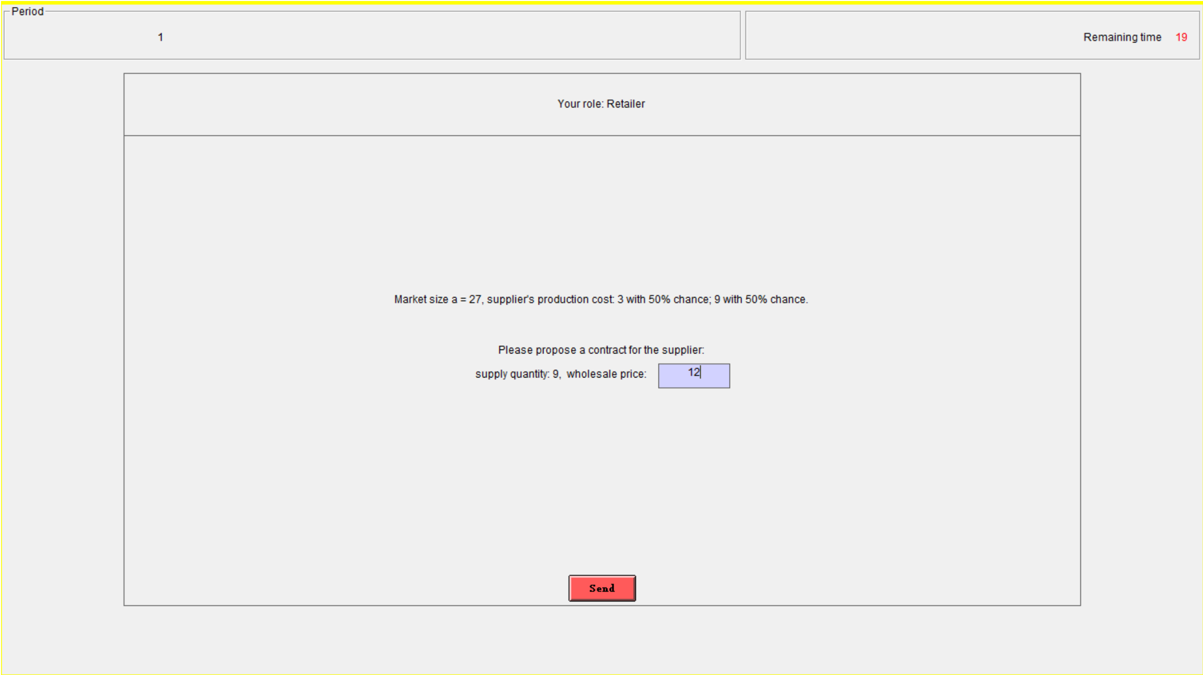

Figure D.11: The retailer's decision screen

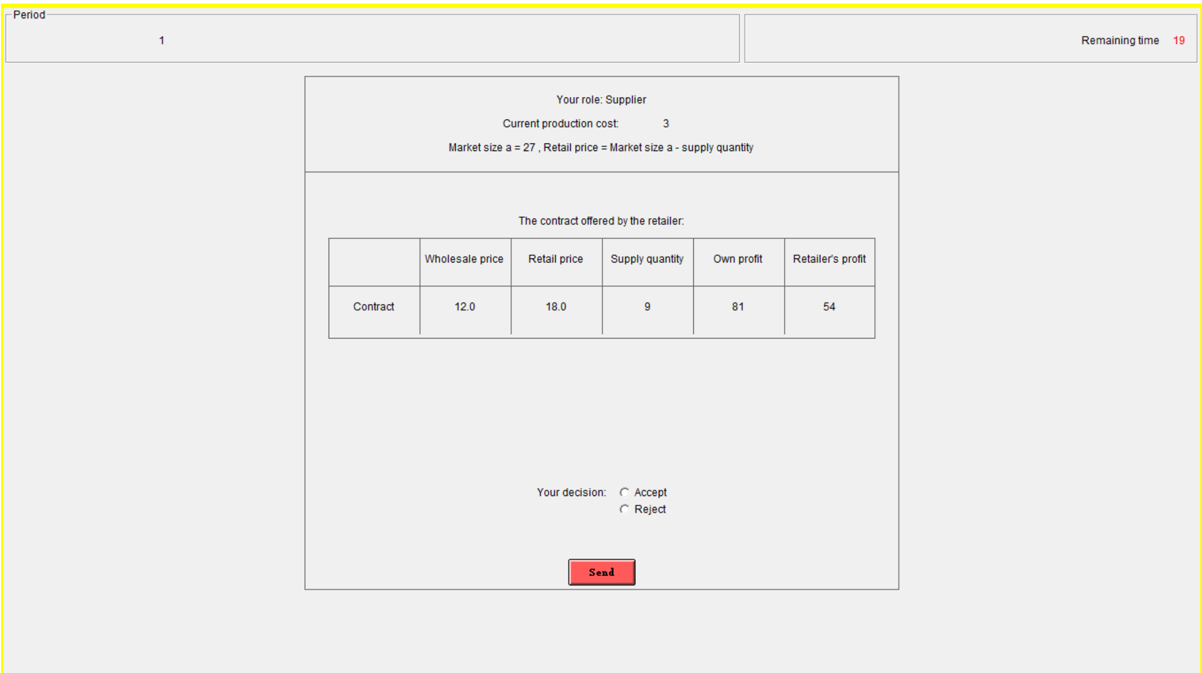

Figure D.12: The supplier's decision screen

Appendix E Theoretical Analysis of Inequity Aversion Model

E.1 Optimal Separating Mechanism with an Inequity Aversion Supplier

We assume that the supplier is concerned only with fairness from the perspective of disadvantageous inequality, for which the fair profit is the retailer's profit. When the supplier chooses contract d in a separating mechanism M, the retailer's profit is as follows:

$$\Pi_R(d|M) = q_d(a - q_d - w_d), \forall d \in \{l, h\}. \tag{C.3}$$

Following the previous discussion of fairness and the literature (e.g., see Cui et al., 2007), when a type-t supplier chooses contract d and concerns with fairness, his utility is defined by Equation (11).

By contrast, the retailer has a first-mover's advantage in the transaction because she dictates the contract terms. Consequently, the retailer typically earns a higher profit than the supplier; she is less concerned about disadvantage inequality aversion than the supplier. Therefore, it is proper to assume that the retailer is a profit maximizer.

Consequently, even with a fairness-concerned supplier, the retailer's objective remains her expected profit in Equation (1). But the IC and IR constraints, which now depend on the supplier's fairness parameter α, are based on his utility function as follows:

