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Strategic risk in contract design

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Abstract:

Supply chains facing asymmetric information can either operate in a cooperative mode with information and benefit sharing or can choose a non-cooperative form of interaction and align their incentives via screening contracts. In the cooperative mode, supply chain efficiency can be achieved, but high levels of trust and trustworthiness are required. In the non-cooperative mode, the contract mechanism guarantees a second best supply chain performance, but only if all parties choose their equilibrium strategies without trembles. Experimental evidence, however, shows that both operating modes often fail due to strategic risk. Cooperation is disrupted by deceptive signals and the lack of trust, whereas non-cooperative strategies suffer from persistent out-of-equilibrium behavior. We present an experiment on supply chain interaction with reduced strategic risk in both operating modes. We find that supply chain performance can reach a second-best level in either operating mode, if strategic risk is sufficiently reduced. We present two means to reduce strategic risk. First, a punishment mechanism leads to a better matching of trust and trustworthiness and supports the cooperative operating mode. Second, an enforcement of self-selection supports the non-cooperative equilibrium by increasing the attractiveness of screening contracts. We conclude that supply chain managers should seek to reduce the variability of the supply chain partners' behavior no matter what operating mode is considered.

Keywords: Behavioral operations management, contracting, asymmetric information, punishment

1 Introduction

Supply chains facing asymmetrically distributed information basically have two opposite means executing their operations. On the one hand, they can choose to operate in a cooperative mode in which private information is communicated truthfully and the benefits are shared. On the other hand, they can choose a non-cooperative form of interaction and align their incentives via complex contract schemes without communicating private information. In the cooperative mode, supply chain efficiency can be achieved, but high levels of trust and trustworthiness are required. In the non-cooperative mode, the contract mechanism guarantees a second best supply chain performance, but only if all parties choose their equilibrium strategies without trembles. However, basically all of the experimental literature on behavior in supply chains shows that neither a perfectly cooperative nor a perfectly non-cooperative outcome can be achieved. Cooperation is frequently shown to be disrupted by deceptive signals or the lack of trust in truthful signals (see Özer et al. 2011 and Inderfurth et al. 2012). The non-cooperative equilibrium and profit maximization often fail due to some persistent degree of out-of-equilibrium behavior that may be due to misperceptions, bounded rationality, or social preferences (see Schweitzer and Cachon 2000, Lim and Ho 200, Bolton and Katok 2008, Katok and Wu 2009, Kremer et al. 2010 and Becker-Peth et al. 2012). Note that the problem that both operating modes face is due to strategic risk resulting from behavioral variance. [1]

In this paper we present an experimental study in which we compare a supply chain interaction with strategic risk to two variations with reduced strategic risk. In one of these settings, we substantially reduce the suppliers' strategic risk of cooperation, while in the other the strategic risk in the non-cooperative operating mode is eliminated. Varying the strategic risk in this way requires a controlled laboratory experiment, in which the player action sets can be adapted as necessary. Furthermore, our laboratory experiments allow us to perfectly control the structure and the distribution of private information.

We consider a simple serial supply chain in which the buyer (she) holds private information. The supplier (he) offers either simple wholesale price contracts (first best under full information) or screening contracts (second best under asymmetric information). While a number of studies have analyzed the effectiveness of either wholesale price contracts or of screening contracts in supply chains with asymmetric information (see Özer et al. 2011 and Inderfurth et al. 2012), this study is the first that examines the endogenous choice of these contract type. This endogenous choice of the contract type allows us to identify the role of strategic risk in the different operational modes. The

[1] We define strategic risk as the risk that the supplier faces either concerning the consistency of the buyers' signal and choice behavior or concerning the buyers adherence to payoff maximizing behavior.

implications for our research provide valuable insights for supply chain managers concerning contract type decisions.

Knowing that the predictability of the buyer's behavior is a key driver when suppliers choose between contract types, we systematically investigate how the reduction of each type of strategic risk affects the subtle interactions between contract offers, information sharing, and contract choices. First, we provide the supplier with a non-contractible punishment mechanism that enables him to punish apparently uncooperative behavior and, thus, to substantially reduce the incentives for deception.[2] Second, we enforce the buyers' self-selection once a screening contract was offered by the supplier. This enforcement eliminates the strategic risk that the buyer destroys supplier's payoffs by contract choices that entail a small loss for the buyer but a substantial loss for the supplier.

The surprising finding is that either contract type can coordinate the supply chain on a second-best level, if strategic risk is sufficiently reduced. With the suppliers' punishment mechanism, buyers' send significantly more truthful signals and the number of profit maximizing contract choices increases significantly. The enforcement of self-selection leads to a significantly greater number of screening contract offers and a significant increase in supply chain performances. Hence, our experimental results support our conjecture that reducing strategic risk improves supply chain performance no matter whether the cooperative or the non-cooperative mode of operation is established.

Our results are highly relevant for the supply chain coordination and contracting literature. Obviously, supply chain managers should seek to reduce the variability and increase the predictability of the supply chain partners' behavior. Non-contractible punishment options – as are often observed in hostile deviations from "business as usual" between supply chain partners – can increase the trustworthiness of communication and can boost performance of supply chains operating under simple wholesale-price contracts. However, in business interactions lacking punishment options, tailoring contracts to signals may cause huge losses. In these cases, suppliers should offer screening contracts, but set the incentives for the buyers high enough to guarantee the desired self-selection and to reduce the strategic risk of buyers' choices deviating from profit maximization.

[2] Apparently uncooperative behavior is defined as an inconsistency between the signaled cost and the selected contract option or if the high cost signal is send significantly too often.

2 Literature review

The present study is most closely related to game-theoretic and behavioral work in the field of supply chain coordination via contracts. We review both game-theoretic and behavioral work on contracting under full and asymmetric information.

Game theoretic models on contracting in supply chains: In non-cooperative supply chains, there is a large body of work showing that the less informed supply chain party maximizes his expected profit by offering a sophisticated menu of contracts, i.e., screening contract (see, for example, Corbett et al. 2004, and the references therein). These screening contracts align the incentives of the supply chain members in a way that the holder of the private information reveals her information by the contract choice. Nonetheless, the outcome is inefficient from a supply chain perspective. In contrast, cooperative supply chains may engage in truthful information sharing and trusting information processing. In such a cooperative operating mode, simple wholesale price contracts are tailored to the truthfully shared information, resulting in supply chain efficient outcomes (see e.g. Goyal 1977). This cooperative view stresses that communication (e.g. Cachon and Fisher 2000) and trust (Moore 1998 and Zaheer et al. 1998) are necessary for successful supply chain management.

