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FACULTY OF ECONOMICS AND MANAGEMENT

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Karl Inderfurth • Abdolkarim Sadrieh • Guido Voigt

FEMM Working Paper No. 01, January 2008

F E M M

Faculty of Economics and Management Magdeburg

Working Paper Series

Otto-von-Guericke-University Magdeburg
Faculty of Economics and Management
P.O. Box 4120
39016 Magdeburg, Germany
http://www.ww.uni-magdeburg.de/

The Impact of Information Sharing on Supply Chain Performance in Case of Asymmetric Information

Karl Inderfurth
Department of Production Management and Logistics, Otto-von-Guericke University, Magdeburg, Faculty of Economics and Management, POB 4120, 39016 Magdeburg karl.inderfurth@ww.uni-magdeburg.de

Abdolkarim Sadrieh
Department of E-Business, Otto-von-Guericke University, Magdeburg, Faculty of Economics and Management, POB 4120, 39016 Magdeburg sadrieh@ww.uni-magdeburg.de

Guido Voigt
Department of Production Management and Logistics, Otto-von-Guericke University, Magdeburg, Faculty of Economics and Management, POB 4120, 39016 Magdeburg guido.voigt@ww.uni-magdeburg.de

The use of screening contracts is a common approach to solve supply chain coordination problems under asymmetric information. One major assumption in this context is that managers without specific incentives will rather use their private information strategically than to reveal it truthfully. This harms supply chain performance. This paper investigates a situation in which a buyer can share information with a supplier in a lotsizing framework given a just-in-time context. We conduct a laboratory experiment to test whether information sharing has an influence on supply chain coordination. We find that some subjects exhibit simple truth-telling and trusting behavior that enhances supply chain performance. Others mistrust and misinterpret even truthful information, leading to worse outcomes than in a setting without information sharing. Furthermore, we find that a large portion of the observed inefficiency is due to an insufficient behavioral robustness of the screening contracts propagated by theory. This implies that managers need to be careful when issuing screening contracts and processing the information they receive.*

Key words: cheap talk; experimental economics; principal-agent theory; screening contracts; supply chain coordination

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1. Introduction

We investigate the effect of pre-play communication on the dyadic interaction between a supplier and a buyer in a two stage supply chain within an environment of just-in-time (JiT) procurement.

* An earlier Version of this paper circulated with the title "The Impact of Cheap Talk on Supply Chain Performance in Case of Asymmetric Information: An Experimental Investigation".

JiT strategies are well-known for saving resources by reducing non-value adding logistic activities. Small order and lot sizes can lead to a substantial cost improvement for the buyer, by reducing the buyer's inventory. [1] Smaller order sizes, however, may also cause an increase of the supplier's setup, holding, and distribution costs (Fandel and Reese (1991)). Suppliers may therefore refuse to deliver JiT (Munson and Rosenblatt (1998)).[2]

Obviously, from a supply chain perspective, the implementation of a JiT strategy is only profitable, if the buyer's cost advantage exceeds the supplier's cost increase. Should a pareto improvement be possible, coordination and side payments will often be necessary to implement the optimal inventory and lot size. However, since the most of the critical information in the supply chain is private, optimality can only be achieved, if the two parties trust each other and engage in truth-telling. Otherwise, if we assume the buyer's strategic and non- cooperative use of her private information (i.e. her cost advantage of the JiT strategy), only a second-best solution can be achieved, in which the supplier offers of a menu of self-selection contracts ("screening contracts") that provide the buyers with incentives to identify their types. [3].

While screening contracts can solve the problem of diverging interests and coordination in a supply chain, they can only do so at some cost for overall efficiency. The supply chain performance could be much better, if the firms would be able to coordinate through truthful information sharing, i.e. if the buyer would communicate her cost advantage truthfully and the seller would trust the signal and choose a corresponding side payment. Kelle and Akbulut (2005), for example, give a comprehensive review on how enterprise resource planning software can be utilized to improve the supply chain performance through cooperation and inventory management.

[1] Inventory reduction can result in a bundle of advantages for the buyer, such as: less tied-up capital, reduced inventory handling, less storage room, less handling equipment, as well as less rework and scrap (Schonberger and Schniederjans (1984)). Additionally, JiT allows for a more uniform workflow with less idle time and more efficient production and material handling. Finally, JiT may also help reduce planning and control complexity.

[2] Myer (1989) finds that a buyer's single-handed JiT implementation causes a supply chain cost increase of 25% to 30% in the food industry (mainly due to transportation, warehousing, unnecessary one-to-one communication on the sales side, as well as ineffective promotion and advertising on the marketing side), and a cost increase in the range of 10% to 20% in other consumer goods fields.

[3] There is an extensive theoretical literature on screening contracts in supply-chain management. See e.g. Corbett and de Groote (2000), Ha (2000), Corbett (2001), Corbett et al. (2004) and Sucky (2006)

Empirically, however, the question remains largely unanswered, whether firms interacting in a supply chain will tend to communicate truthfully and trust each other or whether they are more likely to strategically appropriate any supply chain surplus for themselves. It is not surprising that almost no attempts have been made to answer this question, because of the methodological difficulties faced by interviewers to assess the amount of truth-telling and the extent of trust in actual supply chains. Apart from the difficulties of researchers to fully access the communication between privately owned firms, a large number of confounding effects hamper the empirical assessment. For example, after observing a discrepancy between a reported holding cost and an ex-post statistical estimate, it will typically be impossible to judge, whether the actual cost estimate was wrong or whether the report was strategically biased.

The laboratory experiment we present in this paper avoids many of these problems. The communication between the supply chain members is perfectly observed and all confounding effects are dealt with in the controlled environment. While we have no doubt that other empirical methods (e.g. interview studies) can also provide valuable insight into the issue, we believe that our experiment will offer a complementary source of knowledge that is focused on the behavioral aspects of managing supply-chains.

Our main research question is whether costless, non-binding, pre-play communication ("cheap talk") can be used to achieve a higher degree of efficiency and, thus, more income for the supply chain. We analyze a stylized model of supply chain interaction, where the buyer's disadvantage from large quantity orders is due to substantial inventory holding costs and the supplier's disadvantage from a JiT delivery due to substantial setup costs per order. Hence, our model reflects the basic conflict of interest in supply chains, with buyers preferring many small orders and suppliers preferring large scale deliveries.

We set the default mode of delivery to the JiT strategy and assume the buyer has an outside option (i.e. an alternative supplier) to receive JiT deliveries. Thus, the supplier is aware of the fact that the buyer will only accept large scale deliveries, if there is a side-payment that is sufficiently high. The buyer can use non-binding, pre-play communication to signal the own holding cost.

But, since all information is private and non-verifiable, the supplier must take into account that the buyer may strategically communicate higher holding cost in order to bias the distribution of surplus to the own advantage.

In fact, we find strong evidence for buyers strategic signaling. While the amount of truth-telling varies very strongly amongst our subjects (from a minimum of 10 to a maximum of 100 percent truthful signals), most of the deceptive signals are biased towards higher holding cost. We also observe a very large variance in the responses of the suppliers to the signals. Although no supplier fully trusts the buyers signal, we do find that some of the suppliers, the "believers," systematically and significantly increase their subjective probability for the signaled cost level, while other suppliers, the "non-believers," show no systematic reaction to the buyers signal. Concerning the performance of the supply chains, our experimental data confirm that those supply chains, in which truth-telling buyers are matched to "believers" (i.e. trusting sellers), perform significantly better than any other combination. Interestingly, supply chains that include "non-believers" (i.e. sellers without trust in the signal) often perform worse than they would in the non-cooperative equilibrium of the game. This effect seems to be due to the fact that the non-believers try to decipher the strategic content of the signals, instead of simply treating them as white noise. This leads to seemingly erratic adjustments of beliefs that lead to inefficient contracts.

The most surprising finding, however, concerns the behavioral robustness of screening contracts. The self-selection of types that is based on the differentiated incentives in screening contracts is at the heart of the non-cooperative theory of supply chain coordination. We find the mechanism to be behaviorally highly relevant. In about 79 percent of all cases, buyers are screened perfectly, i.e. exhibit payoff maximizing contract choices. In another 17 percent of the cases, buyers choose the "indifference" contract, which offers them an only slightly lower payoff than the optimal contract. But, while buyers are almost indifferent between the optimal and the indifference contract, choosing the latter is detrimental to the suppliers payoff and sharply reduces the supply chains efficiency. This empirical evidence suggests that real world suppliers should be much more cautious in the providing screening contracts than predicted by theory, because - in contrast to the theoretical prediction - real world buyers sometimes actually choose the indifference contract. Given this result, it seems clear that behavioral robustness criteria should play a greater role in the design of supply chain contracts than they have so far.

Our study contributes in three important ways to the literature. For one thing, we provide the first experimental assessment of truth-telling and trust in supply chains. This takes us beyond the empirical studies based on cases and interviews, because we can measure both truth-telling and trust in a controlled environment[4]. This also takes us beyond the experimental work on truth-telling and trust, because our experiment is the first to study cheap talk in a supply chain setting.[5] To this end, we introduce a novel method of eliciting the degree of trust by measuring subjective probability updates after a signal is received. Our method proves to be useful in detecting decision biases on an individual decision-maker level. Hence, we can assess the relevance of the decision bias for the supply chain performance.

A second contribution of our study is the finding that some subjects exhibit simple truth-telling and trusting behavior in the supply-chain context. However, as is also observed in other cheap talk experiments[6], we find a non-negligible degree of lying. Lying often substantially hurts the supply chain performance, but if the lie is believed, the liar on average earns more than a buyer sending truthful signals. This result is in line with perivious research on cheap talk in other game settings (Croson et al. (2003)). Interestingly, we also find that supply chain performance can be seriously harmed, if the informed party lies, but takes an action that - from the perspective of the non-informed - seems as consistent with the signal. As far as we can tell, our study is the first to report this type deception concealing action in an experimental setting.

A third contribution is indirect. In many principle agent settings, including numerous supply chain models, agents may be indifferent between actions induced by contracts in equilibrium, but

[4] E.g. Fynes et al. (2005) conducted an empirical study to analyse the impact of communication and trust on the supply chains' quality performance.