$$U_S^t(d = t|M, \alpha) \geq U_S^t(d \neq t|M, \alpha), \ \forall t, d \in \{l, h\}, \tag{C.4}$$

$$U_S^t(d = t|M, \alpha) \geq 0, \ \forall t \in \{l, h\}. \tag{C.5}$$

Equation (C.4) is the behavioral IC constraint, which ensures that each supplier type prefers the contract corresponding to his type. The behavioral IC constraint screens and separates the supplier's private production cost information. Equation (C.5) is the behavioral IR constraint, which ensures that each type of the supplier earns nonnegative utility and participates in the transaction.

When the supplier has fairness concerns, the retailer's separating mechanism design problem is specified by Equations (1)-(2) and (C.3)-(C.5). We solve this problem with fairness concern parameter α by studying different cases. These cases are determined by comparing the supplier's profit with that of the retailer, as the relative profit decides the functional forms of the supplier's utility. We obtain the closed-form solution.

Proposition 5 *If $a \geq \frac{c_h - vc_l}{1-v}$, there exists $\alpha' = \frac{a-c_h}{4(c_h-c_l)} + \frac{v}{4(1-v)} - \frac{1}{2}$ such that the retailer's optimal mechanism T^* is as follows. For $\alpha \leq \alpha'$*

$$\begin{aligned} q_l^* &= q_l^{FB}, w_l^* = \frac{\alpha(a - q_l^*)q_l^* + (1+\alpha)c_l q_l^* + (1+\alpha)(c_h - c_l)q_h^*}{(1+2\alpha)q_l^*}, \\ q_h^* &= \frac{a - c_h - \frac{v}{1-v}(c_h - c_l)}{2}, w_h^* = \frac{\alpha(a - q_h^*) + (1+\alpha)c_h}{(1+2\alpha)}; \end{aligned} \tag{C.6}$$