Behavioral studies in full information context: There are numerous studies investigating supply chains that face uncertain demand (e.g. in the newsvendor context) and operate under simple wholesale price contracts. In most of these studies, the wholesale price is an exogenous parameter and is used as a focus variable for identifying decision biases for high- and low profit situations (see, e.g., Schweitzer and Cachon 2000, Bolton and Katok 2008, Katok and Wu 2009, Kremer et al. 2010). In contrast, Keser and Paleologo (2004) investigate the supply chain behavior in the newsvendor context, in case the wholesale price is not exogenously determined, but set by the supplier who has full information regarding the distribution of stochastic demand. Becker-Peth et al. (2012) show that wholesale prices in combination with a buy-back component (buy-back contract) can be systematically manipulated in order to account for decision biases of the buyer. Lim and Ho (2007) experimentally investigate the effect of contract design on the inefficiencies resulting from double marginalization in a deterministic demand setting. Their primary focus lies on how the number of price blocks in a quantity discount scheme under full information impacts the supply chain performance. They also investigate the simple wholesale price contract as a special case with one price-block only.

Behavioral studies in asymmetric information context: Inderfurth et al. (2012) study the impact of information sharing on the supplier’s screening contract offers in a dyadic supplier-buyer supply chain. They do not allow for an endogenous choice of the contract type, but allow suppliers to adjust their screening contract to their subjective probabilities after receiving the buyers' signals. In contrast to that study, we do not allow the supplier to condition the screening contract on the buyer's signal.[3] In addition, the clear separation between wholesale price contracts and screening contracts contrasts two characteristics: while screening contracts allow at least an ex-post assessment on the buyers' consistency, wholesale price contracts do not provide such information. Thus, once the supplier decides to cooperate and offers a wholesale price contract, he has no means of assessing whether the buyer's signal is truthful and the cooperation is bilateral.

Kalkanci et al. (2011) provide an experimental analysis of the impact of contract complexity under asymmetric demand information in a dyadic supplier-buyer supply chain. They analyze how the supplier sets the price-breaks for an all-unit quantity discount. Such a quantity discount creates a non-linear incentive scheme and serves as an instrument to price discriminate between buyers, like a screening contract does. In contrast to our experimental setup, however, buyers' decisions are automated, because the supplier-buyer interaction is not in the focus of their study. Kalkanci et al. (2011) show that suppliers benefit from non-linear pricing schemes. However, the benefits diminish if more than one price-break is set.

Özer et al. (2011) investigate the interaction of supply chain members given a simple wholesale price contract and asymmetric information. They find that there is partial truth-telling and trust although theory predicts that all communication accounts to no more than cheap talk. In contrast to our experimental setup, the supplier in Özer et al. (2011) was limited to only offering wholesale price contracts, while we allow an endogenous choice of the contract type.

3 Outline of the model

We briefly review the strategic lot sizing model (see Voigt and Inderfurth 2011 and Voigt 2011), as it serves as the game theoretic benchmark for all treatments. We assume that the buyer's demand is constant over time and, without loss of generality, it is standardized to one unit per period. Hence, unit profits equal period profits. The supplier incurs fixed cost per period and therefore prefers high order sizes. In contrast, the buyer prefers low order sizes, because she incurs holding cost h for every

[3] In Inderfurth et al.'s (2012) study, there are three buyer types ($n=3$) with a respective a priori distribution. The suppliers could change the a priori distribution in steps of 0.1 (this gives $n \cdot (n+1) / 2 = 66$ combinations) in order to react to shared information. These adjusted probabilities were used to calculate the respective screening contract. In the present study, however, the supplier is restricted to offer only one screening contract that is based on the a priori probabilities. Alternatively, the supplier in the present study can offer a simple wholesale price contract that may be conditioned on the shared information.

unit stored per period. The holding cost may vary from period to period depending on a number of parameters (e.g., cost of capital, handling and storage cost, etc.). Instead of modeling the holding cost explicitly, we assume that the holding cost is a random variable. The distribution of the holding cost is known to both parties, but the actual realization is only known to the buyer.

The model captures a basic conflict of interest in supply chain management. The buyer prefers low order sizes, while the supplier prefers high order sizes (see Corbett and de Groote 2000). We assume that the buyer negotiates the terms of delivery and asks the supplier to ship in smaller lots. The supplier, in turn, tries to induce a higher order size to lower his average cost per unit. The supplier has to take into account the buyer's outside option, i.e., sourcing from an alternative supplier at cost *R*. The supplier and the buyer have fixed revenues of Y_s and Y_b , respectively.

Full information and simple wholesale price contracts: Under full information, the supplier has knowledge of the buyer's realization of holding cost (*h*). Hence, the supplier can offer the buyer an optimal compensation, *Z*, to promote a higher order size. This leads to the contract $\langle q, Z \rangle$ as an outcome of the following optimization problem:

$$\text{Problem FI:} \quad \max \pi_s = Y_s - \frac{f}{q} - Z$$

$$s.t.\ \pi_b = Y_b - \frac{h}{2} \cdot q + Z \geq R.$$

Since demand is standardized to one unit per period, π_s and π_b, denote the supplier's and the buyer's unit profit margins, respectively. The supplier's objective function maximizes his unit profit. The compensation, Z, is required to satisfy the buyer's participation constraint, ensuring that the buyer's profits are not smaller than in her outside option. Z can be interpreted as a discount on the simple wholesale price. The contract parameters $\langle q, Z \rangle$ not only optimize the supplier's profit, but also the overall supply chain performance.

Asymmetric information and screening contracts: Under asymmetric information, the holding cost realization is only known to the buyer, but not to the supplier. The supplier only has the information on the probability distribution $p_i, i = 1,...,n$ over possible values of the buyer's holding cost $h_i, i = 1,...,n; h_1 > ... > h_n$.

The basic screening idea is that the profit maximizing buyer reveals her private information with her contract choice. Let $\pi_{b,i}\left(q_j\right) = Y_b - h_i / 2 \cdot q_j + Z_j$ denote the unit profit margin of the buyer facing holding cost h_i, and choosing the contract $\langle q_j, Z_j \rangle$. Information revelation is ensured by the incentive constraint $\pi_{b,i}(q_i) \geq \pi_{b,i}(q_j), \forall i \neq j; i, j = 1,...,n.$. The buyer facing holding costs h_i will always choose the offer $\langle q_i, Z_i \rangle$ as any other contract $\langle q_j, Z_j \rangle$ will result in a lower unit profit margin. The participation constraint $\pi_{b,i}(q_i) \geq R, \forall i = 1,...,n$ ensures that the buyer will not benefit from choosing the alternative supplier.