[5] Experimental research on interaction in supply chains has so far mainly been focused on the bullwhip effect (Sterman (1989); Croson and Donohue (2006); Wu and Katok (2006)). For an overview of experimental work in operations management see Bendoly et al. (2006).

[6] See Crawford (1998) for an excellent survey.

recognize that their choice can strongly affect the principle's payoff. While a small increase in incentive for the right choice theoretically alleviates the indifference problem, our experiment shows that behaviorally this is not the case. In fact, we find dramatic decreases in the supply chain performance due to the buyer's choice of an action that is theoretically ruled out. This implies that new theoretical approaches are necessary that assign lower reliability to equilibrium behavior based on negligible payoff differences.

The rest of the paper is organized as follows: Section 2 gives a brief summary of the model and section 3 describes the experimental implementation of this model. Sections 4 summarizes the experimental data and findings. Finally, section 5 concludes with a general discussion, managerial insights and an outlook for further research.

2. Outline of the model

This paper transfers the described JiT problem into a simplified Joint-Economic-Lotsizing model [see Goyal (1977), Monahan (1984) and Banerjee (1986)]. In a dyadic relationship, composed of a buyer (B) and a supplier (S), the buyer decides on his order lotsize (Q). The buyer faces a constant demand over time. Without loss of generality, we standardize the demand to one unit per period. Hence, period costs equal unit costs. Since the buyer is the focal player in the supply chain, she requires the supplier to deliver just in time, i.e. she sets $Q = 1$. The supplier incurs a fixed cost of delivery f, so that the JiT cost per period amounts to $\frac{f}{Q}$. Hence, the supplier's cost decreases with increased order size. The buyer's various disadvantages from greater order sizes are summarized in the holding cost parameter h, which describes the additional cost per period for increasing the order size by one unit. The buyer has the outside option to buy from an alternative supplier (AS) who delivers in a JiT mode. The cost of buying from the alternative supplier is C_{AS} per unit. To induce higher order sizes while ensuring that the buyer does not choose her outside option, the supplier must compensate the buyer for the additional holding cost with a side payment T per unit (e.g. by introducing a quantity discount on the wholesale price).

Full Information (FI): If the supplier is perfectly informed on the buyer's holding cost h, he offers a contract, consisting of order size Q and side payment T, that minimizes his unit cost C_S (equal to his cost per period). The supplier's optimal contract is the outcome of the following minimization problem:

Problem FI

$$\min C_S = \frac{f}{Q} + T$$

$$s.t.$$

$$h * Q - T \leq C_{AS} \quad (PC)$$

As is standard in Joint-Economic-Lotsizing models, we assume that the fixed cost of the supplier is greater or equal to the holding cost of the buyer, i.e. $f \geq h$, which means that $Q \geq 1$ holds in the optimum. The solution $Q(SC)^*$ minimizes the overall cost of supply chain and is equivalent to the joint economic lot size. The participation constraint (PC) ensures that the buyer is indifferent between the contract $< Q(SC)^*, T(SC)^* >$ and the outside option (AS). This contract leaves all efficiency gains, compared to the just-in-time contract, to the supplier.

Asymmetric Information (AI): Full Information on the buyer's cost is obviously a critical assumption. Hence, we study a situation, where the supplier does not know the value of the buyer's holding cost h, but is informed on the distribution of possible values, i.e. he knows h_i $(i = 1, ..., n; h_1 < h_2 < ... < h_n)$ and the corresponding probability distribution $p_i(h_i)$ $(i = 1, ..., n)$. This assumption is motivated by the observation that suppliers generally cannot accurately estimate the buyers' various advantages from low order sizes. We assume that buyer and supplier have common knowledge concerning the probability distribution $p_i(h_i)$. One feasible solution to this problem can be obtained by solving problem FI with $h = h_n$. However, this solution is not optimal for the supplier, since he can increase his expected profits by offering a menu of contracts $< Q_i, T_i >$ $(i = 1, ..., n)$, from which the buyer can choose. Offering a menu of contracts is superior to offering a single contract due to the revelation principle [see Corbett and de Groote (2000), Myerson (1986)]. The optimal screening contract includes a different most preferred contract for each possible type of buyer (i.e. for each possible level of holding costs). Buyers reveal their types by self-selection, i.e. by choosing the contract that is best for their own specific holding cost. The menu of contracts is the solution to the following optimization problem [7]:

Problem AI

$$\min E(C_S) = \sum_{i=1}^{n} p_i \left(\frac{f}{Q_i} + T_i \right)$$

$$s.t.$$

$$h_i * Q_i - T_i \leq C_{AS} \quad \text{(PC)} \quad \forall i = 1, ..., n$$

$$h_i * Q_i - T_i \leq h_i * Q_j - T_j \quad \text{(IC)} \quad \forall i \neq j; i, j = 1, ..., n$$

We assume that even the highest holding cost is no greater than the fixed cost of the supplier, i.e. $f \geq h_n$. We minimize the supplier's expected cost when each buyer with holding costs h_i chooses the contract $< Q_i, T_i >$. The incentive constraint (IC) guarantees self-selection. The participation constraint (PC) ensures that no buyer, regardless of his holding costs, will choose the alternative supplier (AS). In the optimal screening contract, the order sizes increase with decreasing holding costs (i.e. $Q^*_{i-1} \geq Q^*_i, \quad \forall i = 2, ..., n$) and the side payments increase respectively (i.e. $T^*_{i-1} \geq T_i, \quad \forall i = 2, ..., n$). Furthermore, the buyer with holding costs h_i is indifferent between the contracts $< Q^*_i, T^*_i >$ and $< Q^*_{i+1}, T^*_{i+1} >$ $(\forall i = 1, ..., n-1)$, and the buyer facing the highest holding cost h_n is indifferent between the contract $< Q^*_n, T^*_n >$ and the alternative supplier. Finally, the resulting order sizes are too low compared to the supply chain optimum (i.e. $Q^*_i < Q_i(SC)^*$ for all $i = 2, ..., n$) except the ordersize Q^*_1. We refer for the proofs of these properties to Sappington (1983).

[7] This linearly contrained convex optimization problem can easily be solved using the Maple Global Optimization Toolbox.

Cheap Talk: Problem AI describes the non-cooperative game, assuming that there is no (credible) communication between the buyer and the supplier. We relax this assumption by allowing the buyer to send a signal to the supplier and allowing the supplier to condition his subjective probability distribution on the signal. The communication takes place via a structured signal H, $(H \in (H_1 = h_1, ..., H_l = h_l, ..., H_n = h_n \quad \vee \quad \text{"No Signal"}))$. The supplier receives an undistorted signal, but does not know, whether the buyer is reporting her holding cost strategically or truthfully. Whether the supplier adjusts his subjective probability distribution after receiving the signal, depends on the supplier's beliefs about the buyer's trustworthiness. If the supplier believes that the buyer's signal is true, he adjusts the probability of observing a holding cost at the level of the signal $(p_i(H = H_i))$ upwards. Otherwise, he does not adjust the probability at all. If the supplier adjusts his subjective probability distribution to the signal, he re-optimizes the menu of contracts offered to the buyer $Q_i(H)^*$ and $T_i(H)^*$ based on the adjusted distribution $(p_i(H))$.
Note that any adjustment of the supplier's subjective probability distribution directly effects the buyer's and the supplier's profits in opposite directions. Hence, the buyer has an incentive to increase her own profits by exaggerating the holding cost and inducing an adjustment of the supplier's subjective probability distribution towards just-in-time delivery.[8] However, under the assumptions of non-cooprative game theory, the supplier anticipates the buyer's exaggeration, he ignores the signal and offers the a-priori screening contract, i.e. $p_i = p_i(H)$. Thus, the signal amounts to no more than "cheap talk" that does not affect the non-cooperative equilibrium of the game.

3. Experimental Design and Implementation

A total of 48 subjects, 24 as suppliers and 24 as buyers, participated in the two sessions of the experiment. The groups were matched randomly at the beginning of the first round. This matching did not change over time. All subjects played 20 rounds. The sessions were run at the MaXLab, Otto-von-Guericke University of Magdeburg. The experimental software was implemented with the toolbox z-Tree (Fischbacher (2007)). Upon arrival, each participant received written instructions

[8] The only exception, of course, is the buyer with highest holding cost h_n, who has no strategic advantage, because she simply cannot exaggerate (see section 2).

(see on-line appendix). The instructions were the same for buyers and suppliers and were read out aloud. Any questions were answered privately. At the end of the experiment, subjects were paid privately, according to their total profits in the experiment.

Parameters: As pointed out earlier, the holding cost per period is an aggregated measure for the advantages of a JiT strategy. The experimental setting assumes that the holding cost parameter h_i (and therefore the profitability of a JiT strategy) can change in every round. This change can be explained by several influencing variables, e.g. the influence of labor unions, variability of lease rental charges for storage room, changing credit ratings or "no-claims"-discounts.

There are three possible holding cost levels with the corresponding probabilities $(h_{low} = 1; p_{low} = 0.3)$, $(h_{med} = 3, p_{med} = 0.4)$ and $(h_{high} = 5; p_{high} = 0.3)$. The holding costs are drawn independently in every round for every subject according to the distribution function $p_i, \forall \quad i \in (low, med, high)$. If the buyer with holding costs $h_j, \forall \quad j \in (low, med, high)$ chooses the contract $< Q_i, T_i >, \forall \quad i \in (low, med, high)$, she incurs a profit per unit of $P_B = R_B - C_B = R_B - h_j * Q_i + T_i$, where $R_B = 85$ are her fixed revenues per unit. Yet, if she chooses the alternative supplier, she incurs cost of 5 $(C_{AS} = 5)$ and her profit per unit is $P_B = R_B - C_{AS} = 80$. The suppplier incurs profits of $P_S = R_S - C_S = R_S - \frac{f}{Q_i} - T_i$ when his buyer chooses the contract $< Q_i, T_i >$, where $R_S = 200$ are the supplier's fixed revenues per period. However, if his buyer chooses the alternative supplier, he makes no profit at all (i.e. $P_S = 0$). As mentioned before, the buyer with holding costs h_i is indifferent between the contracts $< Q_i^*, T_i^* >$ and $< Q_{i+1}^*, T_{i+1}^* >$. Yet, to give the buyer a strict incentive to choose the self-selection contract (i.e. $< Q_i, T_i >$), we solved problem AI with a slight change of the incentive contraint (i.e. $h_i * Q_i - T_i \leq h_i * Q_j - T_j - 0.1 \quad \text{(IC)} \quad \forall i \neq j; i, j = 1, ..., n$). Hence, the buyer faces strictly higher profits if she chooses the self-selection contract.

