The effect of communication media on information sharing in supply chains

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Abstract:

We study in laboratory experiments how communication media affects cooperation in a supply chain when the buyer has private information about the end customer demand. We show that coordinating contracts (i.e. quantity discount) result in almost efficient outcomes if verbal communication about the strategic extent of information sharing takes place before contracting. We further show that our results are not due to reputational building mechanism of repeated interaction.

Keywords: asymmetric information, cheap talk, trust, trustworthiness, behavioral operations management.

1 Introduction

The flow of Information is one of the most important challenges for supply chain management. To share information, many firms have recently experimented with advanced planning systems (APS), or collaborative planning, forecasting and replenishment (CPFR) initiatives. For example, Wal-Mart and Sara Lee Branded apparel successfully implemented a CPFR pilot. The involved parties reported an increase of sales of 32% after 24 week of implementation (1999, Kurtuluş 2017). Nevertheless, while there is no doubt about the potential benefits from information sharing, many firms are reluctant to share demand information with their suppliers (Gümüş 2017). Stein (1998) reports that managers often fear that information sharing may turn into a competitive disadvantage, given the strategic supply chain environment. Similar, Verity (1996) notes the managers' concerns of increasing prices when forecast information are shared. Fraser (2003) surveys 120 firms and outlines that 42% of the respondents perceive a lack of trust as one of the largest obstacle hindering firm's adoption of information sharing systems.

The goal of this paper is to guide managers which communication media to use (textual vs. verbal, anonymous vs. identification) and which topics to address at the very beginning of an information sharing initiative that may be plagued by strategic incentives to misrepresent demand information. We are comparing different means of communication in a typical, yet stylized, supply chain bargaining situation characterized by (a) sequential moves, i.e., contract offer by the supplier and order quantity or rejection by buyer, (b) non-linear quantity discounts schemes that reduce informational rents and efficiency losses from double marginalization (Kolay et al. 2004), and (c) efficiency losses when information is used strategically.

In line with previous research on communication media on social dilemmas (see literature review), we rely on controlled laboratory experiments with a student subject pool. This method allows to internally valid establish the root-cause effects of different communication media in the pre-phase of an information sharing initiative. Although we believe that research on communication media can benefit from other empirical approaches (e.g., interview studies), we see one central advantage in experiments: the critical aspects of underlying economic incentives and information availability can be tightly controlled. To this end, it seems at least difficult to discern whether analytical forecasts (e.g., from an ERP systems) are misrepresented due to good will (e.g., factoring in expert knowledge) or due to strategic considerations.

We first replicate the prior research findings that information sharing improves supply chain efficiency. We therefore compare a baseline treatment without information sharing to a reference treatment with

information sharing (i.e. subject are allowed to send a signal regarding their private demand information, i.e., “low demand” or “high demand”). We then move forward by comparing different forms of pre-phase communication, i.e. chats, verbally but anonymous, and videoconferences, to this reference treatment. In the pre-phase, the supply chain members may, for example, discuss how they are planning to share and process information and/or how to divide the bargaining pie.

We find that particularly any form of verbal communication supports cooperative play in the supply chain. The analysis of the communication content reveals that communication is especially effective when the game relevant aspects of trustworthiness, trust, and the allocation of profits is directly addressed. It seems that the main shortcoming of the text chat medium is that these aspects are less often addressed than under the verbal communication forms. The positive performance effect of verbal pre-phase communication can be further strengthened by providing training to subjects that thoroughly explains the strategic issues and coordination potential when sharing information.

Our research complements previous laboratory research on information sharing in supply chains. One insights from this stream of literature is that supply chains benefit from information sharing, yet, efficient outcomes are generally not achieved (Özer et al. 2011, Özer et al. 2014, Hyndman et al. 2013, Spiliotopoulou et al. 2016). We show that the efficiency enhancing effects of information sharing can be overwhelmingly leveraged by any form of verbal communication taking place prior to actually sharing the private demand information.

The paper is organized as follows: Section 2 reviews the related literature. Section 3 outlines the results from game-theoretic model. Section 4 introduces our experimental design and implementation. Section 5 summarizes our results. Section 6 describe the design and the results from the experiments on reputational effects. Section 7 summarizes the results and concludes the paper.

2 Literature review

2.1 Supply chain coordination and behavioral operations management

Several recent laboratory studies test the effectiveness of non-linear contracts, such as quantity discounts, to coordinate the supply chain both under full information (Ho and Zhang 2008, Lim and Ho 2007) and under asymmetric information (Kalkanci et al. 2011, 2014, Johnsen et al. 2017, Inderfurth et al. 2013, Sadrieh and Voigt 2017). A general pattern in these experiments is that non-linear contracts reduce efficiency losses, but not to the extent expected by standard game theory. The poor performance often

comes from a substantial amount of buyers' contract rejections. Behavioral biases such as bounded rationality (Kalkanci et al. 2011, Wu and Chen 2014) and social preferences (Loch and Wu 2008, Katok and Pavlov 2013, Johnsen et al. 2017) have been identified as the main reasons.

Another source of inefficiency comes from asymmetric information in the supply chain. In the game-theoretic benchmark with rational and profit-maximizing actors, private information will be used strategically and therefore information will not be shared truthfully. Receivers, therefore, ignore any shared information (cheap talk). One stream of research tested this benchmark in supply chains operating under wholesale price contracts (Özer et al. 2011, Özer et al. 2014, Hyndman et al. 2013, Spiliotopoulou et al. 2016, Özer et al. 2018) and non-linear contracting schemes (Inderfurth et al. 2013). All of these studies show that the cheap-talk benchmark is too pessimistic but not obsolete. On average, allowing supply chain parties to share private information enhances performance. Yet, efficiency losses prevail since there is a significant amount of deception and mistrust. All of these lab studies use relatively simple communication devices, i.e., a one-sided textual signals such as a demand forecast (high/low) or a cost position (high/low). Özer et al. (2018) compare the effects of different forms of assistance processes (information sharing, advice provision, task delegation) on trust and trustworthiness in supply chains. Under information sharing the better informed party can share her private information through a one-sided signal, under advice provision the better informed party can give a recommendation for the decision, and under task delegation, the better informed party makes the actual decision from a set of decisions permitted beforehand by the partner. They find that trust and trustworthiness is highest under information sharing and worst under task delegation. In contrast to this study, we use the same assistance process (information sharing) in all treatments but utilize several different communication forms (face-to-face/ telephone/e-mail) to investigate how the media itself affects trust and trustworthiness in the information sharing process.

Means of communication have been extensively investigated in the economic literature. We next link our supply chain environment to this literature and review the insights with respect to communication and information sharing. There are five fundamental economic games related to our supply chain model: public good game, prisoner's dilemma game, sender-receiver game, investment game, and ultimatum bargaining game.

2.2 Sender-receiver game /cheap talk game

In the sender-receiver game a la Crawford and Sobel 1982, a sender has a private information which is relevant to the outcome of both the receiver and the sender. The sender can send a non-verifiable

message to the receiver. The receiver, then, makes a decision effecting the outcome of both players. Basically, the message is expected to be less informative, as receiver's and sender's preferences become less aligned. Our supply chain model covers the the sender-receiver game in which the preferences of sender and receiver are opposed. In this case, the sender's messages are uninformative and, thus, ignored by the receiver in the game theoretic solution. The only equilibria are "babbling" equilibria (Crawford 1998).

The game theoretic solution of this games has been tested in many studies. A robust finding is that a substantial number of players tend to overcommunicate, i.e., the messages are more informative than the standard model predicts (Kawagoe and Takizawa 2009, Erat and Gneezy 2012, Gneezy 2005, Sánchez-Pagés and Vorsatz 2007, Hurkens and Kartik 2009, Wang et al. 2010). While the above mentioned studies are manipulations of the degree of preference alignment, there is little research that considers other forms of communication than restricted messages. Lundquist et al. (2009) observe that trustworthiness increases in free-form text communication compared to restricted text communication. Holm and Kawagoe (2010) investigate subjects lying behavior under face-to-face conditions and find that the previous finding of too much truth telling also occurs in the face-to-face condition. van Zant and Kray (2014) compare subjects trustworthiness under face-to-face condition with an anonymous condition. They find that subjects are more truthful when interacting face-to-face than in an anonymous conditions. In contrast to our model, these studies do not consider efficiency and bargaining aspects, while our model allows for pareto improvements when truthful reports meet trusting and profit sharing suppliers.

2.3 Investment game

In the investment game an investor has a monetary endowment and decides about how much of this endowment to send (investment decision) to the allocator. The amount of money sent is usually tripled. The allocator then decides on how much of the received money to keep and how much to return (Berg et al. 1995). The sum of payoffs is maximized if the investor hands over the whole endowment to the allocator. Assuming rationality and the goal to maximize individual profits, though, the investor anticipates that the allocator will not return money and refrains from sending money either.

Similar, in our supply chain model when the buyer (investor) decides to share her private demand information with the supplier (allocator), she risks that the supplier is fully self-centered and increases the prices to reap all the supply chain profits. The main difference to our setup is that in the investment game all players have full information, while our model considers asymmetric information as the supplier is uninformed about the demand condition.

Laboratory experiments with the investment game show that the inefficient benchmark in the investment game is too pessimistic. Investors often hand over money (trust) and some of the allocators return more than their counterpart sent (trustworthiness) (Berg et al. 1995).

There are several experiments that show that one sided text messages have a positive effect on the investment and return rates for both directions either from the investor to the allocator (Ellingsen and Johannesson 2004, Charness and Dufwenberg 2006) or from the allocator to the investor (Glaeser et al. 2000, Ellingsen and Johannesson 2004, Charness and Dufwenberg 2006, Bracht and Feltovich 2009, Servátka et al. 2011)

Another stream considers different pre-play communication forms in the investment game. Ben-Ner and Putterman (2009) and Ben-Ner et al. (2011) find that pre-play text chat communication increases the investment and return rates significantly compared to a condition with no communication. Fiedler and Haruvy (2009) observe similar results for a text chat in a virtual second life environment. Fiedler (2009) compares treatments with either pre-play text chat or audio chat. She observed no significant differences between the audio and text chat treatments.