For $\alpha > \alpha'$,

$$q_l^* = q_l^{FB}, w_l^* = \frac{\alpha(a-q_l^*)q_l^* + (1+\alpha)c_l q_l^* + ((1+\alpha)(c_h-c_l) + \frac{\alpha(a-q_h-(2+2\alpha)c_h+(1+2\alpha)c_l)}{(1+2\alpha)})q_h^*}{(1+2\alpha)q_l^*},$$

$$q_h^* = \frac{a - c_h - \frac{v(1+2\alpha)}{(1+2\alpha)(1-v+\alpha-v\alpha)-v\alpha}(c_h-c_l)}{2}, w_h^* = \frac{\alpha(a-q_h^*)+(1+\alpha)c_h}{(1+2\alpha)}. \tag{C.7}$$

If $a < \frac{c_h - vc_l}{1-v}$, $q_l^* = q_l^{FB}, w_l^* = (\alpha a + (2+3\alpha)c_l)/[2(1+2\alpha)]; q_h^* = 0, w_h^* = 0.$

The market-size conditions on a carry similar implications to those in Proposition 1. These conditions are not affected by the fairness concern parameter α, however the profit allocation and channel efficiency are affected by it. The fairness threshold α' increases in a and v. When $\alpha \leq \alpha'$ (i.e., the supplier has mild fairness concerns), the optimal contract in Equation (C.6) suggests that the order quantity is the same as the second-best quantity and independent of the fairness parameter α. This implies that the total supply chain profit is independent of the fairness parameter α because the supply chain profit is determined by the order quantity only. However, the optimal wholesale prices increase with α; consequently, with a higher fairness concern parameter α, a larger share of channel profit is allocated to the supplier. Note that if $\alpha = 0$, this contract reduces to the second-best contract. When $\alpha > \alpha'$, according to Equation (C.7), the low-type order quantity q_l^* remains independent of α; the high-type order quantity q_h^* increases in α, even though it does not exceed the first-best solution q_h^{FB}. In this case, the supply chain profit increases with the quantity, and hence increases with α. In consideration of all cases, the channel profit weakly increases with the fairness parameter.

Proof of Proposition 5: When the market size is $a < \frac{c_h - vc_l}{1-v}$, the profit margin is so low that the retailer cuts off the high cost supplier, the optimal contract is same to optimal pooling contract under cutoff condition, i.e., $q_l^* = q_l^{FB}, w_l^* = (\alpha a+(2+3\alpha)c_l)/[2(1+2\alpha)]; q_h^* = 0, w_h^* = 0.$.

When the market size is $a \geq \frac{c_h - vc_l}{1-v}$, there exists optimal separating mechanism satisfying the incentive compatibility and individual rationality constraints. Our approach differs from standard mechanism design because the incorporation of fairness utility results in non-smooth functions in the constraints of incentive compatibility and individual rationality. Hence, we proceed with different cases of the fairness parameter.

First, we consider $0 < \alpha \leq \alpha'$. To solve the problem, we have to deal with the separating function in the supplier's utility Equation (11). To facilitate the discussion of the separating constraints, let $G^t(\tilde{t}|T) = \Pi_R(\tilde{t}|T) - \Pi_S^t(\tilde{t}|T)$ be the payoff difference between the retailer and a type-t supplier, who chooses a contract $\tilde{t}$ contract, $t, \tilde{t} \in \{l, h\}$. As $c_h > c_l$, $G^h(l|T) > G^l(l|T)$

and $G^h(h|T) > G^l(h|T)$.

When $G^t(\tilde{t}|T) > 0$, the disutility arises against the shortfall in financial profit. Therefore, it is crucial to compare each $G^t(\tilde{t}|T)$ with zero to determine the specific form of the supplier's utility function. This gives rise to in total nine cases. Nevertheless, the proofs in each of the cases are similar. So we will go through Case (1) in detail and other cases selectively.