Decision Sequence and Decision Support System: Figure 1 depicts the sequence of decisions in each round. The first decision in every round is the buyer's signal choice ($H \in (H_{low}, H_{med}, H_{high}$, 'No Signal'). Given the buyer's signal, the supplier then chooses a subjective probability distribution $p_i(H)$ $(i \in (low, med, high))$. The choice is limited to steps of 0.1, i.e. $p_i(H) \in (0, 0.1, ..., 1)$ and $\sum_{i \in (low, med, high)} p_i(H) = 1$. The supplier's adjusted subjective probability distribution is then used to generate the menu of contracts (i.e. the optimal screening contract conditioned on $p_i(H)$) that is offered to the buyer. The buyer, then, chooses one of the three contracts from the menu or the alternative supplier.

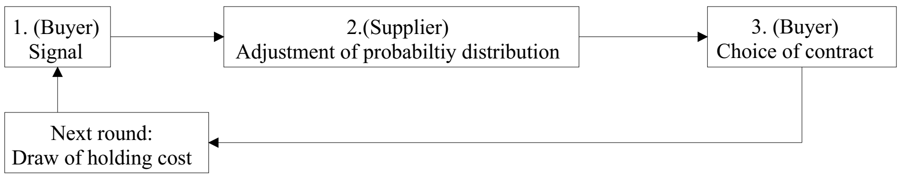

Figure 1 Decision sequence.

The supplier does not need to calculate the optimal menu of contracts. He only has to enter his subjective probability distribution, for which the system automatically calculates the optimal screening contract according to problem AI.[9] Both buyers and suppliers are informed (see the instructions in the appendix) that the generated menu of contracts screens buyers according to their cost levels, i.e. buyers with h_{low}, h_{med}, or h_{high} holding cost should choose the contracts 1, 2, or 3, respectively, to maximize their profits.

In order to facilitate the decision problem for the subjects, we provide a decision support system (DSS) consisting of a 'profit calculator' and a payoff table. The profit calculator can be used by buyers and suppliers to display the relevant outcomes for any subjective probability distribution $p_i(H)$ at any stage of the experiment. Alternatively, the subjects can check the payoff table in the instruction that contains all possible payoff combinations (see on-line appendix).

4. Results

4.1. Do suppliers adjust their subjective probability distributions to the signals sent by the buyers?

Table 1 summarizes the frequency of the subjective probability values. As the highlighted a-priori probabilities show, in more than 20 percent of the cases, subjects report a subjective probability that is equal to the a-priori probability p_i of each holding cost level. There are also considerable

[9] We provide the subjects this 'decision support system', because the calculation of the optimal screening contract takes some computational effort, but we do not expect any behavioral insights from having subjects perform the tedious task.

Table 1 Frequency of subjective probability values.

	p_{low}		p_{med}		p_{high}	
probability	absolute frequency	relative frequency	absolute frequency	relative frequency	absolute frequency	relative frequency
0	77	16	48	10	43	9
10	71	14.8	59	12.3	40	8.3
20	97	20.2	54	11.3	82	17.1
30	126*	26.7*	72	15	111*	22.9*
40	36	7.5	134*	21.7*	58	12.1
50	18	3.8	41	8.5	46	9.6
60	25	5.2	42	8.8	24	5
70	8	1.7	21	4.4	17	3.5
80	11	2.3	27	5.6	17	3.5
90	5	1	10	2.1	16	3.3
100	4	0.8	2	0.4	27	5.6
Total	480	100	480	100	480	100

* a-priori probabilities.

deviations from the a-priori probabilities, however. This indicates that the suppliers' beliefs may have been affected by the buyers' signals. A closer look at the table, however, reveals that most of the probability mass for all three cost levels is on the lower half. Hence, even if buyers' signals affect suppliers' beliefs, suppliers are obviously cautious about believing the signals with high probabilities.

To analyze whether subjects show consistent "believer" or "non-believer" behavior, we focus on the suppliers' relative adjustments of subjective probabilities to the buyers' signals. The relative adjustment compares the observed adjustment of the subjective probability to the maximum possible adjustment for a given signal, i.e. $\frac{p_i(H_i)-p_i}{100-p_i}$, for $p_i(H_i) > p_i$, and and $-\frac{p_i-p_i(H_i)}{p_i}$, otherwise. A perfect believer adjusts his subjective probabilities perfectly upwards (i.e. 100 percent) for the signaled cost level. A perfect non-believer does not adjust the probabilities at all (i.e. 0 percent). A perfect "disbeliever" adjusts his subjective probabilities perfectly downwards (i.e. -100 percent) for the signaled cost level.

Figures 2-4 show the development of the relative adjustment of signal probabilities for every supplier. The different shapes of the nodes refer to the signal sent by the buyer in the corresponding

Table 2 Sign-test.

group	1	2	3	4	5	6	7	8
p-value	0.000*	0.212	0.000*	0.387	0.000*	0.033*	0.073	0.402
group	9	10	11	12	13	14	15	16
p-value	0.000*	0.035*	0.000*	0.002*	0.344	0.029*	0.500	0.750
group	17	18	19	20	21	22	23	24
p-value	0.059	0.000*	0.000*	0.623	0.004*	0.004*	0.019*	0.018*

* believers.

period: squares (triangles, circles) mark periods with a high (medium, low) cost level signal. We find that for some suppliers the graph lies on or above the 0 percent threshold throughout all periods. These are the suppliers who believe that the signals are more likely to be true than to be false.[10] We also find a number of suppliers who believe at times and disbelieve at other times. However, we neither find perfect non-believers (i.e. who consistently exhibit zero percent adjustments, always sticking to the a-priori probabilities), nor suppliers who consistently disbelieve, i.e. believe that it is more likely for a signal to be false than true.

Given the visual inspection of the graphs, we categorize the suppliers in two groups, the "believers" and the "non-believers". The two categories are formed by running the sign test on the alternative hypothesis that the subjective probability for the signaled state is higher than the a-priori probability for that state, i.e. $p_i(H = H_i) > p_i$. Table 2 summarizes the p-values of the sign test for all suppliers in the experiment. Any supplier for whom the sign test is significant at the .05 level, one-tailed, is called a believer. We find that 15 out of 24 suppliers are believers.[11] We refer to the remaining 9 suppliers as "non-believers."[12]

So far, we have only considered the immediate impact of a signal on the subjective probability that is associated with the signaled cost level. Obviously, since signals affect the probability of the signaled cost level, they indirectly also have an impact on the rest of the probability distribution. In order to analyze the effect of signals on the probability profiles of the suppliers, we use the

[10] Note that we do not observe any supplier, who unambiguously believes in the signal sent by the buyers. A perfect believer would increase the probability of the signaled cost level to 100 percent.

[11] Believers are the suppliers in the groups 1,3,5,6,9,10,11,12,14,18,19,21,22,23, and 24.

[12] Non-believers are the suppliers in the groups 2,4,7,8,13,15,16,17, and 20.

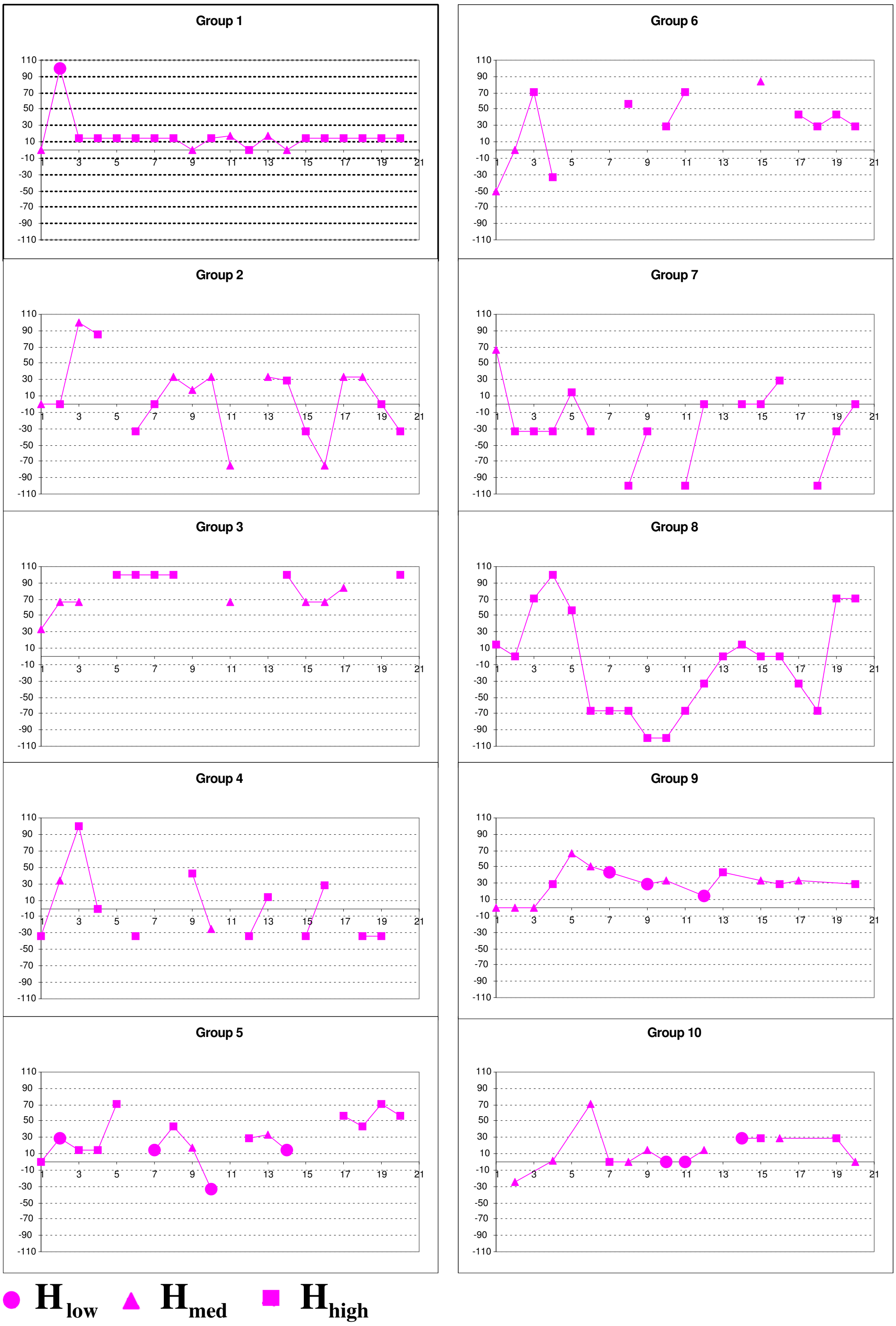

Figure 2 Probability adjustment of the signal probabilty (Groups 1-10).

