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Guido Voigt

Supply Chain Coordination in Case of Asymmetric Information

Information Sharing and Contracting in a Just-in-Time Environment

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Preface

Supply Chain Management has developed to one of the hottest topics over the last two decades both in business research and business practice. Research has contributed quite a lot to support our understanding concerning the impact of the institutional framework and distribution of information on decision making within a supply chain. One of the main questions in this context was how to avoid or, at least, reduce supply chain efficiency losses that are caused by insufficient alignment of goals of independent and selfish actors in such a business relationship. Thereby, main focus lay on the role that contracts between business partners can play for coordinating objectives and actions of supply chain decision makers in such a way that individual actors simultaneously do the best for their own company and for the supply chain as a whole.

Nowadays, we know much about the built-in inefficiency of the simple wholesale price contract and about the design of contracts that achieve coordination for various action fields and supply chain structures. The overwhelming majority of research contributions, however, are assuming the unrealistic situation of symmetrically distributed information within supply chains. Only very few contributions refer to information asymmetry and its impact on supply chain coordination by contacts. From contributions based on principal-agent theory we know that worse informed actors in a supply chain are best off when they offer a so-called screening contract. This contract type, however, leaves some information rent to the better informed parties and fails to achieve supply chain coordination given that all supply chain members act in a fully rational and opportunistic manner. In this context, it is a highly important and interesting question if this type of contract-based lack of coordination can be counteracted by operational actions of single supply chain members for reducing the impact of information deficits and/or by communication that might eliminate information asymmetry at all.

This book deals with this type of research question that has not been addressed in a scientific manner before. As a result it gives many new insights and discusses important managerial implications. The role of communication as an instrument to overcome supply chain inefficiencies in the presence of information asymmetry is not only analyzed in the context of decision making under complete rational behaviour of the supply chain actors. In order to gain deeper insights into the impact of trust and trustworthiness on the coordinating power of contracts under information sharing also an experimental research study of a buyer–supplier interaction in a just-in-time supply chain relationship is conducted. The respective experiments were carried out at the Magdeburg Experimental Laboratory of Economic Research (MaXLab) and revealed distinct deviations of supply chain behaviour from what is expected from theory. Thus, methods of mathematical model analysis and experimental economics are combined in a highly fruitful way. The results of this research give important indications of how to handle screening contracts and how to deal with trust and trustworthiness in a supply chain to overcome coordination deficits caused by information asymmetries.

February 2011 Karl Inderfurth
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I am very thankful to my "Alma Mater", the Otto-von-Guericke University in Magdeburg.

During the early years of my studies, my passion for science and research was stimulated by many great teachers and mentors. Among them are Karl Inderfurth and Alfred Luhmer. Also I would like to thank the "Stiftung der deutschen Wirtschaft" for supporting my studies and research in several ways.

Many colleagues, friends and my family have been supportive and contributed in several ways to this work, and I would like to take the chance to express my gratitude.

My supervisor, Karl Inderfurth, is a great leader and managed to build a team in which researching is not only a pleasure but also rewarding. I regard him as a mentor in many respects, including professional development and personal matters. I trust his judgement, and was never disappointed to do so.

Karim Sadrieh, co-supervisor of this thesis, is an outstanding example that friendship and fun at work while yielding professional results can go along well. I enjoyed very much our nightly research sessions and highly appreciate his commitment to me and my work.

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When my family was moving from Wilhelmshaven to Magdeburg in 1992, no one could anticipate that all of us will stay that long in this nice city. Being the youngest in my family, it was a piece of luck that I had all of my family around while writing the thesis. I would like to thank my sisters Birgit and Kristin and my brother Dirk for supporting and encouraging my work. All of them have now families and children, and it makes me proud to see how you are successfully managing your lives.

Of course, every work has it high- and lowlights. I am very thankful to my spouse, Sylvie Meseberg, who shared all ups and downs with me. You supported me in so many ways that it would be tedious to list all of them. Yet, I would like to highlight that you always encouraged me to do what I would like to do most. We had beautiful times, although commuting between Cologne and Magdeburg. I love you for all what you have done so far.

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Last but not least, I would like to thank my parents, who I love from the bottom of my heart. Having such parents is the prerequisite for all I achieved so far, including this thesis. I thank my mother, Monika Voigt, for understanding my feelings and guiding me in all instances of my life. I thank my father, Rainer Voigt, for always being there for me, and for teaching me to take responsibility for me and my surroundings. To both of them I devote this thesis.

Contents

Abbreviations

AI	Asymmetric information
B	Buyer's decision node
EOQ	Economic order quantity [quantity unit]
FI	Full information
H	High
JELS	Joint-economic-lot-size [quantity unit]
JiT	Just-in-Time
KKT	Karush-Kuhn-Tucker
L	Low
M	Medium
MT	Mistrust
MWU	Mann-Whitney-U
N	Nature's decision node
P&R	Punishment & reward
S	Supplier's decision node
T	Trust
w/o	Without

Notations

a, a^{FI}, a^{AI}	Buyer's promotional effort [monetary units]
A	Menu of contracts
A_i	Contract within the menu of contracts, $A_i = \langle q_i, Z_i \rangle$, $i = 1, ..., n$ or $A_i = \langle Z_i, w_i, a_i \rangle$, respectively
$C_b(q, Z)$	Costs of buyer who chooses contract $\langle q, Z \rangle$ [monetary units per period]
$C_s(q, Z)$	Costs of supplier who chooses contract $\langle q, Z \rangle$ [monetary units per period]
${C_i}^{SC}$	Supply chain costs if buyer chooses contract A_i [monetary units per period]
C_{AS}	Buyer's costs per period when choosing the alternative supplier [monetary units per period]
ΔCD	Change in expected coordination deficit [monetary units per period]
$\Delta {CD_i}^k$	Expected change of the coordination deficit due to communication given holding cost realization h_i and signal S_k [monetary units per period]
$\Delta {C_{s,i}}^k$	Expected change of the supplier's expected costs due to communication given holding cost realization h_i and signal S_k [monetary units per period]
$\Delta {C_{b,i}}^k$	Expected change of the buyer's expected costs due to communication given holding cost realization h_i and signal S_k [monetary units per period]
CD	Coordination deficit [monetary units per period]
$CD^{f_{\max}}$	Coordination deficit if no fixed cost reduction is possible [monetary units per period]
c	Supplier's variable costs [monetary units]
d	Continuous and constant end-customer demand per unit of time [quantity units per period]

$E[P_s]$	Supplier's expected profits per period [monetary units per period]
$E[C_i^{SC}]$	Expected supply chain costs [monetary units per period]
$E(\Delta C_S)$	Expected change in costs of the supplier due to communication [monetary units per period]
$E(\Delta C_b)$	Expected change in costs of the buyer due to communication [monetary units per period]
$E(\Delta C_{b,honest})$	Expected change in cost of the honest buyer due to communication [monetary units per period]
$E(\Delta C_{b,deceptive})$	Expected change in cost of the deceptive buyer due to communication [monetary units per period]
FE	Fixed cost effect [monetary units per period]
F_i	Supply chain optimal contract given private information h_i, i.e. $F_i = \langle q_i^{FI}, Z_i^{FI} \rangle$ or $F_i = \langle Z_i^{FI}, w_i^{FI}, a_i^{FI} \rangle$
I	Relative frequency of indifference contract choices
f_b	Buyer's fixed cost per order q [monetary units]
f_r	Root of $TM^{FI}(\cdot)$ or $TM^{AI}(\cdot)$ [monetary units]
f_s	Supplier's fixed costs per order q [monetary units]
f_i^{FI}	Supply chain's optimal fixed cost level referring to contract F_i under full information [monetary units]
f_i^{AI}	Fixed cost level referring to contract A_i under asymmetric information [monetary units]
$f_{\max}$	Supplier's initial fixed cost level when fixed cost reduction is possible [monetary units]
$f_{\min}$	Supplier's minimum fixed cost level if fixed cost reduction is possible [monetary units]
f_{high}	Benchmark in which the supplier offers constantly F_H
H_i	Dummy variable
h	Holding costs per unit and period [monetary unit per quantity unit and per period]
$\tilde{h}$	Actual holding cost of the buyer in a period [monetary unit per quantity unit and per period]
h_i	Holding cost realization [monetary unit per quantity unit and per period], $i = 1, ..., n$
r	Interest rate [percentage per unit time]
IR_i	Informational rent paid to buyer choosing contract A_i [monetary units per period]
$k(f)$	Investment function [monetary units]
$MR(\cdot)$	Marginal costs of reducing fixed cost level under full information [monetary units per period]
$MR^{FI}(\cdot)$	Marginal revenues of reducing fixed cost level under full information [monetary units per period]
$MR^{AI}(\cdot)$	Marginal revenues of reducing fixed cost level under asymmetric information [monetary units per period]

OE	Overinvestment effect [monetary units per period]
q	Buyer's order size [quantity units]
q_i, q_i^{FI}, q_i^{AI}	Order size in the contract $A_i = \langle q_i, Z_i \rangle$ [quantity units]
q_i^k	Order size in the contract $A_i = \langle q_i, Z_i \rangle$ after observing signal S_k [quantity units]
$q_i^{AI,f_{\max}}$	Optimal order size under asymmetric information if no fixed cost reduction is possible [quantity units]
$q_i^{FI,f_{\max}}$	Optimal order size under full information if no fixed cost reduction is possible [quantity units]
q_i^{RP}	Order size under asymmetric information in dependence of risk preferences [quantity units]
$q_i^{RN}, q_i^{RA}, q_i^{RS}$	Order size under asymmetric information in dependence of risk neutral (RN), risk averse (RA), and risk seeking (RS) preferences [quantity units]
p, p^{FI}, p^{AI}	Price charged from the buyer by the end-customer [monetary units per quantity unit]
p_i	A priori probability of holding cost realization h_i, $i = 1, ..., n$
$p_i(S)$	Adjusted probability, $i = 1, ..., n$
$p_i(\cdot)$	Adjusted probability without communication, $i = 1, ..., n$
$p_i(h_i \mid H_k)$	Actual a posteriori probability, $i = 1, ..., n$; $k = 1, ..., n+1$
$\hat{p}_i(h_i \mid H_k)$	Perceived a posteriori probability H_k; $i = 1, ..., n$; $k = 1, ..., n+1$
$p_i(h_i \cap H_k)$	Actual conjoint probability distribution; $i = 1, ..., n$; $k = 1, ..., n+1$
$\hat{p}_i(h_i \cap H_k)$	Perceived conjoint probability distribution; $i = 1, ..., n$; $k = 1, ..., n+1$
P_b	Buyer's profits per period [monetary units per period]
$P_{b,i}(A_j)$	Buyer's profits per period when facing holding costs h_i and choosing contract A_j [monetary units per period]
P_s	Supplier's profits per period [monetary units per period]
$P_{s,j}$	Supplier's profits per period when buyer chooses the contract A_j [monetary units per period]
ΔP	Change in expected supply chain performance due to fixed cost reduction [monetary units per period]
R	Buyer's profits per period when choosing the alternative supplier [monetary units per period]
R^2	Coefficient of determination
S	Set of signals, $S \in (S_1, ..., S_{n+1})$
S_i	Signal from buyer to supplier, where $S_i = h_i, \forall i = 1, ..., n$ and "no signal" for $i = n+1$
S_{No}	No signal
T	Order interval [time unit]
$T_{i,t}$	Dummy variable

$TM^{FI}(\cdot)$	Total marginal savings of reducing fixed cost level under full information [monetary units per period]
$TM^{AI}(\cdot)$	Total marginal saving of reducing fixed cost level under asymmetric [monetary units per period]
$u(\cdot)$	Neumann-Morgenstern utility function
$u'_{s,i}$	First derivative of $u(\cdot)$ w.r.t. $-P_{s,j}$
w	Wholesale price [monetary unit per quantity unit]
Y_b	Buyer's fixed revenues per period [monetary units per period]
Y_s	Supplier's fixed revenues per period [monetary units per period]
Z	Side-payment from supplier (principal) to buyer (agent) [monetary units per period]
Z_i,Z_i^{FI},Z_i^{AI}	Side-payment from supplier (principal) to buyer (agent) in contract $A_i = \langle q_i, Z_i \rangle$ [monetary units per period]
Z_i^k	Side payment in the contract $A_i = \langle q_i, Z_i \rangle$ after observing signal S_k
Z_i^{RP}	Side-payment from supplier (principal) to buyer (agent) under asymmetric information in dependence of risk preferences [monetary units per period]
Z_P	Size of supplier's punishment of the buyer [monetary units]
Z_R	Additional side-payment (outside the menu of contracts) [monetary units]
$Z_R^{\min}$	Additional side-payment (outside the menu of contracts) that ensures Pareto improvements [monetary units]
α	Fraction of honest buyers
$\hat{\alpha}$	Expected fraction of honest buyers (also: estimated regression coefficient)
α_{crit}	Critical portion of honest agents that are required for communication to be a coordination instrument
β_i	Regression coefficient, $i \in (L, M, H)$
$\hat{\beta}_i$	Estimated regression coefficient, $i \in (L, M, H)$
$\hat{\phi}_i$	Expected unconditioned signaling variable, $i = 1, ..., n+1$
ϕ_i	Actual unconditioned signaling variable, $i = 1, ..., n+1$
$\hat{\phi}_i(h_k)$	Perceived conditioned signaling variable, $i = 1, ..., n+1$; $k=1,\ldots,n$
$\phi_i(h_k)$	Actual conditioned signaling variable, $i = 1, ..., n+1$; k=1,. . .,n
$\tilde{\phi}_i$	Probability of signal S_i ($\tilde{\phi}_i = \alpha p_i + (1-\alpha)\phi_i$); $i = 1, ..., n+1$
σ	Standard deviation
γ_i	Distortion caused by asymmetric information given contract choice A_i

${\gamma_i}^k$	Distortion caused by asymmetric information given contract choice A_i and signal S_k
$l_{\min,i}, {l_{\min,i}}^{FI}, {l_{\min,i}}^{AI}$	Lagrange-parameter
$l_{\max,i}, {l_{\max,i}}^{FI}, {l_{\max,i}}^{AI}$	Lagrange-parameter
$\lambda_{ij} {\lambda_{ij}}^{AI}$	Lagrange-parameter
$\mu_i, {\mu_i}^{FI}, {\mu_i}^{AI}$	Lagrange-parameter

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Chapter 1
Introduction

The research area of supply chain management analyses the interactions of independent firms and provides concepts that can enhance the performance of each supply chain party. However, if the legally independent supply chain members deliberately exploit the supply chain counterpart to enhance own financial ratios, then the implementation of a specific concept is likely to fail, as long as there are no mechanisms avoiding the pitfalls of opportunistic behavior in advance. It is therefore important to develop mechanisms facilitating the implementation of these logistics concepts, even though the supply chain parties pursue individual goals instead of collective supply chain goals.

A major challenge of supply chain management is the so-called supply chain coordination, i.e., the alignment of incentives such that individually optimal actions lead to supply chain optimal actions. Very prominent tools in the coordination literature are contracts that legally stipulate the business relation between the supply chain parties. Since these contracts typically link the actions of the company to individual performance measures, e.g., costs or revenues, they can be designed such that the individual performance is directly linked to the overall supply chain performance. In other words, optimizing the individual performance is in line with optimizing the supply chain performance.

As mentioned before, the concepts discussed in supply chain management have the potential to improve the overall supply chain performance. Utilizing the metaphor of a cake that can be split among the supply chain members, the size of the cake increases if the concept is implemented. Implementing a concept is simple if each firms' fraction of the cake is known from the beginning. In this case, the contract only has to guarantee that the fraction of the cake is at least the same after the implementation, which is no problem since the cake as a whole increases.

Yet, if the allocation of the cake is not known in advance, the self-interested firm has an incentive to misrepresent its fraction before the implementation, since it can claim a larger fraction of the increased cake afterwards. Information asymmetry with respect to the benefits or costs of implementing a concept, thus, is a major problem in supply chain coordination.

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Recently, many studies of supply chain coordination under asymmetric information have been published. All of these studies frame the supply chain planning situations as principal–agent models, in which the agent is the holder of the private information. In this case, the principal offers a sophisticated screening-contract which gives the agent an incentive to reveal his private information truthfully. Yet, there is still a non-negligible lack of coordination if these so-called screening contracts are used to align the incentives within the supply chain, i.e., the size of the cake is smaller than under full information. In other words, these screening contracts fail to coordinate to the supply chain optimum. However, if all supply chain parties act completely opportunistic, the supply chain theoretically cannot perform better than this second best solution.

The problems that arise under asymmetric information heavily rely on the assumptions of the supply chain members acting opportunistically, and having therefore an incentive to misrepresent their private information. Moreover, it is implicitly assumed that the actors are fully rational, i.e., they easily identify how to misrepresent their information or how to exploit truthfully shared information. Yet, there is a growing body of research in the field of behavioral economics showing that these assumptions need to be handled carefully.

In the context of asymmetric information, the assumptions of rationality and opportunistic behavior imply that supply chain parties will prefer inefficient complicated screening-contracts under asymmetric information to efficient and less complicated contract structures under full information. In other words, theory predicts that supply chain members are more likely to use complicated inefficient contracts instead of establishing truthful communication and trust while using simpler contract schemes. However, to our knowledge there is so far no empirical assessment of different contract structures under asymmetric information. This is not surprising, since there are substantial methodological difficulties to assess the amount of truth-telling and the extent of trust in supply chain interactions. First of all, supply chain members are typically reluctant to give fully access to critical information. Yet, even though researchers may have access to detailed communication scripts, they can hardly evaluate whether a report was true or strategically biased, since the underlying benchmark suffers from the estimation's statistical errors. For this reason, the present thesis employs laboratory experiments to address the above questions in a controlled environment, in which communication between the supply chain parties is perfectly observed and the ex post evaluation of trust and truthfulness is possible. Building upon the insights of these experiments, the theoretical model of supply chain interactions under asymmetric information is revisited, and some modifications that capture the observations from the experiment are introduced.

Figure 1.1 depicts the structure of the thesis. All analysis and experiments will refer to a strategic lotsizing model, which is introduced in Sect. 2.2. This strategic lotsizing framework captures that suppliers typically prefer large lot sizes, while buyers prefer smaller lots. In this context, the concept of Just-in-Time (JiT) is frequently discussed. It is shown that this concept can be easily implemented if the buyer's advantages of the JiT delivery is perfectly known. Yet, in case the supplier can only estimate the buyer's advantages of the JiT strategy, it is shown that

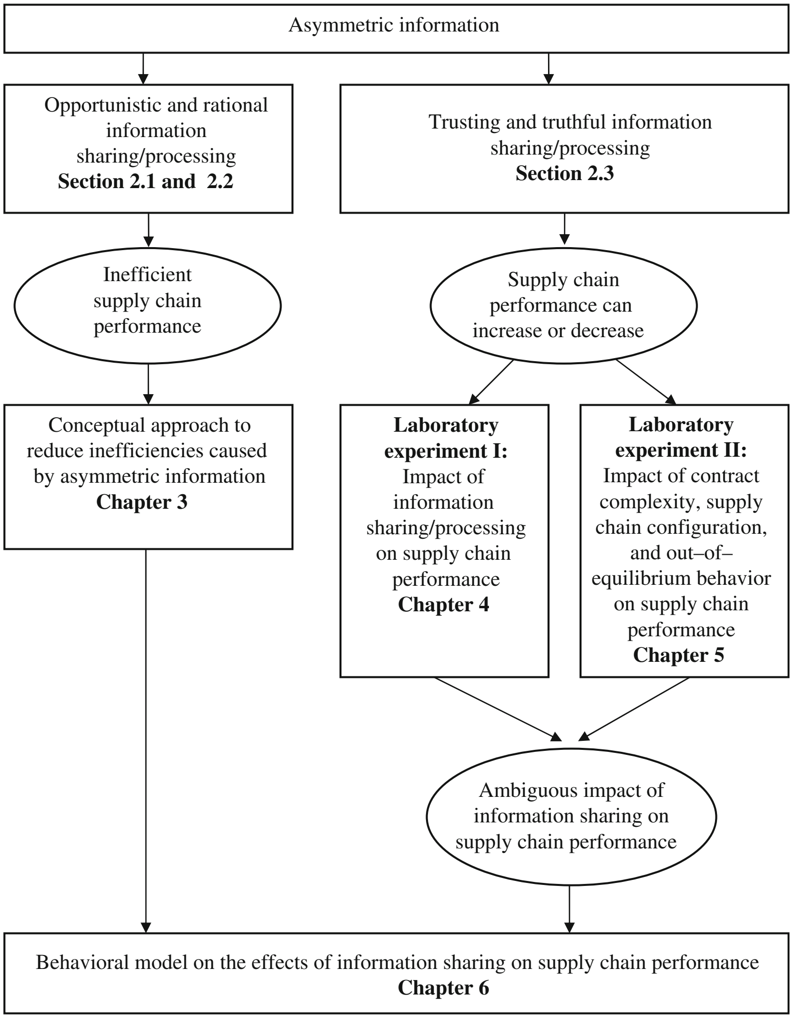

Fig. 1.1 Structure of the thesis

screening contracts can be used to coordinate the supply chain at least to some extent. Besides the highly empirical relevance of JiT strategies, the stylized form of the JiT model is very useful for implementing it as an laboratory experiment, since it can be relatively easy explained to the participants. Hence, the strategic lotsizing model is used as the basis for all sections in the underlying thesis.

Chapter 2 discusses the impact of asymmetric information from two perspectives. The first perspective (Sects. 2.1 and 2.2) assumes that all actors act fully rational and opportunistic. It follows that communication is not reliable, since the private information will be used strategically. Hence, the ill-informed party will offer a screening contract leading to an expected coordination deficit.

The second perspective (Sect. 2.3) takes a cooperative view, showing that information sharing has an impact, if the supplier reacts to the shared information. In this case, however, the impact of the supply chain performance is ambiguous, since the buyer's report can either be truthful or deceptive.

Building upon the first approach in which all parties act fully rational and opportunistic, Chap. 3 analyzes the implementation of the JiT strategy in the strategic lotsizing model under asymmetric information more thoroughly. Since it is regularly mentioned that a JiT strategy should be accompanied by process improvements, it is analyzed whether the efficiency losses due to asymmetric information increase or decrease when the supplier can invest in costly process improvements. Hence, the model allows identifying industrial settings, in which the behavioral assumptions of opportunistic behavior and rationality seem to be crucial when discussing JiT strategies.

Since Chap. 3 shows that inefficiencies arise in the majority of all cases, it seems worthwhile to analyze whether information sharing can enhance supply chain performance, although non-cooperative game-theory predicts otherwise. Yet, Sect. 2.3 highlights that the effect of communication is ambiguous and depends on the interaction of trust and trustworthiness. Hence, a laboratory experiment was designed to analyze the impact of information sharing in a controlled environment, in which the buyer's actual private information can be observed along with his report. This allows measuring the level of truthfulness. Moreover, the adjustment of the supplier's statistical forecast of the private information as a reaction on the report can be observed. This allows measuring the supplier's tendency to trust or mistrust the reported information. This assessment of trust and trustworthiness allows analyzing the interaction of behavioral types (trusting and mistrusting suppliers, deceptive and truthful buyers) under asymmetric information. The results of this experiment are present in Chap. 4.