Buchan et al. (2006) let subjects meet and engage in pre-play face-to-face communication. While they prohibited task relevant content during the communication phase, they observed that investment and return rates increase when communication is personal compared to a treatment where only impersonal communication is allowed. We are not aware of a study that compares face-to-face to other forms of communication in the investment game.

2.4 Ultimatum game

In the standard ultimatum game a proposer decides about the split of a "pie" that he offers to his responder. The responder can either accept or reject the offer. If the responder accepts the offer, the pie is divided according the proposal. If the responders rejects the offer, both earn zero profits (Güth et al. 1982). Similar in our supply chain model the supplier (proposer) makes a take-it-or-leave-it ultimatum offer to the buyer (receiver). In contrast to ultimatum game, the pie size in our supply chain setup is not "constant" but varies due to the suppliers' trade-off between allocative efficiency and informational rents to be paid.

While the game theoretic prediction for the ultimatum game is that responders accept every offer greater than zero, there is the experimental finding that offers of less than 1/3 of the pie are usually rejected. The proposer's modal offer is often found to be about half of the pie (Güth 1995, Güth and Kocher 2014).

One stream of literature considers one-sided text messages in the ultimatum game (Andersson et al. 2010, Rankin 2003, Xiao and Houser 2005). Andersson et al. (2010) give proposers the ability to send a message together with their offers to the responders. They find that the agreement rates increase when messages are allowed. In the experiments of Rankin (2003) the responders have the ability to send a request to the proposers before the proposers decide about their offer. They observe that responders are demanding and request on average more than half of the pie. Surprisingly, this is the only study we identified in which communication significantly destroys efficiency, due to lower agreement rates, compared to a treatment without communication. Xiao and Houser (2005) allow the responders to send a text message together with their acceptance/rejection decision. They find that agreement rates increase significantly when messages are allowed, because responders can express their feelings about an unfair offer through the messages, while in the condition without communication responders are constrained to express their feeling through a rejection decision.

Another stream investigates the effect of more natural face-to-face communication (Roth 1995, Schmidt and Zultan 2005, Zultan 2012, Greiner et al. 2014). Roth (1995) shows that agreement rates increase when subjects are allowed to engage in face-to-face communication before playing the ultimatum game compared to a no communication treatment. Schmidt and Zultan (2005) and Zultan (2012) replicate this finding and expand the results by observing that responders have higher acceptance thresholds in the face-to-face condition, showing that responders are more demanding when communication is allowed. Greiner et al. (2014) compare the effect of text-chat and face-to-face communication with a no communication treatment. They observe significantly higher agreement rates in the communication treatments and, similar to our results, find a more pronounced effect in the face-to-face than in the text-chat treatment.

Another stream of literature considers asymmetric information (e.g., pie size, outside option) in the ultimatum game with cheap talk. While the experiments primarily investigate proposers who are privately informed about the pie size (Besancenot et al. 2013, and Kriss et al. 2013, Vesely 2014, Chavanne and Ferreira 2017), a few authors consider the case when the responder has the information advantage, which is more related to our model.

Koning et al. (2011) privately inform the responders about the exchange value of the chips to be allocated. The responders can send a message to the proposers prior to the allocation decision. They observed that about 38% of the subjects are deceptive. Croson et al. (2003) and Boles et al. (2000) privately inform the responder about his outside option. The authors, too, find that responders often send deceptive messages

(one-sided) to take advantage of the information asymmetry. Those three studies do not compare the results to treatments without communication. As such, identifying internally valid root cause effects of communication are, in contrast to our study, not feasible.

In a different bargaining game (called acquiring a firm), Valley et al. (1998) compare the effect of face-to-face, verbal and written negotiations on the bargaining outcome. In their game a seller is about to sell his firm to a buyer. The seller is privately informed about the value of his firm. The firm's value increases by fifty percent if trade occurs. While the game theoretic prediction is that no transaction occurs, they observe that trade is significantly more likely under face-to-face and verbal negotiation than under written negotiation. The main difference to our study is that in their model the seller is the better informed party while it is the buyer in our model.

2.5 Prisoner's dilemma and public good game

The supplier and buyer in our game are in a social dilemma, since if both cooperate, they can be both better off relative to when both defect. However, if one player defects while the other cooperates, the defecting party maximizes his outcome.

Most of the research on communication concerns two social dilemma games: the prisoner's dilemma and the public good game. The primary focus of this research is if pre-play communication helps subjects to anticipate the other player's intentions regarding their moves in the upcoming game. One primary insight of the literature is that the effect of the pre-play communication strongly depends on the media used (Brandts and Charness 2003).

There is ample experimental evidence that pre-play face-to-face communication has a strong effect on the subjects' propensity to cooperate in a social dilemma game (see the seminal paper of Dawes et al. 1977 and the typical study of Isaac and Walker 1988 and Isaac et al. 1985 and for a review Bordia 1997). Other studies investigate the role of textual pre-play communication (Duffy and Feltovich 2002).

However, since different experimental setups prevent an internally valid comparison of root-cause effects, a few authors compare the impact of different pre-play communication forms under the same experimental conditions.

Brosig et al. (2003) decompose the cooperation enhancing effect of communication. They observe that face-to-face communication significantly increase subjects' cooperative play compared to a no communication baseline treatment. By contrast, in the audio-conference they observe only slightly more cooperation and the visual identification showed no systematic effect. Furthermore, they investigate the

effect of a video-lecture that explained the standard public good game, characterizing both the subgame-perfect equilibrium (zero investment in the public good) and the outcome that maximizes group payments. They do not find a significant effect of the lecture. In line with our findings, Bos et al. (2002) and Bochet et al. (2006) observe that text based communication induces less cooperative play than an audio- or videoconference or a face-to-face meeting.

The main difference between these studies and ours is that players in the prisoner's dilemma games and public good games move simultaneously while players move sequentially in our game. Another difference is that the allocation of profits in the public good or prisoner's dilemma game is given by the rules of the game, while in our game it is endogenous, i.e., an outcome of the bargain process.

Note, Harrison and Hirshleifer (1989) introduced the so called best shot game -- a public good experiment with sequential moves. In the best shot game two person sequentially state their contribution to a public good. Player one moves first announcing his provision q_1 and then, informed about q_1, player two announces his provision q_2. The value of the public good is given by both player's best shot, that is, $\max\{q_1, q_2\}$. We are not aware of any study on communication in best shot games. However, there is a series studies showing that the way information is presented affects outcomes (Prasnikar and Roth 1992, Carpenter 2002). We relate our results to these experiments in the discussion, Section 7.

2.6 Summary and positioning of this study

Table 1 summarizes the literature on communication in economic games. Yet, at least one of the following aspects differentiates our game from the existing economic literature: asymmetric information, sequential decision making, or the possibility of efficiency gains in case of trustworthiness, trust and trustworthiness. The trade-offs to be considered can be best organized by a combination of an ultimatum bargaining game in which efficiency and therefore payoffs can be increased if buyer's share information truthfully (sender-receiver game) while trusting that suppliers reciprocate (investment game). To the best of our knowledge, communication media comparisons have not been rigorously analyzed neither in the basic ultimatum-, sender-receiver, and investment game nor in the combination of those.

Table 1 Overview of the literature.

		Aspects			Communication media			
Game	Study	AI	Seq.	Eff. As	One sided	Chat	Audio	F2F
Ultimatum	Andersson et al. (2010)	No	Yes	No	Yes (+)	No	No	No
	Rankin (2003)	No	Yes	No	Yes (--)	No	No	No
	Xiao and Houser (2005)	No	Yes	No	Yes (+)	No	No	No
	Greiner et al. (2014)	No	Yes	No	No	Yes (+)	No	Yes (++)
	Roth (1995)	No	Yes	No	No	No	No	Yes (++)
	Schmidt and Zultan (2005)	No	Yes	No	No	No	No	Yes (+)
	Zultan (2012)	No	Yes	No	No	No	No	Yes (+)
	Croson et al. 2003)	Yes	Yes	No	Yes (n.m.)	No	No	No
	Boles et al. 2000)	Yes	Yes	No	Yes (n.m)	No	No	No
	Besancenot et al. (2013)	Yes	Yes	No	Yes (n.m.)	No	No	No
	Kriss et al. (2013)	Yes	Yes	No	Yes (++)	No	No	No
	Koning et al. (2011)	Yes	Yes	No	Yes (n.m.)	No	No	No
	Vesely (2014)	Yes	Yes	No	Yes (n.m.)	No	No	No
Investment game	Ellingsen and Johannesson (2004)	No	Yes	Yes	Yes (+/n.s.)	No	No	No
	Bracht and Feltovich (2009)	No	Yes	Yes	Yes (n.s.)	No	No	No
	Charness and Dufwenberg (2006)	No	Yes	Yes	Yes (+/n.s.)	No	No	No
	Servátka et al. (2011)	No	Yes	Yes	Yes (+)	No	No	No
	Schniter et al. (2013)	No	Yes	Yes	Yes (n.m.)	No	No	No
	Ben-Ner et al. (2011)	No	Yes	Yes	No	Yes (++)	No	No
	Ben-Ner and Putterman (2009)	No	Yes	Yes	No	Yes (++)	No	No
	Fiedler and Haruvy (2009)	No	Yes	Yes	No	Yes (++)	No	No
	Buchan et al. (2006)	No	Yes	Yes	No	No	No	Yes (n.m.)
	Fiedler (2009)	No	Yes	Yes	No	Yes (++)	Yes (++)	No
Sender-receiver	Wang et al. (2010)	Yes	Yes	No	Yes (n.m)	No	No	No
	Kawagoe and Takizawa (2009)	Yes	Yes	Yes	Yes (n.m)	No	No	No
	Erat and Gneezy (2012)	Yes	Yes	Yes	Yes (n.m)	No	No	No
	Gneezy (2005)	Yes	Yes	Yes	Yes (n.m)	No	No	No
	Sánchez-Pagés and Vorsatz (2007)	Yes	Yes	No	Yes (n.m)	No	No	No
	Hurkens and Kartik (2009)	Yes	Yes	Yes	Yes (n.m)	No	No	No