Figure 3 Probability adjustment of the signal probabilty (Groups 11-20)

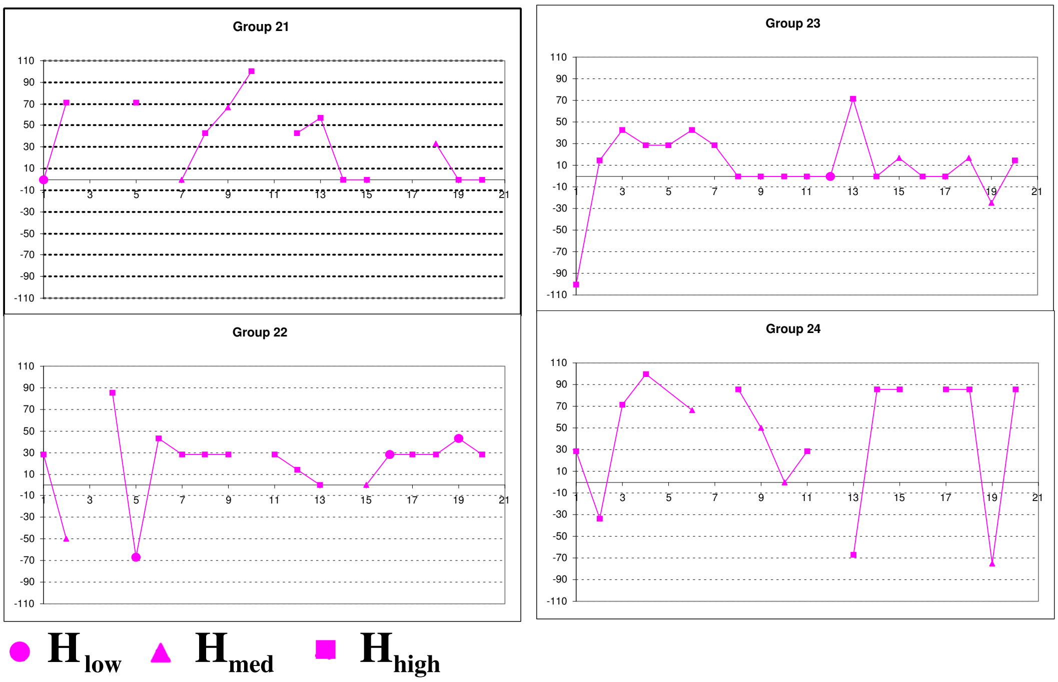

Figure 4 Probability adjustment of the signal probabilty (Groups 21-24)

following regression model, applying it to each cost level probability p_i separately.

$$p_i(H) = \alpha + \beta_{low} * S_{low} + \beta_{med} * S_{med} + \beta_{high} * S_{high} \quad \text{for} \quad i \in (low, med, high)$$

$$\text{where} \quad S_i = \begin{pmatrix} 1 & , & \text{if buyers Signal is} \quad H = H_i \quad \forall i \in (low, med, high) \\ 0 & , & \text{else} \end{pmatrix}$$

Because the sign test presented above shows that we can expect substantial differences in the behavior of "believers" and "non-believers," we run separate regressions for each of the two groups. All regressions include a dummy-variable for each supplier to control individual fixed effects. Table 3 summarizes the estimated parameters for the "believers." The results confirm the sign test finding. The upward adjustment of the subjective probability for the signaled cost level by "believers" is significant. Correspondingly, the subjective probabilities of the cost levels that were not signaled are significantly adjusted downwards when compared to the a-priori probabilities.[13]

[13] The complete regression results, including the estimation parameters for the fixed group effects, are summarized in the appendix (see table 9).

Table 3 Regression results for "believers".

	p_{low}		p_{med}		p_{high}	
	estimator	p-value	estimator	p-value	estimator	p-value
α	34.5	0.000	49.2	0.000	16.3	0.001
β_{low}	22.8	0.000	-12.5	0.005	-10.2	0.040
β_{med}	-6.7	0.024	16.9	0.000	-10.2	0.006
β_{high}	-13.9	0.000	-13	0.000	26.9	0.000

Note that buyers' strategic use of the signal would correspond to deceiving the supplier most frequently with a high cost level signal. The regression, however, shows that our "believers" do not distinguish between signals that are more likely to be deceptive (i.e. used strategically) and signals that are more likely to be true (i.e. have no immediate strategic advantage for the buyers). It is surprising that the strongest upwards adjustment of the subjective probabilities by "believers" is observed when the most strategically relevant signal is received, i.e. $\beta_{high}(p_{high})$ is greater than $\beta_{low}(p_{low})$ and $\beta_{med}(p_{med})$).

As expected, we find no such clear effects for the "non-believers." We only find a single significantly positive effect, $\beta_{med}(p_{med})$, and two significantly negative effects, $\beta_{high}(p_{low})$ and $\beta_{high}(p_{med})$ (see table 4).[14] The former seems to indicate a slight upward adjustment of the subjective probability for a signaled medium cost level. Note, however, that supplier heterogeneity is so strong (all fixed effects are highly significant and the constant term is far away from the a-priori probability .40) that a reliable interpretation of the model coefficients is not possible. In contrast, we find the two significantly negative coefficients in a regression with no significant fixed effects and a regression constant that is close to the a-priori probability. These two coefficients indicate that the "non-believer" suppliers react strongly on low and medium cost signals by reducing the subjective probability of a high cost level.

4.2. Are buyers screened successfully?

Since the contracts that are offered to the buyers provide incentives for the buyers to self-select according to their holding cost levels, we expect to observe the screening of buyers. Knowing this,

[14] The complete regression results, including the estimation parameters for the fixed group effects, are summarized in the appendix (see table 10).

Table 4 Regression results for "non-believers".

	p_{low}		p_{med}		p_{high}	
	estimator	p-value	estimator	p-value	estimator	p-value
α	57.4	0.000	5.5	0.331	37.1	0.000
β_{low}	10.9	0.075	9.3	0.099	-20.2	0.001
β_{med}	2.9	0.564	13.2	0.004	-16.1	0.001
β_{high}	-1.4	0.736	3.5	0.359	-2.1	0.600

theory predicts that buyers should use their signals to manipulate the suppliers' beliefs concerning the holding costs. Once a specific set of screening contracts is chosen, however, buyers are predicted to reveal their true cost level through their choice of contract. In this subsection, we examine whether buyers are screened successfully, i.e. whether they choose the contract that provides them with the greatest incentives ex-post. Then, in the following subsection, we analyze the buyer's signals to see, whether they are used to manipulate the suppliers' beliefs.

We find that buyers are screened rather successfully.[15] In 79% of all cases, buyers choose the profit maximizing contract as theoretically predicted. In 17% of the cases, the buyers choose the indifference contract. Hence, buyers exhibit optimal or nearly optimal choices in about 96% of all cases, once they are offered a specific menu of contracts.[16]

The choice of the indifference contract is now analyzed more detailed. Note, that the choice of the alternative supplier can be the choice of an indifference contract as well (for the buyer facing holding cost h_{high}). In 13% of all cases, buyers choose the alternative supplier, i.e. they refuse to accept any of the contracts offered to them by the suppliers. In the vast majority (84%) of these cases, the rejecting buyers had high holding costs. The choice of the alternative supplier may be interpreted as the buyers attempt to signal bargaining power. If so, the attempts were futile, because we find no indication that suppliers raise their subjective probabilities for the high cost level $p_{high}(H)$ significantly more after observing buyers, who choose the alternative supplier. In 6% of all cases, buyer choose the indifference contract while facing holding costs h_{low} and h_{med}.

[15] Table 11 in the appendix shows the aggregated cross tabulation of signals, holding costs and contract choices.

[16] The payoff from the indifference contract deviates from payoff of the optimal contract only by the amount of 0.1 (see section (3)).

Table 5 Frequencies of contract choices for given signals.

	No Signal	H_{low}	H_{med}	H_{high}
AS	15%	21%	6%	13%
1	30%	43%	22%	22%
2	36%	21%	61%	33%
3	20%	14%	10%	32%

This deliberate choice of indifference contracts may have a strategic reason. Buyers, who had sent a deceptive signal, may attempt to cover it up, by choosing the contract that is consistent with their signal, instead of the contract that is payoff maximizing (i.e. consistent with their true cost level). We observe this behavior in about 3% of all cases. Two buyers persistently cover up their deceptive signals: the buyer in group 6 (4 cases) and the buyer in group 19 (5 cases).

4.3. Are signals cheap talk?

Table 5 summarizes the observed frequencies of contract choices given a signal. These frequencies show that the relationship between signals and contract choices is not uniform across signal types. While low and medium holding cost signals indicate frequencies of the corresponding contract choices that are well above the a-priori probabilities p_i (0.43 compared to $p_{low} = 0.3$ and 0.61 compared to $p_{med} = 0.4$), observing a high holding cost signal should not affect the suppliers' expectations (0.32 compared to $p_{high} = 0.3$). Hence, it seems that high cost signals - on aggregate - are cheap talk, whereas low and medium cost signals are empirically relevant, at least to some small degree.