Chapter 5 discusses the results of a laboratory experiment, in which the supplier is only allowed to offer contracts as if under full information, e.g., because he believes in the shared information, or to offer a screening contract which is optimal if he mistrust the shared information. Hence, the subtle measuring of trust via adjusted statistical forecasts as in Chap. 5 is not possible, while it is possible to directly compare the empirical relevance of complex screening contracts in contrast to simpler contracts (as if under full information). The experiments were conducted for several supply chain configurations, which allows discussing the effect of contract type complexity in different industrial settings.

Thereafter, Chap. 6 incorporates some of the experimental results presented in Chaps. 5 and 6 in the strategic lotsizing model. Particularly, the model can explain why information sharing does not necessarily improve the supply chain performance, although a certain fraction of buyers always reveal their private information truthfully. The model identifies three basic determinants, i.e., trust, trustworthiness, and information sharing behavior that needs to be carefully considered when discussing the benefits and pitfalls of information sharing in supply chain management.

Finally, Chap. 7 summarizes the results and gives some directions for further research.

Chapter 2
Supply Chain Coordination in Case of Asymmetric Information

The following chapter elaborates the impact of asymmetric information in a supply chain context and shows that information sharing can enhance supply chain performance if some level of trust and trustworthiness can be established. Section 2.1 gives a brief overview over related research areas while introducing basic definitions, assumptions and concepts. Section 2.2 discusses the impact of asymmetric information in a supply chain context while showing that specific contract structures can be used to align the incentives in the supply chain. Since these contract structures are not efficient, Sect. 2.3 discusses under which circumstances regarding trust and trustworthiness information sharing can lead to supply chain optimal outcomes. Finally, Sect. 2.4 gives a comprehensive review of supply chain models in which contracts are used for coordinating actions in supply chain management.

2.1 Contracting Under Asymmetric Information: Basic Definitions, Assumptions and Concepts

The techniques used in this thesis do basically stem from the theory of optimal income taxation (see Mirrlees 1971), from the theory of monopolistic pricing (see Mussa and Rosen 1978), and from the regulation literature (see Baron and Myerson 1982). The theory of optimal income taxation analyzes the government's problem to choose a tax policy that maximizes the total surplus of the economy. In this case, the government is ill-informed with respect to the individual productivities (i.e., skills), while the individuals choose between consumption and labor supply.

Mussa and Rosen (1978) consider a monopolistic pricing problem in which the monopolist is ill-informed with respect to the buyer's valuation of the product, which is dependent from the product's quality. Assuming that the monopolist can vary the product's quality, Mussa and Rosen show that a nonlinear price-quality scheme maximizes the monopolist's profits.

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Baron and Myerson (1982) analyze how the government optimally regulates a monopolist who has private information with respect to his variable cost of producing the good. The regulator maximizes the social welfare by determining the price the monopolist is allowed to charge as well as the subsidy that is required for accepting a regulated price.

The aim of the section is to introduce the basic assumptions, definitions and concepts that build the basis of the present work. Therefore, the principal–agent concept as well as the "Revelation Principle" as one of the fundamentals in mechanism design theory is briefly discussed. Finally, the two distinctive types of information asymmetry (moral hazard and adverse selection) that can be analyzed in a principal agent framework are introduced.

2.1.1 The Principal–Agent Framework

All of the models presented in this work are based on the principal–agent framework, in which the principal is the ill-informed party while the agent is the holder of the private information (e.g., productivity or costs). Ross (1973) was first to introduce the terminology of a principal–agent setting and defines that "an agency relationship has arisen between two (or more) parties when one, designated as the agent, acts for, on behalf of, or as a representative for the other, designated the principal, in a particular domain of decision problems" (see Ross 1973, p. 134). Arrow (1985, p. 37) summarizes the main characteristics of a principal–agent relationship:

- Two parties interact in a principal–agent relationship. The number of principals or agents can vary in different settings.
- One party (the agent) has to choose from a number of alternatives.
- The agent's decision influences the utility of both parties.
- Both parties act opportunistically, i.e., both parties maximize their own (expected) utility.
- There is asymmetric information and/or uncertainty.
- The principal observes the result of the decision or other variables that can be linked to the agent's private information.
- The principal has to propose a contract that defines the agent's welfare contingent on the observed result or action.

Many interactions can be characterized as above. Examples range from the insurance market (see Spence and Zeckhauser 1971; Rothschild and Stiglitz 1976), sellers and buyers of cars (i.e., the prominent market of lemons, see Aklerhof 1970), to shareholders and managers (Jensen and Meckling 1976).

Salanié (2005) stresses that principal–agent models are a special case of more general bargaining situations under asymmetric information. These simplified versions of general bargaining situations are used, as the more general frameworks are very complex due to multiple game-theoretic equilibria.[1] The principal–agent framework avoids these problems by assigning all bargaining power to one party, i.e., the principal. The principal makes a "take it or leave it" offer and the agent can only accept or reject the offer. Hence, it is assumed that the interaction stops immediately if the agent rejects an offer. However, Salanié (2005) stresses that this is (often) a simplification, as in real-world settings it is likely that further bargaining steps apply, especially if an agent rejects an offer (see Salanié 2005, p. 5).

2.1.2 Mechanism Design and the Revelation Principle

This subsection gives a short introduction to mechanism design and the revelation principle, as their fundamental results will be used throughout the work. Since the main insights are already observable in the one-principal and one-agent setting, the exposition is restricted to this case. A more rigorous discussion can be found in the early studies of Dasgupta et al. (1979) and Myerson (1979). It is referred to Fudenberg and Tirole (1995) for a textbook introduction as well as many applications of this research stream.

The main characteristic of the mechanism-design approach is that the principal is assumed to maximize his (expected) utility when there is asymmetric information (see Fudenberg and Tirole 1995). In contrast to general principal–agent models, mechanism designers do not only maximize the principals expected utility for a given mechanism (i.e., contract or incentive-scheme), but they also look for the optimal mechanism. In the following, all definitions will be given for a single agent framework.

A mechanism is a function that assigns an agent's message $S \in (S_1, \ldots.., S_k)$, where k is an arbitrarily high number, to a contract $\langle q, Z \rangle$ where q is the agent's decision and Z is a transfer function. The transfer function defines a side-payment which is paid from the principal to the agent, or vice versa. Formally, a mechanism is defined by $S \to \langle q, Z \rangle$. Let $u(q, Z, h)$ denote the agents Neumann–Morgenstern utility function, where $h \in (h_1, \ldots, h_n)$ denotes the agents private information, and n is the number of different types. The probability of interacting with a certain type, $p_i, i = 1, \ldots, n$ is assumed to be common knowledge. It is assumed that $u(\cdot)$ is strictly increasing in Z and twice continuously differentiable. Assuming that the agent maximizes his expected utility, he will choose a message S such that $S^*(h) = \arg\max_s(u(q, Z, h))$. Hence, the principal can anticipate which message the agent of type h will send given a specific mechanism. In turn, the principal can optimize his own utility over the allocation that results through the mechanism. An allocation rule defines a function assigning a decision q and a transfer function Z to each type h, i.e., $h \to \langle q, Z \rangle$.

[1]Ausubel et al. (2002) survey the bargaining literature under asymmetric information.

The revelation principle (see, e.g., Myerson 1979) states that the principal can restrict his attention to mechanisms that are direct and truthful. A direct mechanism means the message space is restricted to possible types, i.e., $S \in (S_1, \ldots, S_n)$ or, in other words, $k = n$. A truthful mechanism ensures that an agent with type h_i will indeed send a message referring to his type. One special type of such a direct mechanism is the screening contract, which is used throughout the underlying thesis as a coordination device. The screening contract consists of n-contracts, where each contract refers to one type h_i. Since the screening contract consists of several contracts from which the agent can choose, another common wording is "menu of contracts".

2.1.3 Moral Hazard and Adverse Selection

In the following the main problems that arise under asymmetric information are summarized (see, e.g., Jost 2001a). Table 2.1 summarizes the different kinds of principal–agent interactions that arise due to asymmetric information.

Principal–agent frameworks can be distinguished by the type of information asymmetry. The type of information asymmetry is dependent on the specific point in time in which the asymmetry emerges (i.e., time of occurrence). Models in which the agent has private information before (i.e., ex ante) the principal offers a contract are so-called models of adverse selection. In contrary, moral hazard problem are prevalent if information asymmetry emerges after (i.e., ex post) the contract is concluded. Both problems, i.e., moral hazard and adverse selection, can occur simultaneously (see, e.g., Desai and Srinivasan 1995). Furthermore, the problems of moral hazard can be subdivided into problems of hidden action and hidden information.

In hidden action frameworks, the principal offers a contract and the agent decides whether to accept or reject the contract afterwards. After contract acceptance, the agent chooses an action which is unobservable for the principal. The principal cannot directly infer the action from the outcome as there are additional influencing variables that have an impact on the outcome. In this case, information asymmetry is endogenously determined as the asymmetry emerges out of the agent's decisions. As an example, the manager (principal) cannot observe how much effort his staff is assigning to a specific task (e.g., promotional effort), because there is uncertainty in demand. Hence, low sales can either result from low realized random demand and/or low promotional effort (see Blair and Lewis 1994 as well as Desai and Srinivasan 1995).

Table 2.1 Classification of principal–agent relationships (Jost 2001, p. 25)

	Hidden action	Hidden information	Hidden characteristics
Source of information asymmetry	Endogenous	Exogenous	Exogenous
Time of occurrence	Ex post	Ex post	Ex ante
Type of information asymmetry	Moral hazard	Moral hazard	Adverse selection

In contrast, hidden information occurs before the agent chooses his action but after the contract was concluded. Under hidden information, the principal can observe the agent's actions, but he cannot assess whether this action was in his own best interest or not. This is, because the agent is privately informed about some decision relevant parameters before he chooses his actions but after he signed the contract, i.e., before the incentives were specified. As an example, Zhang and Zenios (2008) propose a model in which the supplier cannot observe the buyer's inventory level, as there is stochastic demand. Assuming a multi-period context in which a contract is proposed at the beginning of the first period, they show that the hidden information problem is in place as the supplier can observe the buyer's order but not his inventory level. In both cases, i.e., hidden actions and hidden information the principal cannot directly observe whether the agent chooses an effort level which is in his best interest. In contrary, there is a "moral risk" that the agent uses his superior information to uncover inefficient effort.

In adverse selection models, in contrast to moral hazard models, the information asymmetry arises before the principal offers a contract to the agent. As an example, the buyer may have private information with respect to cost parameters, e.g., his holding costs. Assuming that the supplier wants to induce higher order sizes, the buyer may exaggerate his cost position to yield a higher compensation for accepting higher order sizes (see Corbett and de Groote 2000). The following section will intensively discuss a strategic lotsizing model as specific adverse selection problem. This model will be the starting point for all further research presented in the underlying thesis.

The literature discusses mainly two solution concepts that can be applied to **adverse selection models**, namely screening and signaling contracts. In signaling games the agent possessing private information offers a contract conveying his private information credibly, while in screening games the ill-informed party offers the contract. In both cases so-called "agency-costs" are prevalent, i.e., there is a deviation from the first-best solution. Hence, in both cases there are possible efficiency gains through truthful information sharing and trust. The following section shows how screening contracts can be applied in a strategic lotsizing framework. Since all further research in this thesis are solely related to screening contracts, the exposition of signaling contracts is omitted. Yet, the interested reader might refer to Desai and Srinivasan (1995) for a supply chain model with asymmetric demand information.

2.2 The Strategic Lotsizing Framework: Using Screening Contracts in Adverse Selection Models

This section introduces a strategic lotsizing model, which is used as a starting point for all further research in the underlying thesis. Sections 2.2.1 and 2.2.2 briefly recapitulate the classical- and the joint economic lotsizing model, respectively, since these models are closely connected to the strategic lotsizing model, which is

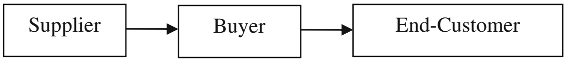

Fig. 2.1 Supply chain configuration

introduced in Sect. 2.2.3 for the case of full information. Finally, Sect. 2.2.4 discusses the impact of asymmetric information in the strategic lotsizing framework.

2.2.1 The Classical Economic Order Quantity Model

There is a long tradition of determining economic order quantities in operations management. In the following the planning problem is described for the buyer who sells a product to a end-customer at a continuous and constant demand rate d (see Fig. 2.1).[2] The buyer himself sources the product from a supplier at a wholesale price of w. The buyer's order size is denoted by q.

The buyer takes into account two decision relevant kinds of cost that occur when an order is triggered. On the one hand, the ordering process itself causes fixed costs (f_b), e.g., the costs of order forms, telephone calls, inspection, and so on. On the other hand, there are costs of carrying items in inventory. These costs mainly include the opportunity costs of the money invested (i.e., working capital), handling costs, deterioration of stock, and so on. Let h denote the holding costs that occur for every unit stored per unit time in inventory.

As the end-customer demand, d, is continuous and constant over time, there is the same outflow of goods at every point in time from the inventory. It is assumed that the total planning horizon is infinite. The inventory level increases to q when the order arrives and decreases with a continuous rate of d afterwards. For the sake of simplicity it is assumed that there is no delivery lead time. Hence, a new order is placed after the inventory is depleted, i.e., after $T = q/d$ periods.

Figure 2.2 depicts the development of the inventory in the course of time. The arrows in Fig. 2.2 imply that the inventory level is on average half of the order size, i.e., $q/2$. Hence, every unit ordered causes on average holding costs of $h/2 \cdot q$ per period. Furthermore, every T periods a new order is placed which causes fixed costs of f_b. Hence, the fixed costs per period result from f_b/T or $f_b \cdot d/q$, respectively. Summarizing, the total costs per period of ordering q units results from $h/2 \cdot q + f_b \cdot d/q + w \cdot d$. Deriving with respect to q and solving for q gives the prominent economic order quantity $\text{EOQ} = \sqrt{2 \cdot f_b \cdot d/h}$.

[2]Note that the complexity of the planning situation increases if the demand rate is price dependent. However, Boyaci and Gallego (2002) argue that even in this case the pricing and order size decisions can be separated as long as the demand rate is sufficiently large. However, it is referred to Weng (1995) for a discussion of order size coordination issues under price-sensitive demand in case of a single-supplier single-buyer supply chain (or multiple identical buyers). Chen et al. (2001) extend the analysis to the case of a diverging supply chain with non-identical buyers.

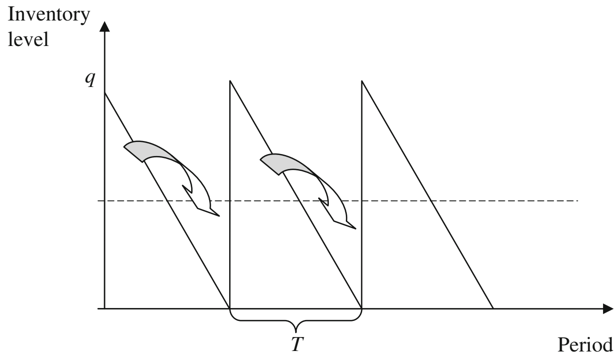

Fig. 2.2 Development of inventory level in the classical economic order quantity model

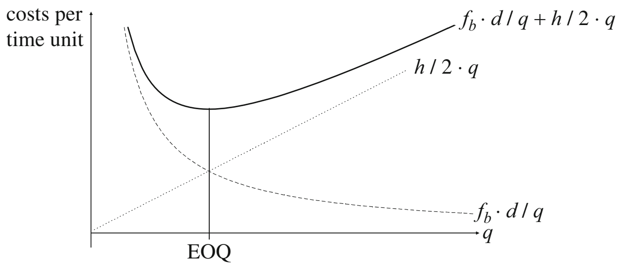

Fig. 2.3 Holding costs, fixed costs, and total costs per period of ordering q units

Figure 2.3 gives a graphical representation of the fixed, holding, and total costs per period in dependence of the order size q.[3] The economic order quantity can easily be identified at the intersection of the holding costs curve and the fixed costs curve. The economic order quantity does therefore depict the basic conflict that low order sizes reduce the holding costs per period while high order sizes lead to low fixed costs per period. Obviously, the optimal order quantity lies somewhere inbetween.

2.2.2 *The Classical Joint-Economic-Lotsizing Model*

Section 2.2 elaborated that there are operational reasons for the buyer to choose an optimal order size that takes into account the fixed costs per order as well as the order size related holding costs. However, the previous section did not consider that

[3] Note that the procurement costs $w \cdot d$ are not decision relevant in this context.

the buyer's order decision, q, causes cost at the supplier's site. It is assumed that the supplier has to setup his production facilities every time he receives an order from the buyer. After producing the order size q, the whole lot is shipped to the buyer. Hence, the supplier carries no inventories. This is the so-called lot-for-lot production (see Monahan 1984; Banerjee 1986).[4] The configuration of the production facilities causes fixed costs of f_s. As the buyer passes through the end-customer demand (although bundled to order sizes q), the supplier faces on average a deterministic demand of d units per period as well, and his average fixed costs per period result from $f_s \cdot d/q$. Hence, every time the buyer orders q units, the total supply chain costs (i.e., the sum of the supplier's and the buyer's costs) results from $f_s \cdot d/q + f_b \cdot d/q + h/2 \cdot q$. The same analysis as in Sect. 2.2.1 applies, and the joint-economic-order-lotsize (JELS) results from $\text{JELS} = \sqrt{(f_s + f_b) \cdot d/q}$. Obviously, JELS $>$ EOQ holds. Hence, the supply chain performance suffers if the buyer makes his order decision while ignoring the suppliers fixed costs per period. Note, however, that the self-interested buyer will not deviate from the EOQ if he gets no incentives to do so. This is the grain of truth in the supply chain coordination intuition: the individual supply chain members will not take joint-optimal decisions as long as there is no incentive alignment. It can be shown that contracts with quantity dependent wholesale-prices, such as all-units and incremental discounts, are able to coordinate the supply chain in this example.[5] Yet, before the contracting and coordination issues are addressed, the scope of the joint-economic-lotsizing idea is expanded by transferring it to a strategic supply chain planning situation.

2.2.3 Strategic Lotsizing Under Full Information

Just-in-time (JiT) strategies are well-known to be highly efficient in reducing non-value adding logistic activities. In the following it is assumed that the buyer carefully evaluates the various advantages and disadvantages of implementing the JiT strategy. Note that this assessment goes far beyond the trade-offs explained in Sect. 2.2.1.

JiT delivery leads on the one hand to small order lotsizes and therefore an inventory reduction. The impact of inventory reduction on the buyer's performance result from a bundle of advantages, such as less tied-up capital, reduced inventory handling, less storage room, less handling equipment, as well as less rework and

[4]The assumption of lot-for-lot production can be easily relaxed. If the supplier adjusts his production schedule to the buyer's orders, it is optimal to produce an integer factor of the buyer's order sizes (see Lee and Rosenblatt 1986; Goyal 1988). Goyal and Gupta (1989) and Weng (1995) review the literature of lotsizing coordination under deterministic demand.

[5]Munson and Rosenblatt (1998) and Benton and Park (1996) give an comprehensive review on the quantity discount literature. Dolan (1987) surveys the quantity discount problem from a marketing perspective.

scrap. Furthermore, JiT allows for a more uniform workflow, less idle time, and more efficient material handling and production. Last but not least, JiT may also help reduce planning and control complexity (see Schonberger and Schniederjans 1984).

The degree of JiT strategy implementation can vary. As an example, the supplier could relocate his production facilities close to the buyer's facilities. This, in turn, would allow for even lower order sizes and a higher supplier's responsiveness (see Benjaafar 2002). The relocation would depict a very high degree of implementation. However, the supplier's costs for the relocation might be too high, and therefore a smaller implementation degree more favorable.

To formalize the above situation, it is assumed that all of the buyer's advantages of a JiT strategy can be captured by a single measure, namely by the holding costs per unit and period, h. Additionally, the degree of the strategy implementation is captured by a linearly dependency between holding costs per period, h, and the order size q. The holding costs per unit time, thus, are equal to $h/2 \cdot q$. Hence, a high degree of implementation (i.e., a small q) stronger benefits a buyer with big advantages of the JiT strategy (i.e., high holding costs).

On the other side, though, the small order sizes favored by the buyer may also cause an increase of the supplier's setup, holding, relocation and distribution costs (Fandel and Reese 1991). In the following, it is without loss of generality assumed that the constant and continuous demand is equal to one, i.e., $d = 1$. Hence, the period costs equal the unit costs. Then, the various disadvantages of low order sizes for the supplier can be captured by one measure, namely the fixed cost that occurs per unit, i.e., f/q.[6]

Note that the introduced planning situation goes beyond determining an order quantity. In fact, the order size is only a proxy for the degree of JiT implementation. Yet, as this planning situation is highly strategically relevant, it is assumed that buyer and the supplier engage in a negotiating process. Additionally, it is assumed that the buyer has the option to choose an alternative supplier. The buyer yields a unit profit margin of R when he chooses the alternative supplier.

As a starting point for the bargaining analysis, it is assumed that the buyer asks the supplier for the highest possible degree of JiT implementation. From a supply chain perspective, an implementation of a JiT strategy is only profitable, if the buyer's cost advantages exceed the supplier's cost increase. Munson and Rosenblatt (1998) report that conflicts often arise when buyers push for JiT deliveries, and the suppliers withstand to switch to this mode of delivery. Additionally, Myer (1989) finds that a buyer's single-handed implementation of the JiT concept causes a supply chain cost increase of 25–30% in the food industry (basically due to transportation,

[6]David and Eben-Chaime (2003) distinguish a literally JiT policy in which the supplier produces lot-for-lot (see, e.g., Monahan 1984) and a Delivery-on-Demand policy in which the supplier holds inventories and delivers directly out of stock. Nonetheless, the stylized JELS model introduced in this section may even capture the supplier's increased holding costs that occur if JiT leads to higher inventories at the supplier's site, as the fixed cost are a highly aggregated measurement that capture the supplier's disadvantages of low order sizes.

warehousing, unnecessary one-to-one communication on the sales side, as well as incentive promotion and advertising on the marketing side), and a cost increase in the range of 10–20% in other consumer good fields. In these cases, the buyer's isolated JiT decision obviously leads to a lack of supply chain coordination due the supplier's cost increase. Hence, if the buyer forces JiT deliveries, the supplier may have a strong incentive to convince the buyer to abandon the JiT strategy.