Case (1): we first consider the following condition:

$$G^h(l|T) > G^l(l|T) > 0, G^h(h|T) > G^l(h|T) > 0. \tag{C.8}$$

The constraints (C.4) - (C.5) can be simplified as:

$$\begin{aligned}
&(IC1) \quad U_S^l(l|T,\alpha) \geq U_S^l(h|T,\alpha) = U_S^h(h|T,\alpha) + (1+\alpha)(c_h - c_l)q_h, \\
&(IC2) \quad U_S^h(h) \geq U_S^h(l) = U_S^l(l) - (1+\alpha)(c_h - c_l)q_l, \\
&(IR1) \quad U_S^l(l|T,\alpha) \geq 0, \\
&(IR2) \quad U_S^h(h|T,\alpha) \geq 0.
\end{aligned}$$

Similar to standard mechanism design, we impose the *monotonicity condition* $q_l \geq q_h$. This allows us to combine (IC1) and (IC2) above as $U_S^h(h|T,\alpha) + (1+\alpha)(c_h - c_l)q_h \leq U_S^l(l|T,\alpha) \leq U_S^h(h|T,\alpha) + (1+\alpha)(c_h - c_l)q_l$. At optimality, we must have (IR2) $U_S^h(h|T,\alpha) \geq 0$ and (IC1) $U_S^l(l|T,\alpha) \geq U_S^l(h|T,\alpha) = U_S^h(h|T,\alpha) + (1+\alpha)(c_h - c_l)q_h$ bind, because otherwise the retailer can extract higher rent from either type of supplier by pushing the boundary of the contracts, which goes against the definition of optimality. Therefore,

$$U_S^l(l|T,\alpha) = (1+\alpha)(c_h - c_l)q_h, U_S^h(h|T,\alpha) = 0.$$

This implies

$$w_l = \frac{\alpha(a-q_l)q_l + (1+\alpha)c_l q_l + (1+\alpha)(c_h - c_l)q_h}{(1+2\alpha)q_l}, w_h = \frac{\alpha(a-q_h) + (1+\alpha)c_h}{(1+2\alpha)}. \tag{C.9}$$

Now we can replace w_l and w_h in the retailer's profit function with equation (C.9),

$$\begin{aligned}
\Pi_R = v\big((a-q_l)q_l - &\frac{\alpha(a-q_l)q_l + (1+\alpha)c_l q_l + (1+\alpha)(c_h - c_l)q_h}{(1+2\alpha)}\big)+ \\
&(1-v)((a-q_h)q_h - \frac{\alpha(a-q_h) + (1+\alpha)c_h}{(1+2\alpha)}q_h\big).
\end{aligned}$$

This removes the transfer payments and makes the retailer's objective as a function solely on the quantities. One can show the concavity of Π_R by checking the negative definiteness of Hessian matrix. We now solve the optimal quantities from the first order condition

$$\begin{aligned}
\frac{d(\Pi_R)}{d(q_l)} &= v\frac{(1+\alpha)(a-2q_l-c_l)}{(1+2\alpha)} = 0, \\
\frac{d(\Pi_R)}{d(q_h)} &= -v\frac{(1+\alpha)(c_h-c_l)}{(1+2\alpha)} + (1-v)\frac{(1+\alpha)(a-2q_h-c_h)}{(1+2\alpha)} = 0.
\end{aligned}$$

The results are as follows:

$$q_l = \frac{a-c_l}{2}, q_h = \frac{a-c_h-\frac{v}{1-v}(c_h-c_l)}{2}, \tag{C.10}$$

which satisfies the monotonicity condition. Meanwhile, when $\alpha \leq \alpha'$, we verify that the condition in (C.8) is satisfied by the solutions in equations (C.9) and (C.10).

Therefore in Case (1), the retailer's optimal separating contract is given by equations (C.9) and (C.10).

Case (2): we consider the second condition as follows.

$$G^h(l|T) > 0 > G^l(l|T), G^h(h|T) > G^l(h|T) > 0.. \tag{C.11}$$

The IC and IR constraints (C.4) - (C.5) are rewritten as:

$$\begin{aligned}
&(IC1) \quad U_S^l(l|T,\alpha) \geq U_S^l(h|T,\alpha) = U_S^h(h|T,\alpha) + (1+\alpha)(c_h-c_l)q_h, \\
&(IC2) \quad U_S^h(h|T,\alpha) \geq U_S^h(l|T,\alpha) = U_S^l(l|T,\alpha) - (\alpha c_h q_l + (c_h-c_l)q_l + \alpha(a-q_l-2w_l)q_l), \\
&(IR1) \quad U_S^l(l|T,\alpha) \geq 0, \\
&(IR2) \quad U_S^h(h|T,\alpha) \geq 0.
\end{aligned}$$