As already mentioned in the previous section, our data allow us to distinguish between truthful signals (i.e. $h_i = H_i$) and consistent contract choices (i.e. choosing the contract $< Q_i, T_i >$ after sending the signal H_i). This differentiation is empirically relevant, because the suppliers cannot observe truthfulness, but can observe consistency. Since supply chain relationship in our experiment (and in general) involve repeated interaction, consistency between signals and choices (signal-to-choice consistency) may affect the development of trust and, thus, the performance of the supply chain.

Table 6 Truthful signals and consistent contract choices.

group	truthful signals	consistent contract choices		group	truthful signals	consistent contract choices
1	20%	20%		13	20%	15%
2	25%	25%		14	25%	25%
3	65%	65%		15	50%	40%
4	20%	10%		16	15%	20%
5	20%	20%		17	15%	35%
6	30%	50%		18	15%	5%
7	10%	10%		19	55%	60%
8	30%	30%		20	60%	20%
9	45%	45%		21	20%	20%
10	35%	30%		22	45%	35%
11	100%	100%		23	45%	30%
12	40%	35%		24	45%	15%

Table 6 summarizes the frequency of truthful signals and of consistent contract choices in each supply chain. A quick inspection reveals the high correlation between truthful signals and the signal-to-choice consistency.[17] While some buyers are less consistent than truthful, many are more consistent than truthful, i.e. cover up some of their deceptive signals by making consistent contract choices. Most deviations are not substantial (only one sixth of the buyers show a deviation of more than 10%) and we observe no systematic effects.

4.4. Does pre-play communication enhance supply chain performance?

In the following, we analyze the impact of pre-game communication on supply chain performance by comparing the observed supply chain profits with the supply chain profits under the a-priori screening contract and self-selection of the buyers. Since we are only interested in supply chain performance, we drop all observations concerning buyers, who choose the alternative supplier. This leaves 418 observations for the analysis.

Table 7 depicts the deviation between the theoretically predicted and experimentally observed profits for suppliers, buyers, and the entire supply chain averaged over all periods, in which the

[17] Spearman's rank correlation coefficient is $r = 0.74$ and significantly different from 0 at a level of 0.1%, two-tailed.

Table 7 Truthful signals and consistent contract choices.

			Supplier		Buyer		Supply Chain		
Group	contracts	indifference	observed	self-selection	observed	self-selection	observed	self-selection	cooperative
1	19	0%	-7.82	-7.82	2.76	2.76	-5.06	-5.06	-21.30
2	19	5%	-3.10	0.30	-4.00	-3.95	-7.10	-3.65	-13.09
3	20	0%	18.15	18.15	-14.46	-14.46	3.68	3.68	-14.05
4	17	6%	-10.80	-6.73	-5.01	-4.97	-15.81	-11.69	-22.32
5	13	31%	-54.36	-3.81	-1.76	3.46	-56.11	-0.35	-59.23
6	18	28%	-29.54	-10.38	-3.67	-2.25	-33.21	-12.63	-40.71
7	20	5%	12.33	16.44	-14.22	-14.18	-1.89	2.26	-11.56
8	19	0%	10.95	10.95	-40.00	-40.00	-29.05	-29.05	-40.18
9	19	0%	26.64	26.64	-37.00	-37.00	-10.35	-10.35	-21.57
10	16	0%	-4.56	-4.56	1.87	1.87	-2.69	-2.69	-16.88
11	20	0%	29.28	29.28	-7.36	-7.36	21.92	21.92	-14.94
12	19	0%	-1.57	-1.57	1.53	1.53	-0.04	-0.04	-10.14
13	14	7%	-14.21	-3.16	-2.35	-2.31	-16.57	-5.47	-21.62
14	20	0%	-32.70	-32.70	9.83	9.83	-22.87	-22.87	-38.78
15	17	0%	-17.46	-17.46	8.56	8.56	-8.89	-8.89	-19.09
16	20	10%	-3.19	4.59	-8.55	-8.48	-11.74	-3.88	-21.33
17	20	5%	50.91	38.80	-58.98	-37.87	-8.07	0.94	-38.11
18	14	0%	-31.24	-31.24	28.34	28.34	-2.90	-2.90	-13.44
19	15	33%	37.61	45.66	-37.14	-36.87	0.47	8.79	-13.54
20	14	29%	-23.42	-7.31	0.65	0.81	-22.77	-6.50	-27.83
21	18	11%	-10.83	-6.07	5.32	5.38	-5.50	-0.69	-9.45
22	16	0%	-2.82	-2.82	1.32	1.32	-1.49	-1.49	-12.32
23	16	0%	6.45	6.45	-7.52	-7.52	-1.07	-1.07	-7.04
24	15	20%	-42.97	-16.56	23.49	23.61	-19.48	7.05	-24.48
		Average	-4.10	1.88	-6.60	-5.41	-10.69	-3.53	-22.21

supplier and the buyer concluded a contract (the total observations for every supply chain are summarized in the column "contract"). The column "self-selection" shows the performance under the assumption that the buyer would have chosen the self-selection contract. Hence, this column only differs from the column with the observed performance, for those supply chains in which the buyer did not always choose the (ex-post) payoff maximizing contract. The frequency of these indifference-contract choices is summarized in the column "indifference". Additionally, the last column of table 7 shows the deviation of the average supply chain payoff from the cooperative optimum. Note that we measure performance by comparing observed outcomes to equilibrium or cooperative outcomes, given the actual realization of the holding cost parameter. This gives us more exact measures than comparisons to the expected equilibrium or expected cooperative outcomes would, because the effect of stochastic cost variations is neutralized.

Observed performance is worse than predicted by theory for most suppliers, buyers, and supply chains. Only 8 suppliers (33%), 10 buyers (42%), and 3 supply chains (13%) can achieve average profits that are greater than in the screening equilibrium. On average, suppliers earned 4.1 points less, buyers 6.6 less, and supply chains 10.69 points less than in the screening equilibrium. The results for the buyers are weakly significant at the 10% level, one-tailed, while the result for the supply chains is highly significant at 0.1% level, one-tailed.[18]

Surprisingly, we find by comparing the columns "observed" and "self-selection" that 68% of the supply chains' average deviation from equilibrium outcome can be explained by no more than 30 ($30/418 \approx 7\%$) of the buyers' indifference contract choices.

While we do observe three cases (groups 3, 11, and 19), in which the overall supply chain performance is improved, it seems clear that pareto improvements compared to the screening equilibrium are hard to achieve in spite of pre-game communication. Interestingly, the three supply chains with superior performance have buyers with the highest signal-to-choice consistency and believing suppliers. However, cooperative behaviour requires more than consistent signals and trusting suppliers. A closer look at group 19 shows, that most of the supply chain's efficiency gains are compensated by the buyer's indifference contract choices. In contrast, group 3 and 11 that do not exhibit any indifference contract choices show the best supply chain performance in this experiment.

In six supply chains the buyers' as well as the suppliers' performance deteriotes. This is somehow suprising, as one might believe that either the buyers truthful signals or the suppliers tendency to believe simply reallocate the profits within the supply chain. We find three variables, however, that

[18] We compare the deviations from the theoretical prediction with the Wilcoxon signed-ranks test.

interact, causing a deterioration of the performance for both the suppliers and the buyers. First, in all of these supply chains the indifference contract was chosen at least once. Second, in five of the six supply chains the signal-to-choice consistency is smaller than 25%. Finally, four of these six supply chains have non-believing suppliers. At first sight, it may seem surprising that these supply chains are performing worse than the benchmark case of the non-cooperative equilibrium, since sending non-informative signals that are not believed seems to resemble equilibrium behavior well. Note, however, that a non-believer can react in different ways to the signal of the buyer. If buyers ex-post always choose the profit-maximizing contract and suppliers simply ignore the signals and always choose the a-priori probabilities, the supply chain can achieve the equilibrium performance. But, if non-believers - as we observe - do not stick to the a-priori probabilities, instead trying to interpret the buyers' signals, profits are on average much lower for the buyers.

Summarizing these results, it seems that the choice of the indifference contract, the signal-to-choice consistency, and the suppliers tendency to believe or not believe are the main drivers of the observed performance. We run a regression to test the influence of these explanatory variables on the buyers, suppliers and supply chains deviations from the equilibrium outcome with an ordinary least squares (OLS) estimation.[19]

Table 8 summarizes the regressions for the buyers, the suppliers, and the supply chains separated for the groups with "believer" and "non-believer" suppliers. All the regression parameters for the suppliers and the supply chains are significant within the believer groups. Not suprisingly, the frequency of the indifference contract for the buyers is not significant at all, because choosing the indifference contract comes at almost no costs for the buyer. These results indicate, that a better-than-equilbrium performance of the supply chain can hardly be expected, as long as the buyers continue to choose the indifference contracts. Furthermore, the regression results show that the suppliers' performance improves, the more consistent contract choices are observed, while

[19] Please notice that the relative frequencies of consistent contract choices differ slightly from table 6 as we drop all observations where the buyers choose the alternative supplier.

Table 8 Influence of signal-to-choice consistency and the choice of the indifference contract on suppliers', buyers' and supply chains' performance.

	believer		non-believer	
	estimator	**p-value**	**estimator**	**p-value**
	Supplier			
constant	-36.10	0.002	7.30	0.761
frequency indifference contract	-83.15	0.039	-99.46	0.362
signal-to-choice consistency	86.31	0.001	1.20	0.988
R^2	0.67		0.14	
	Buyer			
constant	18.96	0.027	-15.03	0.535
frequency indifference contract	-11.65	0.700	69.01	0.517
signal-to-choice consistency	-48.35	0.009	-14.99	0.846
R^2	0.47		0.09	
	Supply Chain			
constant	-17.14	0.020	-7.73	0.413
frequency indifference contract	-94.80	0.003	-30.44	0.460
signal-to-choice consistency	37.96	0.014	-13.79	0.644
R^2	0.62		0.11	

the buyers' performance deteriorates. Since the improvement for the sellers is stronger than the deterioration for the buyers, the total performance of the supply chains with "believers" increases the more consistent choices are observed.