These results indicate that the highest implementation degree of the JiT strategy is not always profitable. However, the buyer will not be convinced to abandon the JiT strategy unless he yields lower costs than choosing the alternative supplier. Yet, as long as there is a lack of coordination (i.e., as long as Pareto improvements are possible), the supplier can compensate the buyer while improving his own performance. Therefore, the supplier carefully evaluates the cost impact of the JiT implementation and makes a counter offer to the buyer.

Obviously, the supplier has to take into account the buyer's outside option, i.e., sourcing from an alternative supplier. Hence, if the supplier favors a smaller degree of JiT implementation, he has to compensate the buyer for the cost increase. Otherwise, the buyer could simply choose the alternative supplier. The compensation is denoted by Z. To simplify the forthcoming argumentation, it is only referred to holding costs, fixed costs, and order sizes respectively. Note, however, that these variables and expressions are just exemplary for the complex advantages and disadvantages that go along with the JiT implementation. Additionally, it is assumed that the supplier yields fixed revenues of Y_s per period, and the buyer Y_b, respectively. In the above described planning situation, the supplier maximizes his unit profit margin by solving the following optimization problem:

Problem FI.

$$\max\ P_s = Y_s - \frac{f}{q} - Z \tag{2.1}$$

s.t.

$$P_b = Y_b - \frac{h}{2} \cdot q + Z \geq R \quad \text{(Participation constraint).} \tag{2.2}$$

P_s and P_b denote the supplier's and the buyer's unit profit margin, respectively. The supplier's objective function maximizes the unit profit. As the fixed revenues are not decision relevant, this objective is equivalent to minimizing the fixed costs per period in addition to the compensation paid to the buyer. The compensation is required to satisfy the buyer's so-called participation constraint (2.2). Again, the participation constraint ensures that the buyer has never lower profits than in his outside option if he accepts the contract offer $\langle q, Z \rangle$. Obviously, the participation constraint needs to bind in the optimum. Otherwise, the supplier could reduce the compensation, Z, while offering the same order size q. For notational convenience, the buyer's unit costs for sourcing from the alternative supplier are introduced, i.e., $C_{AS} = Y_b - R$. Solving the participation constraint for Z and inserting in the objective function yields:

max $P_s = Y_s - f/q - h/2 \cdot q - C_{AS}$. Deriving with respect to q and solving for q yields $q = \sqrt{2 \cdot f/h}$, which is in fact the economic order quantity. Hence, in this planning situation, the supplier accounts for all relevant supply chain costs.[7] The outcome is therefore efficient, i.e., the supply chain optimal solution is implemented.

2.2.4 Strategic Lotsizing and Screening Contracts Under Asymmetric Information

The previous section introduced a stylized Joint-Economic-Lotsizing model, which captured the supplier's and the buyer's bargaining situation when negotiating about the implementation of the JiT concept. In this section it is taken into account that the buyer's advantages of the JiT strategy are multidimensional and contain to a major extent private information. Thus, they can certainly not be easily observed and valued by the supplier. In other words, the buyer has superior information with respect to the advantages of the JiT implementation. This information asymmetry is formalized with a probability distribution $p_i, i = 1, ..., n$ over possible values of the buyer's holding costs $h_i, i = 1, ..., n; h_1 > ... > h_n$. Hence, the supplier cannot accurately estimate the buyer's various advantages from low order sizes. One feasible solution to this problem can be obtained by solving Problem FI (see Sect. 2.2.3) with $h = h_n$. However, this solution is not optimal for the supplier, since he can decrease his expected costs by offering a so-called screening contract, which is in fact a menu of contracts $\langle q_i, Z_i \rangle, i = 1, ..., n$. The basic screening idea is that the profit maximizing buyer reveals his private information by his contract choice. Let $P_{b,i}(q_j) = Y_b - h_i/2 \cdot q_j - Z_j$ denote the unit profit margin of the buyer facing holding costs h_i, and choosing the contract $\langle q_j, Z_j \rangle$. The information revelation is ensured by the following incentive constraint:

$$P_{b,i}(q_i) \geq P_{b,i}(q_j), \forall i \neq j; i,j = 1, ..., n. \quad \text{(Incentive constraint)} \qquad (2.3)$$

The buyer who faces holding costs h_i will always choose the offer $\langle q_i, Z_i \rangle$ as any other contract $\langle q_j, Z_j \rangle$ will result in a lower unit profit margin, i.e., the left hand side of (2.3) is bigger than the right hand side. Again, the supplier has to take into account that the buyer always prefers one of the contracts $\langle q_i, Z_i \rangle, i = 1, ..., n$ over the alternative supplier. As (2.3) ensures that the buyer with holding costs h_i chooses the contract $\langle q_i, Z_i \rangle, i = 1, ..., n$, this condition can easily be ensured by the following participation constraint:

$$P_{b,i}(q_i) \geq R, \forall i = 1, ..., n \qquad (2.4)$$

[7] Note that the strategic interpretation of this model assumes no fixed costs at the buyer's site. Hence, the classical EOQ-formula instead of the JELS-formula depicts the supply chain optimal solution.

Let $P_{s,j} = Y_s - f/q_j - Z_j$ denote the supplier unit profit margin if the buyer chooses the contract q_j. Due to the incentive constraint (2.3), the supplier knows that the buyer will choose the contract $\langle q_i, Z_i \rangle$ with probability p_i. Hence, the supplier can maximize his expected unit profit margin with the following optimization problem:

Problem AI.

$$\max \ E[P_s] = \sum\nolimits_{i=1}^{n} p_i \cdot P_{s,i} \tag{2.5}$$

s.t.

$$P_{b,i}(q_i) \geq P_{b,i}(q_j), \quad \forall i \neq j; i,j = 1, \ldots, n. \tag{2.6}$$

$$P_{b,i}(q_i) \geq R, \quad \forall i = 1, \ldots, n \tag{2.7}$$

The Karush-Kuhn-Tucker conditions as well as a detailed derivation of the optimal menu of contracts can be found in the Appendix. The following notation is used to refer to the supplier's optimal menu of contract $A = (A_i | i = 1, \ldots, n)$ where $A_i = \langle q_i^{AI}, Z_i^{AI} \rangle, \forall i = 1, \ldots, n$. Furthermore, $F_i = \langle q_i^{FI}, Z_i^{FI} \rangle, \forall i = 1, \ldots, n$ denotes the supply chain optimal contract when the buyer faces holding costs h_i. For illustrative reasons the optimal menu of contracts is derived for two possible holding cost realizations $L = low$ and $H = high$, i.e., $i \in L, H$ and $n = H$.

Basically, the key to solving the Problem AI is to identify the participation- and incentive constraints that bind in the optimal solution. Sappington (1983) shows that only the participation constraint for the buyer with the highest possible holding cost realization, h_H, binds. From this finding it follows directly that $Z_H = \frac{h_H}{2} \cdot q_H - C_{AS}$ holds. Hence, the buyer who faces holding costs h_H is indifferent between the contract $\langle q_H, Z_H \rangle$ and the alternative supplier. Furthermore, Sappington shows that always two adjacent incentive constraints bind in the optimal solution. Hence, the buyer facing holding costs h_L is indifferent between the contracts $\langle q_L, Z_L \rangle$ and $\langle q_H, Z_H \rangle$. It follows from (2.6) that $Z_L = \frac{h_L}{2} \cdot (q_L - q_H) + Z_H$. Substituting the compensations Z_L and Z_H into the supplier's objective function gives:

$$\max E[P_s] = Y_S - \left[p_L \cdot \left(\frac{f}{q_L} + \frac{h_L}{2}(q_L - q_H) + \frac{h_H}{2} \cdot q_H - C_{AS} \right) + p_H \left(\frac{f}{q_H} + \frac{h_H}{2} \cdot q_H - C_{AS} \right) \right]. \tag{2.8}$$

Deriving (2.8) w.r.t. q_L gives:

$$\frac{\partial E[P_s]}{\partial q_L} = p_L \frac{f}{{q_L}^2} - p_L \frac{h_L}{2} = 0. \tag{2.9}$$

Solving (2.9) for q_L gives the well-known EOQ-formula, i.e.,

$$q_L{}^{AI} = \sqrt{\frac{2 \cdot f}{h}}. \tag{2.10}$$

Hence, as long as the buyer faces the lowest possible holding cost realization, the supply chain optimal solution will be implemented.

Deriving (2.8) w.r.t. q_H gives:

$$\frac{\partial E[P_s]}{\partial q_H} = p_L \frac{h_L}{2} - p_L \frac{h_H}{2} + p_H \frac{f}{q_H{}^2} - p_H \frac{h_H}{2} = 0 \tag{2.11}$$

Solving (2.11) for q_H gives:

$$q_H{}^{AI} = \sqrt{\frac{2 \cdot f}{h_H + p_L/p_H \cdot (h_H - h_L)}}. \tag{2.12}$$

From $p_L/p_H{}^*(h_H - h_L) > 0$ it follows directly that

$$q_H{}^{AI} = \sqrt{\frac{2 \cdot f}{h_H + p_L/p_H \cdot (h_H - h_L)}} < \sqrt{\frac{2 \cdot f}{h_H}} = EOQ. \tag{2.13}$$

Hence, if the buyer faces strictly higher holding costs than h_L, then there is a deviation from the supply chain optimal solution characterized by a downward distortion of order sizes.

The compensation in the optimal menu of contracts simply results from :

$$Z_L{}^{AI} = \frac{h_L}{2}\left(q_L{}^{AI} - q_H{}^{AI}\right) + Z_H{}^{AI} \tag{2.14}$$

$$Z_H{}^{AI} = \frac{h_H}{2} \cdot q_H{}^{AI} - C_{AS} \tag{2.15}$$

For simplifying forthcoming formulas $p_o = h_o = 0$ is defined. Then, the above results can be generalized to the following optimal menu of contracts A (see Appendix):

$$q_i^{AI} = \sqrt{\frac{2 \cdot f}{h_i + \gamma_i}} \tag{2.16}$$

where

$$\gamma_i = \frac{\sum_{t=0}^{i-1} p_t}{p_i} (h_i - h_{i-1}), \forall i = 1, ..., n. \tag{2.17}$$

$$Z_n^{AI} = \frac{h_n}{2} q_n^{AI} - C_{AS} \tag{2.18}$$

and

$$Z_i^{AI} = \frac{h_i}{2} \left(q_i^{AI} - q_{i+1}^{AI}\right) + Z_{i+1}^{AI}, \forall i = 1, ..., n-1. \tag{2.19}$$

Note that the above optimal menu of contracts requires an additional assumption which has been suppressed so far. For certain combinations of probabilities and holding costs the order sizes relation $q_i^{AI} = q_{i+1}^{AI}$ may hold. In this case, there is no information revelation through the buyer's contract choice, as the supplier cannot distinguish the buyer facing holding costs h_i and h_{i+1}. In the screening literature it is common to rule out these cases by imposing a restriction on the probability distribution, e.g., in models with a continuous distribution over the private information a monotone hazard rate of the probability distribution is usually assumed (see, for example, Corbett and de Groote 2000). Throughout the analysis in the underlying work, the same approach is followed, and the analysis is restricted to the setting in which information revelation is prevalent, as this is the main feature of screening models. The cases of no information revelation are excluded by assuming that the following condition between probabilities and holding costs holds:

$$h_i + \gamma_i < h_j + \gamma_j, \forall i = 1, ..., n-1, j = 2, ..., n; j > i. \tag{2.20}$$

This condition does always hold if there are only two possible holding costs realizations as $p_0 = 0, p_1 > 0$ and $h_1 < h_2$ holds. Nonetheless, if there are more than two possible holding costs realizations, there exist combinations of p_i and h_i for which this assumption is not satisfied, and information revelation might not be observable for every holding cost parameter h_i. The optimality conditions for the optimal menu of contracts in these cases are specified in Spence (1980). Yet, even though the assumption is not satisfied, there are always at least two contracts in the supplier's optimal menu of contracts (see Spence 1980). As all the results in the underlying work are already observable for this case, this assumption has no impact on the main results in this study but simplifies the derivation of the supplier's optimal decision.

The properties of the optimal menu of contracts can be summarized as follows:

1. ${q_{i-1}}^{AI} > {q_i}^{AI}$ and ${Z_{i-1}}^{AI} \geq {Z_i}^{AI}$, $\forall i = 2, ..., n$
2. The participation constraint of the buyer with holding costs h_n is binding
3. The buyer with holding costs $h_i, i = 1, ..., n-1$ is indifferent between the order sizes ${q_{i+1}}^{AI}$ and ${q_i}^{AI}$, $\forall i = 1, ..., n-1$
4. The buyer with holding costs $h_i, i = 1, ..., n-1$ yields higher unit profits than if he would source from the alternative supplier
5. ${q_i}^{AI} < {q_i}^{FI}, \forall\ i = 2, ..., n$ and ${q_1}^{AI} = {q_1}^{FI}$

The first property states that the order sizes increase with decreasing holding costs, and the side payments increase respectively. Hence, the compensation Z_i can be interpreted as a quantity discount in the EOQ model.

Conditions (2) and (3) show that the buyer is always indifferent between two alternatives. As a tie-breaking rule it is assumed that the indifferent buyer chooses the contract which is in the supplier's best interest. This contract is denoted as the "self-selection"-contract, as the incentive structure of the menu of contract ensures that the buyer self-selects the contract that reveals his private information.

Condition (4) stresses the reason why the screening contracts cannot coordinate to the supply chain optimum, i.e., ${q_i}^{FI}$. The participation constraint under asymmetric information does not bind for $h_i, i = 1, ..., n-1$, resulting in lower cost for this buyer in comparison to sourcing from the alternative supplier. Particularly, the buyer facing holding costs h_i saves

$$IR_i = P_{b,i}({q_i}^{AI}) - R > 0, \quad i = 1, ..., n-1 \tag{2.21}$$

compared to the outside option, where IR_i denotes the informational rent. The informational rent denotes the buyer's cost advantages that he realizes compared to the outcome under full information. If the buyer truthfully reported his holding costs parameter, h_i, the profit maximizing supplier would offer the contract $\langle {q_i}^{FI}, {Z_i}^{FI} \rangle$. However, in this case the buyer's participation constraint binds in every state of nature, i.e., $P_{b,i}({q_i}^{FI}) = R,\ \forall i = 1, ..., n$, and the buyer foregoes the informational rent.

Condition (5) shows that asymmetric information leads to supply chain inefficiencies caused through a downward distortion of order sizes. On can easily see that the distortion stems from $\gamma_i = \sum_{t=0}^{i.-1} p_t \cdot (h_i - h_{i-1})/p_i$. Hence, analyzing the distortion caused by asymmetric information reduces to analyzing γ_i. In particular, the higher γ_i the higher ${q_i}^{FI} - {q_i}^{AI}$, i.e., the distortion rises with increasing γ_i.

The distortion, thus, increases with an increasing ratio $\sum_{t=0}^{i-1} p_t/p_i$. The higher this ratio, the higher the probability that the buyer will choose an order size ${q_k}^{AI}, k < i$ due to the screening. Hence, the expected cost minimizing supplier will decrease (the less likely chosen order size) q_i as he can decrease the compensation Z_k for all $k \leq i$ as well. The order size deviation from the supply chain optimum $({q_i}^{FI} - {q_i}^{AI})$ therefore increases.

Furthermore, the distortion depends on the distance between h_i and h_{i-1}. Intuitively, there are no asymmetric information if the difference of the respective holding costs is zero. Hence, the asymmetry of information increases the more different the respective holding costs. The total expected coordination deficit that occurs due to asymmetric information is equal to:

$$CD = \sum\nolimits_{i=1}^{n} p_i \left[\frac{f}{q_i^{AI}} + \frac{h_i}{2} \cdot q_i^{AI} - \left(\frac{f}{q_i^{FI}} + \frac{h_i}{2} \cdot q_i^{FI} \right) \right]. \tag{2.22}$$

The main objective of the underlying work is to investigate whether this coordination deficit can effectively be reduced as this enhances the supply chain performance. A numerical example follows in Sect. 2.3.2.

2.3 Benefits and Pitfalls of Information Sharing Under Asymmetric Information

So far, it was claimed that communication cannot solve the problem of supply chain coordination under asymmetric information, simply because all private information will be used strategically. Hence, the supplier is predicted to offer a screening contract, in which the buyer's informational rent is reduced by deteriorating the order sizes downwards. However, this subsection will discuss under which circumstances communication could be used to enhance supply chain performance by eliminating the distortion of order sizes. Section 2.3.1 starts introducing how information sharing is interpreted in the underlying thesis. Afterwards, Sect. 2.3.2 shows how information can be formalized in the strategic lotsizing model, and highlights why no credible information sharing will be observed in the non-cooperative equilibrium Yet, since there is substantial experimental evidence that subjects are not fully opportunistic and/or sequential rational (see, e.g., Kagel and Roth 1995), Sect. 2.3.3 discusses the impact of information sharing if some level of trust and/or trustworthiness can be established in the supply chain.

2.3.1 Information Sharing

In the underlying work communication and information sharing are used as synonyms. This is abstracting from the fact that information sharing can take place via different communication channels (face-to-face, e-mail, cell phone). Nonetheless, the reader should be aware that the mean of communication might also have an impact on the effectiveness of information sharing. It is referred to Brosig et al. (2003) and Valley et al. (1998) who analyze the impact of the mean of communication in an experimental setting.

In Supply Chain Management, information sharing is regarded as one of the main drivers to improve or even optimize the overall supply chain performance. Chen

(2003) gives a comprehensive review on the potential gains from upstream and downstream sharing of information such as demand, cost or capacity information.

Mohr and Spekman (1994) find that there are basically three dimensions of communication (as a possible way to share information) that are important to determine the effectiveness of communication in a relationship. One dimension includes all aspects which refer to the quality of the conveyed information such as adequacy, accuracy or timeliness. Throughout the underlying work it is ensured that all communication fulfills certain quality standards by restricting the buyer's possible messages to only relevant information, which is in-line with the revelation principle (see Sect. 2.1). If the buyer communicates a holding cost realization, then he actually communicates which contract out of the menu of contracts he is going to choose. As the number of contracts in the screening contract is equal to the number of possible holding cost realizations, it seems reasonable to restrict the buyer's message space.

Obviously, another dimension that influences the effectiveness of communication is whether the shared information is actually considered in joint decision making. In other words, communication can only have an impact on supply chain outcomes if the shared information is decision relevant as well as taken into account while making the decision. In the underlying settings communication will have an effect on the supply chain outcome as long as the supplier conditions his expectations regarding the buyer's private information on the messages sent by the buyer. Otherwise, he will simply ignore any communication and use his a priori probabilities instead. Communication, in this case, will have no impact on supply chain outcomes.

Finally, the third dimension includes the extent and frequency of information sharing. There is a high extent of information sharing if critical data is shared in many decision situations (e.g., strategic and operational decisions). A high degree of information sharing does typically indicate a high integration and dependence of the supply chain parties. The frequency of communication describes how often information sharing takes place. If information is exchanged at a high frequency (e.g., point-of-sale data on a daily basis), the supply chain parties typically have a more or less reliable feedback to infer whether the shared information was truthful or not. In contrast, if highly strategic cost information is only shared once, then a feedback may not be possible at all. In the underlying work it is assumed that the extent of information sharing is limited by merely considering one decision situation in which only one parameter is private information. The frequency of information sharing is limited by the decision sequence, i.e., in every period in which the supply mode is negotiated, the buyer is allowed to communicate his private cost information to the supplier.

2.3.2 *Cheap Talk: Game-Theoretic Ineffectiveness of Information Sharing*

There are basically two alternatives to reduce information asymmetry: via actions and via communication. The reduction of information asymmetry by actions typically includes a basic assumption: the member of the supply chain who takes the action behaves rationally. If this is the case, it is possible (leaving out other circumstances) to conclude from the action to other parameters of the decision problem. Consider as an example the following optimal decision rule $x + y = z$, where x is the decision, z is the outcome and y is the private information. Obviously, if the outcome and the decision are observable, then the private information can easily be inferred.

In terms of a screening contract, the action that conveys information is the buyer's self-selection. Unfortunately, this self-selection reduces the information asymmetry only ex-post, and has therefore no potential to improve supply chain coordination.

The most obvious way to reduce information asymmetry is simply to communicate the private information. However, according to the standard homo oeconomicus assumption, actors within the supply chain would rather use their private information strategically than to reveal them truthful.

Games, in which a sender (i.e., buyer) gives a signal based on his private information about his own type (i.e., holding costs), with the receiver (i.e., supplier) reacting to this signal, are called cheap talk games. The payoffs of both, supplier and buyer, do not depend on the signal, but on the supplier's decision and the buyer's type. As the buyer has a strong incentive to misrepresent his type, the supplier does not take the signal into consideration when making his decision, i.e., the sender is randomizing his signals, is giving the same signal all the time or is simply giving no signal at all (see Farrell and Rabin 1996, and Crawford 1998, for a comprehensive survey on cheap talk theory). Crawford (1998) gives the following intuition for equilibrium strategies in cheap talk games:

> In a sequential equilibrium, the Sender's message to the Receiver means, in effect, "Given the realization of my private information variable, I like what you will do when I send this message at least as much as anything I could get you to do by sending a different message." When players' preferences are perfectly opposed, such a message cannot convey any useful information. Then the only equilibria are "babbling" equilibria, in which the Sender's message is uninformative and is ignored by the Receiver. (If the Receiver could do better by responding to the Sender's massage, his response would (by definition) make the Sender worse off.) This is the grain of truth in the cheap-talk intuition. (Crawford 1998, p. 287)

In this section it is referred to the strategic lotsizing model introduced in Sect. 2.2. In this strategic lotsizing model the profit maximizing buyer will not report his holding cost realization truthfully before the supplier offers the contract. This is, because the profit maximizing supplier will only leave the buyer his reservation profit R, if he knows his holding cost realization with certainty [see Sect. 2.2, (2.1) and (2.2)]. In contrast, the profit maximizing buyer yields an informational rent $IR_i = P_{b,i}(q_i^{AI}) - R > 0, i = 1, ..., n-1$ [see (2.2.1)] if he faces holding costs h_i and the supplier offers the menu of contracts $A = (A_i | i = 1, \ldots, n)$.

Furthermore, the buyer has always a strict incentive reporting the highest possible holding cost realization, as his informational rent is highest in this case. Intuitively, this is the case because the information rent paid to the buyer with holding cost h_n needs to be paid to the buyer with holding cost $h_{n-1}, h_{n-2}, \ldots, h_1$ as well. Otherwise, the incentive constraint would not be satisfied. Thus, if the buyer is able to convince the supplier that he has the highest holding cost realization h_n, then the supplier will offer a low order size q_n which leaves a higher information rent to a buyer with lower holding costs $h_{n-1}, h_{n-2}, \ldots, h_1$. This is, because they are compensated as if they have holding costs h_n. However, the supplier anticipates this behavior and simply ignores any communication with the buyer. In the game theoretic equilibrium, thus, communication has neither a performance impact for the buyer nor for the supplier. Finally, it is argued that the buyer can even randomize his communicated holding cost realization as the supplier ignores all communication anyway. Thus, all communication accounts to no more than cheap talk, and the supply chain members are caught in a "babbling-equilibrium".