Like in Case (1), we impose the monotonicity constraint

$$\alpha c_h q_l + (c_h-c_l)q_l + \alpha(a-q_l-2w_l)q_l \geq (1+\alpha)(c_h-c_l)q_h, \tag{C.12}$$

in order to integrate (IC1) and (IC2). Then the principal's optimality implies that (IR2) $U_S^h(h|T,\alpha) \geq 0$ binds, and so does (IC1). Therefore we obtain

$$U_S^l(l|T,\alpha) = (1+\alpha)(c_h-c_l)q_h,\ U_S^h(h|T,\alpha) = 0,$$

and solve for the wholesale prices,

$$w_l = \frac{c_l q_l + (1+\alpha)(c_h - c_l)q_h}{q_l}, w_h = \frac{\alpha(a - q_h) + (1+\alpha)c_h}{(1+2\alpha)}.$$

So, we rewrite the retailer's profit as a function of quantities only.

$$\Pi_R = v((a - q_l)q_l - (c_l q_l + (1+\alpha)(c_h - c_l)q_h)) + (1-v)((a - q_h)q_h - \frac{\alpha(a - q_h) + (1+\alpha)c_h}{(1+2\alpha)} q_h),$$

which is jointly concave in quantities. The first order conditions

$$\frac{d(\Pi_R)}{d(q_l)} = v(a - 2q_l - c_l) = 0,$$
$$\frac{d(\Pi_R)}{d(q_h)} = -v(1+\alpha)(c_h - c_l) + (1-v)\frac{(1+\alpha)(a - 2q_h - c_h)}{(1+2\alpha)} = 0.$$

The results are as follows:

$$q_l = \frac{a - c_l}{2}, q_h = \frac{a - c_h - \frac{v}{1-v}(1+2\alpha)(c_h - c_l)}{2}.$$

However in this case, the entry condition (C.11) and the monotonicity constraint (C.12) cannot be met simultaneously. That disqualifies the optimal solution in this case.

Case (3): we consider the condition,

$$0 > G^h(l|T) > G^l(l|T),\ G^h(h|T) > G^l(h|T) > 0.$$

Case (4): we consider the condition,

$$G^h(l|T) > G^l(l|T) > 0,\ 0 > G^h(h|T) > G^l(h|T).$$

Case (5): we consider the condition,

$$G^h(l|T) > 0 > G^l(l|T),\ 0 > G^h(h|T) > G^l(h|T).$$

Case (6): we consider the entry condition,

$$0 > G^h(l|T) > G^l(l|T),\ 0 > G^h(h|T) > G^l(h|T).$$

Case (7): we consider the condition,

$$G^h(l|T) > G^l(l|T) > 0,\ G^h(h|T) > 0 > G^l(h|T).$$

Case (8): we consider the condition,

$$G^h(l|T) > 0 > G^l(l|T),\ G^h(h|T) > 0 > G^l(h|T).$$

Case (9): we consider the condition,

$$0 > G^h(l|T) > G^l(l|T),\ G^h(h|T) > 0 > G^l(h|T).$$

Similar to Case (2), Cases (3) to (9) do not have a feasible optimal solution if $0 < \alpha \leq \alpha'$. Therefore, if the fairness parameter falls into $0 < \alpha \leq \alpha'$, the retailer's optimal separating contract is expressed by Equations (C.9) and (C.10) in Case (1).

Second, we consider the case of the fairness parameter $\alpha > \alpha'$. Under the strong disadvantage inequality aversion, the wholesale price of optimal contract design would increase with α. Similar to the above solution procedure, only Case (7) have an feasible optimal solution, Cases (1) - (6), (8) - (9) do not have feasible optimal solution, it means that the retailer's profit is less than supplier's profit occurs in where a type-l supplier chooses a contract h contract.