Finally, the regressions for the "non-believers," have poor R^2s and none of the parameters is significant. This supports the hypothesis that this group is rather heterogeneous, making it difficult to identify general decision biases. However, we stress again that four out of six supply chains in which the suppliers' as well as the buyers' performance deteriorates have non-believing suppliers. Hence, the interpretation of signals by non-believing suppliers seems to be a major source for inefficiencies within these supply chains.

5. Managerial Insights and Conclusions

Previous research on supply chain coordination highlights that contracts are a powerful instrument to align the incentives of the supply chain members. Under asymmetric information, these incentive schemes basically ensure the revelation of private information. In this paper we present a laboratory experiment which shows the strengths and the weeknesses of this contracting approach. The experimental results show, that the incentive schemes (formalized by the incentive and participation constraints) ensure the revelation of private information in most cases (79%). Hence, theory predicts the buyer's contract choice behavior fairly well. However, in 17 % of all observations the buyers choose only a nearly optimal contract, namely the indifference contract. In these cases, the theory fails to induce an incentive compatible revelation of information. Surprisingly, the impact of this failure is immense. In the case of our experiment, for example, we can show that the average equilibrium deviations of supply chains would have been decreased by 7.16 points (i.e. 68 %) if buyers had chosen the self-selection contract every time. Note, however, that these numbers exclude all observations, in which the buyers chose the alternative supplier. Hence, 68% of the deviation can be explained by no more than about 7% of the contract choices. If we assume that more inefficiencies arise if the buyer switches to an alternative supplier, the welfare losses would be even higher.

These findings imply, that the indifference-modelling approach can seriously harm the supply performance. Hence we conclude, that managers should not doubtlessly assume that business partners will always take the profit-maximizing action, especially if the payoff differences to the next alternative (or as the case may be of actual indifference) are small. Thus, it seems worthwhile to investigate whether a varying size of the incentive relative to the impact on overall performance can affect the frequency of buyer's self-selection of the equilibrium contract.

Another approach might be the development of "behavioral robust" contracts. These contracts should limit the performance deterioration, caused by out-of-equilibrium behavior.

Another basic assumption within the screening literature is that a probability distribution over the private information is common knowledge. Although the screening literature says little on how the decision-maker forms this probability distribution, it generally is not assumed that communication affects this process.

The results indicate that suppliers are cautious to believe the buyers signal with high probabilities. Thus, we observed persistent, but only slight deviations from equilibrium behavior. However, we find that these deviations seriously harm the supply chain performance.

Yet, even though the deviations from equilibrium behavior cause a performance deviation on the aggregate level, the performance deterioration is not uniform over the observed behavioral types. We identified suppliers who have an unambiguous tendency to believe in the buyers signal, and suppliers who do not believe. In contrast, we observed that some buyers signals are more informative than others. The interaction of these behavioral types indicates that cooperative and trusting behavior can enhance the supply chain performance, whereas deception and mistrust is a major source for inefficiencies. Our experiment shows that the mere fact that signaling exists can be extremely harmful to the performance of the supply chain, if suppliers, who do not trust the buyers' signals, attempt to guess the true cost parameter values. Such totally uncoordinated supply chains, in which buyers' signals are non-informative and suppliers distrust them, exhibit the worst overall performance, with losses for both buyers and suppliers compared to the non-cooperative equilibrium.

Hence, communication seems to be very valuable for supply chains which mangage to estabilish high trust. Yet, managers need to be careful when processing the information they receive. Especially, the misinterpretation of signals may lead to substantial losses for both supply chain parties. In fact, low quality communication seems worse than no communication at all, because it harms supply chain coordination more seriously. Hence, the main implication of our results for supply chain managers is that partial communication marked by deception and suspicion should be avoided altogether. The manager should establish decisions either based on trust or on statistical information such as an a-priori distribution elicited through market research.

Finally, even if we assume that managers in real business operations are well informed of the circumstances under which screening contracts are reasonable, our results will be valuable to managerial decision-making. We show that communication influences the subjective probabilities that are key inputs of the DSS and have a substantial impact on the recommendations made by the DSS. Hence, the human factor seems relevant no matter whether we assume that it affects the supply chain performance directly or indirectly.

Our study is subject to some limitations. First, our model limits the scope of the subjects' actions. Particularly, the limited flexibility of the compensation format rules out some of the possibilities for a better distribution of pareto-improvements of the supply chain. Nonetheless, we did observe non-negligible amounts of cooperative behavior even using this restrictive compensation format. Further research is necessary to examine, whether a broader scope of actions (e.g. more flexibility in the compensation format) can be combined with communication to facilitate pareto-improvements. Furthermore, 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 communications can affect outcomes in other settings (Valley et al. (1998), Brosig et al. (2003)).

All in all, our study indicates that laboratory experiments can be an appropriate technique to disclose the impact of even slight deviations from equilibrium behavior. This means that "behaviorally robust" contracts can be identified experimentally, providing valuable insights both for the improvement of theoretical modelling and of managerial implementation of supply chain concepts.

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6. Appendix

Table 9 Regression results for groups with "believers".

	p_{low}		p_{med}		p_{high}	
	estimator	p-value	estimator	p-value	estimator	p-value
α	34.5	0.000	49.2	0.000	16.3	0.001
β_{low}	22.8	0.000	-12.5	0.005	-10.2	0.040
β_{med}	-6.7	0.024	16.9	0.000	-10.2	0.006
β_{high}	-13.9	0.000	-13	0.000	26.9	0.000
group 1	9.7	0.050	-11.2	0.045	1.5	0.806
group 2	-15.0	0.002	-4.2	0.442	19.3	0.002
group 5	-7.5	0.127	-7.9	0.154	15.4	0.012
group 6	4.7	0.338	-17.9	0.001	13.2	0.032
group 10	0.7	0.878	-10.7	0.053	9.9	0.103
group 11	0.0	0.993	-9.3	0.096	9.2	0.134
group 12	-9.3	0.056	-0.1	0.982	9.5	0.121
group 14	-4.7	0.344	-9.6	0.087	14.3	0.022
group 18	-14.8	0.003	-29.5	0.000	44.3	0.000
group 19	-12.7	0.010	-4.2	0.444	16.9	0.006
group 21	-4.7	0.333	-9.6	0.083	14.4	0.019
group 22	5.5	0.259	-21.2	0.000	15.7	0.011
group 23	3.4	0.490	0.3	0.962	-3.7	0.552
group 24	-15.9	0.001	-24.8	0.000	40.7	0.000
R^2	0.43		0.48		0.58	

Table 10 Regression results for groups with "non-believers".

	p_{low}		p_{med}		p_{high}	
	estimator	p-value	estimator	p-value	estimator	p-value
α	57.4	0.000	5.5	0.331	37.1	0.000
β_{low}	10.9	0.075	9.3	0.099	-20.2	0.001
β_{med}	2.9	0.564	13.2	0.004	-16.1	0.001
β_{high}	-1.4	0.736	3.5	0.359	-2.1	0.600
group 2	-37.3	0.000	37.5	0.000	-0.2	0.976
group 4	-18.9	0.004	16.8	0.006	2.2	0.731
group 7	-37.5	0.000	48.7	0.000	-11.2	0.069
group 13	-28.6	0.000	20.8	0.001	7.7	0.240
group 15	-32.7	0.000	20.2	0.002	12.5	0.062
group 16	-39.5	0.000	50.1	0.000	-10.6	0.129
group 17	-25	0.000	34.8	0.000	-9.8	0.150
group 20	-29.9	0.000	24.9	0.000	5.0	0.442
R^2	0.26		0.45		0.24	

Table 11 Crosstabs aggregated.

	Signal				
holding costs	No Signal	H_{low}	H_{med}	H_{high}	Total
h_{low}	34	20	26	60	140
	7.08%	4.17%	5.42%	12.50%	29.17%
h_{med}	40	6	60	83	189
	8.33%	1.25%	12.50%	17.29%	39.38%
h_{high}	33	16	10	92	151
	6.88%	3.33%	2.08%	19.17%	31.46%
Total	107	42	96	235	480
	22.29%	8.75%	20.00%	48.96%	100.00%
	Signal				
contract	No Signal	H_{low}	H_{med}	H_{high}	Total
AS	16	9	6	31	62
	3.33%	1.88%	1.25%	6.46%	12.92%
low	32	18	21	51	122
	6.67%	3.75%	4.38%	10.63%	25.42%
med	38	9	59	78	184
	7.92%	1.88%	12.29%	16.25%	38.33%
high	21	6	10	75	112
	4.38%	1.25%	2.08%	15.63%	23.33%
Total	107	42	96	235	480
	22.29%	8.75%	20.00%	48.96%	100.00%
	contract				
holding costs	AS	low	med	high	Total
h_{low}	1	120	16	3	140
	0.21%	25.00%	3.33%	0.63%	29.17%
h_{med}	9	2	164	14	189
	1.88%	0.42%	34.17%	2.92%	39.38%
h_{high}	52	0	4	95	151
	10.83%	0.00%	0.83%	19.79%	31.46%
Total	62	122	184	112	480
	12.92%	25.42%	38.33%	23.33%	100.00%

Contract low (med, high) corresponds to the contract for the low holding cost level $h_{low}, (h_{med}, h_{high})$. Contract AS refers to the alternative supplier.

Instruction

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

Starting position

In a supply chain, composed of a buyer and a supplier, new supply terms are being negotiated.

The buyer faces a demand of one unit per period. The previous contract provided a just-in-time delivery, the buyers order size was exactly one unit per period (Q=1). However, this just-in-time contract is expired in the meantime. Hence, your task is to negotiate a new supply contract.
The supplier faces fixed costs of 800 per delivery.

Example: The fixed costs amount to 800. If the order size is Q = 1, the supplier bears costs of 800 per item, if Q = 2, the costs amount to 400 per item, if Q = 3 the cost amount to 266.67 and so on.

The buyer faces holding costs, as stock on hand averages out at half of the order size.
Example: The holding cost amount to 5 (per item and period). If the order size is Q = 1, the buyer faces holding cost of 2.5. If the order size is increased, the holding costs increase as well, e.g. if Q = 2 to 5 or if Q = 3 to 7.5 (always for holding costs of 5 per unit and period). Furthermore, the buyer is always allowed to choose an alternative supplier. This option causes costs of 5 per unit. The supplier is aware of this option as well.