Let $\pi_{s,j} = Y_s - f / q_j - Z_j$ denote the supplier's unit profit margin if the buyer chooses the contract q_j. Due to the incentive constraint the supplier knows that the buyer will choose the contract $\langle q_i, Z_i \rangle$ with probability p_i. Hence, the supplier can maximize his expected unit profit margin with the following optimization problem:

$$\text{Problem AI:} \qquad \max E[\pi_s] = \sum\nolimits_{i=1}^{n} p_i \cdot \pi_{s,i}$$
$$s.t. \quad \pi_{b,i}(q_i) \geq \pi_{b,i}(q_j) \qquad , \forall i \neq j; i, j = 1,...,n$$
$$\pi_{b,i}(q_i) \geq R \qquad , \forall i = 1,...,n$$

The following notation is used to refer to the supplier's optimal menu of contracts (screening contract) $A = (A_i \mid i = 1,...,n)$ where $A_i = \langle q_i^{AI}, Z_i^{AI} \rangle, \forall i = 1,...,n.$ Furthermore, $F_i = \langle q_i^{FI}, Z_i^{FI} \rangle, \forall i = 1,...,n$ denotes the supply chain's optimal contract when the buyer faces holding costs h_i. We refer to Voigt and Inderfurth (2011) for a derivation of the optimal menu of contracts, and a thorough discussion of its properties. One import feature of the screening contracts is that both order sizes and compensations are increasing with decreasing holding cost levels, i.e., $q_i^{AI} \geq q_{i+1}^{AI}$ and $Z_i \geq Z_{i+1}, \forall i = 1,...,n$. The menu of contracts can, therefore, be interpreted as a quantity discount that is inefficient, since all order sizes except q_1^{AI} are downward distorted. If the supplier would have full information, he could offer q_i^{FI} instead of letting the buyer self-select the distorted order size q_i^{AI} and, thus, enhance the supply chain performance. A numerical example follows in the next section on the basis of the parameters we use in our experiment.

4 Experimental design, implementation, and research hypotheses

The experimental software was implemented with the toolbox z-Tree (Fischbacher, 2007). Participants were recruited online using ORSEE (Greiner 2004) and randomly distributed over the treatments. Upon arrival, each participant received written instructions that were read out aloud (see appendix). All remaining questions were answered privately in the subject's cubical at the experimental laboratory. Subjects were paid according to their performance in the experiment. The average earnings were 9.7 EUR (Max: 18.5 EUR / Min: 7 EUR). Sessions lasted no longer than 90 minutes. The experiment consisted of three treatments with a total of 48 subjects. Each subject participated in only one treatment (between subjects design).

4.1 Experimental design – Baseline

The baseline treatment considers the simplest form a supply chain consisting of one buyer and one supplier, i.e. a serial supply chain. We have 16 subjects in this treatment, 8 buyers and 8 suppliers. The matching of buyers and suppliers remains unchanged over time. All subjects play 30 rounds.

Parameters: There are three holding cost realizations $h_L = 1, h_M = 5$ and $h_H = 9$ that occur with the corresponding a priori probabilities $p_L = 0.4, p_M = 0.3$ and $p_H = 0.3$. The holding costs are drawn independently in every round according to the distribution function which is common knowledge. The supplier's total fixed cost is $f = 800$ and the buyer's unit cost of sourcing from the alternative supplier is $R = 2$. The buyer's revenue is fixed at $Y_b = 5$ per round. The supplier's revenue is fixed at $Y_s = 155$ per round.

Decision sequence:

(t=1): At the beginning of each round, the buyer sends a signal *S* that may communicate her holding cost to the supplier, where $S \in \left[S_L = h_L, S_M = h_M, S_H = h_H, S_{No} \doteq No\ Signal\right]$.

(t=2): After the buyer sends her signal, the supplier offers a contract. Contract offers are restricted to (i) $F_L = \left\langle q_L^{FI}, Z_L^{FI} \right\rangle$, (ii) $F_M = \left\langle q_M^{FI}, Z_M^{FI} \right\rangle$, (iii) $F_H = \left\langle q_H^{FI}, Z_H^{FI} \right\rangle$ and (iv) $A = \left(A_L, A_M, A_H\right)$ where $A_i = \left\langle q_i^{AI}, Z_i^{AI} \right\rangle$, $i \in L, M, H$. Thus, the supplier may either offer one of the three fixed wholesale price contracts F_i (i.e. one of the contracts that are optimal under full information, see Problem FI) or the screening contract *A* that is optimal (but second best) under asymmetric information (see Problem AI).

(t=3): If the supplier offers a fixed wholesale price contract in t=2, then the buyer can either accept or reject this offer. If the supplier offers the screening contract A in t=2, the buyer chooses A_L, A_M, A_H, or rejection. If the buyer rejects the offer, she sources from the alternative supplier at the cost R, the supplier realizes zero profits, and the next round starts.

(t=4): If the buyer did not reject, the supplier has the option to withdraw the offer. If the supplier withdraws, the profits of both the buyer and the supplier are equal to zero. If the supplier does not withdraw, he has the option to give the buyer a reward. The maximum size of the reward is limited to 60 per round. The reward allows the supplier to share the benefits of coordinated supply chain actions (i.e. share the benefits of increasing the order size from q_i^{AI} to q_i^{FI} with the buyer).

(t=5): A new holding cost parameter is drawn in every round. Thus, the supplier can neither infer the buyer's holding cost parameter of the next round through the buyer's signal nor through the buyer's action in the current period.

Table 1 depicts the parameter values and the resulting payoffs for our experiment. For example, if the buyer has low holding costs of h_L and accepts the contract F_M, she realizes a profit of $\pi_b = 38.88$ (net of the additional reward in t=4) and the supplier realizes $\pi_s = 67.46$ (net of the additional reward in t=4).