Case (7): we consider the condition,

$$G^h(l|T) > G^l(l|T) > 0,\ G^h(h|T) > 0 > G^l(h|T). \tag{C.13}$$

Similar to Case (1), we impose the monotonicity constraint,

$$\alpha c_h q_h + (c_h - c_l)q_h + \alpha(a - q_h - 2w_h)q_h \leq (1+\alpha)(c_h - c_l)q_l. \tag{C.14}$$

Then, the incentive compatible constraint for the low-cost type is binding. In this case we obtain an optimal solution

$$\begin{gathered} w_l = \frac{\alpha(a-q_l)q_l + (1+\alpha)c_l q_l + \alpha c_h q_h + (c_h - c_l)q_h + \alpha(a - q_h - 2w_h)q_h}{(1+2\alpha)q_l}, \\ w_h = \frac{\alpha(a-q_h) + (1+\alpha)c_h}{(1+2\alpha)}, \end{gathered} \tag{C.15}$$

and

$$q_l = \frac{a - c_l}{2}, q_h = \frac{a - \frac{(1+\alpha)(1+2\alpha-2v\alpha)c_h - v(1+2\alpha)c_l}{(1+2\alpha)(1-v+\alpha-v\alpha)-v\alpha}}{2}. \tag{C.16}$$

With a strong disadvantage inequality parameter $\alpha > \alpha'$, we verify the entry condition (C.13) and monotonicity condition (C.14) by substituting equations (C.15) and (C.16). Therefore in Case (7), the retailer's optimal separating contract is given by equations (C.15) and (C.16).

Summarizing all cases, we conclude the proof. ■

E.2 Optimal Pooling Mechanism with A Inequity Aversion Supplier

In the pooling mechanism, the retailer designs a pooling contract $M \equiv (w, q)$ to transact with all types of supplier. Given the pooling contract, the supplier might or might not accept this pooling contract depending on his utility gained from the transaction. Let d be the supplier's decision with 1 standing for acceptance and 0 for rejection. If a t-cost type supplier accepts the pooling contract, i.e., $d = 1$, then his utility is as follows:

$$U_S^t(d = 1|M, \alpha) = q(w - c_t) - \alpha[q(a - q - w) - q(w - c_t)]^+, \forall t \in \{l, h\}, \tag{C.17}$$

where the second term captures the supplier's disadvantageous fairness concerns. As rejection results in zero utility to the supplier— that is $U_S^t(d = 0|M, \alpha) = 0$ for all t, he will accept the pooling contract if and only if his utility is greater than or equal to zero.

The retailer obtains profit $q(a - q - w)$ if the supplier participates in the contract and earns no profit otherwise, regardless of the supplier's production cost. Hence, the retailer aims to maximize the expected profit as follows:

$$\max_{M \equiv \{(q,w)\}} \quad q(a - q - w) \ \mathrm{E}_t[\mathbb{1}(U_S^t(d = 1|M, \alpha) \geq 0)], \tag{C.18}$$

where $\mathbb{1}$ is the indicator function, that is, its value equals 1 if $U_S^t(d = 1|M, \alpha) \geq 0$ and 0 otherwise. Note that when $d = 0$, the retailer's profit is 0; thus, this case is excluded from the objective function. We solve the optimization problem for the optimal pooling mechanism by analyzing different cases, and obtain the closed-form solutions.

Proposition 6 *The retailer's optimal pooling contract is*

$$(q^*, w^*) = \begin{cases} (\frac{a-c_l}{2}, \frac{\alpha a+(2+3\alpha)c_l}{2(1+2\alpha)}), & \textit{if } a \leq \frac{c_h-\sqrt{v}c_l}{1-\sqrt{v}}; \\ (\frac{a-c_h}{2}, \frac{\alpha a+(2+3\alpha)c_h}{2(1+2\alpha)}), & \textit{otherwise.} \end{cases} \tag{C.19}$$

The retailer's profit decreases with the fairness parameter α, but the supplier's profit increases with it; the supply chain profit does not change with it.

This proposition implies that the fairness concern does not affect the supply chain profit, because it does not affect the optimal order quantity based on Equation (C.19). However, as the wholesale price increases with fairness concerns, the supplier's profit increases but the retailer's profit decreases with it.