Note, however, that this solution does only result in the second best outcome compared to truth-telling and trust. Yet, if there is no additional flexibility in the contracts $F_i = \langle q_i^{FI}, Z_i^{FI} \rangle$ and $A_i = \langle q_i^{AI}, Z_i^{AI} \rangle$, this problem cannot be solved as no win-win situations are possible.

Hence, an additional side-payment Z_R is introduced that can be paid from the supplier to the buyer after a contract was concluded. This additional side payment can be interpreted as a reward from the supplier to the buyer for cooperative behavior.

On the other hand, the supplier might want to punish the buyer for uncooperative behavior. This punishment can be modeled in two distinctive ways. First, the supplier might withdraw an offer even though it was accepted by the buyer. In this case both parties yield zero profits. Second, one might argue that the supplier can harm the buyer, for example, by blaming him for uncooperative behavior by other suppliers, e.g., the alternative supplier. In this case, the buyer is assumed to face costs of Z_P and the supplier, in turn, faces himself costs of $k \cdot Z_P$, $k > 0$. The first formalization of punishment is utilized in Chap. 4 while both approaches are applied in Chap. 5. In the following, the punishment and reward option is abbreviated with P&R and the following decision sequence results (see Fig. 2.4)[8]:

The following example will show that under this additional flexibility Pareto-improvements are generally possible. It is assumed that there are three possible holding cost realizations, $h_L = 1, h_M = 5$ and $h_H = 9$ with the a-priori probabilities $p_L = 0.4, p_M = 0.3$ and $p_H = 0.3$, respectively. The following summarizes the payoffs of the buyer and the supplier assuming $Y_s = 155$, $Y_b = 5$, $R = 2$, and $f = 800$.[9]

Table 2.2 shows the side-payment Z_i and the order sizes q_i that result when the supplier offers the contract $F_i, i \in [L, M, H]$ or the menu of contracts $A \in (A_L, A_M, A_H)$. The supplier's profits P_s are only contingent upon contract

[8]Note that punishments and rewards can be used in the one shot game, or under repeated interaction. However, it is likely that a P&R mechanism are more effective under repeated interaction, since the absolute gains from cooperative behavior are higher.

[9]This example will also be the basis for the laboratory experiments discussed in Chap. 5.

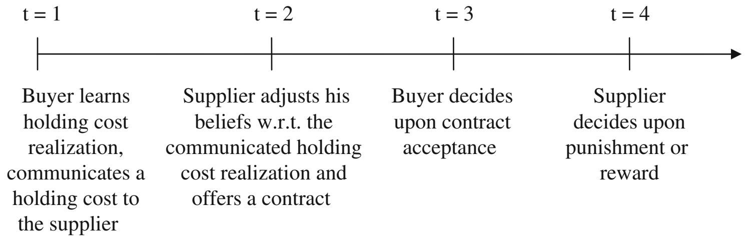

Fig. 2.4 Decision sequence given additional flexibility in the contract structure

Table 2.2 Payoffs given three possible holding cost realizations under the full- and asymmetric information contract type

		Order size: q_i	Side-payment: Z_i	Profit supplier: P_S	Profit buyer: P_b h_L	h_M	h_H
	F_L	40.00	18.00	117.00	3.00	−77.00	−157.00
	F_M	17.89	42.72	67.56	38.78	3.00	−32.78
	F_H	13.33	58.00	37.00	56.33	29.67	3.00
Menu of contracts: **A**	A_L	40.00	61.57	73.43	46.57	−33.43	−113.43
	A_M	12.44	47.79	42.92	46.57	21.68	−3.20
	A_H	9.34	40.04	29.33	40.37	21.68	3.00

acceptance. In contrast, the buyer's profits are dependent upon his specific holding cost realization. As an example, if the buyer faces holding costs of h_L and accepts the contract F_H, he earns a profit of $P_b = 56.33$.

Assuming that all parties act rational under homo-oeconomicus preferences, the supplier will offer the menu of contracts $A \in (A_L, A_M, A_H)$ and the buyer choosing the profit maximizing contract. In this case, the supplier's and buyer's expected profits are equal to $E[P_s] = 51.05$ and $E[P_b] = 26.03$, respectively. The total supply chain performance, thus, is equal to $E[P_s] + E[P_b] = 77.08$. This outcome is inefficient, since the expected supply chain performance could be increased to 81.17 by agreeing upon efficient F_i- contracts, i.e., there is a coordination deficit of $CD = 4.09$.

To illustrate the coordination problem, it is assumed that the buyer faces holding costs h_M. Furthermore, it is assumed that the buyer always chooses the profit maximizing action, and chooses the action that is in the supplier's best interest if he is indifferent between two actions. It is assumed, that the buyer can report his holding cost realization truthfully, overstate by reporting h_H, or reject communication.[10] In turn, the supplier can either trust and offer $F_i, i \in (M, H)$, or mistrust and offer the menu of contracts. If there is no communication, the supplier cannot choose the action "trust".

[10]Note that the buyer's participation constraint is violated if he understates his holding costs and this understatement is believed by the supplier.

Table 2.3 Payoffs given holding cost realization h_{med} in dependence of additional side-payment Z_R

(P_s, P_b)	Report truthfully	Overstate holding costs	Reject communication
Trust	$(67.56 - Z_R,\ 3 + Z_R)$	$(37 - Z_R,\ 29.67 + Z_R)$	–
Mistrust	$(42.92,\ 21.68)$	$(42.92,\ 21.68)$	$(42.92,\ 21.68)$

Finally, it is assumed that the supplier only gives an additional side-payment Z_R if he trusts the reported holding cost realization. Then, the payoffs summarized in Table 2.3 in dependence of the additional side-payment Z_R result, where the number in brackets denote the supplier's and the buyer's profits respectively, i.e., (P_s, P_b). Obviously, cooperative behavior (i.e., report truthfully and trust) can lead to Pareto improvements compared to mistrust, as long as the additional side-payment is sufficiently high. The required side-payment that can induce a win-win situation can be calculated from $67.56 - Z_R \geq 42.92$ and $3 + Z_R \geq 21.68$, i.e., $18.67 \leq Z_R \leq 24.64$. Nonetheless, note that the supplier has actually no incentive to give an additional side-payment Z_R as long as the game is only finitely repeated. This is, because the supplier will make the same decision in the last repetition as in the one-shot game. Again, the reason is that the additional side-payment in the last repetition cannot influence future behavior. Using backward induction (see, e.g., Fudenberg and Tirole, Section 3), both players anticipate this behavior in the last but one round. In other words, they anticipate that there will be no cooperation (i.e., truthful information sharing, trust and a sufficiently high additional side-payment) in the last round. Hence, there is no reason to cooperate in the last but one period, and so on. The basic idea of backward induction, thus, is that finitely repeated games can basically be treated as one shot games. The same arguments hold for punishing the buyer. As this action is costly for the supplier he will not punish simply because he cannot influence future behavior with that action.

Summing up, coordination through communication will theoretically not occur as long as both supply chain parties act fully rational and opportunistic, and the interaction is finite.

2.3.3 Reputation, Trust, and Trustworthiness: Cooperative Information Sharing and Processing

The former section established that full coordination of the supply chain is not possible as long as all supply chain parties act fully opportunistic and rational. However, there is some experimental studies of cheap talk games showing that information sharing can increase the efficiency of outcomes (see, e.g., Rode 2006, and Gneezy 2005). Therefore, it is analyzed whether information sharing is a feasible instrument for improving supply chain performance by establishing some level of trustworthiness, trust, and reputation.

2.3.3.1 Trust

Castaldo (2007) identified 72 definitions regarding the concept of “trust”. It is referred to this study for an extensive textbook review on this topic. Yet, three dimensions of trust were mentioned in most of the definitions, namely expectation, willingness, and attitude.

Sako and Helper (1998) define trust by the expectation of the counterpart being trustworthy. In this case, the trustor’s expectation reduces the perceived uncertainty about the trustee’s actions and in turn increases the predictability of these actions. In the underlying strategic lotsizing model, trust does therefore describe the supplier’s belief that the buyer will not lie. In this case, the supplier adjusts the a-priori probability that refers to the signal perfectly upwards, i.e., he chooses a subjective probability of 100%. In other words, he offers a contract as if under full information.

Zand (1972) highlights that an important dimension of trust is the willingness to accept the vulnerability associated with deviations from expected actions. In the underlying context, thus, the buyer accepts that the supplier may leave him only his reservation profit after he reports his holding costs truthfully.

Ben-Ner and Putterman (2001) argue that trust can be interpreted as a decision under uncertainty. In this case, the definition of trust is closest to Gambetta (1988a) who states that trust is the principal’s subjective probability that an agent acts trustworthy. In the very underlying model, the supplier faces the risk of believing an overstated holding cost. In this case, he would be better off by ignoring the message.

Finally, there is some literature that focuses specifically on trust in supply chain management. Ireland and Webb (2007) stress that there is an important interaction between trust and the specific power structure within the supply chain. Johnston et al. (2004) present an empirical study in which 164 supply chain managers were interviewed. They find that the supplier’s trust in the buyer’s firm is strongly connected to successful implementation of shared planning and the flexibility of arrangement. Laaksonen et al. (2009) provide empirical data which allows evaluating the financial impacts of different levels of trust in sourcing and pricing decisions in the paper industry. In particular, a high level of trust from the buyer’s side means that he chooses a single source while increasing his dependency on this source. In contrast, the supplier can increase (low level of trust) or decrease (high level of trust) the prices as a reaction to the buyer’s sourcing decision.

2.3.3.2 Reputation

Mui and Halberstadt (2002) point out the differences between reputation and trust. Reputation is a concept that focuses on previous actions whereas trust focuses on future actions. Reputation can affect the level of trust in a relationship.

Thus, reputation is only a useful concept as long as the interactions in the supply chain are repeated. As an example, if the buyer reports truthfully right from the beginning (even though theory predicts otherwise), then he can probably build up a reputation for being trustworthy. However, it has been shown that the finitely repeated game can basically treated as a one-shot game in which reputation is not useful concept. However, if the game is infinitely repeated, then the famous "Folk"-theorem applies which states that any feasible payoff that is higher than the outside option can be enforced by an equilibrium as long as the game is infinitely repeated and the discount-factor is sufficiently high (see Fudenberg and Tirole 1995, Sect. 5.1.2). In other words, even the supply chain optimum is achievable under certain circumstances although theory predicts otherwise in the finitely repeated game. The intuition is as follows. In the short term each player obviously benefits from being uncooperative (i.e., lying or rejecting rewards). This is the one-shot game equilibrium. However, if the supply chain parties expect that uncooperative behavior leads to punishments in (infinitely) future repetitions of the game, it might be favorable to skip the short-term strategy in favor of a long term strategy in which the supply chain parties cooperate. This intuition works as long as the supply chain parties do not put too much weight on short-term payoffs, or technically, if the discount factor is sufficiently high.

Summing up, actions that have been taken in the past (i.e., the reputation that has been build up) can influence future decisions as long as the termination of the relationship is unknown. However, Mui and Halberstadt (2002) argue that trust can be prevalent even in non-recurring actions. This fact was also highlighted by Eckel and Wilson (2004). They state that the principal's level of trust is influenced by previous interactions that are similar in nature, even though there have been no interactions with the respective agent. Hence, even though the principal cannot assess the agent's tendency to be cooperative or uncooperative from past actions, he might have an initial level of trust which is determined, for example, by experience from prior similar interactions with other agents.

2.3.3.3 Trustworthiness

The main difference between trust and trustworthiness can be summarized as follows. Trusting describes the action of the trustor, while trustworthiness refers to the characteristics of the subject which is being trusted (trustee). Mayer et al. (1995) highlight the difference between trust and trustworthiness. They identify three characteristics that affect the trustworthiness of a trustee.

One determinant is the perception that a person is able to perform a specific task, e.g., because the person is very competent in a specific area. In the underlying context this determinant is straight-forward as the buyer knows his private information with certainty.

Another identified determinant is benevolence, which describes the trustee's intention to interact without exploitation, even though exploitation is possible. In the underlying context, thus, trustworthiness in this dimension means that the supplier will not exploit a truthful signal by leaving only the reservation profit to the buyer. In turn, trustworthiness with respect to the signal means that the buyer does not overstate the holding cost with the intention to improve his profits.

Finally, the trustee's integrity is a main determinant of trustworthiness. Integrity describes the trustor's perception that interactions are based on a set of principles such as consistency and fairness (see Morgan and Hunt 1994). As an example, a supplier is likely to be perceived as fair (i.e., trustworthy) if he shares the coordination benefits of truth-telling and trust, e.g., fifty-fifty. Consistency, in the underlying context, means that the buyer takes the action he signals.

Note that consistency and truthful reporting might not be the same given a screening contract. As the screening literature basically uses an indifference modeling approach (see Sect. 2.2.4), the buyer is always indifferent between two contracts. Thus, he can choose an offer out of the menu of contracts which is not designed for his type while reporting truthfully. In this case, he is inconsistent even though he reports truthful.

2.3.3.4 Interaction of Trust, Reputation, and Trustworthiness in the Strategic Lotsizing Model

There are basically two conditions necessary for enabling full coordination of the supply chain under asymmetric information. First, the buyer must indeed be trustworthy. Second, the supplier must trust in the signal. This argumentation seems straight-forward, but in the following it is shown that the coordination deficit can even increase if the supplier trusts a deceptive buyer. The following extensive game form in Fig. 2.5 may illustrate this argument.

The buyer's decision node is denoted with “B” and the supplier's with “S”, respectively. Additionally, “N” denotes the so-called nature's decision node, i.e., the nature decides with respect to the a-priori probabilities which holding cost realization is assigned to the buyer. The buyer is able to communicate with the supplier via a signal $S \in (S_L, S_M, S_H, S_{No})$ whereas $S_i = h_i, i \in (L, M, H)$ holds and the signal S_{No} refers to the situation in which the buyer denies to give any signal at all. Note that the nature's assignment of the holding costs is the buyer's private information. Hence, the supplier cannot distinguish whether a report is truthful or not. This fact is captured by the shaded boxes. Each of these boxes contains the same signal, e.g., S_H, but this signal is not necessarily identical to the holding cost realization, e.g., h_H.

The supplier's decision to trust is denoted with “T” and to mistrust with “MT” respectively. Also note that Fig. 2.6 only shows the cases in which the buyer reports truthfully, overstates his holding costs or refuse to give a signal. Particularly, an understatement of holding costs (i.e., claiming a lower compensation than actually needed) is only indicated by dotted circles. Yet, an extension of the figure is straight-forward. All payoffs that result for a specific action sequence do directly follow from Table 2.2.

Consider a buyer who faces holding costs h_L and reports S_H. If the supplier trusts and offers F_H than the supplier yields profits of $P_S = 37 - Z_R$ and the buyer $P_B = 56.33 + Z_R$, respectively (see bolded line in Fig. 2.5).

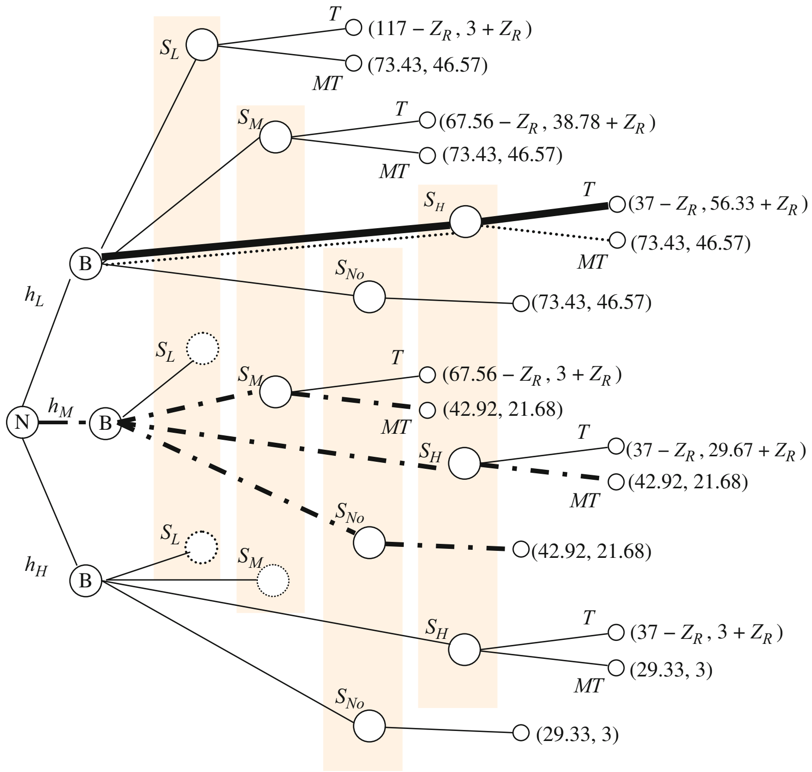

Fig. 2.5 Extensive game form of the strategic lotsizing model

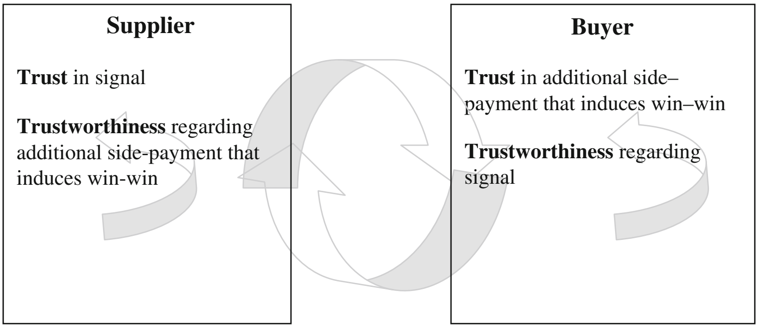

Fig. 2.6 Interdependencies between trust- and trustworthiness along the side-payment and signal dimension

To highlight the fact that trust can lead to efficiency losses it is first assumed that the buyer is deceptive while the supplier trusts in the signal. As an example, the buyer faces holding costs h_L and signals that a high compensation is required, i.e., S_H. If the supplier trusts the signal, than the supply chain profits result from

$37 + 56.33 = 93.33$.[11] The actions that lead to this outcome are marked with a bolded line in Fig. 2.5. Yet, in the second-best solution (i.e., mistrust and offering the menu of contracts) the supply chain profits would amount to $73.43 + 46.57 = 120$ (see dotted line in Fig. 2.5). Hence, trust in comparison to mistrust leads to an efficiency loss of $120 - 93.33 = 26.67$.

On the other hand, communication can only be an effective coordination instrument as long as the supplier does not simply ignore all signals (as he believes that communication is only cheap talk). In this case, the menu of contracts would be offered regardless of the buyer's signal. The interrupted line in Fig. 2.5 highlights this for the holding cost realization h_M. Obviously, the outcome is independent of the buyer's signal and communication is not effective.

Next, the interdependencies of trust and trustworthiness are discussed. First, the level of the buyer's and supplier's trust may be influenced by their own attitude of being cooperative. On the one hand, the supplier's level of trust in the signal may be dependent on how trustworthy he is himself with respect to the additional side-payment. As an example, if the supplier always give sufficiently high rewards, then he might believe that the buyer's signals are more likely to be true, and vice versa. On the other hand, the buyer's level of trust in receiving sufficiently high side-payment may be dependent on his own signaling behavior. As an example, if he always reports truthfully he is more likely to anticipate cooperative rewards that induce win-win situations, and vice versa.

Second, the level of the buyer's and supplier's trust may be dependent on the expectations regarding the other side's trustworthiness. The supplier who expects the buyer to be trustworthy with respect to the signal will apparently trust in the signal. In turn, the buyer who expects sufficient rewards is more likely to report truthfully.

Figure 2.6 depicts the interdependencies between trust and trustworthiness. The arrows within the respective box depict that the level of trust may be influenced by own actions while the arrows between boxes depicts that the level of trust may also be influenced by the expected actions of the counterpart.

2.4 Supply Chain Interactions Under Asymmetric Information: Literature Review

Supply chain interactions under asymmetric information have received an increasing attention in the recent past. The following section reviews the main contributions in this field. All of these studies basically employ the methods and concept which have already been summarized in Sect. 2.1. Hence, this section focuses on the main qualitative insights that results under different supply chain

[11]Note that the additional side-payment does not influence the overall supply chain performance, as it is simply a transfer payment between the supplier and the buyer.

Table 2.4 Asymmetric information in distinctive supply chain planning situations

Lotsizing decisions	• Corbett and de Groote (1997, 2000) • Corbett (2001) • Sucky (2004, 2006) • Burnetas et al. (2007) • Karabati and Kouvelis (2008)
Pricing decisions	• Blair and Lewis (1994) • Corbett and Tang (1999) • Ha (2001) • Corbett et al. (2004) • Lau et al. (2008) • Hsieh et al. (2008) • Ha and Tong (2008) • Mukhopadhyay et al. (2008) • Wang et al. (2009)
Capacity planning	• Cachon and Lariviere (2001) • Iyer et al. (2005) • Özer and Wei (2006) • Cachon and Zhang (2006) • Chakravarty and Zhang (2007) • Lutze and Özer (2008)
Product specification and backup production	• Iyer et al. (2005) • Yang et al. (2009)

configurations and/or planning situations in which screening or signaling contracts are used to coordinate the supply chain. This is, because the analyses carried out in the forthcoming sections do basically investigate the effectiveness of screening contracts. Section 7.1 discusses how the results of the underlying thesis can be transferred to the literature review presented in this section.

The review is divided into four categories that refer to the specific supply chain planning situation, namely lotsizing decisions, pricing decisions, and capacity planning decisions. Finally, there is an additional category for the studies that do not fit into the first three categories. Table 2.4 gives a first overview over the main contributions under the respective planning situation.

2.4.1 Lotsizing Decisions

This planning situation was already introduced in Sect. 2.2 and the same framework applies here. Corbett and de Groote (1997, 2000) analyze the impact of the buyer's private holding cost information in this context. The higher the holding cost per period, thus, the higher the required compensation for agreeing upon higher order sizes. The self-interested buyer has therefore a strong incentive to exaggerate this cost position.

Corbett and de Groote (1997, 2000) assume that the supplier holds a continuous probability distribution with support of possible holding cost realizations. Demand per unit time is deterministic and constant. Corbett and de Groote (2000) assume lot-for-lot production, i.e., the supplier's production lot size is equal to the lot size shipped to the buyer. Therefore, the supplier faces no holding costs. Corbett and de Groote (1997) relax this assumption by allowing the supplier to choose his production lot size independently from the buyer's order size. The main qualitative results do not change due to this assumption. Corbett and de Groote (1997, 2000) find that there is a downward distortion of order sizes due to asymmetric information, except the buyer facing the lowest possible holding costs.