Table 1: Contracts and corresponding profits

		Order size: q_i	Side-payment: Z_i	profit supplier: π_s	profit buyer: π_b		
					h_L	h_M	h_H
	F_L	40.00	18.10	116.90	3.10	-76.90	-156.90
	F_M	17.89	42.82	67.46	38.88	3.10	-32.68
	F_H	13.33	58.10	36.90	56.43	29.77	3.10
Screening contract: ***A***	A_L	40.00	61.87	73.13	46.87	-33.13	-113.13
	A_M	12.44	47.99	42.72	46.77	21.88	-3.00
	A_H	9.34	40.14	29.23	40.47	21.78	3.10

Note that the participation constraint makes the buyer of type *i* (with holding cost h_i) indifferent between her outside option and the wholesale price contract F_i. To avoid indifference in the experiment, we add 0.1 to the buyer's profit when accepting the wholesale price contract F_i. Similarly, we break the tie between accepting the self-selection option of the screening contract for the true holding cost versus the next higher holding cost, by adding 0.1 to the true option. For example, if a buyer with h_M chooses the contract A_H, she earns 0.1 less than she earns by choosing the self-selection option A_M. In this case, we refer to A_H as the *indifference contract* and to A_M as the *self-selection contract*.

4.2 Treatment variables and research hypotheses

4.2.1 Game-theoretic benchmark

The game theoretic equilibrium is the same for all three treatments.

Hypothesis 1a: *Communication is uninformative.*

Since the preferences in the underlying game are perfectly opposed (i.e., the buyer always tries to convince the supplier that she has high holding cost), and since private information is independently distributed between periods, credible information sharing cannot take place in the non-cooperative equilibrium (see Crawford 1998 and Fudenberg et al. 1990).

Hypothesis 1b: *Suppliers ignore signals.*

As the fully rational supplier anticipates that all signals are uninformative (see Hypothesis 1a), we will not observe any correlation between the buyer's signals and the supplier's behavior.

Hypothesis 1c: *Suppliers only offer screening contracts.*

Without informative signals (see Hypothesis 1a), the screening contract maximizes the supplier's expected profits. Hence, we will only observe screening contracts.

Hypothesis 1d: *Buyers choose the self-selection option of the screening contract.*

The optimal choice of profit maximizing buyers, who are offered a screening contract (see Hypothesis 1c), is the self-selection option.

Hypothesis 1e: *Punishments and rewards are not observed.*

Since suppliers offer screening contracts and buyers self-select into their profit maximizing option (Hypotheses 1a-1d), we only observe equilibrium play, in which – by definition of a game-theoretic equilibrium – payoffs cannot be increased using the reward and punishment options (see, e.g., Fudenberg and Tirole 1995).

4.2.2 *Punishment treatment*

In the punishment treatment, the supplier has the option to punish the buyer by arbitrarily reducing her profits in t=4. Punishment, however, is costly. Every unit of punishment costs 0.2. Hence, the only difference to the baseline treatment is that the supplier here is empowered with a smooth and credible mechanism to punish the buyer, in addition to the coarse, all-or-nothing punishment that is available in both treatments by withdrawing the contract. The maximum punishment per round is limited to 60. A total of 16 subjects participated in the punishment treatment, 8 suppliers and 8 buyers.

Hypothesis 2a: *The frequency of truthful signals is higher in the punishment than in the baseline treatment.*

We hypothesize that buyers send truthful signals more often in the punishment treatment compared to the baseline, because they fear to be punished more frequently for *apparently uncooperative* behavior when suppliers have a smooth and credible punishment option. We define buyers' behavior as apparently uncooperative if the high cost signal is send significantly more often as statistically expected or if there is an inconsistency between the signaled cost and the selected contract option.

Hypothesis 2b**:** *The supplier offers the wholesale price contract tailored to the signal more frequently (i.e., he shows a higher level of trust) in the punishment treatment than in the baseline treatment.*

We expect the supplier to show a higher level of trust in the punishment treatment, in which the threat of punishment enhances truthful and consistent signals. A higher level of trust is characterized by a higher frequency of simple wholesale price contracts that are tailored to the respective signal.

Hypothesis 2c**:** *The supply chain performance is higher in the punishment treatment than in the baseline treatment.*

We have two reasons to believe that the punishment option may enhance supply chain performance. First, we expect punishment to increase truthful signaling (2a) and trust (2b). Thus, supply chain actions are better coordinated, because simple wholesale price contracts fit to the actual holding cost level. Second, we expect the punishment option to decrease the frequency of inconsistent indifference contract choices.

4.2.3 *Enforced self-selection treatment*

The only difference between the baseline treatment and this treatment is that the buyers in this treatment are forced to choose the profit-maximizing self-selection contract in t=3 whenever offered a menu of contracts. In particular, indifference contract choices are not possible which means that the self-selection mechanism of the screening contract works perfectly, substantially reducing suppliers' strategic risk. A total of 16 subjects participated in this treatment, 8 being suppliers and 8 being buyers.

Hypothesis 3: *Screening contracts are offered more frequently in the enforced self-selection treatment than in the baseline treatment.*

Consider a buyer giving a deceptive signal, e.g., she signals high holding costs although he only incurs medium holding costs. In case the supplier offers the menu of contracts, the buyer can easily pretend to be honest by choosing the high cost contract that fits to her signal (but not to her holding cost realization). If the supplier anticipates that the buyer may choose an indifference contract in order to cover up her deceptive signal, then offering a simple wholesale price contract tailored to the signal might be profit maximizing. In these cases, offering a simple wholesale contract does not result from trust in the signal, but from mistrust towards the buyers' self-selection behavior. Thus, eliminating the strategic risk of not choosing the self-selection contract allows us to disentangle trust from strategic risk avoidance in this treatment.

5 Experimental results

We present the results of the experiments in the sequence of the decisions taken, i.e., the signal, the contract offers, the contract choices, and the cooperation facilitating role of punishments and rewards. We conclude the analysis with analyzing the impact of observed behavior on supply chain performance.

5.1 Buyers' signaling behavior

Table 2 presents the frequencies of truthful signals across treatments. The data clearly show that on average signals are informative, since observed frequencies of truthful signals are well above the a-priori probability except for the case of the low cost signal in the enforced self-selection treatment. It seems, however, that low and medium cost signals are on average more informative than high costs signals. While we observe that truthfulness is higher in the two treatments than in the baseline treatment, we only find significant differences comparing the punishment treatment to the baseline and the enforced self-selection treatment (both MWU, $\alpha<0.05$, two-sided) which supports hypothesis 2a.[4] Hence, hypothesis 1a (communication is uninformative) is not supported, since signals convey information to some extent in all treatments, but even more so in the punishment treatment.