The just-in-time delivery causes high costs for the supplier, as he faces fixed costs of 800 per unit. Hence, the supplier tries to induce higher order sizes by offering a special contract type.

The supplier compensates the buyers increasing holding costs (which correspond to a higher order size) through an additional side payment. This payment is to prevent the buyer from choosing the alternative supplier.

Your task: Agree upon new supply conditions.

Information availability:

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

There are three possible types of holding costs realisations, i.e. 1, 3 and 5 per unit 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	3	5
probability	30%	40%	30%

Contract type:

The suppliers offers consist of an order size Q and a respective side payment. The buyer knows his true holding costs before the supplier offers a contract. This holding cost is not known to the supplier. Yet, the buyer has the opportunity to signal his holding costs. This signal can, but does not necessarily need to, be truthful.

Based on the buyers signal, the supplier can adjust his beliefs about the buyers holding costs. On this basis, three offers are generated, from which the buyer can choose one. This offers maximize the suppliers expected profits (as long as his adjusted beliefs are accurate). The buyer chooses no contract, if he decides for the alternative supplier.

Example: The buyer has drawn holding costs of 1. He now has the possibility to signal 1, 3 or 5. Furthermore, he can give No signal.

If the buyer signals holding costs of 5, and if the supplier believes in this signal, the supplier will adjust his subjective probabilities to:

subjective probability holding costs 1	0
subjective probability holding costs 3	0
subjective probability holding costs 5	100

The supplier is allowed to adjust his expectations discretionary (with the choice being limited to steps of 10%), e.g.

subjective probability holding costs 1	10
subjective probability holding costs 3	40
subjective probability holding costs 5	50

Alternatively, the supplier can abstain from adjusting his expectations:

subjective probability holding costs 1	30
subjective probability holding costs 3	40
subjective probability holding costs 5	30

How are the contract corresponding profits calculated?

The suppliers offers differ with his subjective beliefs regarding the buyers holding costs. The table on the last page of this instruction summarizes all relevant data (order sizes, side payments and profits) in dependence on the suppliers expectations.

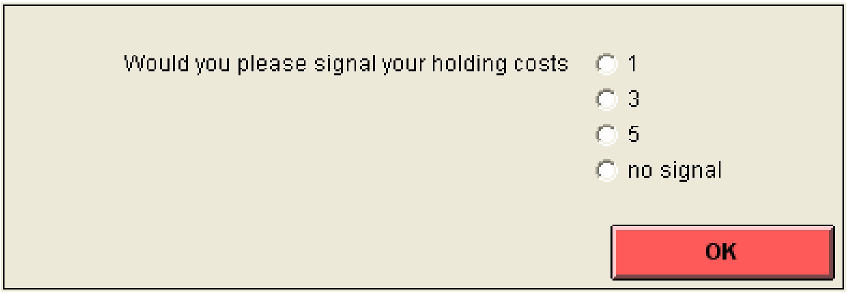
The buyers profits amount to a fixed revenue per period (85) minus the respective holding costs plus the suppliers side payment. If the buyer chooses the alternative supplier, he faces cost of

5 per unit. For each subjective probability distribution, a computer screen shows the maximum profit, which the buyer can realize dependent on his holding costs. Hence, the buyer can sample the consequences of the alternative suppliers beliefs (the beneath example is basing on a holding cost of 1).

subjective probability of holding costs

1	3	5	Profit
0	0	100	113.89
10	40	50	114.30
30	40	30	109.52

The buyer can base his signal on this information.



The suppliers profit amounts to a fixed revenue per period (200) minus the fixed costs per unit and minus the side payment. If the buyer chooses the alternative supplier, the suppliers respective round profit amounts to 0.

On a computer screen the supplier sees the contract specific profits dependent on his subjective beliefs. The resulting profits though depend on the buyers actual contract choice.

subjective probability of holding costs			Profit maximum for buyer with holding costs of:		
			1	3	5
1	3	5	Profit contract 1	Profit contract 2	Profit contract 3
0	0	100	128.14	115.54	115.46
10	40	50	128.20	120.19	114.19
30	40	30	132.98	121.23	110.58

Yet, the supplier knows, that for the buyer with holding cost 1 the contract choice 1, that for the buyer with holding cost 3 the contract choice 2 and that for the buyer with holding cost 5 the contract cost 3 yields in the maximum round profit.

The supplier chooses an offer by selecting the respective array and confirming this selection.

Please notice, the computer screen does just summarize the data in the table on the last page of this instruction. All decision relevant data can be looked up there as well.

How many rounds are being played?

20 rounds are going to be played. The buyers holding costs a drawn independently in every round.

Who are your team-mates?

Your role as supplier/buyer is the same in every round. Your team-mate does not change in the course of the experiment. His identity is confidential throughout and after the experiment.

How is the experimental pay-off calculated?

The experimental pay-off will take place at the end of the experiment. Your pay-off results from the sum of the round profits multiplied by 0.01, i.e. every experimental monetary unit exchanges to 1cent.

If there are any questions, please raise your hand.

Please leave the instructions on your place after the experiment. Good luck.

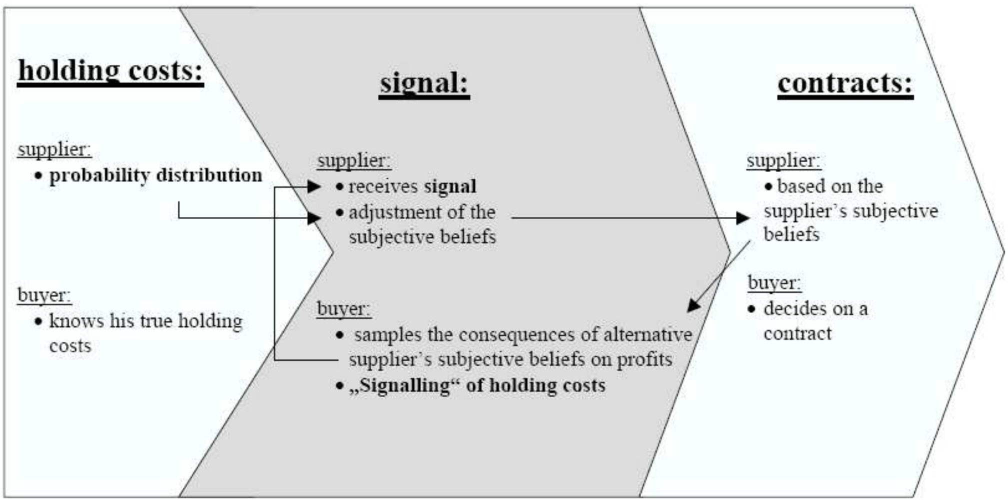


Table 12 This table was handed out on sheets DIN A3.