	Lundquist et al. (2009)	Yes	Yes	Yes	Yes (+)	No	No	No
	Holm and Kawagoe (2010)	Yes	Yes	No	Yes (n.m.)	No	No	Yes (n.m)
	van Zant and Kray (2014)	Yes	Yes	No	Yes (n.m.)	No	No	Yes (+)
Public good/ Prisoner's Dilemma	Brosig et al. (2003)	No	No	Yes	No	No	Yes (+)	Yes (++)
	Bos et al. (2002)	No	No	Yes	No	Yes	Yes (+)	Yes (++)
	Frank et al. (1993)	No	No	Yes	No	No	No	Yes (n.m.)
	Dawes et al. (1977)	No	No	Yes	No	No	No	Yes (++)
	Isaac and Walker (1988)	No	No	Yes	No	No	No	Yes (++)
	Isaac et al. (1985)	No	No	Yes	No	No	No	Yes (+)
	Duffy and Feltovich (2002)	No	No	Yes	Yes (+)	No	No	No
Supply chain coordination	Özer et al. (2011)	Yes	Yes	Yes	Yes (n.m.)	No	No	No
	Özer et al. (2018)	Yes	No	Yes	Yes (+)	No	No	No
	Hyndman et al. (2013);	Yes	Yes	Yes	Yes (n.m.)	No	No	No
	Spiliotopoulou et al. (2016)	Yes	Yes	Yes	Yes (n.s.)	No	No	No
	Inderfurth et al. (2013)							

Note: ++/+/n.s./- indicate the effect of communication on the efficiency. ++: strong positive, +: positive,-: negative, *n.s.*: not significant, -: negative effect, *n.m.*: indicates that the medium was not a manipulation in the experiment. Abbreviations: AI: Asymmetric information with the buyer having the information advantage, Seq.: Sequential game, Eff. As.: efficiency aspects.

3 Outline of the model

We consider a supply chain that consists of a supplier (male pronouns, s) and a buyer (female pronouns, b). The supplier produces a product at marginal cost c and sells q units of the product to the buyer. The buyer serves end-customer demand q at price p. The deterministic and price-sensitive end-customer demand follows a linear function with $q = a_i - p$ with $a_i, i \in \{l, h\}$, and $a_l < a_h$. For a higher choke-off price a_i, a buyer sells more units to the end-customer for a given price p and vice versa. Information regarding the choke-off price a_i and therefore the exact specification of end-customer demand is asymmetrically distributed. The supplier only knows the likelihood $\theta_i, i \in \{l, h\}$ with $\theta_l + \theta_h = 1$, of the respective choke-off price when offering a contract to the buyer. The buyer, in turn, knows the choke-off price realization a_i when making her order quantity decision q which is tantamount to making the end-customer price decision p. The choke off price represents all factors that affect demand, except the price, for example, the potential size of the market, or the strengths of the buyer's private-label brand (Desiraju

and Moorthy 1997). The supplier as a Stackelberg leader offers a price contract on a take-it-or leave it basis to the buyer. If a buyer rejects the offer, both parties earn zero profits.

The contract offered by the supplier is an all-unit quantity discount. We use quantity discounts, because of its long business tradition and its frequent application in many industries (Munson and Rosenblatt 1998). Formally, this quantity discount contract is a menu of contracts consisting of pairs Geben Sie hier eine Formel ein. of a per unit price w_j, $j \in \{0, l, h\}$ and quantities $\overline{q}_j$,$j \in \{0, l, h\}$ for which the per unit price applies. The total payment from the buyer to the supplier, $T(q)$, is then defined by

$$T(q) = \begin{cases} w_0 \cdot q & \text{for } \bar{q}_0 = 0 \leq q < \bar{q}_l \\ w_l \cdot q & \text{for } \bar{q}_l \leq q < \bar{q}_h \\ w_h \cdot q & \text{for } \bar{q}_h \leq q \end{cases} \quad (1)$$

We define $q_{ij}(p)$ as the order size of the buyer with choke-off price a_i ordering in an interval that qualifies for the per unit price w_j and setting the end-customer price p. The buyer's profit function P_i^b with choke-off price a_i is

$$P_i^b = p \cdot q_{ij} - T(q_{ij}) \quad (2)$$

and the optimal order size of buyer type a_i follows from [1]

$$q_{ij}^* = \max_{q_{ij}} P_i^b = p \cdot q_{ij} - T(q_{ij}). \quad (3)$$

The supplier's profit is

$$P^s = T(q_{ij}) - c \cdot q_{ij} \quad (4)$$

respectively. Kolay et al. (2004) show that buyer type a_i will always buy the threshold quantity $q_{ij}^* = \bar{q}_{j=i}$ under the optimal menu of contracts. The supplier's therefore needs to determine the optimal threshold quantities $\bar{q}_j$ and the corresponding per unit prices w_j:

$$\max_{\bar{q}_i, w_i} E[P_s] = \sum_{i=1}^{2} \theta_i \cdot P^s(\bar{q}_i) \quad (5)$$

$$P^b(q_{i,i}^* = \bar{q}_i) - 0.1 \geq P^b(q_{ij}^*) \qquad \forall i, j \in \{l, h\} \quad (6)$$

$$P^b(q_{i,i}^* = \bar{q}_i) - 0.1 \geq 0 \qquad \forall i, j \in \{l, h\} \quad (7)$$

[1] The optimal end-customer price is therefore $p_{ij}^* = a_i - q_{ij}$

The incentive constraint (6) ensures that buyer type a_i will choose the order quantity $\bar{q}_i$. Thus, the supplier maximizes expected profits in (5) by anticipating that the order size $\bar{q}_i$ and the resulting per unit price w_i will be chosen with a probability of θ_i. The participation constraint (7) ensures that all buyer types will accept the contract, since they make profits larger than zero when ordering $\bar{q}_i$. Note that we provide strict incentives for a_i to choose $\bar{q}_i$ as well as to accept the contract by ensuring that profits are strictly larger by the amount of 0.1 compared to any alternative.

Note that the above optimal all-unit quantity discount relies on two basic assumptions that are common in the contract design literature: (expected) profit maximization and rationality. These two assumptions guarantee that the supplier can anticipate that the buyer type a_i chooses the quantity $\bar{q}_i$. The incentive compatible constraint (6), then, ensures that the buyer is provided with sufficient incentives to voluntarily select (=self-select) the quantity $\bar{q}_i$. However, other studies (Johnsen et al. 2017, Inderfurth et al. 2013, Sadrieh and Voigt 2017) have shown that other factors such as bounded rationality or fairness preferences may lead to unpredicted contract choices. A closer look at the incentive constraint (6) reveals that, e.g., the buyer type a_h is just indifferent between ordering in the interval $\bar{q}_l \leq q < \bar{q}_h$and the order size $\bar{q}_h$ (see Table 3 for an example). Johnsen et al. (2017) show that increasing the profit differences between these contracts increases the frequency of self-selection, which in turn increases both supplier's and buyer's profits. We account for this by allowing the supplier to issue a cash-discount, i.e., the buyer gets a discount δ on her total payment $T(q_{ij})$. Thus, the buyer's and supplier's profit function change to

$$P_i^b = p \cdot q_{ij} - (1-\delta) \cdot T\left(q_{ij}\right) \tag{8}$$

$$P^s = (1-\delta) \cdot T\left(q_{ij}\right) - c \cdot q_{ij}. \tag{9}$$

In the game theoretic solution with a fully rational and strictly profit-maximizing buyer, the supplier sets the cash discount to zero since any positive cash discount decreases his profit. Furthermore, we allow for communication between the buyer and the supplier in our experiment. As we will elaborate, this may change the supplier's perception regarding the a-priori distribution of buyer types θ_i.

Next, we discuss the impact of information sharing in the game theoretic solution. Note, under the optimal menu of contract it is conventional wisdom that (1) the buyer with a low demand state earns zero surplus. (2) The buyer with high demand state earns an informational rent. (3) The supplier trades off the informational rent paid to the high type buyer and the efficiency loss when trading with the low demand type buyer. Hence, (4) in order to reduce the high demand buyer's rent, the threshold quantity $\bar{q}_l$ is downward distorted. The threshold quantity $\bar{q}_h$ is efficient.

If the supplier increases the probability for the buyer's actual choke-off price realization a_l, he offers a more efficient menu-of-contracts. In contrast, if he decreases the probability for the buyer's actual choke-off price realization a_l, he offers a less efficient menu-of-contracts compared to the contract based on the a priori probabilities. The probability adjustment impacts the supplier's and buyer's profits in opposed directions. The high demand type buyer's profit (informational rent) is strictly increasing in the probability θ_l. Thus, the buyer with a high demand has a strict incentive to understate the demand realization and inducing the supplier's subjective probability adjustment towards a_l. Thus, in the game theoretic solution communication is uninformative, since the buyer's signal aims at increasing the supplier's subjective probability that demand is low. Since the shared information is unverifiable and does not involve any direct cost, communication is cheap talk in the sense of Kartik (2009).

4 Experimental design

4.1 Protocol

The experimental software was implemented with the toolbox z-Tree (Fischbacher 2007). Participants were recruited the software *hroot* (Bock et al. 2014). 390 Subjects participated in our experiments. The subjects were randomly drawn from a pool of about 2300 graduate and undergraduate students of a mid-size university in Germany. Each treatment was administered in one session in a between-subjects design. The instructions (see Online Appendix EC.5) were handed out to the subjects upon arrival and were read aloud. Then subject were randomly assigned to sound-proof cubicles that were equipped with a video conferencing technology (headset, video camera, video monitor). Then each subjects was assigned the role of the buyer or the supplier. Neither the role as a buyer or a supplier nor the matching of suppliers and buyers changed in the course of the experiment (partner matching). Then, after a short individual rereading time, the subjects had the possibility to ask questions that were answered privately. All subjects had to pass a comprehension quiz. Afterwards, the experiment started.