Table 2: Observed frequencies of truthful signaling given the respective signal.

	h_L	h_M	h_H	**Average**
Baseline	57%	33%	35%	**42%**
Punishment	85%	97%	50%	**77%**
Enforced self-selection	76%	58%	29%	**54%**
Average	**73%**	**63%**	**38%**	**58%**

5.2 *Suppliers contract offers*

The previous section shows that buyers share their cost information to some extent in all treatments. Yet, even if all buyers truthfully report their holding cost, there would be no effect of communication if the signals are ignored by the suppliers. Table 3 summarizes the frequency of contract offers by types. The high degree of variance in the suppliers' contract offer behavior shows that we have no empirical support for hypothesis 1c (only screening contracts are offered).

Simply comparing the ratio of F_i - contracts to screening-contracts across treatments is not a good measure for the suppliers' trust in the signal, since a F_i – contract offer is not necessarily related to the respective signal. Furthermore, note that the frequency of signal consistent F_i - contracts does not necessarily measure the suppliers' trust in the buyers' signals either. For suppliers to offer signal tailored F_i - contracts, it suffices that the suppliers trust in the buyers' consistent signal-choice behavior, even if the signals are not truthful. Hence, we must cautiously distinguish between trust in the truthfulness of the signal, trust in signal consistent contract choices, and the lack of strategic risk resulting from indifference contract choices. The first concept plays no role if suppliers offer screening contracts. It is, however, essential for coordinating the supply chain based on signal tailored wholesale price contracts. The second concept is essential for suppliers' payoffs, because suppliers' payoffs only depend on the signal-choice consistency, but not on the truthfulness of the signal. The third concept mainly plays a role when suppliers offer screening contracts, because with a screening contract suppliers' payoffs can be substantially affected by buyers' out-of-equilibrium play at minor costs for the buyers.[5] Comparing the two contract types, we can conjecture that an increase in (either form of) trust or an increase in strategic risk (in the screening contract) will lead to an increased use of the wholesale price contracts (see also hypothesis 3).

[4] Note that a relative frequency of truthful signals of about 30% is not very high, since we would expect this frequency if the buyer always exaggerates her cost position to the maximum extent.

[5] Additionally, suppliers face the strategic risk that an offer is rejected. However, this kind of strategic risk cannot explain treatment differences, because this option is available in all treatments.

Table 3: Frequency of F_i - and screening-contract offers.

	F_L	F_M	F_H	Menu
Baseline	4,5%	9,5%	34%	52%
Punishment	5%	17%	33%	45%
Enforced self-selection	3%	13%	10%	74%

Figure 1 depicts the relative frequency of suppliers who offered tailored wholesale price contracts per period. Although the variance in the observed frequency of tailored wholesale price contracts is relatively high in all treatments, looking at Figure 1 it is evident that tailored wholesale price contracts are offered throughout the experiment in the baseline and the punishment treatments, but significantly decline (approaching zero percent) in the enforced self-selection treatment.[6] From the latter result we can conclude that suppliers prefer screening contracts without strategic risk to tailored wholesale price contracts with the risk of deceptive signals which supports hypothesis 3 (screening contracts are offered more frequently in the enforced self-selection treatment).

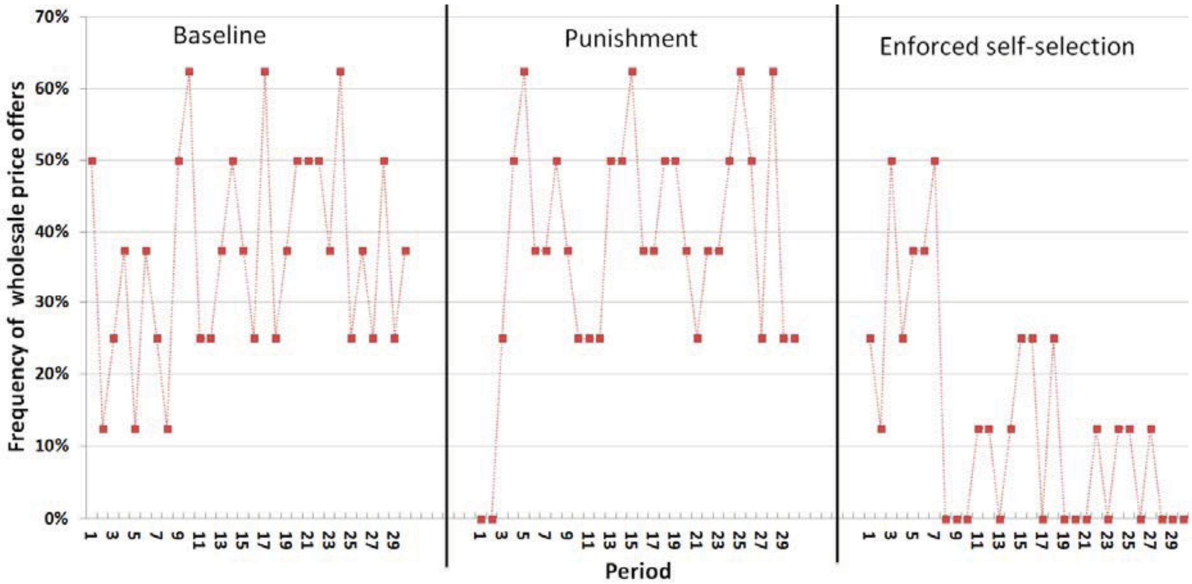

Figure 1: Frequency of contract offers F_i after receiving signal S_i per period and treatment.

[6] The spearman rank correlation coefficient measuring the dependency between frequencies of signal tailored wholesale prices and the period is positive and non-significant for the baseline and the punishment treatments (0.225 and 0.175, respectively) but negative and highly significant for the enforced self-selection treatment (-0,539, $\alpha<0.01$, two-tailed). The stable level of wholesale price offers in the baseline treatment and the punishment treatment contradicts hypothesis 1b (suppliers ignore signals). However, since we do not identify any significant differences in the level of wholesale price contract offers, we have to reject hypothesis 2b (wholesale price contracts are offered more frequently in the punishment treatment). This indicates that the actual decline of strategic risk in the punishment treatment is not fully perceived by the supplier.