Corbett (2001) extends the above framework by assuming stationary and stochastic demand. He analyses two settings. First, the supplier has private information with respect to his fixed costs per period while the buyer makes the contract offer. Second, the buyer has private information with respect to his backorder costs while the supplier makes the contract offer.

In the first setting, the supplier has an incentive to exaggerate his fixed cost per period (and therefore to increase the order size per period). As a result, the average inventory level (which depends on the order size) is too high compared to the supply chain optimum. Corbett supposes that a consignment stock (in which the supplier bears all the inventory related costs) gives the supplier an incentive to reduce the orders size.[12]

However, in the second setting Corbett shows that the consignment stock concept can also harm supply chain performance. He shows that the safety stock is chosen suboptimally high, if the supplier offers the menu of contracts and the buyer strategically exaggerates his costs of a stockout.

The main managerial insight is that the incentive alignment in this context should take into account the specific supply chain situation. Particularly, in some situation consignment stock can improve the overall supply chain performance, while it can seriously harm supply chain performance in other situations. In fact, if high inventories in the supply chain mainly stem from long production cycles, then a consignment scheme in which the supplier bears at least some of the resulting holding costs seems appropriate. In contrary, if the demand uncertainty is the main driver of high inventories due to safety stocks, then the buyer should bear the costs for the safety stock himself. To put it differently, it is important to analyze which information are crucial for making supply chain efficient decision and to assign the decision right to the actor who is the holder of this information.

Burnetas et al. (2007) show how a supplier can influence the buyer's stocking decisions, when the end-customer demand is stochastic. The buyer has superior information about the distribution of demand as well as the demand realization. In this case, fixed quantity/side-payment pairs (as introduced in Sect. 2.2.4) are problematic if the buyer's optimal order quantity differs from the fixed quantity.

[12] It is referred to Zavanella and Zanoni (2009) for a discussion of this concept.

Burnetas et al. (2007) show that all-unit discounts as well as an incremental quantity discounts (implemented via screening contracts) can be used in this case to prevent the buyer from sourcing additional units from an outside option, or to combine contracts within the menu of contracts. Interestingly, they show that the all-unit discount performs better than the incremental discount, even though they lead to identical results under full information (see, e.g., Weng 1995).

Sucky (2004, 2006) argues that there is actually no problem of asymmetric information if there is only uncertainty in one dimension (e.g., holding costs or fixed costs), and the supplier knows the buyer's individual rational order sizes, for example, from previous interactions. One can easily see that by solving the well-known economic order quantity formula (see Sect. 2.2.1) for either the holding costs or the fixed costs, respectively. Starting from this insight, he analyses a lotsizing problem with constant and deterministic end-customer demand, and assumes that both, the buyer's fixed costs as well as the buyer's holding costs are unknown to the supplier. In this case, the derivation of the optimal menu of contracts becomes much more complicated. The main problem is that one cannot distinguish high cost buyers from low cost buyers. As an example, a buyer may have high fixed costs and low holding costs, and vice versa.[13] Sucky (2004, 2006) solves this problem for the discrete case of two possible holding cost realizations, while Karabati and Kouvelis (2008) present a solution procedure for a finite set of possible holding costs realizations.

2.4.2 Pricing Decisions

It is frequently assumed that the buyer faces a price-sensitive end-customer demand, i.e., the higher the end-customer price the lower the demand, and vice versa. If it is assumed that the supplier's pricing format is restricted to a simple one-part tariff (i.e., a simple wholesale-price), then the prominent double-marginalization problem occurs (see Spengler 1950), and the quantities sold to the end-customer are chosen too low compared to the supply chain optimum.

This is, because the profit maximizing supplier anticipates that the buyer takes the wholesale-price into consideration when determining the end-customer price (and therefore the total quantity sold to the end-customer). Hence, the supplier faces a price-sensitive demand himself. Standard straight-forward economic calculus shows that the supplier charges a wholesale-price that is higher than his marginal costs, as the marginal revenues equal the marginal costs in the optimal solution.

[13]Typically, this situation is ruled out in the economic literature by imposing a single-crossing property on the agents' utility functions. (see, e.g., Andersson 2008). Intuitively, the single-crossing property is satisfied, if the agent with higher costs has also higher marginal costs. It is referred to Andersson (2008) for a discussion of the welfare effects that arise for utility functions that do not satisfy the single-property condition.

The buyer maximizes his profits as well. Yet, his marginal costs are dependent on the supplier's wholesale-price. Thus, the buyer chooses an end-customer price such that the marginal revenues equal his marginal costs, which depend on the supplier's wholesale-price.

In contrary, the supply chain optimal solution results, if the buyer only takes into consideration the actual supply chain costs, and not the wholesale price charged by the supplier. However, the actual supply chain costs are distorted as the supplier maximizes his profits by charging a wholesale-price that is higher than the marginal costs. Hence, the end-customer price is higher than in the supply chain optimal solution, and the total quantity sold to the end-customer too low, respectively.

An incentive alignment can easily be achieved with a two-part tariff under full information. The two-part tariff is a contract that defines a wholesale-price for every unit sold in addition to a fixed payment from the buyer to the supplier that is independent from the quantity (e.g., a franchise fee). In this case, the supplier simply chooses a wholesale-price that is equal to his marginal costs. This is, because he simply anticipates that the supply chain profit is maximized in this case. The fixed side-payment, in turn, does not influence the buyer's decision, and can therefore be used to allocate the (supply chain optimal) profits between the supplier and the buyer. Typically, it is assumed that the supplier chooses a side-payment that leaves only the reservation profit-level to the buyer.

Corbett and Tang (1999) show that simple two-part tariffs do not suffice to fully coordinate the supply chain under asymmetric information. They assume that the buyer faces additional variable costs of selling the product to the end-customer, and that these costs are the buyer's private information. If the supplier offers a simple two-part tariff, the buyer would have a strong incentive to exaggerate his cost position. This is, because the supplier tries to set the fixed fee in way that the buyer only yields his reservation profit level. However, if the buyer is able to exaggerate his cost position, than the supplier assessment of this reservation profit is wrong, leaving an information rent to the buyer. However, if the supplier anticipates that the buyer will claim high costs, then it is in his best interest to offer a menu of contracts. Again, there is no distortion of quantities sold to end-customers for the buyer with the lowest cost position. However, there is a downward distortion of selling quantities if the buyers cost position increases, yielding a lack of coordination.

Wang et al. (2009) solve a problem similar to Corbett and Tang (1999). However, they assume that the buyer generates the menu of contracts, and has asymmetric information with respect to the supplier's variable costs. Yet, the qualitative results do not change.

Corbett et al. (2004) extend the analysis from Corbett and Tang (1999) by explicitly including reservation profit levels for both, the supplier and the buyer. The buyer's reservation profit level is simply considered in the participation constraint, while the supplier's reservation profit level is considered via a cut-off policy (Ha 2001, proves in a more general setting that such policies are optimal). Hereby, the cut-off policy takes into account that it can be profitable for the supplier to deny trade with a buyer, if the buyer's variable costs are too high. The cut-off policy is directly determined by the supplier's reservation profit level. However, closed form solutions cannot be obtained for the cut-off point policy. Yet, in an extensive numerical experiment they find that the fraction of buyer's that are excluded from trade can be substantial (up to 25%). This highlights that it is a strong assumption to force the supplier to deal with all buyers, regardless of their actual cost position. Furthermore, Corbett et al. (2004) find that the supplier's value of using more general contracts can be substantial under asymmetric information. Particularly, they show in a numerical study that the supplier's performance can increase by up to 25% if the supplier uses two-part tariffs instead of the one-part tariff under asymmetric information. However, the supplier's performance increases by only less than 1%, if he offers the menu of contracts instead of the two-part tariff.[14] This is, because the two-part tariff performs well compared to the menu of contracts, as long as the cut-off point policy is allowed. In fact, the supplier's performance under the two-part tariff would decrease by up to 16% if the cut-off policy is not allowed, i.e., if the supplier cannot deny to trade with a buyer.

Ha and Tong (2008) extend the double-marginalization framework with asymmetric demand information to the case of two competing supply chains. Basically, they analyze whether information sharing can be an equilibrium strategy when there is Cournot competition between the supply chains. The following sequence of events is assumed. First, the supplier decides whether to invest in information sharing technology or not. If he invests, then the buyer can communicate the private demand information. However, the buyer will only report truthfully, if he has the incentive to do so. In the second stage, the supplier offers a menu of contract (while taking his previous investment decision into consideration). The retailers engage in Cournot competition after choosing a contract out of the menu.

Ha and Tong investigate the effectiveness of two contract types, namely the one-part tariff and the menu of contracts. They find that the one-part tariff (i.e., simple wholesale-price contract) is not able to coordinate the supply chain members to an equilibrium with truthful information sharing. This is, because the one-part tariff allows the supplier to extract a larger fraction of the overall supply chain profits by better fitting the wholesale-price to the demand state. Nonetheless, the negative effect of double-marginalization increases and the respective supply chain becomes less aggressive in competition with the other supply chain. The one-part tariff, thus, allows only the supplier to improve his profits, while the buyer is always worse off. Information sharing can therefore never be an equilibrium strategy under one-part tariffs.

Yet, if the supply chains use more sophisticated menu of contracts, then truthful information can indeed be an equilibrium strategy. The prevalence of asymmetric information in combination with a menu of contracts leads to a downward distortion of selling quantities to the end-customer. Yet, if truthful information sharing takes

[14] Note, however, that Ha (2001) finds in another numerical study in a more general setting that the supplier's performance can decrease by up to 15%, if he offers the two-part tariff instead of the menu of contracts.

place, then the supplier can avoid this downward distortion and the supply chain becomes more aggressive in cournot competition. This effect can align the buyer's and the supplier's incentives to engage in truthful information sharing. The higher flexibility of contract menus, which allows the allocation of supply chain profits along with influencing the buyer's quantity decisions, enables truthful information sharing.

Blair and Lewis (1994) present a double-marginalization problem under asymmetric information, in which the buyer is privately informed about the demand condition (i.e., the actual shape of the price-demand curve). Additionally, the buyer can influence the end-customer demand with costly promotional efforts. Hence, this study couples the traditional adverse-selection model (i.e., the demand is not observable) with a moral hazard model (i.e., the promotional effort is not observable). They show that a menu of contracts coordinate the supply chain to some extent. However, the buyers who face a higher demand can earn greater profits, because less costly promotional effort is required to achieve the same level of sales. Hence, the buyer with high demand yields an informational rent, which leads to a lack of coordination.

Mukhopadhyay et al. (2008) consider a supply chain, in which the supplier uses two channels to distribute his product. First, the supplier establishes a direct customer access through internet sales. Second, the supplier uses the traditional distribution channel, i.e., the buyer. It is assumed that the demand of the direct channel as well as the buyer's demand is price sensitive. Mukhopadhyay et al. (2008) show that possible channel conflicts can be mitigated by allowing the buyer to add value to the respective product. Given information asymmetry with respect to the cost of adding value, Mukhopadhyay et al. (2008) derive the supplier's and the buyer's optimal pricing decisions, as well as the buyer's optimal level of value added.

They show that the supplier can induce the supply chain optimal solution under full information. Turning to the asymmetric information case, they propose an optimal menu of contracts that consists of three parameters per offer, i.e., the end-customer price charged in the direct channel, the wholesale-price charged to the buyer and a fixed side-payment from the buyer to the supplier. They show that the typical double-marginalization problem occurs, as the supplier charges higher wholesale-prices than in the supply chain optimal solution.[15] Hence, the buyer charges higher prices to the end-customer as well, which leads to the well-known downward-distortion of selling quantities. Interestingly, though, there are no further distortions of decisions due to asymmetric information. In fact, the buyer's value added as well as the wholesale prices charged through the direct channel resemble the first best solution.

Ha (2001) analyzes a setting in which the buyer faces stochastic and price-sensitive demand. In this case wholesale-prices that are higher than the supplier's

[15]Note that double-marginalization occurs even under full information as long as the supplier is restricted to offer simple wholesale-prices.

marginal costs also lead to a distortion of the buyer's safety stock decision (in addition to the end-customer price distortion). If the buyer faces a random demand (regardless whether the demand is price-sensitive or not), the buyer might hold extra stock (so-called safety stock) to buffer against stockouts. The classical newsvendor approach states that the buyer optimally determines his safety stock by carefully balancing the costs of overstocking (i.e., inventory is higher than demand) and the costs of understocking (i.e., inventory is lower than demand).[16] Assuming every unit overstocked to be simply worthless at the end of the period, the buyer's overage cost is simply the wholesale price charged by the supplier. In turn, the buyer foregoes a profit of the supplier's wholesale price minus his variable cost for every unit of demand he cannot satisfy. Under these assumptions, it can be shown that the buyer's safety stock increases with increasing profit margin (i.e., with decreasing wholesale-price charged by the supplier). Again, the double-marginalization problem occurs as the buyer optimizes his safety stock with respect to the charged wholesale price instead of the supplier's marginal costs. As the wholesale price is higher than the marginal costs, the buyer chooses a suboptimally low safety stock level. Cachon (2003) gives a comprehensive review on how contracts, such as revenue sharing or buy-back contracts, can coordinate the supply chain under full information.

Ha (2001) shows that the supply chain optimum solution is achievable as long as there is full information. However, the first best solution is no longer achievable if the buyer holds private information with respect to his variable costs, as the supplier will offer a menu of contracts. All the qualitative results from Corbett and Tang (1999) apply. Additionally they show that the amount of safety stock is smaller under asymmetric information (than in the coordinated case under full information). These results highlight that properly designed contracts can generally be used to fully solve both double-marginalization problems under full information. However, if there is information asymmetry, too low selling quantities as well as too low safety stocks continue to be prevalent.

2.4.3 Capacity Planning

Cachon and Lariviere (2001) analyze how a buyer can credible share private forecast information with his supplier. The following sequence of events is assumed. The buyer sources from a single supplier and offers this supplier a contract to build up capacity. The buyer also communicates an initial forecast to the supplier. Assuming the acceptance of the contract, the supplier builds up capacity. After the capacity is build, the buyer places an order, which is based on an updated forecast. Obviously, the supplier can only satisfy the buyer's order up to

[16] It is referred to Silver et al. (1998) for an extensive discussion of the newsvendor model and its applications.

the size of the available capacity. However, the supplier who bears the cost of installing the capacity has take into account the costs of overage and underage capacity. In contrary, the buyer who does not pay for installing the capacity always fancies the highest possible capacity. The buyer has therefore a strong incentive to inflate his initial forecast to influence the supplier capacity decision. Yet, if the supplier anticipates this behavior, he will ignore the initial forecast, as it is not credible. However, the supply chain optimal solution requires truthful information sharing of the initial forecast.

The buyer sells the product at a constant price to the end-customer. In the uncoordinated situation, the buyer offers a simple one-part tariff (i.e., wholesale-price) to the supplier, i.e., he pays the wholesale-price for every unit received from the supplier. Yet, this wholesale-price is lower than the constant price charged to the end-customer. The typical supply chain argumentation follows, i.e., the supplier does not take into account the actual supply chain revenue per unit (i.e., the constant end-customer price) while making the capacity decision. The supplier bases the capacity decision solely on the wholesale-price instead. Thus, the supplier's assessment of the underage costs is too low compared to the overall underage costs of the supply chain, and the resulting capacity is therefore too low.

Cachon and Lariviere (2001) utilize a signaling approach in which the privately informed buyer offers a signaling contract to the supplier. This signaling approach ensures that a buyer with a lower demand forecast has no incentive to communicate a higher demand forecast. In other words, a buyer who has a good forecast has to design the contract in a way that a buyer with a bad forecast would never want to offer this contract. The buyer with a good forecast can, for example, offer a two-part tariff consisting of a wholesale-price and a fixed-payment. Then the buyer has to ensure that a buyer with a bad forecast would never pay the offered fixed-payment given a specific wholesale-price.

Cachon and Lariviere (2001) show that signaling actually improves the supply chain performance. Particularly, they show that the buyer with the high demand forecast induces higher capacities by increasing the wholesale-price in the two-part tariff compared to the uncoordinated outcome with a one-part tariff. Hence, the supplier faces higher underage costs if the capacity does not suffice to fill the order. Since the wholesale-price without coordination is too low to induce the supply chain optimal capacity, a higher wholesale-price in the menu of contracts shifts the supplier's capacity decision closer to the supply chain optimum. In other words, the supplier takes a more accurate profit margin into consideration when making the capacity decision. Nonetheless, the buyer still faces agency costs, and the supply chain outcome is therefore inefficient.

Özer and Wei (2006) analyze a setting which is close to the work of Cachon and Lariviere (2001). In this setting the supplier decides on how much capacity he builds up before the buyer, who possesses private forecast information, places an order. In contrast to Cachon and Lariviere (2001), thus, the supplier offers the contract instead of the buyer. Interestingly, they show that the buyer has no incentive to misrepresent his forecast information as long as the supplier sets a wholesale-price equal to the end-customer price, and pays the buyer a fixed-payment equal to the buyer's reservation profit level. In this case the supplier bases his decision on the actual supply chain profit margin and builds up the supply chain optimal capacity.[17] However, Özer and Wei (2006) extend this setting to the case, in which the wholesale-price is exogenously determined, as the wholesale-price negotiation is often decoupled from capacity and forecast sharing decisions. Given this exogenously determined wholesale-price, they propose two types of contracts that can be offered by the supplier. The first contract type is the so-called "nonlinear capacity reservation"-contract under which the buyer pays a fixed fee to reserve capacity. The second type of contracts is a so-called "advance purchase"-contract under which the manufacturer is induced to place a firm order before the supplier builds up capacity.

In the nonlinear capacity reservation contract, the buyer with good forecast information is induced to reserve a higher capacity than the buyer with a rather bad forecast by implementing a screening contract. In the optimal menu of contracts, the buyer pays less for each additional unit of capacity reserved. Thus, the buyer with a good forecast has an incentive to reserve more capacity than the buyer with a bad forecast. However, the resulting capacity is less than as if under full information. This is, because the buyer's informational rent increases with his private forecast information (i.e., the better the private forecast, the higher the informational rent). This, in turn, leads to a downward distortion of capacity for buyers with relatively low forecasts.

In the advance purchasing contract, the supplier demands a quantity commitment from the buyer. The buyer, thus, reveals his private forecast to the supplier by paying an advanced purchase price for each ordered unit before the capacity is build up. Paying an advanced purchase price is therefore a signaling instrument. Generally, the same argumentation as in Cachon and Lariviere (2001) follows, with the exception that signaling the demand information by an advanced purchase does not unambiguously enhance supply chain performance in contrast to the one-part tariff. This is, because the wholesale price is exogenously determined. However, Özer and Wei (2006) show that the supplier can enrich the advance purchasing contract structure with a payback-price, which is paid by the buyer for every unit of excess capacity. In this case full coordination is achievable even though the wholesale-price is exogenously determined.

Iyer et al. (2005b) analyze a single-supplier multiple-buyer framework. Under normal conditions the supplier is able to fulfill all buyers' demands. However, if contingencies, such as fire, earthquakes or a machine breakdown occur, the buyer has to restore the capacity. Yet, the restoration of capacity takes time and is costly. The supplier decision now is how fast to restore the capacity, considering that a faster restoration is more expensive. As long as the capacity is not restorated, the buyers' incur backorder costs. All buyers are assumed to be identical except of their

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[17] This highlights that asymmetric information can only harm supply chain performance if it is decision relevant. As an example, if the buyer would hold private information with respect to his reservation profit level, than the coordination problem would be significantly harder to solve.

backorder costs. Under full information, the supplier simply chooses the optimal restoration speed, and charges every buyer a fixed-payment such that each buyer only yields his reservation profit level.

However, in case of asymmetric information, the buyer's backorder costs are private information. Obviously, in an uncoordinated setting all buyers will claim that they face high backorder cost to induce a fast restoration of capacity and/or paying a low side-payment to the supplier. As the supplier anticipates this behavior, it is in his best interest to offer a menu of contracts that specifies a restoration speed and side-payment for every possible backorder cost. Iyer et al. (2005) show that the restoration speed in this case is higher than under full information. This is, because a faster restoration speed allows the supplier to reduce the information rent paid to the buyers with low backorder costs.

Cachon and Zhang (2006) analyze a single-supplier single-buyer supply chain with uncertain end-customer demand. In this setting the supplier can influence his lead time, i.e., the time span it takes to deliver an incoming order to the buyer. Faster lead times are more expensive than slower lead times. The costs that are associated with reducing the lead-time are the supplier's private information. Obviously, the buyer prefers low lead times as his optimal safety stocks decrease with decreasing lead times.[18] From an overall supply chain perspective the optimal lead time results from balancing the benefits of lower safety stocks and the costs of reducing the lead time.

Cachon and Zhang (2006) point out that capacity and lead-times can be interpreted analogically, as a higher capacity typically results in lower lead-times. As an example, an order can be produced in one day instead of two days given a higher capacity. In this context, the supplier has an incentive to exaggerate the costs of building up capacity. Therefore, the buyer offers a menu of contract that consists of pairs of capacity investments and side-payments. Again, the buyer cannot avoid paying an informational rent to the supplier. Hence, the resulting capacity is lower (or the lead time is higher) than under full information.

Additionally, Cachon and Zhang (2006) argue that an analytical derivation of the optimal menu of contracts is not possible due to the complexity of the underlying planning situation. Hence, the optimal menu of contracts can only be computed numerically. Therefore, they propose much simpler contracts, such as a "Late-fee"-contract and "Lead-time"-contract. In a numerical study, these contracts increase the buyer's costs on average only by 1% while do not substantially changing the supplier profits. The late-fee contract defines a fixed-fee for all outstanding orders per unit time in addition to a wholesale price for every unit procured. The lead-time contract, in contrary, defines a fixed lead-time in addition to a simple wholesale-price. Summarizing, these simple mechanisms seem to be superior to the rather complicated menu of contracts, as the implementation effort is lower and the allocation of profits does not significantly change.

[18] See Silver et al. (1998).

Lutze and Özer (2008) analyze a single-supplier single-buyer supply chain in which the buyer possesses private information with respect to his backorder costs.[19] They show that a "promised lead-time"-contract in addition to a base-stock policy, which is optimal for this classical serial system (see Clark and Scarf 1960), can be used to coordinate the supply chain to some extent. Given a promised lead-time contract, the retailer places advance orders with the supplier. The supplier, in turn, guarantees the timely delivery of the order within the promised lead-time.[20] The buyer benefits from the guaranteed lead-time, as this eliminates the risk from uncertain supply. On the other hand, the buyer's forecast horizon is extended beyond the standard lead-time. The supplier, in turn, benefits from the advance orders, which help to decrease the risk of uncertain demand.