4.2 Sequence of events

All our experiments comprise three consecutive phases: the training phase, the pre-play communication phase and the game phase. In the game phase subjects repeated the following game 20 times. Each game round entails four stages as shown in Figure 1.

Game phase

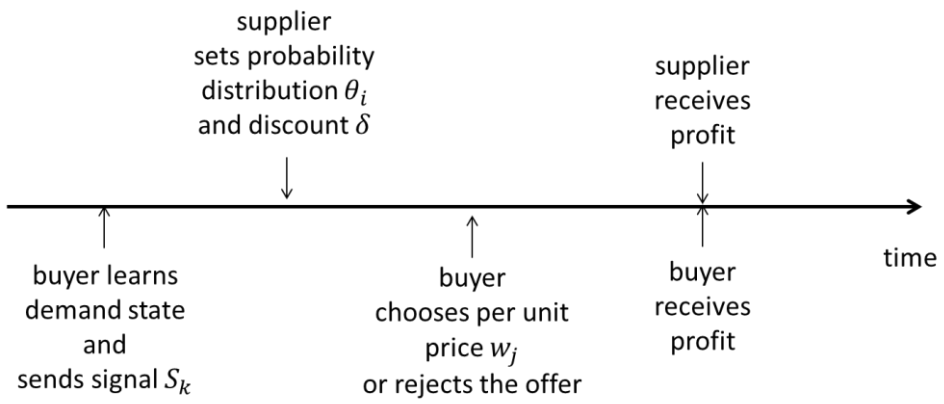
In the first stage, the buyer learns her private information a_i and can send one of the following computerized messages: "demand is low" (in the following formalized as S_l), "demand is high" (S_h) or "no message" (S_{no}). The buyer is provided with a decision support tool that is identical to the tool of the supplier in the second stage (see below). The tool provides her the opportunity to simulate the consequences of the supplier's reaction to her message.

In the second stage, the supplier designs his menu of contracts by (a) stating the subjective probability (i.e., the a-posteriori belief after receiving signal S_k) that the buyer has a choke-off price a_i, i.e., $\theta_i(S_k)\ \forall i \in \{l, h\}$ and $k \in \{l, h, no\}$ with $\theta_i(S_k) \in \{0\%, 10\%, \dots, 90\%, 100\%\}$ and by (b) stating a cash discount ranging from $\delta \in \{0\%, 1\%, \dots, 49\%, 50\%\}$. We enforced that $\theta_l(S_k) + \theta_h(S_k) = 100\%$. This information is then passed on to a decision support tool that solves the optimization problem (5)-(7) with $\theta_i(S_k) = \theta_i$. The supplier's and buyer's profits are then calculated according to equation (8) and (9), respectively. The decision support tools shows for the given input of θ_i and δ the profits of the supplier and the buyer for each possible realization of a_i (which is unknown to the supplier when offering the contract) and for each per unit price w_j offered in the menu-of-contract (see Table 3 for an example). Suppliers had the chance to check as many contract offers that vary with the $\theta_i(S_k)$ and δ before submitting the final offer.

In the third stage, the buyer only chooses the per unit price w_j under which she wants to order, whereas the optimal order size q_{ij} is determined by the experimental software. As decision support tool, the buyer sees on the computer screen her profits as well as her supplier's profit resulting from her per unit price choice w_j.

In the last stage, the following results were summarized: the contract offer from the supplier, the buyer's contract choice with resulting per unit price w_j, and the own profit of the current game round.

Figure 1 Sequence of events in the game



Practice rounds

At the beginning of each session the subjects played six practice rounds of the game explained above in the training phase. In the practice round each subject played with a computerized counterpart. The subjects knew that the decisions of the computer followed a preprogrammed and randomly determined algorithm. In particular, the messages sent by the computerized buyer, the contract offers from the computerized supplier, and the contract choices from the computerized buyer were randomly determined beforehand.

Pre-play communication and treatments

After the training phase, the subjects engaged the pre-play communication phase. We manipulated in our experiment the means of pre-play communication. Table 2 summarizes the treatments of our experiment. The numbers in parentheses indicate the number of independent observations.

Baseline treatment: Communication was not allowed throughout the game, i.e., there is no pre-play communication phase and buyers were not allowed to send signals in the first stage of the game phase. This treatment allows identifying if other factors, as the received signal or pre-play communication, affect the suppliers' subjective probabilities that are the basis for the contract offer.

***Reference treatment*:** Subjects played the game as described above without pre-play communication but with restricted messages ("demand is low/high") sent by the buyer to the supplier in the first stage of the game phase.

Identification treatment: We allowed subjects to visually identify their partner in the pre-play communication phase. Subjects saw their matching partner on the computer screen. The video transmission lasted for at least 10 seconds. We prohibited any kind of visual signaling.

Chat treatment: Subjects have the opportunity to communicate with their matching partner via a text-chat program. There was no video transmission in this treatment to prevent visual identification. We did not limit the content of communication, neither in this nor in one of the following treatments with verbal communication. The pre-play communication phase in this treatment as well as in any of the following treatments lasted for up to ten minutes[2].

Audio treatment: Subjects have the opportunity to communicate with their matching partner via the audio headset for at most ten minutes. There was no video transmission in this treatment to prevent visual identification.

Video treatment: Subjects engaged in a video conference that allowed for both visual identification and auditory communication via the headset.

Consulting treatment: In addition to the "video" treatment, participants were shown a tutorial explaining the game dynamics. Every participant saw the same standard powerpoint slide deck including verbal explanations recorded by the experimenter. The tutorial was given just before the video conference. The tutorial is available upon request from the authors. In the training, we showed how trustworthiness (i.e., honest messages) and trust (in the message) interact. We highlighted the potential gains from adjusting the beliefs $\theta_i(S_k)$ as well as the risk of deception on individual profits. We further discussed in the tutorial how the cash discount needs to be set in order to ensure that truthful messages result in a win-win outcome.

Table 2 Treatment overview

treatment	signals allowed	pre-play communication	visual identification	tutorial
Baseline (n=26)	No	No	No	No
Reference (n=29)	Yes	No	No	No
Identification (n=27)	Yes	No	Yes	No
Chat (n=29)	Yes	Text	No	No
Audio (n=27)	Yes	Verbal	No	No
Video (n=28)	Yes	Verbal	Yes	No
Consulting (n=30)	Yes	Verbal	Yes	Yes

In the first column, the numbers in parentheses indicate the number of independent observations. The second column indicates whether information exchange through a restricted message is allowed between supplier and

[2]If subjects reached the ten minutes limit, they were asked to finish the communication phase by a blinking text message. The phase did not terminate automatically.

buyer. The third column indicates the medium of the pre-play communication. The fourth column indicates whether the interaction is anonymous. The fifth column shows whether additional training was given to the subjects.

Parameters

We set choke-off prices of $a_l = 15$ and $a_h = 25$, marginal costs of the supplier of $c = 7$, and the a-priori distribution of types $\theta_l = \theta_h = 0.5$.[3] The all unit quantity discount with the a-priori distribution and zero cash-discount is displayed in Table 3. As an example: a buyer type a_h ordering under the contract with $\bar{q}_l = 1.3$ and $w_l = 13.6$ earns 32.5 while her supplier earns 37.6. This information was obtained by the subjects when entering the respective values in the decision support tool. We provide a table with possible contracts for $\theta_i \in [0\%, 100\%]$ and $\delta \in [0\%, 50\%]$ both in steps of 10% in the Online Appendix, EC.4.

Table 3 Supplier's and buyer's profits under the menu-of-contracts.

discount scheme			profit supplier		profit buyer	
j	$\bar{q}_j$	w_j	a_l	a_h	a_l	a_h
0	0	15.0	0	10.5	0	11.4
l	1.3	13.6	8.7	37.6	0.1	32.5
h	9.0	12.4	48.5	48.5	−57.5	32.6

4.3 Incentives

In addition to a 3.00EUR show-up fee, subjects were paid proportionally to the sum of their profits in their experiments (measured in "Taler") in all rounds in cash, immediately after the experiment. The exchange rate was set to 0,025EUR/Taler, i.e. subjects received 2.50EUR for 100 Taler. In our experiments, participants earned 14.87EUR on average (suppliers: 15.35EUR, buyers: 14.40EUR). Each experimental session lasted about 70 minutes.

4.4 Behavioral theory and predictions

A series of studies consider information sharing in supply chains providing empirical evidence that the game theoretic cheap-talk benchmark is too pessimistic. Subjects are often found to be trusting and trustworthy to some extent. We therefore expect the subjects in our experiments to be more trusty and trustworthy than standard theory expects even without any form of pre-play communication. In our

[3] The set of choke-off price realizations was randomly drawn in advance of the experiment. We created three parameter tables with different orders of these realizations. Each buyer was randomly assigned one of these tables. The used the same parameter tables across treatments.

experiments we measure trustworthiness by the buyer's willingness to share her private information truthfully, e.g. by sending a truthful message.

Hypothesis 1: In the reference treatment the buyer's signal S_k and the realized demand are positively correlated.

Trust is measured by the supplier's willingness to rely on the buyer's signal when designing the contract offer, e.g. adjusting the subjective probabilities towards the demand information of the buyer's signal.

Hypothesis 2: In the reference treatment the supplier's subjective probability θ_h is positively correlated with the received signal.