5.3 Buyers contract choice behavior

Table 4 gives an overview of buyers' contract choices. We divide the buyers' contract choices into five categories: (1) the buyer chooses the profit maximizing contract, (2) the buyer chooses the indifference-contract, i.e. she chooses A_M (A_H) although she faces holding costs of $h_L\,(h_M)$, (3) the buyer chooses the alternative supplier when (almost) indifferent between the offered contract and the outside option, i.e., whenever she faces holding costs h_H or is offered the wholesale price contract that fits her actual holding cost $F_i = h_i, i \in (L, M)$, (4) the buyer chooses the alternative supplier because the participation constraint is not satisfied, which is only possible if the supplier offers F_L or F_M, and (5) the buyer has a loss greater than 0.1. The values in Table 4 indicate the percentages of the cases in each treatment.

First note that only 2% of all choices fall in category 5 and therefore 98% of all observations are optimal or nearly optimal contract choices. Interestingly, we observe that the frequency of indifference contract choices (2) is significantly higher in the baseline treatment than in the other two treatments. While the percentage must be zero in the enforced self-selection treatment by design, in the punishment treatment it is very low by choice. Obviously, the buyers in the punishment treatment prefer to avoid apparently uncooperative behavior as stated in hypothesis 2c. The hypothesis finds even more support when comparing the rejection rates that are much lower in the punishment treatment than in the other two treatments.[7] The especially high frequency of rejections in the enforced self-selection treatment may be due to the fact that rejection is the only possibility for buyers to react to perceived unfairness.

Table 4: Buyers' contract choices.

Treatment	Profit Maximum (1)	Indifference contract (2)	Reject - Indifference contract (3)	Reject – Participation constraint (4)	Profit Loss > 0.1 (5)
Baseline	73%	7%	11%	6%	3%
Punishment	88%	2%	5%	3%	2%
Enforced self-selection	78%	0%	16%	5%	1%
Average	**79.66%**	**3%**	**10.66%**	**4.66%**	**2%**

A series of Mann-Whitney U tests (comparing frequencies of choice types per independent observation type for type across treatments) reveal that the buyers in the punishment treatment

[7] They are significantly lower in the punishment treatment than in the enforced self-selection treatment (MWU, α<0.01). The average frequencies are also higher in the baseline treatment than in the punishment treatment, but not significantly when comparing the average rejection rates by independent observations.

choose significantly more often the profit maximizing contract compared to the baseline treatment ($\alpha<0.01$, two-sided) and enforced self-selection treatment ($\alpha<0.05$, two-sided). The punishment option, thus, has two favorable effects. It increases the informativeness of the reports and the frequency of profit maximizing contract choices.

Overall, the results only partly confirm hypothesis 1d (i.e. profit maximization of buyers), leaving a substantial number of non-profit maximizing choices (≈ 20%; cases 2 to 5). In most of these cases, however, the buyer incurs only a marginal loss (≈18%, cases 2 to 4).

5.4 Cooperation, contract rejection, punishments, and rewards

Table 5 summarizes the number of contract offers by categories and treatments, how many of these contracts are tailored to the signal, and the rejection rate. Moreover, we introduce the Trust/Mistrust ratio that measures the ratio of tailored contracts to screening contracts. A ratio of 0.57 is interpreted such that the menu of contracts was offered 1/0.57 ≈ 1.75 more often after a signal S_L than the tailored wholesale price contract F_L. The higher this ratio the higher the suppliers' trust in consistent contract choices, i.e. the more often tailored wholesale price contracts are offered. Finally, Table 5 shows the average reward and the absolute number of rewards given in the respective contract offer state.

The Trust/Mistrust ratio highlights that the signals are perceived quite differently across treatments by the supplier. The strategically most relevant high cost signal is trusted most frequently in the punishment treatment (2.39). This underlines that the existence of the punishment option significantly increases the trust that suppliers have in the buyers' signals. The surprising finding is that the suppliers' Trust/Mistrust ratio is so small for the low signals even though buyers cannot use this signal strategically. Since a large fraction of the low and medium signals are actually truthful, we would expect suppliers to offer more tailored wholesale price contracts after low/medium signals than after high signals. Note, however, that the rejection rates of the tailored wholesale price contracts for low/medium signals are extremely high. This indicates that buyers who truthfully signal low/medium cost prefer screening contracts to wholesale price contracts, because with screening they do not pass the entire cost advantage to the supplier. The high rejection rates expose the suppliers to a high degree of strategic risk, which they avoid by offering screening contracts after receiving a low/medium signal.

Table 5: Contract offers, rejection rates and awards by treatments and contract type

		Baseline	Punishment	Enforced self-selection
F_L	# of offers	11	18	8
	tailored to signal	36.4%	44.44%	62.5%
	Trust/Mistrust ratio	0.572	0.133	0.200
	rejection rate	63.6%	44.44%	87.50%
	# of rewards	3	7	1
	Average rewards	7,5	40	16,9
F_M	# of offers	23	36	30
	tailored to signal	34.8%	47.22%	23.3%
	Trust/Mistrust ratio	0.571	1.546	0.369
	rejection rate	65.2%	61,11%	43.33%
	# of rewards	7	12	7
	Average rewards	6,4	4	3,7
F_H	# of offers	81	74	24
	tailored to signal	93.8%	90.54%	83.3%
	Trust/Mistrust ratio	0.950	2.392	0.230
	rejection rate	9.9%	2.70%	8.33%
	# of rewards	9	47	10
	Average rewards	0,2	5,6	1,45
Menu	# of offers	125	112	178
	rejection rate	10.4%	3.57%	17.42%
	# of rewards	30	37	78
	Average rewards	1	2,1	2,1

An alternative to using screening contracts for profit sharing in the case of low and medium cost would be tailored wholesale price contract combined with a sufficiently large reward payment. As we can see in Table 5 there are two reasons why this mechanism does not work in our experiment. First, the wholesale price contracts are frequently rejected making it impossible for suppliers to share profits by providing rewards. Second, even in those cases in which the tailored wholesale price contracts are implemented, the suppliers on average provide rewards that are too low to establish win-win outcomes. In all treatments, we only found 4 cases in which rewards were sufficiently high to ensure a win-win outcome in the low or medium cost state.[8] In particular, given the contract choice F_L the minimum win-win reward is 43.77. The average reward we observe in this treatment is below this threshold as shown in Table 5. The same is true for F_M where the minimum win-win reward is 18.78. Even though we must reject the strictly payoff maximizing hypothesis 1e, because

[8] In the high cost state, any reward will make the buyer better off, since she is only left with her reservation profit for both contract types.

we observe a substantial number of non-zero rewards, we also cannot detect a cooperation sustaining behavioral effect of rewards.