Nonetheless, under asymmetric information the supplier has an incentive to exaggerate his backorder costs (or the optimal service level). In this case, the supplier offers a menu of contracts in which each offer consists of a promised lead time and a respective side-payment. A buyer with higher backorder costs is offered a lower promised lead-time. However, this lead time is downward distorted, as the buyers with low backorder costs yield an information rent which increases with decreasing lead-times. As in other studies (e.g., Ha 2001), Lutze and Özer (2008) allow the supplier to apply a cut-off policy, i.e., they allow to refuse trade if the buyer's backorder costs exceed a certain cut-off level.

Chakravarty and Zhang (2007) investigate the collaboration between two firms with contingent capacities, which are both required to provide a joint service to the end-customer. In this sense, both capacities are needed to offer the service. The profit margins to offer the integrated service might be different. In the context of the underlying work, these two firms can either be two suppliers or two buyers, respectively.

It is assumed that both firms have two invest in capacity before demand is realized. The investment cost of one firm is private information. Yet, if the two firms are totally uncoordinated, and no contract is in place, the performance suffers from profit margin differentials (i.e., not the whole profit margin is taken into account while making the capacity decision). In this case, the ill-informed party offers a menu of contracts which consists of pairs of capacity commitments and side-payments. This, in turn, gives the privately informed firm an incentive to invest in higher capacities. Nonetheless, the privately informed party yields an informational rent if the investment costs are low (as the firm has an incentive to claim high costs of the capacity investment). Hence, the capacities under asymmetric information are still too low compared to the supply chain optimum, but higher than in the totally uncoordinated setting without any incentive alignment.

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[19]Lutze and Özer (2008) take a cost minimization approach in which both, the supplier and the buyer, only consider holding- and backorder costs while making their inventory decision. Hence, there is no double-marginalization problem, as the supplier does not optimize his wholesale-price in this setting.

[20]It is assumed that the supplier has an alternative source that can deliver immediately any excess demand in case the promised lead-time is at stake.

2.4.4 Product Specification and Backup Production

Iyer et al. (2005a) present a model in which the buyer delegates the majority of the product design, specification and production activity to the supplier. The supplier has to assign his own resources to produce the goods. However, the buyer cannot observe how much effort the supplier invests in performing the tasks. Additionally, the supplier's capability of performing the task is private information. The buyer, in turn, commits himself to allocate some of his own resources to the required task to help the supplier (e.g., engineering hours). The buyer has to decide upon his resource commitment, which is observable. In this case, the buyer offers a menu of contracts which consists of resource-commitment and side-payment pairs.

Iyer et al. (2005) show that the supply chain optimal solution is not achievable with this contract structure. In particular, the buyer's resource allocation is deteriorated. Interestingly, the direction of deterioration (i.e., upward or downward distortion) depends on whether the buyer's resource and the supplier's capabilities are complements or substitutes. They are complements if the buyer's resource benefits more the capable than the incapable supplier. In this case the gap between capable and incapable suppliers increases with increasing buyer's involvement. Hence, increasing buyer's involvement requires increasing informational rents paid to the more capable suppliers. Therefore, the supply chain observes a downward distortion of buyer's involvement. In contrast, they are substitutes if the buyer's resource benefits more the incapable than the capable supplier. Thus, given substitutes increases in buyer's involvement reduces the gap between different buyers. This in turn allows the buyer to pay less informational rent, and the supply chain observes an overinvestment in buyer's resource allocation.

Finally, Yang et al. (2009) analyze a one-supplier one-buyer supply chain, in which the supplier's reliability is private information. In case the supplier incurs a disruption during regular production, he has the option to use backup production, which is perfectly reliable. Backup production is more expensive than regular production. The supplier's reliability is private information. Yang et al. (2009) propose a menu of contracts offered by the buyer which consists of three parameters, i.e., a fixed payment, an order quantity and a unit penalty for delivery shortfall. The buyer uses the unit penalty to control for the supplier backup-production decision, i.e., he either sets a unit-penalty price which is higher or lower than backup-production. Under that contract scheme, the supply chain optimum is not achievable as the buyer has to pay an informational rent to more reliable suppliers. In particular, the buyer stops using the backup production of a less reliable supplier. This is, because the side-payment to the less reliable supplier must at least been paid to the more reliable supplier as well. Yet, if the backup production costs are too high it might be unprofitable to use this option for the low reliable supplier at all. Allowing a cut-off policy, the buyer may even stop ordering from the less reliable supplier.

Appendix

Optimal Menu of Contracts in the Strategic Lotsizing Framework

Setting up the Lagrange-function gives:

$$\min\ L\left(q_i, Z_i, \lambda_{ij}, \mu_i | i, j = 1, \ldots, n \text{ and } i \neq j\right) = -Y_s + \sum\nolimits_{i=1}^{n} p_i \left(\frac{f_i}{q_i} + Z_i\right)$$
$$+ \sum\nolimits_{i=1}^{n} \mu_i \left(\frac{h_i}{2} q_i - Z_i - C_{AS}\right)$$
$$+ \sum\nolimits_{j=1, j\neq i}^{n} \sum\nolimits_{i=1}^{n} \lambda_{ij} \left(\frac{h_i}{2} q_i - Z_i - \frac{h_i}{2} q_j + Z_j\right). \tag{2.23}$$

The Karush-Kuhn-Tucker conditions are:

$$\frac{\partial L}{\partial q_i} = -p_i \frac{f}{{q_i}^2} + \mu_i \frac{h_i}{2} + \sum\nolimits_{j=1, j\neq i}^{n} \left(\lambda_{ij} \frac{h_i}{2} - \lambda_{ji} \frac{h_j}{2}\right) \leq 0 \tag{2.24}$$

$$\frac{\partial L}{\partial Z_i} = p_i - \mu_i + \sum\nolimits_{j=1, j\neq i}^{n} \left(\lambda_{ji} - \lambda_{ij}\right) \leq 0 \tag{2.25}$$

$$\frac{\partial L}{\partial \mu_i} = \frac{h_i}{2} q_i - C_{AS} - Z_i \leq 0 \tag{2.26}$$

$$\frac{\partial L}{\partial \lambda_{ij}} = \frac{h_i}{2} q_i - Z_i - \frac{h_i}{2} q_j + Z_j \leq 0 \tag{2.27}$$

$$\frac{\partial L}{\partial q_i} q_i = 0, \frac{\partial L}{\partial Z_i} Z_i = 0, \frac{\partial L}{\partial \mu_i} \mu_i = 0, \frac{\partial L}{\partial \lambda_{ij}} \lambda_{ij} \tag{2.28}$$

$$\mu_i \geq 0, \lambda_{ij} \geq 0 \tag{2.29}$$

Solving (2.25) for μ_i and substituting in (2.23) while considering $q_i > 0$ results in

$$p_i \left(\frac{h_i}{2} - \frac{f}{{q_i}^2}\right) + \frac{1}{2} \sum\nolimits_{j=1, j\neq i}^{n} \lambda_{ji} \left(h_i - h_j\right) = 0 \tag{2.30}$$

From (2.30) and Sappington's (1983) results $\mu_i = 0\ \forall i = 1, ..., n-1,\ \mu_n = 1$ and $\lambda_{ij} = 0$, for $j < i$ and $j > i+1$ it follows that

$$\begin{aligned}
&\text{for } i = n \\
&p_n + \lambda_{n-1,n} = 1 \\
&\text{for } i = n-1 \\
&p_{n-1} + \lambda_{n-2,n-1} - \lambda_{n-1,n} = 0 \ \Rightarrow\ \lambda_{n-2,n-1} = 1 - p_n - p_{n-1} = \sum\nolimits_{t=1}^{n-2} p_t \\
&\vdots \\
&\text{for } i = 2 \\
&p_2 + \lambda_{12} - \lambda_{23} \Rightarrow\ \lambda_{12} = 1 - p_n - ... - p_2 = p_1
\end{aligned} \tag{2.31}$$

Substituting this result in (2.30) and solving for q_i gives:

$$q_i^{AI} = \sqrt{\frac{2 \cdot f}{h_i + \gamma_i}} \tag{2.32}$$

where

$$\gamma_i = \frac{\sum_{t=0}^{i.-1} p_t}{p_i} (h_i - h_{i-1}), \forall i = 1, ..., n. \tag{2.33}$$

As $\mu_n = 1$ (see Sappington 1983) it follows that

$$Z_n^{AI} = \frac{h_n}{2} q_n^{AI} - C_{AS}. \tag{2.34}$$

Furthermore, $\lambda_{ij} = 0,$ for $j < i$ and $j > i+1$ and $\lambda_{ij} > 0$ for $i = j-1$ holds (see Sappington 1983) and it follows from (2.27)

$$Z_i^{AI} = \frac{h_i}{2}\left(q_i^{AI} - q_{i+1}{}^{AI}\right) + Z_{i+1}{}^{AI}, \forall i = 1, ..., n-1. \tag{2.35}$$

Chapter 3
On the Impact of Fixed Cost Reduction in the Strategic Lotsizing Framework

This section elaborates the impact of costly fixed cost reduction on the coordination deficit arising through asymmetric information in the strategic lotsizing framework (see Sect. 2.2.2). Section 3.1 reviews the relevant literature of fixed cost reduction in the (joint) economic lotsizing model, and motivates why fixed cost reduction is introduced in the strategic lotsizing framework. Section 3.2 derives the optimal fixed cost level and contract parameters under full and asymmetric information. Section 3.3 analyses the distorting impact of asymmetric information on the fixed cost level decision. Section 3.4 illustrates the general results for a numerical example, in which the fixed cost investment costs are convex in the respective fixed cost level. Section 3.5 summarizes the results and gives some managerial insights.

3.1 Moving Towards Just-in-Time

In Sect. 2.2.2 the model of strategic lotsizing under asymmetric information was introduced. In this model the buyer asks the supplier to switch the delivery mode to JiT. It is assumed that a JiT delivery is more favorable for a buyer with high holding costs per unit and period, as smaller order sizes (i.e., a tendency towards JiT) lead to lower average inventories. In contrast, smaller order sizes lead to a cost increase for the supplier, which is captured by higher fixed costs per unit.

Yet, it is well known that small order sizes are not sufficient for a successful implementation of the JiT concept (see Schonberger and Schniederjans 1984). Fixed cost reduction, thus, is regarded to be one main facilitator for JiT to be efficient. In the following, it is analyzed whether the distortions elaborated in Sect. 2.2.2 increase or decrease due to the supplier's option to invest in fixed cost reduction. If a complete cut of fixed costs could be achieved at no (or very minor) cost, the supplier would offer the JiT contract and perfect coordination would result. However, the impact of costly fixed cost reduction on supply chain coordination is not clear at all, since the investment decision might also be deteriorated by asymmetric information.

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Porteus (1985) was the first to analyse the potential benefits of fixed cost reduction in the economic order quantity-framework. Consecutive research often focused on the specific form of the investment function in either the economic production or economic order quantity model (e.g., van Beek and van Putten 1987; Hahn et al. 1988; Kim et al. 1992). Leschke (1996) gives a comprehensive review of this stream of research and conducts an empirical study to explore a realistic shape of the investment function. Other authors extend Porteus initial work to the case of stochastic lead times (and demand) or backorders (see Paknejad and Affisco 1987; Keller and Noori 1988; Nasri et al. 1990). Paknejad et al. (1996) extend this research line to the case of two stage systems under full information. Also, Affisco et al. (2002) and Liu and Cetinkaya (2007) use this two-stage framework to incorporate quality aspects in the supplier's decision problem.

Summing up, this section builds upon the insight that information asymmetries arise when supply chain members negotiate the terms of delivery (e.g., JiT delivery), and that these information asymmetries lead to a lack of supply chain coordination. However, as JiT strategies are regularly accompanied by process improvements it is not clear if this lack of coordination is still present in this case. Therefore, the forthcoming section provides the reader valuable insights under which circumstances process improvements, such as fixed cost reduction, can reduce the inefficiencies within the supply chain. Additionally, the analysis gives an analytical framework for assessing the value of long-term investment decisions in supply chain settings under asymmetric information.

3.2 Fixed Cost Reduction in the Strategic Lotsizing Framework

As mentioned before, the supplier's disadvantages of the JiT delivery are captured by the fixed costs per period, f/q. Allowing to invest in process improvement, such as setup cost reduction, these fixed costs are a decision variable for the supplier's decision problem. The costs for reducing the fixed costs from its original level $f_{\max}$ by $f_{\max} - f$, $\forall f \geq f_{\min} \geq 0$ are captured by the investment function $k(f)$. The investment $k(f)$ results in a fixed cost reduction over the whole (infinite) planning horizon. Hence, the supplier faces costs of $r \cdot k(f)$ in every period, where r denotes the company specific interest rate.[1] All the other assumptions and notations from Sect. 2.2 apply. First, Sect. 3.2.1 will derive the optimal fixed cost level and contract parameters under full information, while Sect. 3.2.2 extends the analysis to the case of asymmetric information.

[1]The interest rate r can be defined as the annuity factor in case of a finite time horizon. In this case, a constant order size q is still optimal (see Brimberg and Hurley 2006).

3.2.1 Fixed Cost Reduction Under Full Information

If the supplier knows the buyer's holding costs h with certainty, he offers the following contract, consisting of order size q, side payment Z and the corresponding fixed costs f, to maximize his profit margin per period, P_s. Again, the buyer has the option to source from an alternative supplier (AS) leaving him a unit profit margin of R. To encourage higher order sizes while ensuring that the buyer does not pick his outside option, the supplier has to compensate the buyer for the additional holding cost with a side payment Z per unit (e.g., by offering a quantity discount on the wholesale price). The supplier's optimal contract offer $F = \langle q^{FI}, Z^{FI} \rangle$ is the outcome of the following optimization problem:

Problem FI.

$$\max P_s(q,Z,f) = Y_s - \frac{f}{q} - Z - r \cdot k(f) \tag{3.1}$$

s.t.

$$P_b = Y_b - \frac{h}{2} \cdot q + Z \geq R \qquad \text{(Participation constraint)} \tag{3.2}$$

$$f_{\min} \leq f \tag{3.3}$$

$$f \leq f_{\max} \tag{3.4}$$

It is easy to verify that the participation constraint (3.2) needs to be binding for an optimal solution. Substituting $Z = \frac{h}{2} \cdot q - C_{AS}$ where $C_{AS} = Y_B - R$ in the objective function (3.1), and setting up the Lagrange function gives for the cost minimizing problem[2]:

$$L(q,f,l_{\min},l_{\max}) = \frac{f}{q} + \frac{h}{2} \cdot q - C_{AS} + r \cdot k(f) + l_{\min}(f_{\min} - f) + l_{\max}(f - f_{\max}). \tag{3.5}$$

As in previous sections, the indices AI and FI refer to the situation under asymmetric information and full information, respectively. The solution of $\min_{q,f,l_{\min},l_{\max}} L(q,f,l_{\min},l_{\max})$ gives the supply chain optimal contract parameters q^{FI}, Z^{FI}, the optimal fixed cost level f^{FI} and the supply chain optimal Lagrange parameters ${l_{\min}}^{FI}$ and ${l_{\max}}^{FI}$, i.e., the order size q^{FI} is the cost minimizing order size

[2]Note that the following analysis uses the cost minimizing instead of the profit maximizing formulation. As the fixed revenues per period are not decision relevant, these approaches are equivalent. However, the cost minimizing approach is notational more convenient. Nonetheless, note that risk preferences might alter the results (see Sect. 4.3.1).

for the overall supply chain. This order size is the well-known economic order quantity with respect to the reduced fixed costs, i.e., $q^{FI} = \sqrt{2 \cdot f^{FI}/h}$. Kim et al. (1992) show that the optimal fixed cost level of problem FI depends on the actual shape of the total cost function. Also, they provide an optimization procedure for any investment function $k(f)$, which can easily be transferred to the underlying framework. Particularly, Kim et al. (1992) show that for a concave and a linear investment function the optimal investment level f^{FI} is either $f_{\min}\left(\Rightarrow {l_{\min}}^{FI} > 0\right)$ or $f_{\max}\left(\Rightarrow {l_{\max}}^{FI} > 0\right)$. For a convex investment function the optimal investment level is either an interior solution $\left(\text{i.e. } {l_{\min}}^{FI} = 0 \text{ and } {l_{\max}}^{FI} = 0\right)$ or a corner solution $\left(\text{i.e. } {l_{\min}}^{FI} > 0 \text{ or } {l_{\max}}^{FI} > 0\right)$. In the following, the analysis is extended to the case of asymmetric information.

3.2.2 Fixed Cost Reduction Under Asymmetric Information

As mentioned in Sect. 2.2, the buyer's multi-dimensional advantages from a JiT delivery are captured by an aggregated measure, namely the holding costs. As the supplier's full information about these JiT related advantages is certainly a critical assumption, it is assumed that the supplier can only estimate these advantages. This estimation is formalized with a probability distribution $p_i, i = 1, \ldots, n$ over all possible holding cost realizations h_i $\left(h_i < h_j, \forall i < j; i, j = 1, \ldots, n\right)$. Common knowledge of this probability distribution is assumed. For simplifying forthcoming formulas it is defined that $p_0 = 0$ and $h_0 = 0$. The following decision sequence is assumed (see Fig. 3.1):

The optimal menu of contracts $A_i = \left({q_i}^{AI}, {Z_i}^{AI}\right), \forall i = 1, \ldots, n$ is the solution to the following optimization problem:

Problem AI.

$$\max\ E[P_S] = \sum\nolimits_{i=1}^{n} p_i \cdot P_{s,i}, \quad \forall i = 1, \ldots, n \tag{3.6}$$

s.t.

$$P_{b,i}(A_i) \geq R, \quad \forall i = 1, \ldots, n \tag{3.7}$$

$$P_{b,i}(A_i) \geq P_{b,i}\left(A_j\right), \quad \forall i \neq j; i, j = 1, \ldots, n \tag{3.8}$$

$$f_i \leq f_{\max}, \quad \forall i = 1, \ldots, n \tag{3.9}$$

$$f_{\min} \leq f_i, \quad \forall i = 1, \ldots, n \tag{3.10}$$

where $P_{s,i} = Y_s - (f/q_i + Z_i + r \cdot k(f_i))$ denotes the supplier's profits if the contract A_i is accepted, and $P_{b,i}\left(A_j\right)$ the buyer's profits if he faces holding costs h_i and chooses the contract $A_j, \forall i, j = 1, \ldots, n$, respectively.

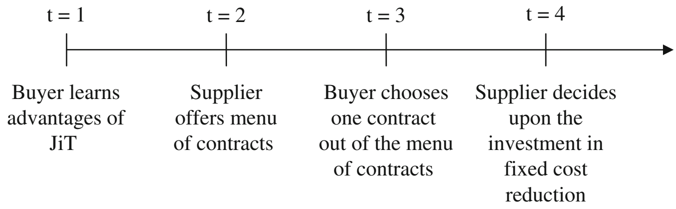


Fig. 3.1 Decision sequence under fixed cost reduction

Again, the incentive constraint (3.8) theoretically ensures the buyer's self-selection, i.e., the buyer with holding costs h_i realizes the highest profit margin per period when choosing the order size q_i. The participation constraint (3.7) ensures that no buyer, regardless of his holding costs, will choose the alternative supplier. Again, the cost minimization approach instead of the profit maximization approach is shown. Setting up the Lagrange-function gives:

$$\begin{aligned} &L\left(q_i, Z_i, f_i, \lambda_{ij}, \mu_i, l_{\min,i}, l_{\max,i} \middle| i,j = 1, \ldots, n \text{ and } i \neq j\right) \\ &= \sum\nolimits_{i=1}^{n} p_i \left(\frac{f_i}{q_i} + Z_i + r \cdot k(f_i)\right) + \sum\nolimits_{i=1}^{n} \mu_i \left(\frac{h_i}{2} q_i - C_{AS} - Z_i\right) \\ &\quad + \sum\nolimits_{i=1}^{n} \sum\nolimits_{j=1, j\neq i}^{n} \lambda_{ij} \left(\frac{h_i}{2} q_i - Z_i - \frac{h_i}{2} q_j - Z_j\right) + \sum\nolimits_{i=1}^{n} l_{\min,i} (f_{\min} - f_i) \\ &\quad + \sum\nolimits_{i=1}^{n} l_{\max,i} (f_i - f_{\max}) \end{aligned} \tag{3.11}$$

The Karush–Kuhn–Tucker (KKT) conditions for an optimal solution are summarized in Appendix 1. The optimal solution of the problem AI gives the optimal menu of contracts $A = (A_1, \ldots, A_n)$ the optimal investment level f_i^{AI} and the optimal Lagrange-parameters $\mu_i^{AI}, l_{\min,i}^{AI}, l_{\max,i}^{AI}$ and λ_{ij}^{AI}. The order size that minimizes the supply chain costs given the holding cost parameter h_i is denoted by q_i^{FI}.

The optimal menu of contract can be derived from the KKT-conditions (see Appendix 2):

$$q_i^{AI} = \sqrt{\frac{2 \cdot f_i^{AI}}{h_i + \gamma_i}}, \quad \forall i = 1, \ldots, n \tag{3.12}$$

$$\textit{where } \gamma_i = \frac{\sum_{t=0}^{i-1} p_t}{p_i} (h_i - h_{i-1}), \quad \forall i = 1, \ldots, n \tag{3.13}$$

$$Z_n^{AI} = \frac{h_n}{2} q_n^{AI} - C_{AS} \tag{3.14}$$

$$Z_i^{AI} = \frac{h_i}{2}\left(q_i^{AI} - q_{i+1}{}^{AI}\right) + Z_{i+1}{}^{AI}, \quad \forall i < n \tag{3.15}$$

As long as the optimal fixed cost level is an interior solution, the optimal fixed cost level f_i^{AI} results from solving [see Appendix 2, (3.44)]

$$\sqrt{\frac{h_i + \gamma_i}{2 \cdot f_i^{AI}}} = -r \cdot \left.\frac{dk(f_i)}{df_i}\right|_{f_i = f_i^{AI}}. \tag{3.16}$$

Otherwise, the optimal fixed cost level is a corner solution, i.e., $f_{\min}$ or $f_{\max}$. Note that the optimal contract parameters are the same as in Sect. 2.2.4, with the exception that the supplier has to take the fixed cost reduction option into account while offering the menu of contracts. Hence, his decision $t = 4$ is already considered in $t = 2$ (see Fig. 3.1). Otherwise, he offers suboptimally high order sizes as (3.12) is calculated w.r.t. f_i^{AI} and f_i^{AI}, in turn, is computed from (3.16).

As already elaborated in Sect. 2.2, there is a downward distortion of order sizes, which follows directly from (3.12) and $\gamma_i > 0$. This is, given any fixed cost level f_i, the supply chain performance can always be increased by increasing $q_i, i > 1$. Additionally, a closer look at (3.16) reveals that the fixed cost level might also be distorted due to $\gamma_i \geq 0$. The next section will discuss this distortion extensively with respect to a convex, concave and linear investment function. Figure 3.2 depicts the shape of the analyzed investment functions.[3] A marginal approach will illustrate the intuition behind the results. This approach seems reasonable since a graphical exposition of the problem is possible. It is referred to Kim et al. (1992) who base their arguments on the total cost function. However, as this total cost function is more complicated under asymmetric information, this approach can only be applied under full information.