									profit supplier			profit buyer								
			contract 1		contract 2		contract 3		contract 1	contract 2	contract 3	contract 1			contract 2			contract 3		
subjective probability distribution			profit maximum for buyer with holding costs 1		profit maximum for buyer with holding costs 3		profit maximum for buyer with holding costs 5					profit maximum for buyer with holding costs			profit maximum for buyer with holding costs			profit maximum for buyer with holding costs		
1	3	5	order size	side payment	order size	side payment	order size	side payment				1	3	5	1	3	5	1	3	5
1	0	0	40,00	19,42	no contract offer				160,58	0,00	0,00	84,42	44,42	4,42	80	80	80	80	80	80
0,9	0,1	0	40,00	25,99	8,73	10,25			154,01	98,11	0,00	90,99	50,99	10,99	90,89	82,16	73,43	80	80	80
0,8	0,2	0	40,00	29,32	12,06	15,25			150,68	118,42	0,00	94,32	54,32	14,32	94,22	82,16	70,1	80	80	80
0,7	0,3	0	40,00	31,71	14,45	18,83			148,29	125,81	0,00	96,71	56,71	16,71	96,61	82,16	67,71	80	80	80
0,6	0,4	0	40,00	33,59	16,33	21,65			146,41	129,36	0,00	98,59	58,59	18,59	98,49	82,16	65,83	80	80	80
0,5	0,5	0	40,00	35,15	17,89	24,00	no contract offer		144,85	131,28	0,00	100,15	60,15	20,15	100,06	82,17	64,28	80	80	80
0,4	0,6	0	40,00	36,48	19,22	25,98			143,52	132,40	0,00	101,48	61,48	21,48	101,37	82,15	62,93	80	80	80
0,3	0,7	0	40,00	37,63	20,37	27,71			142,37	133,02	0,00	102,63	62,63	22,63	102,53	82,16	61,79	80	80	80
0,2	0,8	0	40,00	38,64	21,38	29,23			141,36	133,35	0,00	103,64	63,64	23,64	103,54	82,16	60,78	80	80	80
0,1	0,9	0	40,00	39,54	22,28	30,59			140,46	133,50	0,00	104,54	64,54	24,54	104,45	82,17	59,89	80	80	80
0	1	0	40,00	40,89	23,09	31,80			139,11	133,55	0,00	105,89	65,89	25,89	105,26	82,17	59,08	80	80	80
0,9	0	0,1	40,00	28,00	6,45	11,12	6,25	10,72	152,00	64,85	61,28	93	53	13	92,9	86,45	80	92,6	86,35	80,1
0,8	0,1	0,1	40,00	32,82	9,18	17,31	8,34	15,95	147,18	95,54	88,13	97,82	57,82	17,82	97,72	88,54	79,36	96,78	88,44	80,1
0,7	0,2	0,1	40,00	36,29	12,65	22,51	8,34	15,95	143,71	114,25	88,13	101,29	61,29	21,29	101,19	88,54	75,89	96,78	88,44	80,1
0,6	0,3	0,1	40,00	38,76	15,12	26,22	8,34	15,95	141,24	120,87	88,13	103,76	63,76	23,76	103,66	88,54	73,42	96,78	88,44	80,1
0,5	0,4	0,1	40,00	40,70	17,06	29,12	8,34	15,95	139,30	123,99	88,13	105,7	65,7	25,7	105,59	88,53	71,47	96,78	88,44	80,1
0,4	0,5	0,1	40,00	42,29	18,65	31,52	8,34	15,95	137,71	125,58	88,13	107,29	67,29	27,29	107,2	88,55	69,9	96,78	88,44	80,1
0,3	0,6	0,1	40,00	43,64	20,00	33,54	8,34	15,95	136,36	126,46	88,13	108,64	68,64	28,64	108,54	88,54	68,54	96,78	88,44	80,1
0,2	0,7	0,1	40,00	44,81	21,17	35,29	8,34	15,95	135,19	126,92	88,13	109,81	69,81	29,81	109,71	88,54	67,37	96,78	88,44	80,1
0,1	0,8	0,1	40,00	45,83	22,19	36,82	8,34	15,95	134,17	127,13	88,13	110,83	70,83	30,83	110,73	88,54	66,35	96,78	88,44	80,1
0	0,9	0,1	40,00	47,67	23,09	38,18	8,34	15,95	132,33	127,17	88,13	112,67	72,67	32,67	111,64	88,55	65,46	96,78	88,44	80,1
0,8	0	0,2	40,00	32,96	8,93	17,32	8,73	16,92	147,04	93,09	91,44	97,96	57,96	17,96	97,86	88,93	80	97,56	88,83	80,1
0,7	0,1	0,2	40,00	36,50	10,70	21,75	10,50	21,35	143,50	103,48	102,46	101,5	61,5	21,5	101,4	90,7	80	101,1	90,6	80,1
0,6	0,2	0,2	40,00	39,73	13,33	26,29	11,09	22,84	140,27	113,69	105,02	104,73	64,73	24,73	104,63	91,3	77,97	102,3	91,21	80,12
0,5	0,3	0,2	40,00	42,29	15,89	30,14	11,09	22,84	137,71	119,51	105,02	107,29	67,29	27,29	107,2	91,31	75,42	102,3	91,21	80,12
0,4	0,4	0,2	40,00	44,28	17,89	33,13	11,09	22,84	135,72	122,15	105,02	109,28	69,28	29,28	109,19	91,3	73,41	102,3	91,21	80,12
0,3	0,5	0,2	40,00	45,91	19,52	35,57	11,09	22,84	134,09	123,45	105,02	110,91	70,91	30,91	110,81	91,29	71,77	102,3	91,21	80,12
0,2	0,6	0,2	40,00	47,28	20,89	37,63	11,09	22,84	132,72	124,07	105,02	112,28	72,28	32,28	112,19	91,3	70,41	102,3	91,21	80,12
0,1	0,7	0,2	40,00	48,46	22,07	39,39	11,09	22,84	131,54	124,36	105,02	113,46	73,46	33,46	113,36	91,29	69,22	102,3	91,21	80,12
0	0,8	0,2	40,00	50,82	23,09	40,94	11,09	22,84	129,18	124,41	105,02	115,82	75,82	35,82	114,4	91,31	68,22	102,3	91,21	80,12
0,7	0	0,3	40,00	36,63	10,77	21,91	10,57	21,51	143,37	103,81	102,80	101,63	61,63	21,63	101,53	90,76	79,99	101,23	90,66	80,09
0,6	0,1	0,3	40,00	39,52	12,21	25,53	12,01	25,13	140,48	108,95	108,26	104,52	64,52	24,52	104,43	92,22	80,01	104,13	92,12	80,11
0,5	0,2	0,3	40,00	42,31	14,14	29,28	12,87	27,26	137,69	114,14	110,58	107,31	67,31	27,31	107,21	93,07	78,93	105,83	92,96	80,09
0,4	0,3	0,3	40,00	44,97	16,80	33,27	12,87	27,26	135,03	119,11	110,58	109,97	69,97	29,97	109,87	93,07	76,27	105,83	92,96	80,09
0,3	0,4	0,3	40,00	47,02	18,86	36,35	12,87	27,26	132,98	121,23	110,58	112,02	72,02	32,02	111,92	93,06	74,2	105,83	92,96	80,09
0,2	0,5	0,3	40,00	48,68	20,52	38,84	12,87	27,26	131,32	122,17	110,58	113,68	73,68	33,68	113,58	93,06	72,54	105,83	92,96	80,09
0,1	0,6	0,3	40,00	50,07	21,91	40,93	12,87	27,26	129,93	122,56	110,58	115,07	75,07	35,07	114,98	93,07	71,16	105,83	92,96	80,09
0	0,7	0,3	40,00	52,04	23,09	42,71	12,87	27,26	127,96	122,64	110,58	117,04	77,04	37,04	116,17	93,08	69,99	105,83	92,96	80,09
0,6	0	0,4	40,00	39,62	12,26	25,65	12,06	25,25	140,38	109,10	108,42	104,62	64,62	24,62	104,52	92,26	80	104,22	92,16	80,1
0,5	0,1	0,4	40,00	42,09	13,50	28,74	13,29	28,34	137,91	112,00	111,46	107,09	67,09	27,09	106,99	93,49	79,99	106,7	93,41	80,12
0,4	0,2	0,4	40,00	44,56	15,12	32,02	14,14	30,46	135,44	115,07	112,96	109,56	69,56	29,56	109,46	94,34	79,22	108,39	94,25	80,11
0,3	0,3	0,4	40,00	47,33	17,89	36,17	14,14	30,46	132,67	119,11	112,96	112,33	72,33	32,33	112,23	94,34	76,45	108,39	94,25	80,11
0,2	0,4	0,4	40,00	49,44	20,00	39,34	14,14	30,46	130,56	120,66	112,96	114,44	74,44	34,44	114,34	94,34	74,34	108,39	94,25	80,11
0,1	0,5	0,4	40,00	51,14	21,69	41,88	14,14	30,46	128,86	121,24	112,96	116,14	76,14	36,14	116,04	94,35	72,66	108,39	94,25	80,11
0	0,6	0,4	40,00	53,53	23,09	43,98	14,14	30,46	126,47	121,37	112,96	118,53	78,53	38,53	117,44	94,35	71,26	108,39	94,25	80,11
0,5	0	0,5	40,00	42,17	13,53	28,83	13,33	28,43	137,83	112,04	111,55	107,17	67,17	27,17	107,07	93,54	80,01	106,77	93,44	80,11
0,4	0,1	0,5	40,00	44,32	14,61	31,53	14,41	31,13	135,68	113,71	113,35	109,32	69,32	29,32	109,23	94,62	80,01	108,93	94,52	80,11
0,3	0,2	0,5	40,00	46,75	16,33	34,81	15,12	32,90	133,25	116,20	114,19	111,75	71,75	31,75	111,65	95,32	78,99	110,34	95,22	80,1
0,2	0,3	0,5	40,00	49,63	19,22	39,14	15,12	32,90	130,37	119,24	114,19	114,63	74,63	34,63	114,53	95,31	76,09	110,34	95,22	80,1
0,1	0,4	0,5	40,00	51,80	21,38	42,39	15,12	32,90	128,20	120,19	114,19	116,8	76,8	36,8	116,7	95,32	73,94	110,34	95,22	80,1
0	0,5	0,5	40,00	56,04	23,09	44,96	15,12	32,90	123,96	120,39	114,19	121,04	81,04	41,04	118,42	95,33	72,24	110,34	95,22	80,1
0,4	0	0,6	40,00	44,39	14,65	31,62	14,45	31,22	135,61	113,77	113,42	109,39	69,39	29,39	109,3	94,65	80	109	94,55	80,1
0,3	0,1	0,6	40,00	46,32	15,61	34,02	15,41	33,62	133,68	114,73	114,47	111,32	71,32	31,32	111,22	95,61	80	110,92	95,51	80,1
0,2	0,2	0,6	40,00	49,08	17,89	37,93	15,89	34,84	130,92	117,35	114,81	114,08	74,08	34,08	113,99	96,1	78,21	111,9	96,01	80,12
0,1	0,3	0,6	40,00	52,08	20,89	42,43	15,89	34,84	127,92	119,27	114,81	117,08	77,08	37,08	116,99	96,1	75,21	111,9	96,01	80,12
0	0,4	0,6	40,00	56,98	23,09	45,74	15,89	34,84	123,02	119,61	114,81	121,98	81,98	41,98	119,2	96,11	73,02	111,9	96,01	80,12
0,3	0	0,7	40,00	46,37	15,64	34,09	15,44	33,69	133,63	114,76	114,50	111,37	71,37	31,37	111,27	95,63	79,99	110,97	95,53	80,09
0,2	0,1	0,7	40,00	48,11	16,51	36,26	16,31	35,86	131,89	115,28	115,09	113,11	73,11	33,11	113,01	96,5	79,99	112,71	96,4	80,09
0,1	0,2	0,7	40,00	51,83	20,00	41,73	16,53	36,42	128,17	118,27	115,18	116,83	76,83	36,83	116,73	96,73	76,73	113,16	96,63	80,1
0	0,3	0,7	40,00	57,48	23,09	46,37	16,53	36,42	122,52	118,98	115,18	122,48	82,48	42,48	119,83	96,74	73,65	113,16	96,63	80,1
0,2	0	0,8	40,00	48,16	16,53	36,32	16,33	35,92	131,84	115,28	115,09	113,16	73,16	33,16	113,06	96,53	80	112,76	96,43	80,1
0,1	0,1	0,8	40,00	50,24	17,89	39,09	17,06	37,74	129,76	116,19	115,37	115,24	75,24	35,24	115,15	97,26	79,37	114,21	97,15	80,09
0	0,2	0,8	40,00	57,29	23,09	46,90	17,06	37,74	122,71	118,45	115,37	122,29	82,29	42,29	120,36	97,27	74,18	114,21	97,15	80,09
0,1	0	0,9	40,00	49,79	17,34	38,36	17,14	37,96	130,21	115,50	115,37	114,79	74,79	34,79	114,69	97,35	80,01	114,39	97,25	80,11
0	0,1	0,9	40,00	55,90	23,09	47,34	17,50	38,86	124,10	118,01	115,43	120,9	80,9	40,9	120,8	97,71	74,62	115,11	97,61	80,11
0	0	1	40,00	51,86	18,09	40,24	17,89	39,82	128,14	115,54	115,46	116,86	76,86	36,86	116,2	98,11	80,02	115,88	97,99	80,1