Another aspect in our experiment is the role of social preferences in the bargaining stage. There is a series of studies on supply chain contracts showing that buyers often refuse to choose the profit-maximizing outcome when suppliers make a take-or-leave contract offer (Inderfurth et al 2013, Katok et al. 2013). One potential explanation is participants' inequality aversion. The idea is that participants do not solely care about their own profit but also about how profits are allocated among each other (Fehr and Schmidt 1999, Bolton and Ockenfels 2000). An aversion to inequality in income allocation implies that participants incur psychological costs from earning less than the opponent (disadvantageous inequality) and costs from earning more than the opponent (advantageous inequality). The buyer's contract choice from a menu-of-contracts is in particular sensitive to inequality aversion due to the indifference modeling approach: A closer look at the Table 3 reveals that the a_h-buyer ordering at the (self-selection) per unit price w_h earns 32.6 while the supplier earns 48.5. If the buyer orders at the per unit price w_l, her profit marginally decreases to 32.5 while the supplier's profit decreases substantially to 37.5. Hence, the inequity averse a_h-buyer may choose ordering from the contract with w_l because it yields a more equitable profit allocation without decreasing his own payoff too much. For each buyer type a_i, we designate the choice to order at the contract with the per unit price w_i as *self-selection*. In contrast to the standard theory we expect the buyer to order less often at the self-selection price.

Hypothesis 3: In the reference treatment the buyer's average self-selection frequency is less than 100%.

Impact of the communication media

A large body of research has shown that face-to-face communication affects subjects' decisions in many economic settings including strategic communication games (van Zant and Kray 2014) and bargaining games (Roth 1995), see literature review for details. Therefore, we expect that face-to-face communication also affects subjects' decisions in our supply chain model. Our experimental design allows

us to decompose the cooperation-enhancing effect of face-to-face communication to distinguish those aspects of face-to-face communication that are crucial for establishing cooperation from others aspects included in face-to-face communication.

The communication media differ in terms of their richness. The media richness relates to the amount of information that can be conveyed through the communication process. Face-to-face is the richest media since it allows to identify each other and to share information through visual and auditory channels. Audible communication is less rich because it does not provide visual information cues, such as facial expressions. Text-chat communication provides a relatively low richness because it uses solely textual messages excluding verbal or visual cues that may embellish meaning. Furthermore, it is relatively slow in feedback because of the typing. Bordia (1997) synthesizes the empirical comparisons of text based communication with face-to-face communication. It is found that groups under text communication use fewer number of words and state fewer separable units of thoughts (Kiesler et al. 1985, McGuire et al. 1987, Hiltz et al. 1986). Text communication leads to fewer spontaneous questions (Kiesler et al. 1985), and involves a poorer understanding of the partner, his decision, and the task (Adrianson and Hjelmquist 1991, Daly 1993, Straus and McGrath 1994). Visual identification has the lowest richness since it does not provide a channel to communicate, yet, it dissolves the anonymity between subjects.

Subjects in our supply chain model are in a social dilemma because if both players defect the outcome is inefficient, but if both cooperate the supplier and the buyer can be both better off allowing a win-win situation. The optimal first-best outcome can be achieved if the buyer truthfully shares her private information and selects the consistent price from the menu, while the supplier trusts the shared information and shares the benefits by allocation the profits appropriately.

While standard theory expects that any pre-play talk is cheap, a series of research provides evidence that cooperation rates increase when subjects are allowed to participate in pre-play communication. However, it is somewhat unknown why that happens (Kollock 1998). At the heart of this issue is that communication allows to gather information about the opponent's interests and intentions which increases the own confidence that the opponent will reciprocate to cooperative behavior (Rockmann and Northcraft 2008). In the following, we provide three explanations for why the communication media affects cooperation: psychological cost from lying, the salience of the mutual benefits, and trust.

Following Kartik (2009), talk is cheap when it is not possible for players to check the truth of the information they receive from other players and when it is possible to lie without incurring costs. However, there may be several reasons to bear costs from a lie. Even in the absence of any direct monetary costs

(e.g. penalty for ex post verification of a misreport), recent experimental work shows that people incur psychological cost (disutility) from deception, specifically from not being true to one's word, or from betraying someone's trust (Charness and Dufwenberg 2006, Gneezy 2005, Erat and Gneezy 2012, Battigalli and Dufwenberg 2009). Therefore, in situations in that talk seems to be cheap at first glance (no monetary cost for lying), talk can be strategically relevant because players incur latent psychological costs from betraying. The form and the content of communication likely affect these costs. Clearly, lying to some one's face incurs higher psychological costs than lying under anonymous conditions (Von Zant and Kray 2014). Since a richer communication media offers more social context cues making the interaction more personalized (Kiesler et al. 1984), we expect that the psychological cost from deception increase with the richness of the communication media.

Weimann et al. (2018) show that a critical factor to establish cooperative behavior is the salience of the mutual advantages among players. They show that the participants' willingness to cooperate in a social dilemma increases when each other's advantageous from cooperation become more salient. Hence, only if all players share the view that cooperation is to everyone's advantage, the willingness to cooperate rises. In our complex supply chain model the mutual benefits from cooperative behavior are less obvious because the subjects play different roles making different decisions. The transmission of information may be, therefore, critical to establish cooperative behavior. Communication likely promotes the subject's confidence that cooperative behavior produces mutual benefits. We, therefore, expect that communication works as a mechanism to convey the salience of the mutual benefits from cooperation. Since a richer communication media allows transferring more information, we expect that the salience of the mutual advantages increases with the richness of the utilized media which in turn increases the willingness to cooperate.

The richness of the communication media may also affect the subjects' trust. Trust is important achieve cooperation in a social dilemma. Only if the subject believes that the opponent will act in the own best interest by cooperating the subject will be willing to cooperate, too (Rockmann and Northcraft 2008). Trust contains cognitive and affective elements (Lewis and Weigert 1985). The cognitive elements of trust refer to the belief that the opponent is reliable and understood the game and the dilemma they are in. The affective elements refer to the emotional ties between the subjects. The subject express concerns for the opponent's welfare and beliefs that the opponent reciprocates by also acting in the subjects' own best interest (McAllister 1995). Rockmann and Northcraft (2008) outline why the richness of the communication media affects both the cognitive and affective elements of trust. With respect to the cognitive elements, a richer communication media may transfer more information and therefore may

convey more task relevant information increasing the comprehension of the game and the dimensions of the dilemma. Regarding the affective elements, a richer communication media offers more social context cues making the interaction more personalized (Kiesler et al. 1984). Burgoon et al. (2011) observes that participants interacting through a richer communication media are more effective in building a positive relationship increasing the emotional ties between subjects.

Hypothesis 4: (a) Buyer's trustworthiness, (b) supplier's trust, (c) supplier's discounts, (d) buyer's self-selection rate, and (e) the supply chain performance increase with the richness of the communication media.

In the consulting treatment the participants were shown a tutorial explaining the game dynamics. The tutorial explained the potential gains from adjusting the beliefs as well as the risk of deception on individual profits. Furthermore, it was shown how the cash discount needs to be set in order to ensure that trust and trustworthiness result in a win-win outcome. A series of research shows that communication is especially effective when the participants addresses the relevant aspects of the dilemma. It is found that cooperation rates substantially decrease when the participants are not allowed to discuss the dilemma (Dawes et al. 1977, Bouas and Komorita 1996). Since our supply chain model comprises bargaining and information sharing aspects, it is relatively complex, making it likely that participants do not address all relevant aspects of the dilemma. We therefore hypothesize that the tutorial promotes the effect of face-to-face communication on subjects' cooperative behavior.

Hypothesis 5: (a) Buyer's trustworthiness, (b) supplier's trust, (c) supplier's discounts, (d) buyer's self-selection rate, and (e) the supply chain performance increases in the consulting treatment compared to the video treatment.

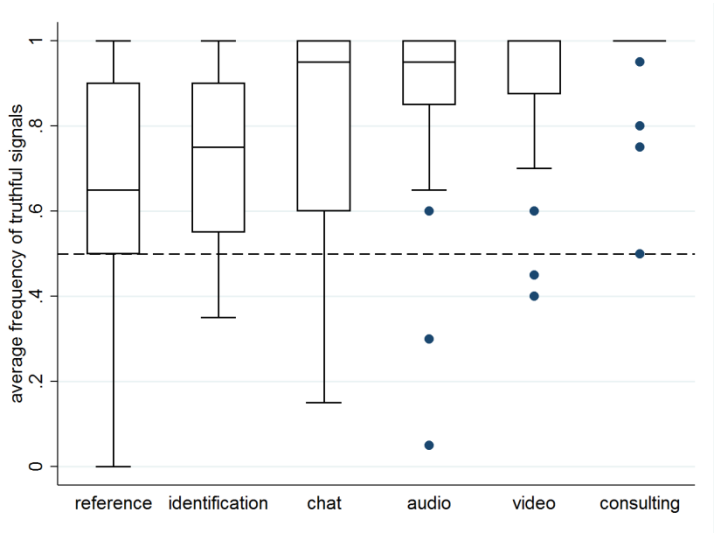
5 Results

We present the results according to the sequence of events in our game phase. The unit of analysis is the average decision of each supplier-buyer pair over the 20 periods. In Section 5.1 we discuss the buyer's trustworthiness, in Section 5.2 the supplier's trust and contract offer, in Section 5.4 the buyer's contract choice behavior and in Section 5.5 the implication for the supply chain performance.

5.1 Buyer's trustworthiness

Figure 2 shows the boxplots of average frequencies of buyer's truthful signals by treatment. The horizontal dashed line indicates the a-priori distribution of 50% for each demand state. Note that we do not report on the baseline treatment in which signals were not allowed at stage 1.

Figure 2 Buyers' trustworthiness.



We test differences between all treatment combinations in all further analysis with two-sided Mann-Whitney U (MWU) tests if not indicated otherwise. The results are summarized in the Online Appendix (see Table 1 in EC.1 in the Online Appendix). We account for the problem of multiple testing by Bonferroni corrected p-values of p<0.0045 and p<0.0091 at a group level of alpha equal to 0.05 and 0.1, respectively, for eleven tests[4].