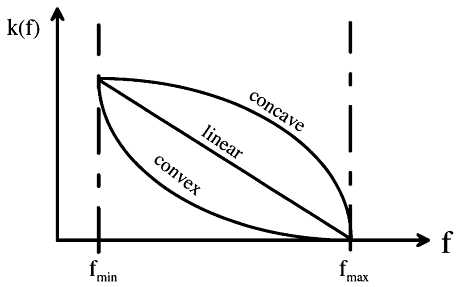


Fig. 3.2 Progressive shapes of the analyzed investment functions

[3]It is referred to Leschke and Weiss (1997) for a review of commonly assumed investment functions. The convex followed by the linear investment function is most commonly assumed.

3.3 Overinvestment in Fixed Cost Reduction due to Asymmetric Information

The following sections elaborate the optimal fixed cost levels f_i^{AI} and f_i^{FI} in case of a concave and linear investment function (Sect. 3.3.1) as well as in case of convex investment function (Sect. 3.3.2). The standard economic argument of balancing marginal revenues and marginal costs will be applied.

3.3.1 *Concave or Linear Investment Function*

Let $MR^{FI}(f_i)$, $MR^{AI}(f_i)$ denote the marginal revenues (i.e., cost savings) under full and asymmetric information, and $MC(f_i)$ denote the marginal cost of reducing the fixed cost f_i. If the optimal fixed cost level is an interior solution, then the marginal revenues should equal the marginal costs (see 3.16), where

$$MR^{AI}(f_i) = \sqrt{\frac{h_i + \gamma_i}{2 \cdot f_i}} \tag{3.17}$$

$$MR^{FI}(f_i) = \sqrt{\frac{h_i}{2 \cdot f_i}} \tag{3.18}$$

$$MC(f_i) = -r \cdot \frac{\partial k(f_i)}{df_i}. \tag{3.19}$$

Next it is shown, however, that this interior solution is a cost maximum instead of a cost minimum. Hence, a corner solution must be the optimal solution.

Figure 3.3 depicts $MC(f_i)$, $MR^{FI}(f_i)$ and $TM^{FI}(f_i) = MR^{FI}(f_i) - MC(f_i)$, where $TM^{FI}(f_i)$ depicts the total marginal savings. The MC-curve is monotonically increasing for concave investment functions as $\frac{d^2k(f)}{d^2f} < 0 \rightarrow -\frac{d^2k(f)}{d^2f} > 0$. As the MR-curves are always monotonically decreasing in f_i it follows directly that the TM^{FI}-curve is strictly monotonically decreasing as well. Thus, there is at most one interior solution. To evaluate the profitability of a fixed cost reduction the integral over $TM^{FI}(f_i)$ needs to be evaluated. Let f_r denote the root of $TM^{FI}(f_i)$, i.e., the interior solution to problem FI. If $f_r \in (f_{\min}, f_{\max})$, a reduction of fixed costs to f_r causes a loss of $\int_{f_r}^{f_{\max}} TM^{FI}(f_i)df_i$ (i.e., area 2, Fig. 3.3).[4] Hence, f_r is a local cost maximum. In contrary, a fixed cost reduction beyond the level f_r is profitable as

[4]Note that the graphical representation in Fig. 3.3 depicts the fixed cost level f_i instead of the total reduction $f_{\max} - f_i$. The higher the fixed cost reduction, thus, the lower the fixed cost level (i.e., f_i is closer to the point of origin).

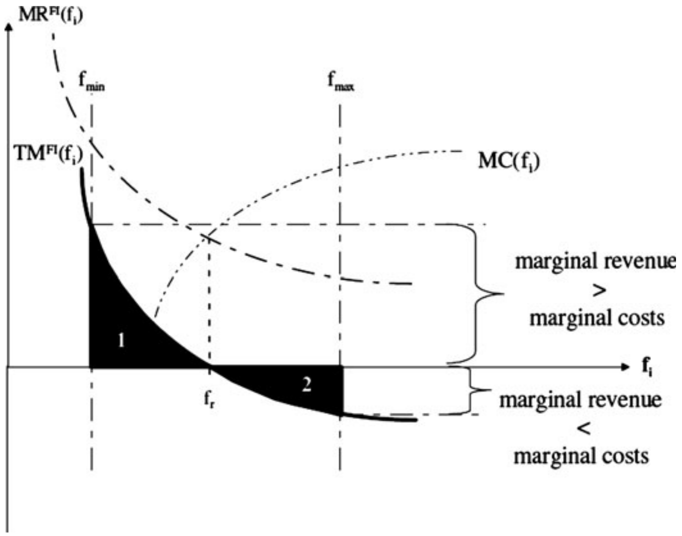


Fig. 3.3 Optimal investment level given a concave investment function

$TM^{FI}(f_i)$ is strictly monotonically decreasing. Hence, if there is a reduction beyond f_r at all, this reduction will be rigorously carried out to the maximum extent, yielding profits of $\int_{f_{\min}}^{f_r} TM^{FI}(f_i)df_i$(i.e., area 1). Hence, if TM intersects the abscissa between $f_{\min}$ or $f_{\max}$, the optimal investment level depends on the ratio of the areas 1 and 2. If area 1 is bigger than area 2, then the optimal fixed cost level is $f_{\min}$, otherwise it is $f_{\max}$. Therefore, ${l_{\min}}^{FI} > 0$ or ${l_{\max}}^{FI} > 0$ holds. Figure 3.3 depicts the case in which a fixed cost reduction to the maximum extent is optimal.

The same argumentation can simply be applied in case of a linear investment function. As the marginal costs are constant for a linear investment function, it follows directly that $TM^{FI}(f_i)$ is strictly monotonically decreasing. For that reason, there is at most one intersection with the abscissa, and the optimal fixed cost level is as well a corner solution (i.e.$f_{\min}$ or $f_{\max}$). Therefore, ${l_{\min}}^{FI} > 0$ or ${l_{\max}}^{FI} > 0$ holds.

These findings resemble the results reported by Kim et al. (1992). Under full information, thus, the optimal (corner) solution results from comparing two strategies, i.e., either maximum investment or no investment at all.

Next, it is considered whether asymmetric cost information distorts this investment decision. Equation (3.17) shows that the marginal revenue of reducing the fixed costs increases with increasing γ_i. From $\gamma_i > 0, \forall i = 2, ..., n$ follows that the MR-curve under full information lies beneath the MR-curve under asymmetric information, i.e., $MR^{AI}(f_i) \geq MR^{FI}(f_i)$. It follows directly that $TM^{FI}(f_i) \leq TM^{AI}(f_i)$, $\forall f_i$. Hence, area 1 increases and area 2 decreases in size if the supplier offers a screening contract. For this reason, a distortion of the investment decision is only observable if the supplier chooses $f_i^{AI} = f_{\min}$(i.e., area 1 > area 2) although the supply chain optimal investment level is equal to $f_i^{FI} = f_{\max}$(i.e., area 1 < area 2). Figure 3.4 depicts this case. Note that an underinvestment cannot be an optimal

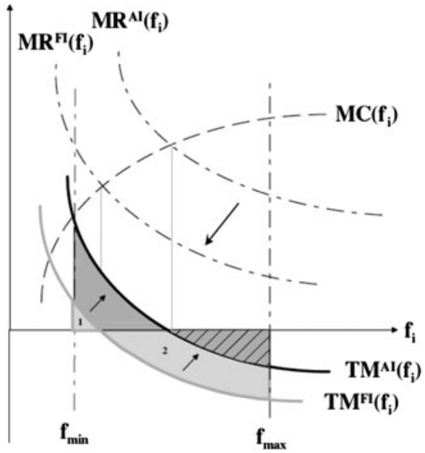


Fig. 3.4 Overinvestment in case of a concave investment function

solution given a concave or a linear investment function. As area 1 (i.e., the profits of fixed cost reduction) will never decrease due to asymmetric information, an underinvestment cannot be optimal from the supplier's perspective. The same arguments hold for a linear investment function.

3.3.2 Convex Investment Function

Next, the distortionary effect of asymmetric information on the investment level in case of a convex investment function is analyzed. Again, the situation under full information is considered first. As both $MR^{FI}(f_i)$ and $MC(f_i)$ are monotonically decreasing $\left(\frac{d^2k(f)}{d^2f} > 0\right)$, it is not clear if $TM^{FI}(f_i)$ is monotonic at all. Figure 3.5 depicts the case of (a) a monotonically increasing TM-curve and (b) a monotonically decreasing TM-curve.

Note that there might be multiple interior solutions if the TM-curve is not monotonic at all. Nonetheless, the same arguments developed in this section can be applied as the argumentation can either be reduced to case (a) or (b).

In case of a monotonically decreasing TM-curve, i.e., case (b), the same argumentation as in Sect. 3.3.1 for the concave or linear investment function follows, and an interior solution will result in a cost maximum. Consequently, the optimal fixed cost level is either $f_{\min}$ or $f_{\max}$, and there is also the possibility of an overinvestment due to asymmetric information.

In contrast, the optimal investment level is typically not a corner solution as long as the TM-curve is monotonically increasing, i.e., case (a). In this case the root of $TM^{FI}(f_i)$ is the supply chain optimal investment level, i.e.,

$$f_i^{FI} = \begin{pmatrix} f_r \quad , & if\ f_r \in [f_{\min}, f_{\max}] \\ f_{\min}, & if\ f_r < f_{\min} \\ f_{\max}, & else \end{pmatrix}. \tag{3.20}$$

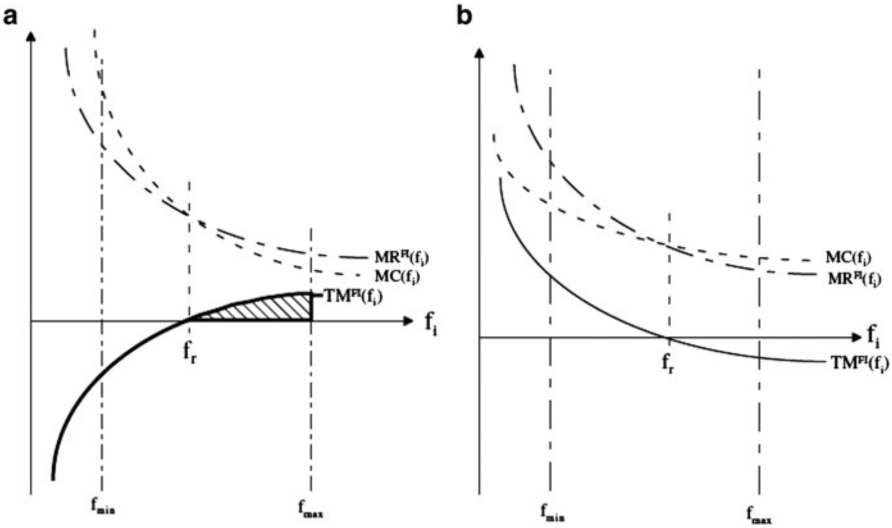
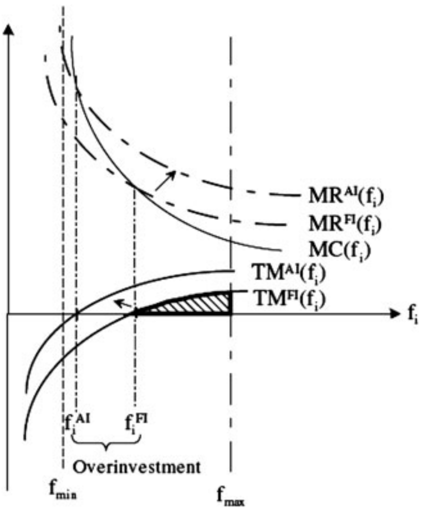


Fig. 3.5 Optimal investment level in case of a convex investment function

Fig. 3.6 Overinvestment in case of a convex investment function



Obviously, in contrast to case (b), all fixed cost reductions beyond f_r are not profitable at all, and f_r results in a cost minimum instead of a cost maximum.

Next, the effect of asymmetric information on the investment decision is evaluated. As long as the optimal investment level under asymmetric information is an interior solution it is obvious that a upward shift of $MR^{AI}(f_i)$ leads directly to a distortion of the investment level. More precisely, as long as the order sizes change due to a screening $\left(\text{i.e.} MR^{AI}(f_i) > MR^{FI}(f_i)\right)$ and the supply chain optimal fixed cost level is not a corner solution, there is an overinvestment in fixed cost reduction. Figure 3.6 illustrates this case.

Yet, if $TM^{AI}(f_i)$ is not monotonic at all, the same arguments as for the separated cases (a) and (b) in Fig. 3.5 hold, and only an overinvestment can be observed due to an upward shift of $TM^{AI}(f_i)$, i.e., due to asymmetric information.

As such, it can be summarized that there is always the possibility of an overinvestment in fixed cost reduction, regardless of the actual shape of the investment function. This result is basically driven by the fact that the supplier screens the buyer regarding his private information. This, in turn, leads to order sizes which are smaller than the supply chain optimal order sizes (i.e.$q_i^{AI} < q_i^{FI}, \forall i = 2, ..., n$). This leads to higher marginal revenues from the investment in fixed cost reduction. Yet, it is not clear at all if the coordination deficit (i.e., the performance gap between supply chain optimum and screening contract) is increasing or decreasing due to the investment option, as there are two countervailing effects.

Overinvestment effect. As stated above, an overinvestment in fixed cost reduction due to asymmetric information is likely. From a supply chain perspective this overinvestment causes a coordination deficit.

Fixed cost effect. As shown in Sect. 2.2, the coordination deficit due to asymmetric information is essentially caused by a downward distortion of the supply chain optimal order quantity (i.e.$q_i^{AI} < q_i^{FI}$), and it follows that there is no supply chain optimal trade-off between holding costs and fixed costs per period.[5] The fixed costs per period are suboptimally high and the holding costs suboptimally low. Yet, as there is the opportunity to invest in fixed cost reduction (and even an overinvestment is possible), this unbalanced trade-off carries less weight. The fixed cost effect, thus, measures the isolated coordination gains from reducing the fixed costs while ignoring the overinvestment costs.

The following section will analyze the impact of the overinvestment- and fixed cost effect on the coordination deficit for two possible holding cost realization.

3.4 Example: Convex Investment Function

In the following, the previous analysis is illustrated for the "Power Cost Function Case" (see Porteus 1985) as an example for a convex investment function. Section 3.4.1 derives the optimal fixed cost level and contract parameters and evaluates them for specific parameter values. Finally, a sensitivity analysis with respect to the coordination deficit (Sect. 3.4.2) and the supply chain performance (Sect. 3.4.3) illustrates the impact of changing parameters values.

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[5]In the classical economic lotsizing model, the fixed- and holding costs per period are equal in the optimum (see Fig. 2.3). Yet, lower order sizes due to asymmetric information lead to fixed cost per period that are higher than the holding costs per period.

3.4.1 Numerical Evaluation

If a “Power Cost” investment function is utilized, decreasing marginal percentage returns are presumed. Therefore, the supplier faces investment costs in the amount of $k_i(f) = g \cdot f^{-b} - d, \forall g, b, d, f > 0$ if he reduces the fixed costs from the initial value $f_{\max}$ to f, where $f > f_{\min} = 0$. Let e denote the costs of reducing the fixed costs $f_{\max}$ by $\pi\%$, then an additional reduction by $\pi\%$ results in an investment of $(1+\beta) \cdot e$. Then, the investment function has the following shape: $k_i(f_i) = g \cdot {f_i}^{-b} - d$ where $b = -\frac{\ln(1+\beta)}{\ln(1-0.01\pi)}$, $g = \frac{e \cdot {f_{\max}}^{b}}{(1-0.01\pi)^{-b}-1}$, and $d = g \cdot {f_{\max}}^{-b}$. As the side payments Z_i^{AI} and Z_i^{FI} are not necessary for analyzing the impact of fixed cost reduction on supply chain coordination and performance the presentation of details on these side-payments is omitted.

Full Information: In the following the analysis is restricted to $n = 2$ (i.e. $h \in [h_L, h_H]$). The optimal contract parameters under full information are (see Porteus 1985):

$$q^{FI} = \min\left(\sqrt{\frac{2 \cdot f_{\max}}{h}} \cdot \left(\frac{2}{h}\right)^{\frac{b}{2b+1}} \cdot \left(\frac{2 \cdot g \cdot b \cdot r}{h}\right)^{\frac{1}{2b+1}}\right) \tag{3.21}$$

$$f^{FI} = \min\left(f_{\max}, \left(\frac{2(gbr)^2}{h}\right)^{\frac{1}{2b+1}}\right). \tag{3.22}$$

Asymmetric information: The optimal contract parameters for two possible holding cost realizations h_L and h_H are (see Appendix 3)

$$ {f_H}^{AI} = \begin{pmatrix} f_r, & \text{if } f_r \in [f_{\min}, f_{\max}] \\ f_{\min}, & \text{if } f_r < f_{\min} \\ f_{\max}, & \text{else} \end{pmatrix} \tag{3.23}$$

$$\textit{where } f_r = \left(\sqrt{\frac{2}{h_H + \gamma_H}} \cdot r \cdot g \cdot b\right)^{\left(\frac{1}{b+0.5}\right)} \tag{3.24}$$

$$ {q_H}^{AI} = \sqrt{\frac{2 \cdot {f_H}^{AI}}{h_H + \gamma_H}} \tag{3.25}$$

$$\textit{where } \gamma_H = \frac{p_L}{p_H}(h_H - h_L) \tag{3.26}$$

$$f_L^{AI} = f_L^{FI} = \min\left(f_{\max}, \left(\frac{2 \cdot (gbr)^2}{h_L}\right)^{\frac{1}{2b+1}}\right) \tag{3.27}$$

$$q_L^{AI} = q_L^{FI} = \min\left(\sqrt{\frac{2 \cdot f_{\max}}{h_L}}, \left(\frac{2}{h_L}\right)^{\frac{b}{2b+1}} \left(\frac{2gbr}{h_L}\right)^{\frac{1}{2b+1}}\right) \tag{3.28}$$

Suppose that $\beta = 0.01, \pi = 10[\%]$ $(\Rightarrow b = 0.094), e = 25, f_{\max} = 800$ $(\Rightarrow g = 4700, d = 2500, k_i(f_i) = 4700 \cdot f^{-0.094} - 2500), C_{AS} = 2.5, f_{\min} = 0, h_L = 1, h_H = 5$, $p_L = 0.5$, and $p_H = 0.5$. Let $\langle q_i^{AI,f_{\max}}, Z_i^{AI,f_{\max}} \rangle, i \in [L,H]$ denote the optimal menu of contracts under asymmetric information with no fixed cost reduction possible. In this case, $q_i^{FI,f_{\max}}, i \in [L,H]$ denotes the supply chain optimal order quantity. Furthermore, $C_i^{SC}(q_i,f_i) = \frac{f_i}{q_i} + \frac{h_i}{2} q_i + r \cdot \left(g \cdot f_i^{-b} - d\right), i \in [L,H]$ denotes the supply chain costs that result if the buyer faces holding costs h_i. Finally, $E[C_S] = \sum_{i=L,H} p_i C_i^{SC}$ denote the expected supply chain costs.

If no fixed cost reduction is possible, the optimal order sizes and respective supply chain costs are

$$
\begin{aligned}
&q_L^{AI,f_{\max}} = 40 && q_L^{FI,f_{\max}} = 40 \\
&C_L^{SC}\left(q_L^{AI,f_{\max}}, f_{\max}\right) = 40 && C_L^{SC}\left(q_L^{FI,f_{\max}}, f_{\max}\right) = 40 \\
&q_H^{AI,f_{\max}} = 13.33 && q_H^{FI,f_{\max}} = 17.89 \\
&C_H^{SC}\left(q_H^{AI,f_{\max}}, f_{\max}\right) = 93.34 && C_H^{SC}\left(q_H^{FI,f_{\max}}, f_{\max}\right) = 89.44 \\
&E\left[C^{SC}\right] = 66.67
\end{aligned}
$$

In contrary, if fixed cost reduction is feasible, the following optimal contract parameters and fixed costs level result:

$$
\begin{aligned}
&q_L^{AI} = 40 && q_L^{FI} = 40 \\
&f_L^{AI} = 800 && f_L^{FI} = 800 \\
&C_L^{SC}\left(q_L^{AI}, f_L^{AI}\right) = 40 && C_L^{SC}\left(q_L^{FI}, f_L^{FI}\right) = 40 \\
&q_H^{AI} = 6.08 && q_H^{FI} = 10.45 \\
&f_H^{AI} = 166.6 && f_H^{FI} = 273.15 \\
&C_H^{SC}\left(q_H^{AI}, f_H^{AI}\right) = 82.52 && C_H^{SC}\left(q_H^{FI,f_{\max}}, f_{\max}\right) = 78.97 \\
&E\left[C^{SC}\right] = 61.26
\end{aligned}
$$

Figure 3.7 depicts a graphical representation of the marginal analysis presented Sect. 3.3.2 to proof that asymmetric information can only lead to an overinvestment

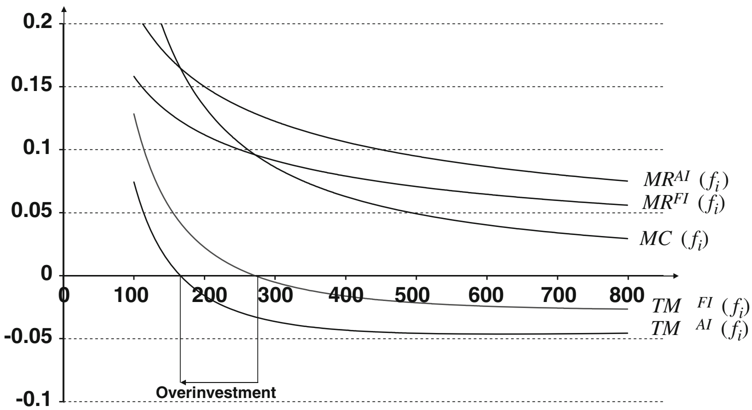


Fig. 3.7 Marginal analysis and overinvestment in the numerical example

in fixed cost reduction. In particular, there is an overinvestment in the amount of ${f_H}^{AI} - {f_H}^{FI} = 106.6$ due to asymmetric information. Nonetheless, due to the fixed cost effect the impact on the overall supply chain performance and the coordination deficit is not obvious. For this reason, the next section will examine the joint impact of the fixed cost and the overinvestment effect on the coordination deficit as well as on the supply chain performance.