Proof of Proposition 6: First, we derive the optimal pooling mechanism. Recall the retailer's problem of pooling mechanism design is defined by Equation (C.18). The supplier utility functions are

$$\begin{aligned} U_S^l(T|\alpha) &= (w-c_l)q - \alpha[(a-q-w)q-(w-c_l)q]^+ \\ &= \begin{cases} (1+\alpha)(w-c_l)q - \alpha(a-q-w)q, & \text{if } w < \frac{a-q+c_l}{2}, \\ (w-c_l)q, & \text{if } w \geq \frac{a-q+c_l}{2}, \end{cases} \\ U_S^h(T|\alpha) &= (w-c_h)q - \alpha[(a-q-w)q-(w-c_h)q]^+ \\ &= \begin{cases} (1+\alpha)(w-c_h)q - \alpha(a-q-w)q, & \text{if } w < \frac{a-q+c_h}{2}, \\ (w-c_h)q, & \text{if } w \geq \frac{a-q+c_h}{2}, \end{cases} \end{aligned}$$

where $c_h > c_l$, Thus we have

$$U_S^h(T|\alpha) - U_S^l(T|\alpha) = \begin{cases} -(1+\alpha)(c_h-c_l)q, & \text{if } w < \frac{a-q+c_l}{2}; \\ -\alpha q(a-q-w) + (1+\alpha)q(w-c_h) - q(w-c_l), & \text{if } \frac{a-q+c_l}{2} \leq w < \frac{a-q+c_h}{2}; \\ -(c_h-c_l)q, & \text{if } w \geq \frac{a-q+c_h}{2}. \end{cases}$$

It is easy to verify that $U_S^l(T|\alpha) > U_S^h(T|\alpha)$. Next we study both cases where (1) the retailer purchases from both types of suppliers, and (2) the high cost supplier is ruled out from the transaction. Then we compare the profits obtained from both cases to determine the retailer's optimal contract.

Case (1): since $U_S^l(T|\alpha) > U_S^h(T|\alpha)$, at optimum the Participation constraint for the high cost supplier will bind. Solving $U_S^h(T|\alpha) = 0$ allows us to express w in terms of q,

$$w = \begin{cases} \frac{\alpha(a-q)+(1+\alpha)c_h}{(1+2\alpha)}, & \text{if } w < \frac{a-q+c_h}{2}; \\ c_h, & \text{if } w \geq \frac{a-q+c_h}{2}. \end{cases} \tag{C.20}$$

Maximizing the retailer's profit $q(a-q-w)$ in consideration of Equation (C.20) produces the optimal order quantity as $\frac{a-c_h}{2}$, which satisfies $w < \frac{a-q+c_h}{2}$ in (C.20) given $a > c_h$. Thus, the retailer optimal pooling contract in Case (1) is as follows

$$\left(q^* = \frac{a-c_h}{2}, w^* = \frac{\alpha a + (2+3\alpha)c_h}{2(1+2\alpha)}\right), \quad \Pi_R = \frac{1+\alpha}{1+2\alpha}\frac{(a-c_h)^2}{4}. \tag{C.21}$$

Case (2): in this case, the high cost supplier is excluded from the trade, i.e. $U_S^h(T|\alpha) < 0$. Thus the retailer will fully exploit the low cost supplier by setting $U_S^l(T|\alpha) = 0$. This allows us to rewrite the wholesale price as a function of q,

$$w = \begin{cases} \frac{\alpha(a-q)+(1+\alpha)c_l}{(1+2\alpha)}, & \text{if } w < \frac{a-q+c_l}{2}; \\ c_l, & \text{if } w \geq \frac{a-q+c_l}{2}. \end{cases} \tag{C.22}$$

Maximizing the retailer's profit considering (C.22) yields

$$\left(q^* = \frac{a-c_l}{2}, w^* = \frac{\alpha a + (2+3\alpha)c_l}{2(1+2\alpha)}\right), \quad \Pi_R = \frac{1+\alpha}{1+2\alpha}\frac{(a-c_l)^2}{4}v. \tag{C.23}$$

The optimal solution satisfies the condition (C.22). As the optimal retailer profit is lower in Case (1) than in Case (2) if $v \geq (\frac{a-c_h}{a-c_h})^2$, i.e, $a \leq \frac{c_h - \sqrt{v}c_l}{1-\sqrt{v}}$, the retailer's optimal pooling contract is expressed by Equation (C.19).

Second, we prove the impact of fairness on the profits of the supply chain partners. As the optimal quantities in Equations (C.21) and (C.23) do not change, the supply chain profit does not change with fairness parameter. By the same equations, the retailer's profit decreases with fairness parameter. Consequently, the supplier's profit increases with it. ■