We test for a positive correlation between the buyer's signal and her demand realization in the reference treatment. We observe a significant correlation coefficient of 0.38 ($p < 0.01$). Further, we find that the buyer's average rates of truthful signals are significantly higher than the theoretical 50% benchmark supporting the Hypothesis 1 that buyers are more trustworthy than standard theory suggests.

The results show that verbal communication (audio/video/consulting) has a significant and by all means the largest impact on buyer's trustworthiness. If communication takes place with or without video transfer has – if all – a minor impact on trustworthiness. Lifting anonymity in the identification treatment has no significant effect. If communication takes place via text-chat, we observe a positive but not significant

[4] The Bonferroni correction controls for the familywise error rate, that is, the probability of making at least one type I error. Note, this procedure is relatively conservative and increases the probability of type II errors.

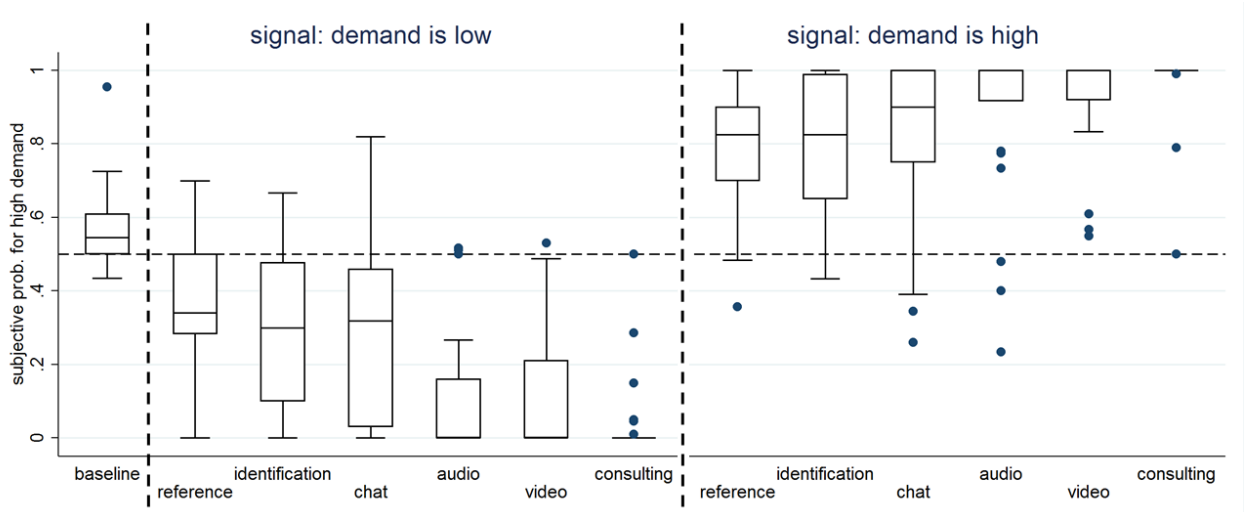
effect on buyer's trustworthiness. We see no significant effects between the chat/audio treatment and the video treatment. Our results partly support Hypothesis 4(a) that buyer's trustworthiness increases with a richer (verbal) communication media since we observe significant effects only for verbal communication forms but no significant differences between the chat and audio/video treatments. Furthermore, the tutorial additionally shown just before the videoconference has a slight positive effect that partially supports the Hypothesis 5(a).

Our analysis of the content of the communication indicates that the ability to commit to trustworthiness is the main driver of this results (see Section 5.8, content analysis). We further tested whether buyer's behavior changes over time, we find that buyer's trustworthiness slightly decreases in the verbal communication treatments and more so in the chat treatment, see Online Appendix EC.4. We consider one-shot interactions in Section 6.

5.2 Suppliers' trust

Figure 3 compares the supplier's subjective probability adjustments by treatments. On the y-axis we plot the supplier's subjective probability $\theta_h(S_k)$ that demand is high. On the left hand side of Figure 3 we have the subjective probabilities from the baseline treatment without communication as a benchmark. In the middle we plot the subjective probabilities $\theta_h(S_l)$ and on the right hand side we have the subjective probabilities $\theta_h(S_h)$. Note, the subjective probability for a low demand is given by the complementary probability. The horizontal dashed line indicates the game theoretic solution, that is, the supplier ignores the signal and uses the a priori distribution to calibrate the contract.

Figure 3: The suppliers' trust. (Left) The supplier's subjective probabilities $\theta_h(S_{no})$ in the baseline treatment with no signals. (Middle) The Supplier's subjective probabilities $\theta_h(S_l)$ after receiving the signal: demand is low. (Right) Supplier's subjective probabilities $\theta_h(S_h)$ after receiving the signal demand is high.



The MWU tests show (see Table 2 in EC.1 in the Online Appendix, Bonferroni correction, p<0.004 and p<0.008 for an alpha group level of 0.1 and 0.05, respectively, and twelve tests) that suppliers' do not ignore the buyers' signals, as we find significant differences in the suppliers' subjective probabilities between the baseline and the reference treatment. We further find that the supplier's subjective probabilities θ_h are significantly positively correlated with the signal S_k ($\rho = 0.38, p < 0.001$). Hence, we find support for the Hypothesis 2 that suppliers are more trusting than expected by game theory.

We observe that verbal communication (audio/video) has a significant and by all means the strongest effect on supplier's trust. In these treatments, higher levels of trust meet high levels of trustworthiness. Lifting anonymity has no significant effect on trust, while it has also no effect on buyers' trustworthiness. This is consistent with a missing effect between the audio treatment and the video treatment. Interestingly, suppliers seem reluctant to trust text-form communication. While, in Section 5.1, we did not find a significant difference in buyer's trustworthiness between the chat and the audio/video treatment, we, now, observe that suppliers' trust is significantly stronger in the audio and video treatment compared to the chat treatment. In sum, the results support the Hypothesis 4(b) that the supplier's willingness to trust increases with the richness of the communication media, while the strongest effect is found between the verbal and text communication formats. The training video has a positive effect on the suppliers' trust, but the effect (p=0.037) is not significant given the Bonferroni corrected alpha level providing slight support for Hypothesis 5(b). The analysis using all the round data reveals that supplier's trust decreases over the time in the chat treatment while it slightly increases in the audio treatment. Furthermore, in all

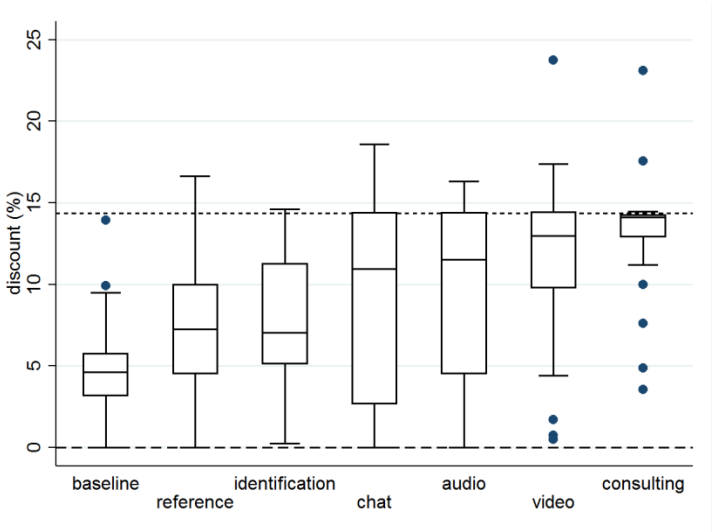
treatments suppliers trust decreases in the last few rounds. This is well in line with the experiments on cooperation in dilemma games that usually find that cooperation rates decline in the last round (Brosig et al. 2003, Bos et al. 2002).

We finally note that we find not any systematic differences in the adjustments of the counter-probabilities $\theta_h(S_h)$ and refer for these results to the Online Appendix (see Table 2 and Table 3 in EC.1).

5.3 Suppliers' discount offers

Figure 4 shows the average discounts given by the supplier per treatment. The dashed line indicates the theoretical benchmark ($= 0\%$). The short-dashed line shows the discount which on average results in equal payoffs, given a truthful signal and a supplier who fully trusts the signal.

Figure 4: Suppliers' average discounts.



The average discounts in the baseline treatment is well above the theoretical benchmark (see Table 4 in EC.1 in the Online Appendix for the results of pairwise comparisons of two-sided MWU tests between treatments with respect to suppliers' discount offer). Because in the game theoretic solution the supplier makes higher profits than the buyer, one potential explanation may be a preference for advantageous inequity aversion (Bolton and Ockenfels 2000, Fehr and Schmidt 1999). Another explanation might be the anticipated strategic risk of the buyer's contract rejection or indifference contract choices (Johnsen et al. 2017).

We find that only the videoconference has a significant effect on the supplier's discount offers. The other communication forms (chat and audio) show a positive but not significant effect. The identification has no

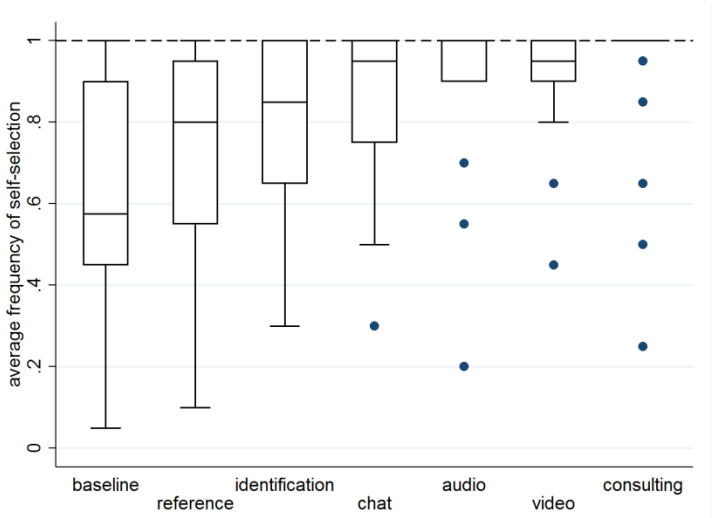
significant effect, neither between the reference and the identification treatment nor between the audio and video treatment. While we observed, in Section 5.2, that supplier's trust increases significantly in the audio treatment, we find that suppliers' willingness to give (by high discount offers) does not increase in the audio treatment. It seems that only the combination of verbal communication with visual identification makes the suppliers less demanding which translates to higher discount offers. Overall, we find that the richness of communication media affect the supplier's discount offers which is in line with Hypothesis 4(c).