Finally, it is worth mentioning that the punishment option is rarely used. Nevertheless, we observe significant differences between the punishment and the baseline treatment, indicating that the mere presence of the punishment option has an impact on supply chain behavior.

5.5 Supply chain performance

Figure 2 displays the supply chains' observed performance in ascending order across treatments.[9] We have added three benchmarks to the graphs in Figure 2 that enable a visual assessment of the observed performance. We have calculated each benchmark given the actual realization of the holding cost. Conditioning the benchmarks on the actual realization gives more exact measures than the expected benchmark, because the effect of stochastic cost variations is neutralized.

The first benchmark (F_{high}) captures the situation in which the supplier always offers F_H. This benchmark is meaningful because for this contract type the participation constraint of all buyers is satisfied and the variance of the supplier's payoff is zero. The second benchmark (Screening) is the equilibrium performance based on self-selection in screening contracts (second best). The third benchmark is the supply chain efficient outcome (first best).

The Wilcoxon-ranked signed test reveals that the supply chain performance is lower than the screening benchmark in the baseline treatment ($p<0.012$, two-sided), while there is no such significant deviation in the punishment treatment (supporting hypothesis 2c) or in the enforced self-selection treatment. Moreover, a Mann-Whitney U test confirms that the deviations from the screening equilibrium are significantly higher in the baseline treatment than in the punishment and enforced self-selection treatment (MWU, $\alpha<0.05$, two-sided).

The analysis highlights, that there are basically two means for reducing the unfavorable effects of mismatched wholesale prices to signals and indifference contract choices. First, if a sufficiently credible punishment mechanism can be installed, then the supply chain performance is significantly enhanced and reaches second best. The performance enhancement is mainly due to a larger number of truthful signals (punishment: 77%; baseline: 42%) leading to more correctly tailored wholesale price contracts. Hence, even if the number of wholesale price contracts in the punishment treatment

[9] The Figure shows the sum over all rounds for each supply chain performances in each treatment sorted by ascending observed performance. We exclude all observations in which the alternative supplier is chosen, since additional assumptions are required regarding the welfare effects of these choices.

is not significantly higher than in the baseline treatment (punishment: 55%; baseline: 48%), we observe a performance enhancing alignment of trust and trustworthiness.

Second, if self-selection is enforced, the supply chain performance can be enhanced because the effectiveness of the screening contract is improved due to the obliteration of indifference contract choices. Without indifference contract choices, the number of screening contract offers increases. Correspondingly, we observe significantly more screening contracts (enforced self-selection: 74%; baseline: 52%) and a significantly better performance in the enforced self-selection treatment than in the baseline treatment. Note that even if no buyer in the baseline treatment had chosen an indifference contract after being offered a screening contract, the performance would still be lower than the screening benchmark. The important issue here is that suppliers offer too few screening contracts in the baseline treatment due to strategic risk of indifference contract choices.

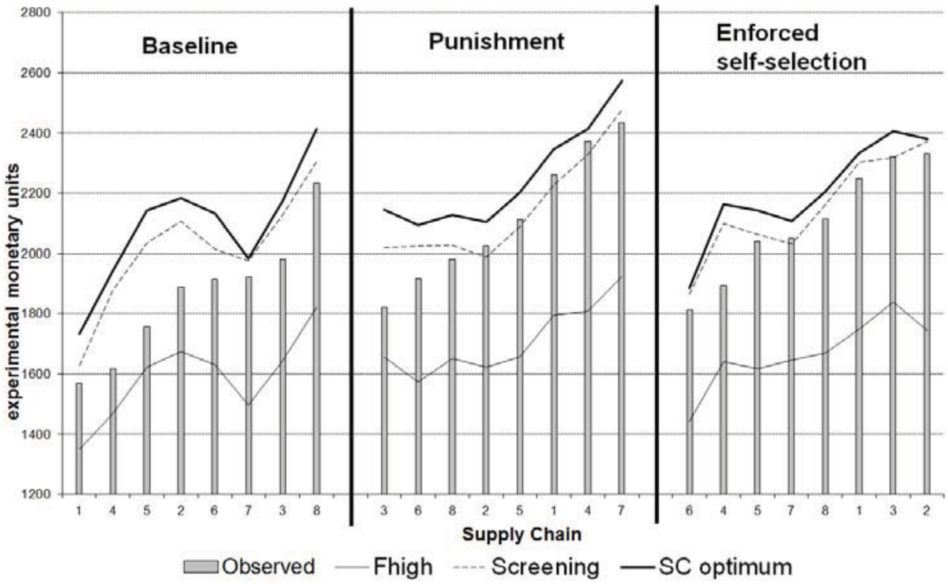

Figure 2: Supply chains' observed performance compared to benchmarks.

6 Discussion and managerial insights

The main message of our study is that supply chain environments with a high degree of strategic risk, such as the one we study in the baseline treatment, are detrimental to supply chain performance and should be avoided as much as possible. We examine two possible ways to reduce the degree of strategic risk. In our punishment treatment, the supplier has the possibility to punish buyers who exhibit apparently uncooperative behavior, i.e., if the high cost signal is send significantly too frequently or if there is an inconsistency between the signaled cost and the selected contract option. In our enforced self-selection treatment, we technically limit strategic risk by ruling out the buyers' possibility to choose indifference contracts, i.e., contracts that entail a small loss for the buyer but a substantial loss for the supplier.

Our results show that a reliable second best supply chain outcome can only be achieved with screening contracts if the incentives for self-selection are sufficiently high to reduce the behavioral variance in contract choices and, thus, the strategic risk that the suppliers face. Clearly, our experimental design, which provides the most extreme form of incentives for self-selection (i.e. the buyers have no other option to earn income, except by choosing the self-selection contract), cannot be used to assess the optimal threshold for the buyers' self-selection incentives. While theoretical approaches to robust contracts are already available (see Voigt 2012), the assessment of optimal incentive thresholds in the field will depend on specific market parameters and characteristics. Interestingly, however, when managers can only choose between classical screening contracts with marginal incentives and wholesale price contracts, we observe that a punishment option significantly increases trustworthiness of buyers' signals and consistency of contract choices. In this environment, suppliers can tailor wholesale price contracts to achieve a supply chain performance that may even be better than second-best.