A closer look at Figure 4 shows that one benefit of the training (consulting treatment) may be less variance in the supplier's discount offers. The F-test confirms this observation ($p < 0.01$). However, we do not find support for Hypothesis 5(c) that the supplier's provide higher discounts in the consulting treatment than in the video treatment. The analysis of all the round data provides that the supplier's discounts decrease over the time in the chat treatment and slightly decreases in the video treatment, see Online Appendix EC.4 for details.

5.4 Buyers' contract choice behavior

Figure 5 shows the buyers' average self-selection frequency per treatment. To recap, self-selection describes that buyer type a_i orders at a wholesale price w_i in the eligible order size range. The dashed line indicates the theoretical benchmark, that is, the buyer always chooses the profit maximizing self-selection contract. Table 5 in EC.1 in the Online Appendix summarizes the results of MWU test on pairwise treatment comparisons.

Figure 5: The buyers' average self-selection frequency.



We observe a mean frequency of self-selection of 62% in the baseline treatment. This observation resembles the observations from Inderfurth et al. (2013) and Johnsen et al. (2017) that the frequent assumption of the agents' profit maximizing contract choice (self-selection) is a fragile mechanism.

We find that allowing the buyer to send one sided text message to the supplier slightly increases the self-selection frequency to 72%, but the effect is not significant (comparing the reference and baseline treatments). Furthermore, we find that the buyers' self-selection rates in the reference treatment is significantly lower than the theoretical benchmark of a rate of 100% ($p < 0.01$), supporting Hypothesis 3.

Comparing the pre-play communication treatments, we find that only under verbal communication the self-selection mechanism is significantly and effectively restored. In case communication takes place via text chat, we observe a positive but not significant effect. Further, when allowing for visual identification leads to no significant differences in the results. The results support Hypothesis 4(d) that richer communication media increase the buyer's self-selection rates.

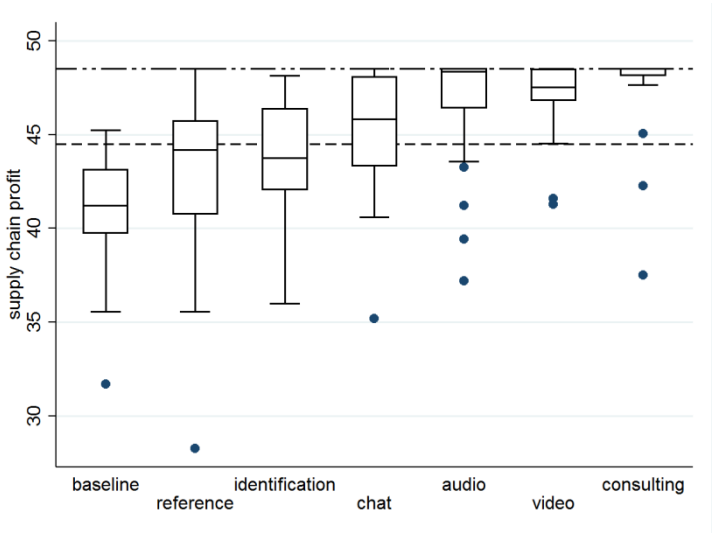
The training tutorial in the consulting treatment shows a positive effect on the buyers' self-selection frequency but the effect is not significant (Hypothesis 5(d)).[5] Furthermore, we do not find any changes in buyer's self-selection rates over the time, see Online Appendix EC.4 for details.

[5]Note that the pairwise comparison of the video and the consulting treatment results in a p-value of 0.012, which indicates that the Bonferroni corrected alpha level might be too conservative to detect a significant effect.

5.5 Supply chain performance

Figure 6 shows the average profits of the supply chains per treatment. The dashed line indicates the theoretical second-best benchmark and the dashed-dotted line the first-best benchmark. We summarize the results of pairwise treatment comparison of MWU tests with respect to the supply chain performances in Table 6 in EC.1 in the Online Appendix.

Figure 6: Supply chain performance



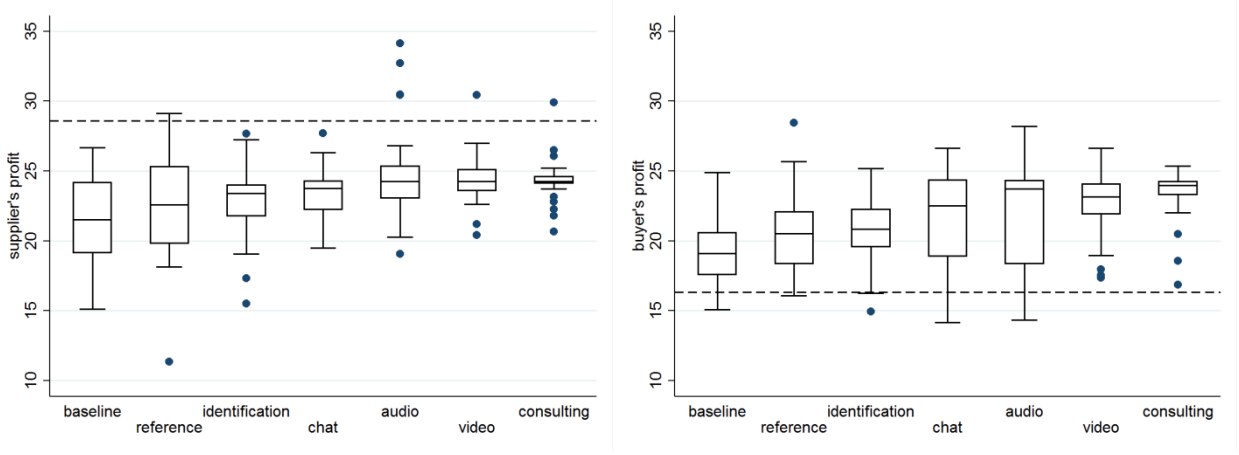
Comparing the pre-play communication treatments, we observe that verbal communication has a strong significant effect on the supply chain performance, while text-chat communication has no significant effect. Lifting the anonymity without further communication has no significance effect on the supply chain performance. Overall, the results support the Hypothesis 4(e) that richer forms of communication increase the supply chain performance. Further, the results show that training has a significant positive effect on the supply chain performance supporting Hypothesis 5(e).

Moreover, we observe that with no communication (baseline treatment) the average supply chain performance is far below the second best benchmark. When we allow for verbal communication (audio, video and consulting treatment) the supply chain performances significantly outperform the second-best benchmark, while we observed no significant differences when we allow for text-chat, visual identification, or one-sided text messages.

5.6 Supplier's and buyer's profits

Figure 7 plots the supplier's and buyer's average profits. The horizontal dashed lines indicate the profits in the game theoretic solution. In the Table 7 and Table 8 in EC.1. in the Online Appendix, we summarize the pairwise treatment comparisons with MWU tests on suppliers' and buyers' profits, respectively.

Figure 7: Supplier's (left) and buyer's (right) profits. The dashed line indicates the profits in the game theoretic solution.



The results show that the supplier's average profits are in all treatments significantly below game theoretic solution, while the buyers' profits are all significantly above the game theoretic solution. We observe that communication per se has a positive effect on both suppliers' and buyers' profits. Thus, both parties benefit from communication. From the suppliers' perspective, we find the largest effects from verbal communication[6] (audio and video), while from the buyers' perspective, it seems relevant that verbal communication is combined with visual identification. This observation is a consequence of suppliers' discount offers, since we observed larger discounts in the video than in the audio treatment (see Section 5.3).

Further, the results show that lifting the anonymity condition as such has no significant effect for both suppliers' and buyers' profits. The training tutorial seems to have a slight benefit for the buyers, while it does not significantly pay off for the suppliers.

[6] Note that the pairwise comparison of the video and audio treatment with the reference treatment results in a p-value of 0.011 and 0.018, that indicates that the Bonferroni corrected alpha level might be to too conservative to detect a significant effect.

5.7 Overall comparisons

We summarize in Table 4 the main effects of the four pre-play communication treatments in comparison to our reference treatment and the effect of consulting in comparison to the video treatment.

Table 4 Summary of the main effects.

	Identification	Chat	Audio	Video	Consulting
Trustworthiness	n.s.	n.s.	+	+	n.s.
Trust	n.s.	n.s.	+	+	n.s.
Discount Factors	n.s.	n.s.	n.s.	+	n.s.
Self-selection	n.s.	n.s.	+	+	n.s.
SC performance	n.s.	n.s.	+	+	+
Supplier performance	-	n.s.	n.s.	n.s.	n.s.
Buyer performance	n.s.	n.s.	n.s.	+	n.s.

+ significant positive effect, - significant negative effect, n.s. not significant

We observe that communication is very helpful for players to coordinate the supply chain, which contradicts the game theoretic prediction. Communication is especially successful when a verbal communication channel is available. In contrast, text based communication shows positive effects, but these effects are much weaker. Lifting the anonymity by identification seems not to have relevant effects. Hence, the cooperation enhancing effect of face-to-face communication seemed not to be due to social sanctions and the increased social closeness that arises from mutual identification but rather due to the transmission of information.

5.8 Communication content analysis

We observed that pre-play communication has a strong effect on the supply chain coordination and more so when a verbal communication media is used (audio/ video conference). But what makes verbal communication more effective than text based communication? And why do some groups of subjects cooperate while others do not? We analyzed the transcripts in the communication treatments with respect to the following variables: (a) $introduce$: Do subjects introduce themselves? (b) sum_up: Do subjects summarize the sequence of events of the game? (c) $truthfulness$: Do subjects address that the signal must be truthful? (d) $trust$: Do subjects address the need to trust the signal? (e) $profit\_alloc$: Do subjects address the allocation of profits? (f) $cooperation$: Do subjects address the potential to increase both profits through cooperation?

The average communication time in the four treatments was 6.40, 4.42, 5.20, and 3.62 minutes in the chat, audio, video, and consulting treatments, respectively. Two subjects in the chat treatment exceeded the time limit allowed by 63 and 27 seconds. Although chat communication took on average longer than verbal communication, we believe the ten minutes time limit was sufficiently dimensioned for all treatments. Moreover, in the chat treatment 3 subjects (1 supplier and 2 buyers) refused to communicate with the partner. This did not occur in the other treatments.

Table 5 summarizes how often these aspects have been addressed in the communication treatments (chat, audio, video, and consulting). The results indicate that the strategic aspects of $thruthfulnes, trust, profit\_alloc$ and $cooperation$ are less often addressed in the chat treatment than in the audio and video treatment. Further, the effect of the training video can be clearly seen as these aspects are almost always addressed in the consulting treatment. We employ pairwise Fisher exact tests, to test whether there are statistical significant differences between the treatments with respect to the communication content. In the Online Appendix, in Table 9 in EC.2, we summarizes the resulting p-values. The tests show that $trust$ is significantly less often addressed in the chat treatment compared to the video or audio treatment at the Bonferroni corrected p-value level of 0.002 (for 24 tests at a group level of $\alpha = 0.05$). The differences with respect to $thruthfulnes, profit\_alloc, and\ cooperation$ are not significant. The difference in addressing trust may explain why we observed that suppliers appeared to be reluctant to trust buyer's reports after chat communication. The test further show a slight positive effect of the consulting video on the content but the effects are only statistical significant at non Bonferroni corrected (i.e. less conservative) significance levels.

Table 5 Summary of transcripts.

Treatment	$introduce$	sum_up	$truthfulness$	$trust$	$profit\_alloc$	$cooperation$
Chat	13.8	79.3	72.4	17.2	75.7	69.0
Audio	3.7	96.3	81.5	66.7	74.1	77.8
video	14.3	100	85.7	82.1	82.1	82.1
Consulting	10.0	100	100	96.7	96.7	96.7

Notes. The numbers indicate the percentage of supplier-buyer pairs that addressed the respective aspects during the pre-play communication phase.

We next investigate the effects of the communication content on the subjects' decisions. We use four linear regressions regarding the dependent variables: buyers' trustworthiness, the suppliers' trust, the suppliers' discount offer, and the buyers' self-selection. We include our coded variables and treatment

dummies in the models. We use the data from the communication treatments (chat, audio, video and, consulting) and treat each subject's average decisions as one independent observation. The results (see EC.2, Table 10 in the Online Appendix) confirm a strong correlation between the buyers' trustworthiness and the mentioning of it in the communication phase. Further, we observe a strong correlation between the suppliers' subjective probability adjustments and the mentioning of *trust* in the communication phase. The suppliers' discount offers increase significantly when the subjects discuss the profit allocation. The coded variable cooperation, which indicates whether subjects discuss the potential scope to increase profits by *cooperation,* is positively correlated with the buyers' self-selection. Moreover, we find that discussing the profit allocation has a weak but negative effect on the self-selection frequency. The results imply that communication is especially successful when the relevant aspects of the game are addressed.

6 One-shot interactions

So far we have investigated which communication media foster cooperation in supply chains. We used in all our experiments a partner matching design. This setting likely increases cooperative play. In this section, we investigate how one-shot interactions affect our results.

6.1 Experimental Design

There is empirical evidence that repeated play leads to more cooperative behavior because subjects may be willing to cooperate in the expectation of future reciprocation (Palfrey and Rosenthal 1994). We ran another experiment with the use of a round-robin matching procedure to investigate the effects from repeated play. In the round robin matching procedure, subjects played only once with each other possible partner. Thus, effects from repeated play against a fixed opponent could not arise (Cooper et al. 1996, Kamecke 1997). We choose to use the videoconference communication medium in the pre-play communication phase as the baseline, because this medium showed the strongest effect in fostering cooperation.[7] We expect that one-shot interactions decrease subjects' willingness to cooperate compared to repeated interactions.

[7] Note, since subjects engage in videoconferences social concerns about reputation (e.g., participants may not wish be identified as selfish) may not be ruled out. However, this design rules out any effects arising from the expectations about future interactions (e.g., participants may cooperate in the expectation of higher profits in future periods).

Hypothesis 6: (a) Buyer's trustworthiness, (b) supplier's trust, (c) supplier's discounts, (d) buyer's self-selection rate, and (e) the supply chain performance is higher in the video treatment than in the round robin treatment

The procedure of the round robin treatment is the following. In the first phase, subjects play six practice rounds. In the second phase, players engage the video conference with their first partner. In the third phase, the players play one payoff relevant round of the standard game described above with their partner. Then, players are matched with a new partner, engage a videoconference and play again one payoff relevant round of the game. This procedure is repeated until each player has played with each other possible partner.

Given the round robin matching, the potential number of rounds is restricted by the number of subjects in a session. The laboratory is endowed with a limited set of ten soundproof cabins. Therefore, we are restricted to five corresponding rounds. Thus, altogether every subject engages five videoconferences and plays five payoff relevant rounds.

In order to keep the performance based payment constant between the video and round robin treatment, we use the exchange rate of 0.1 in the round robin treatment. Thus, in the game-theoretic equilibrium supplier's and buyer's expected payoffs are the same in the round robin and video treatment (Becker and Miller 2009).

6.2 Results

In this chapter we compare the results from the round robin treatment to the video and the reference treatment. To have a fair comparison, we consider from the video and reference treatment only the first five decisions with the same demand realizations. For the statistical analysis we use the session averages as one independent observation. In the Online Appendix in Table 11 in EC.3, we summarize the results of the two-sided MWU tests.

When we compare the round robin with the reference treatment, we find that the buyer's trustworthiness, and supplier's trust and buyer's self-selection frequency is significantly higher in the round robin than in the reference treatment. The supply chain performance, suppliers and buyers' profits are also significantly higher in the round robin than in the reference treatment. Comparing the video and round robin treatments, the results show no significant differences for buyer's trustworthiness, supplier's trust and for buyer's contract choices. Further, we find no significant differences for the overall performances, that is, the suppliers', buyers', and the supply chain profits. The results contradict the

Hypothesis 6(a) to 6(e) suggesting that the high levels of cooperation after video communication are not driven by the expectation of future reciprocation. Thus, the strong effect of the video communication on the supply chain coordination remains significant under one-shot interactions.

7 Discussion

We find in laboratory experiments with a student subject pool that (a) simple one-sided text messages improve supply chain performance and (b) even more so if the supply chain parties communicate verbally before the demand data is exchanged.

Our stylized supply chain setup considers central aspects of bargaining in supply chains (sequential moves, quantity discounts, efficiency losses) while abstracting from other ones that set bounds on the generalizability that we discuss below.

First, we used a student subject pool for our experiments. This is well in line with other studies that analyze information sharing in supply chains (Özer et al. 2011, Özer et al. 2014, Hyndman et al. 2013, Spiliotopoulou et al. 2016). Yet, a cautionary note that decision makers in practice might have another set of skills, experiences and beliefs that render communication less effective is warranted. We further note that all of the students were at least fluent in German. As an example, the study from Özer et al. (2014) shows that the extent of trust and trustworthiness varies with the social distance of the supply chain members. It is certainly an interesting avenue for future research to analyze how personal traits and social background interact with effectiveness of communication media on a tactical level.

Second, we made the payoff consequences of contract design and contract choices via a decision support tool very transparent on all stages of the game. Carpenter (2002) shows in the best shot game, a version of a sequential move public good game, that this information provision has a strong effect on the fairness of the final profit allocation. In line with Carpenter (2002) we observe much fairer profit allocations than theoretically predicted, particularly in our verbal communication treatments. As such, the information provision of payoff consequences may be an important antecedent and therefore a limitation for verbal communication to be effective. A rigorous assessment is left for future research.

Third, we restrict our setting to supply chains with deterministic supply and demand. In this situation, quantity discounts are among the most widely used contract forms in practice (Munson and Rosenblatt 1998) and are theoretically also effective to coordinate supply chain with asymmetric information and stochastic demand (Burnetas et al. 2007). It is an interesting avenue for future research to analyze if

communication over contract terms on a tactical planning level can also boost supply chain performance when supply and demand are uncertain. Thereby, other contract formats that allow for risk sharing (buy-back or revenue sharing, see Katok and Wu 2009 for laboratory experiments or Arya and Mittendorf 2004 for asymmetric information and buy-back contracts) might also be considered.

Fourth, we assume that there are two buyer types, i.e. low demand and high demand. While there are most likely more types prevalent in practice, one might certainly consider quantity discounts with more price breaks. Yet, Kalkanci et al. (2011) show in a laboratory supply chain experiment that, due to decision biases, an increase in contract complexity does not necessarily lead to an increase of supplier's profit and thus, simpler contracts can be sufficient for a supplier.

Fifth, we only introduced pre-play communication for enhancing cooperation in the supply chain. While more elaborate communication media may be employed during the actual demand information sharing phase, our results indicate that management can automate those decision if the critical strategic issues are discussed before-hand.

8 Conclusion

We revisit one of the fundamental topics in supply chains: information sharing. We replicate in a different setting the findings from previous laboratory experiments that the simplest form of information sharing, i.e. one-sided messages, enhances supply chain performance, however, efficiency losses prevail (Özer et al. 2011, Özer et al. 2014, Hyndman et al. 2013, Spiliotopoulou et al. 2016). We find that those efficiency losses can be significantly and almost fully reduced if the supply chain parties verbally communicate before the actual demand information is exchanged. We show that this effect remains significant in one-shot supply chain interactions. Our communication content analysis suggests that it is rather a common understanding of the strategic issues and levers that support the successful implementation of information sharing initiatives.

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