In essence, our study shows that contract design should factor in behavioral mechanisms that reduce the strategic risk inherent in many supply chain interactions. On the one hand, non-contractible allocation mechanisms that seem ineffective from a game-theoretic perspective (such as our punishment option) can reduce the strategic risk resulting from buyers' deceptive signals and buyers' non-profit maximizing behavior. The reduction of strategic risk leads to more coordinated supply chain outcomes. On the other hand, contractible incentives that are excessive from a game-theoretic perspective can also reduce behavioral variance, increasing suppliers' willingness to offer screening contracts and, thus, enhancing supply chain coordination. Hence, it seems that from a behavioral perspective the reduction of strategic risk is essential in a supply chain setting no matter which type of contract is considered.

There are several promising directions for future research. It seems interesting to further understand the variance in buyer's contract choice behavior. Theoretical explanations range from bounded rationality (see Basov 2009) to social preference (see Voigt 2012). A better understanding of the underlying behavioral concepts might help to identify other forms of behavioral mechanisms that can reduce strategic risk. As an example, while we observe that a punishment option seems to be highly relevant for reducing strategic risk, it seems that the reward mechanism as it was provided in the present study (i.e., voluntary payment after contract choice) is not appropriate for incentivizing cooperative play, since we hardly identify rounds in which win-win communication took place. Thus, different forms of reward mechanisms might be analyzed in future work (e.g., a non-binding commitment is made before the signal is given). Finally, we should point out that the communication technology used in our experiment is rather crude. More elaborate communication, e.g. face-to-face negotiations, may enhance the supply chain outcomes, especially since there is evidence that the means of communication can affect outcomes in other settings (Valley et al. 1998 and Brosig et al. 2003).

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8 *Appendix: Sample instruction*

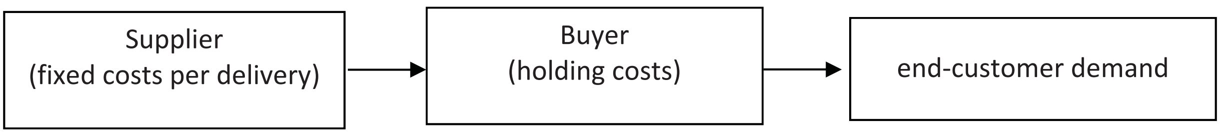
In the following we present the main body of the instruction (translated into English). In the original version handed out to the subject, more tables (indicated in the text) for illustrative purposes were provided. The complete version of instructions is available from the authors upon request.

Read the instructions carefully and raise your hand if you have any questions. If there are questions during the experiment, please raise your hand as well.

Starting position

You are in a supply chain consisting of one supplier and one buyer. The supplier offers a contract to the buyer in order to deliver a certain product at the market price. The buyer decides whether she accepts the offer or not. If the buyer rejects the supplier's contract offer, she can source the product from an alternative supplier. In that case, the buyer yields a profit of 3 and the supplier yields zero profits.

If a buyer accepts the supplier's contract offer, the supplier has the opportunity to withdraw the offer. In that case, both, the supplier and the buyer, yield zero profits.



The buyer faces holding costs, as half of the order size is stored on average per period. Hence, the buyer's holding costs increase the higher the order size and the higher the holding costs per item and period.

The supplier faces fixed costs per delivery. Since the supplier prefers large order sizes, and the buyer prefers low order sizes, the supplier has to compensate the buyer for agreeing upon larger order sizes.

Your task: Agree upon new supply conditions!

Information availability

The supplier does not exactly know the buyer's true holding costs. Yet, the supplier knows a probability distribution over the possible holding costs realizations. In the course of the experiment, the buyer's holding costs are drawn independently from this probability distribution in every round. The buyer knows her true holding costs in every round.

There are three possible types of holding cost realizations, i.e. 1€, 5€, and 9€ per item and period. The probabilities, with which these holding costs are realized, are summarized in the table below. These probabilities are known to both, the buyer and the supplier.

holding costs	1€	5€	9€
probability	40%	30%	30%

Contract type

The buyer knows her true holding cost realizations before the supplier's contract offer. The supplier does not know this holding cost realization. The buyer can signal her realization to the supplier. This signal can – but does not necessarily need to – be truthful.

The supplier has four contract offer options. He can either offer a single contract F1, F5, or F9, or a package consisting of three offers A = (A1, A5, A9). These options are mutually exclusive.

The contract offers F1, F5 and F9 maximize the supplier profits if the buyer faces holding cost of 1, 5 or 9, respectively.

However, if the supplier is uncertain about the buyer's holding cost realization, the package A maximizes his expected profits instead, as long as he believes that the buyer chooses the contract A1 with probability 40%, A5 with 30%, and A9 with 30%.

In case the supplier offers package A, the buyer has to choose one of the three contracts in the package. If the buyer chooses no offer, she sources from an alternative supplier. Given the buyer faces the holding cost realization 1, 5, or 9, then the contracts A1, A5, and A9 maximize her respective profits.

After the contract is concluded, the supplier can transfer an amount between 0 and his profits of the respective round to the buyer.

[In the original instruction, a figure displaying the decision sequence with the screenshots from the z-tree program follows here].

How are the contract corresponding profits calculated?

The following Table summarizes the profits of the supplier and the respective buyer depending on the contract offer and the holding cost realization. Negative amounts depict a loss.

Example: The supplier offers the package A to the buyer. If the buyer faces holding cost of 5 per item and period and if she accepts A5, she yields a profit of 21.88. The supplier yields a profit from the contract of 42.27.

If the buyer rejects the offer, she yields a profit of 3 and the supplier yields zero profits. If the supplier withdraws the offer, the supplier and the buyer yield zero profits.

Note that the table does not depict the amount transferred from the supplier to the buyer.

[A table similar to the one displayed as Table 1 *in the main body of the paper follows here.*Table 2*]*

How many rounds are going to be played?
30 rounds are going to be played. In every round the holding cost realizations are drawn independently from previous rounds.

Who is the participant you are matched to?
Your role as supplier/buyer is the same in every round. Your matching with the other participant does not change in the course of the experiment. The identity of the other participant is confidential throughout – and after – the experiment.

How is the experimental payoff calculated?
The experimental payoff will take place at the end of the experiment. Your payoff results from the sum of the round's profits multiplied by 0.01, i.e. every experimental monetary unit exchanges to 1 cent.

If there are any questions, please raise your hand.

Good luck.

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