3.4.2 Comparative Static Analysis with Respect to the Coordination Deficit

Let $CD = {C_H}^{SC}\left({q_H}^{AI}, {f_H}^{AI}\right) - {C_H}^{SC}\left({q_H}^{FI}, {f_H}^{FI}\right)$ denote the coordination deficit with the option to invest in fixed cost reduction and $CD^{f_{\max}} = {C_H}^{SC}\left({q_H}^{AI;f_{\max}}, f_{\max}\right) - {C_H}^{SC}\left({q_H}^{FI;f_{\max}}, f_{\max}\right)$ the coordination deficit without the option to reduce fixed costs.[6] In the numerical example, the coordination deficit decreases from $CD^{f_{\max}} = 3.9$ to $CD = 3.56$. The changes in the coordination deficit $\Delta CD = CD - CD^{f_{\max}}$ can be split into the overinvestment effect (OE) and the fixed cost effect (FE), i.e., $\Delta CD = OE - FE$ (please refer to Appendix 4 for a mathematical formulation of $\Delta CD, FE$ and OE). When $\Delta CD < 0$, the coordination deficit decreases due to an investment in fixed cost reduction, and vice versa. The overinvestment effect amounts to $OE = 13.23$ and the fixed cost effect amounts to $FE = 13.56$. Hence, the

[6]As there is no coordination deficit, if the buyer faces holding costs h_L the analysis is restricted to the cases in which the buyer faces the holding costs h_H.

coordination deficit changes by $\Delta CD = 3.56 - 3.9 = 13.22 - 13.56 = -0.34$ resulting in a decrease of the coordination deficit due to fixed cost reduction. Note that this reduction completely benefits the supplier. In contrast, a positive ΔCD would completely increase the supplier's cost. The participation constraint in problem AI (see Sect. 3.2.2) ensures that the buyer with holding cost realization $h_n = h_H$ yields the same cost for all parameter values of the problem. Hence, a change in the coordination deficit by ΔCD only affects the supplier's costs.

Next, a comparative static analysis for all possible parameter values r is conducted to investigate whether this result is robust against changing parameter values. Note that there is still a coordination deficit if $\Delta CD < 0$. This deficit is always observable when there is a deviation from the optimal order quantity due to screening. ΔCD only depicts the effect of investments in fixed cost reduction compared to no fixed cost reduction. Figure 3.8 depicts the changes of ΔCD in dependence of the interest rate r. When the investment in fixed cost reduction is inexpensive (i.e., if the interest rate r is low), the overinvestment effect carries less impact. However, the impact of the overinvestment effect becomes predominant if r increases. The impact of the investment on supply chain performance is worst if r takes a value such that $f_H^{FI} = f_{\max}$ and $l_{\max}^{FI} = 0$ holds, i.e., if $f_{\max}$ is the interior solution to problem FI ($r \approx 0.19$).[7] In this case overinvestment reaches its maximum. The total overinvestment $f_{\max} - f_H^{AI}$ decreases beyond this interest rate r. Therefore, the overinvestment effect as well as the fixed cost effect decreases. Nonetheless, the overall effect on the supply chain performance is negative. Note that the coordination deficit vanishes if the fixed cost reduction is costless (i.e., $r = 0$) because the supplier will reduce the fixed cost to the maximum extend. Figure 3.12 in Appendix 5 shows that this coordination deficit reduction is accompanied by low order sizes q_H^{FI} and q_H^{AI}. Hence, the supply chain tends to a JiT strategy if fixed cost reduction is inexpensive. Additionally, Fig. 3.12 in Appendix 5 points out that the downward distortion of order sizes (i.e., $q_H^{AI} \leq q_H^{FI}$), which is already known from Sect. 2.2, continues to be responsible for the inefficiencies within the supply chain.

More comparative static analyses for the parameters $f_{\max}$, h_H and π can be found in Appendix 5, Fig. 3.11. After all, the main finding does not change for this analysis: whether the investment in fixed cost reduction reduces the coordination deficit or not depends on the specific parameter values.

Finally it is worthwhile to stress that the menu of contracts $\langle q_i^{AI}, Z_i^{AI} \rangle$ and the corresponding f_i^{AI} is optimal for a supplier with risk neutral preferences, even if the expected coordination deficit increases due to the investment in fixed cost reduction. This highlights that the supplier may prefer to distort the investment decision in order to limit the buyer's informational rent (Fig. 3.8).

[7]This value results from solving (3.24) with $f^{AI} = f_{\max} = 800$ and $\gamma_H = 0$ for r.

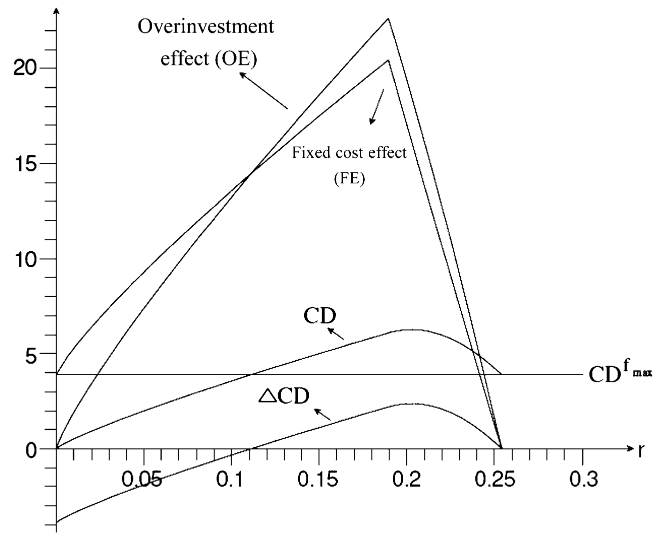


Fig. 3.8 Comparative static analysis w.r.t. interest rate r

3.4.3 Comparative Static Analysis with Respect to Supply Chain Performance

So far, the analysis mainly focused on the coordination deficit and therefore on the absolute inefficiencies that arise due to asymmetric information. However, an increase of the supply chain deficit does not necessarily result in a deterioration of supply chain performance. To analyze the effect of the investment decision on the overall supply chain performance the expected change in supply chain costs that result if fixed cost reduction is possible is computed, i.e., $\Delta P = E\left[C^{SC}\left(q_i^{AI,f_{\max}}, f_{\max}\right)\right] - E\left[C^{SC}\left(q_i^{AI}, f_i^{AI}\right)\right]$. Therefore, the investment option enhances supply chain performance even under asymmetric information if $\Delta P > 0$ holds. In contrary, the investment option will never decrease the supply chain performance under full information as no fixed cost reduction is a feasible solution. In the numerical example the expected supply chain performance increases by $\Delta P = 66.67 - 61.26 = 5.41$. Hence, the expected supply chain performance increases if the supplier reduces his fixed costs. Again, the robustness of this result is tested for changing parameter values r. Figure 3.9 depicts the changes in supply chain performance in dependence on r.[8] In contrast to the results under full information the overall supply chain performance deteriorates due to fixed cost

[8]The interested reader can find more comparative static performance analyses for the parameters $f_{\max}, h_H$ and π in Appendix 5, Fig. 3.11. As in the analysis for the coordination deficit, the basic result does not change for this analysis: whether the investment in fixed cost reduction reduces the supply chain performance or not depends on the parameter values.

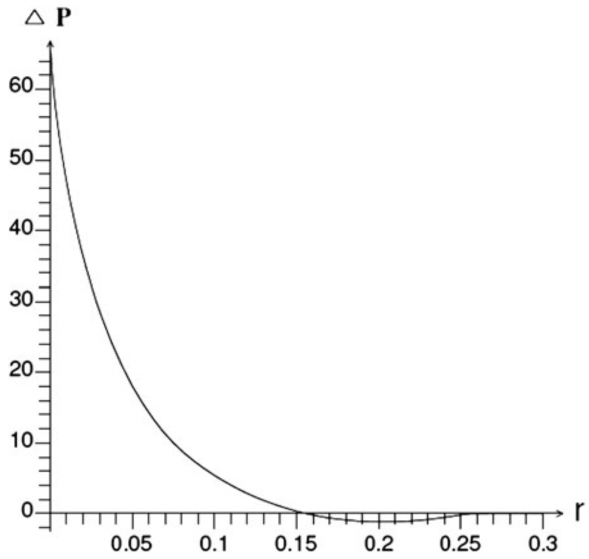


Fig. 3.9 Changes of supply chain performance in dependence of interest rate r

reduction in some regions. The parameter values for which the expected supply chain performance deteriorates are a subset of the parameter values for which $\Delta CD > 0$ holds. This is not surprising, as the supply chain performance is always improved under full information or, in turn, if there is the lowest possible holding cost realization h_L. In this case, there is no downward distortion of order sizes and therefore no distortion of the investment decision (Fig. 3.9).

The evaluation of ΔCD and ΔP, thus, implies different interpretations for the overall supply chain. If the parameter values are such that $\Delta P < 0$, then the option of fixed cost reduction harms the overall supply chain performance. In contrast, if $\Delta CD > 0$ and $\Delta P > 0$ holds, then the option of fixed cost reduction improves the supply chain performance, but truthful information sharing would have an even greater impact on improving supply performance as if no fixed cost reduction is possible. Finally, if $\Delta CD < 0$, then the distortionary effects of asymmetric information lessens or even vanishes.

3.5 Conclusion and Managerial Insights

JiT delivery has received ever-increasing attention in the recent past. Usually, the implementation of JiT strategies is accompanied by process improvements, such as fixed cost reductions. The analysis of fixed cost reduction under asymmetric information reveals that the supplier should take the investment option into account while offering a Pareto improving screening contract, if he only possesses imperfect information about the buyer's cost position.

Obviously, the supplier will not be worse off in terms of expected profits, as the status quo (i.e., $f_{\max}$) is still feasible. Nonetheless, the effect on supply chain performance and coordination is ambiguous, as there are two contrary effects: the overinvestment and the fixed cost effect. The screening of the buyer's private information leads to a downward distortion of order sizes (except for the lowest possible holding cost realization). This, in turn, can lead to an overinvestment for a wide variety of investment functions.

To obtain more differentiated insights on the impact of fixed cost reduction on the overall supply chain performance as well as on the coordination deficit, the case of two possible holding cost realizations was analyzed. Closed form solutions were computed, and a comparative static analysis was conducted. The analysis shows that supply chain performance is particularly vulnerable, if the costs of fixed cost reduction are relatively high.

Additionally, the same analysis can easily be transferred to other settings in which, for example, the product's variable costs also vary with the fixed cost level. This extension can be captured by an adaption of the investment function, and the main results remain valid.

Finally, it is worthwhile to stress that a buyer should account for the overinvestment effect when carrying out negotiations with a strategic partner in the supply chain. As the fixed cost reduction is assumed to hold over the whole planning horizon, the overinvestment effect adversely impacts the supply chain performance even in the long run.

One of the main assumptions in this section is that the buyer will use the private information strategically, instead of sharing it truthfully with his supplier. The following sections will analyze whether this behavior is actually an empirical observable problem.

Appendix

Appendix 1: Karush–Kuhn–Tucker Conditions

$$\frac{\partial L}{\partial q_i} = -p_i \frac{f_i}{q_i^2} + \mu_i \frac{h_i}{2} + \sum\nolimits_{j=1, j \neq i}^{n} \left(\lambda_{ij} \frac{h_i}{2} - \lambda_{ji} \frac{h_j}{2} \right) \leq 0 \tag{3.29}$$

$$\frac{\partial L}{\partial Z_i} = p_i - \mu_i + \sum (\lambda_{ji} - \lambda_{ij}) \leq 0 \tag{3.30}$$

$$\frac{\partial L}{\partial f_i} = \frac{p_i}{q_i} + p_i \cdot r \cdot \frac{\partial k(f_i)}{\partial f_i} + l_{\min,i} - l_{\max,i} \leq 0 \tag{3.31}$$

$$\frac{\partial L}{\partial \mu_i} = \frac{h_i}{2} q_i - C_{AS} - Z_i \leq 0 \tag{3.32}$$

$$\frac{\partial L}{\partial \lambda_{ij}} = \frac{h_i}{2} q_i - Z_i - \frac{h_i}{2} q_j + Z_j \leq 0 \tag{3.33}$$

$$\frac{\partial L}{\partial l_{\min,i}} = f_{\min} - f_i \leq 0 \tag{3.34}$$

$$\frac{\partial L}{\partial l_{\max,i}} = f_i - f_{\max} \leq 0 \tag{3.35}$$

$$\begin{aligned}
&\frac{\partial L}{\partial q_i} q_i = 0, \frac{\partial L}{\partial Z_i} Z_i = 0, \frac{\partial L}{\partial f_i} f_i = 0, \frac{\partial L}{\partial \mu_i} \mu_i = 0, \\
&\frac{\partial L}{\partial \lambda_{ij}} \lambda_{ij} = 0, \frac{\partial L}{\partial l_{\min,i}} l_{\max,i} = 0, \frac{\partial L}{\partial \gamma_i} \gamma_i = 0, \\
&l_{\min,i}, l_{\max,i}, \mu_i \geq 0, \lambda_{ij} \geq 0
\end{aligned}$$

Appendix 2: The Optimal Menu of Contracts

Solving (3.30) for μ_i and substituting in (3.29) while considering $q_i > 0$ results in

$$p_i \left(\frac{h_i}{2} - \frac{f_i}{q_i^2} \right) + \frac{1}{2} \sum\nolimits_{j=1, j \neq i}^{n} \lambda_{ji} (h_i - h_j) = 0. \tag{3.36}$$

From (3.30) and Sappington's (1983) results (i.e., $\mu_i = 0 \; \forall i = 1, ..., n-1$, $\mu_n = 1$ and $\lambda_{ij} = 0$, for $j < i$ and $j > i + 1$) it follows that

$$\begin{aligned}
&\text{for} \quad i = n \\
&p_n + \lambda_{n-1,n} = 1 \\
&\text{for} \quad i = n-1 \\
&p_{n-1} + \lambda_{n-2,n-1} - \lambda_{n-1,n} = 0 \Rightarrow \lambda_{n-2,n-1} = 1 - p_n - p_{n-1} = \sum\nolimits_{t=1}^{n-2} p_t \\
&\vdots \\
&\text{for} \quad i = 2 \\
&p_2 + \lambda_{12} - \lambda_{23} \Rightarrow \lambda_{12} = 1 - p_n - \ldots - p_2 = p_1
\end{aligned} \tag{3.37}$$

Inserting this result into (3.36) and solving for q_i gives:

$$q_i^{AI} = \sqrt{\frac{2 \cdot f_i^{AI}}{h_i + \gamma_i}} \tag{3.38}$$

where

$$\gamma_{\mathrm{i}} = \frac{\sum\nolimits_{t=0}^{i-1} p_t}{p_i} (h_i - h_{i-1}) \tag{3.39}$$

and

$$\forall \gamma_i < \gamma_{i+1}, \; i = 1, \ldots, n-1 \tag{3.40}$$

where (3.40) follows directly from assumption (2.20). As $\mu_n = 1$ (see Sappington 1983) it follows that

$$Z_n{}^{AI} = \frac{h_n}{2} q_n{}^{AI} - C_{AS} \tag{3.41}$$

Furthermore, $\lambda_{ij} = 0$, for $i < j$ and $j > i + 1$ and $\lambda_{ij} > 0$ for $i = j - 1$ holds (see Sappington 1983) and it follows from (3.33):

$$Z_n{}^{AI} = \frac{h_i}{2} \left(q_i{}^{AI} - q_{i+1}{}^{AI} \right) + Z_{i+1}{}^{AI} \quad \forall i = 1, \ldots, n-1 \tag{3.42}$$

From (3.31) and $l_{\min,i} = 0$, $l_{\max,i} = 0$ (i.e., as long as the optimal investment level is an interior solution) it follows that:

$$\frac{1}{q_i} = -r \frac{dk(f_i)}{df_i}. \tag{3.43}$$

For $l_{\min,i} > 0$ $\left(l_{\max,i} > 0\right)$ the optimal fixed costs are $f_{\min}(f_{\max})$. Substituting (3.38) into (3.43) shows that the optimal fixed cost level f_i^{AI} is obtained by solving the following equation (as long as the optimal investment level is an interior solution):

$$\sqrt{\frac{h_i + \gamma_i}{2 \cdot f_i^{AI}}} = -r \cdot \frac{dk(f_i)}{df_i} \bigg|_{f_i = f_i^{AI}}. \tag{3.44}$$

Appendix 3: Power Cost Function for Two Holding Cost Realizations

The expressions (3.27) and (3.28) follow directly from Porteus (1985). The expressions (3.25)–(3.26) are simply obtained by exerting (3.38)–(3.44) for $n = 2$. Expression (3.24) is obtained by solving (3.44) w.r.t. the power cost function, i.e.,

$$\sqrt{\frac{h_H + \gamma_H}{2 \cdot f_r}} = -r \cdot g \cdot (-b) \cdot f_r{}^{-b-1}$$

$$\Rightarrow f_r = \left(\sqrt{\frac{2}{h_H + \gamma_H}} \cdot r \cdot g \cdot b \right)^{\frac{1}{b+0.5}} \tag{3.45}$$

Appendix 4: Mathematical Formulations

$$\begin{aligned}\Delta CD = & \left[C_H{}^{SC}\left(q_H{}^{AI}, f_H{}^{AI}\right) - C_H{}^{SC}\left(q_H{}^{FI}, f_H{}^{FI}\right)\right] \\ & - \left[C_H{}^{SC}\left(q_H{}^{AI, f_{\max}}, f_{\max}\right) - C_H{}^{SC}\left(q_H{}^{FI, f_{\max}}, f_{\max}\right)\right]\end{aligned} \tag{3.46}$$

$$OE = r \cdot \left[k\left(f_H{}^{AI}\right) - k\left(f_H{}^{FI}\right)\right] \tag{3.47}$$

$$\begin{aligned}FE = & \left[\left(\frac{f_{\max}}{q_H{}^{FI, f_{\max}}} + \frac{h_H}{2} q_H{}^{FI, f_{\max}}\right) - \left(\frac{f_{\max}}{q_H{}^{AI, f_{\max}}} + \frac{h_H}{2} \cdot q_H{}^{AI, f_{\max}}\right)\right] \\ & - \left[\left(\frac{f_H{}^{FI}}{q_H{}^{FI}} + \frac{h_H}{2} q_H{}^{FI}\right) - \left(\frac{f_H{}^{AI}}{q_H{}^{AI}} + \frac{h_H}{2} q_H{}^{AI}\right)\right]\end{aligned} \tag{3.48}$$

Appendix 5: Additional Comparative Static Analysis

Figures 3.10 and 3.11 show additional comparative static analyses for the parameters $f_{\max}$, π and h_H. Furthermore, Fig. 3.12 depicts the changes in order sizes in dependence of the interest rate r.

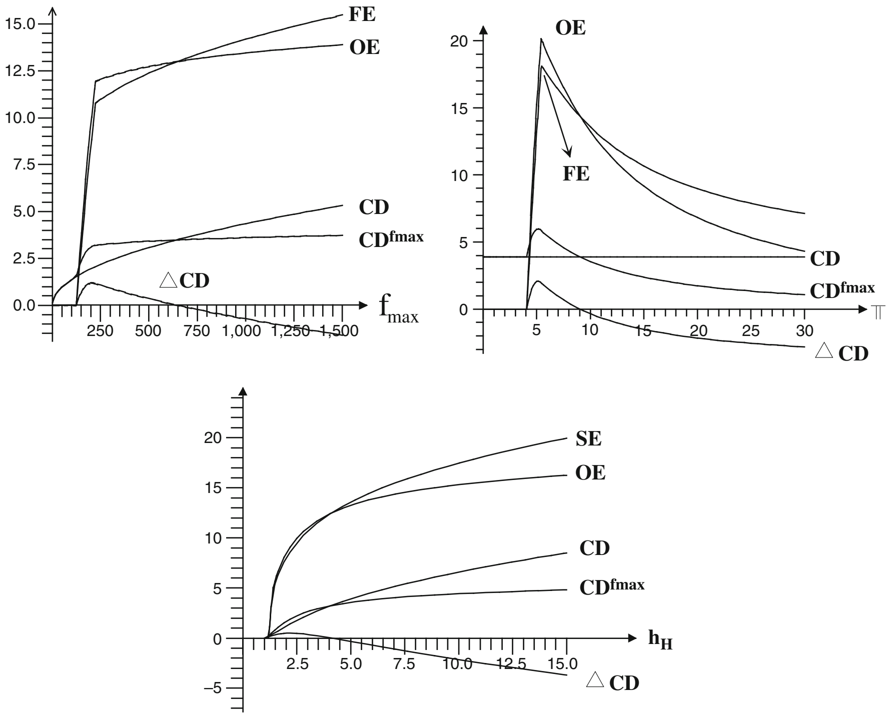


Fig. 3.10 Coordination deficit in dependence of $f_{\max}$, π and h_H

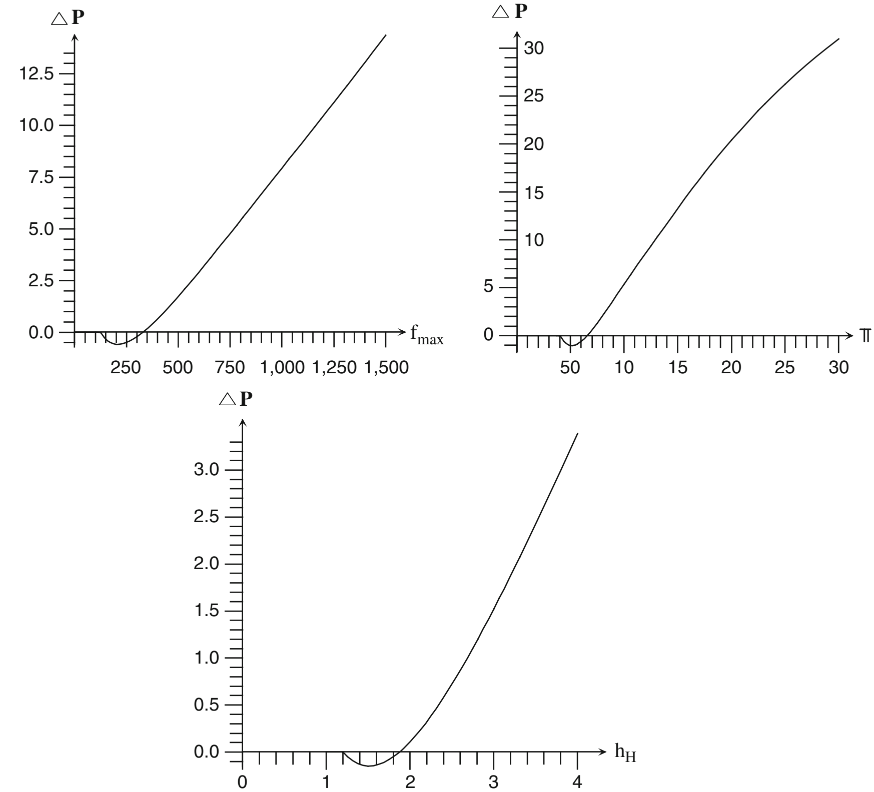


Fig. 3.11 Changes in supply chain performance in dependence of $f_{\max}$, π and h_H

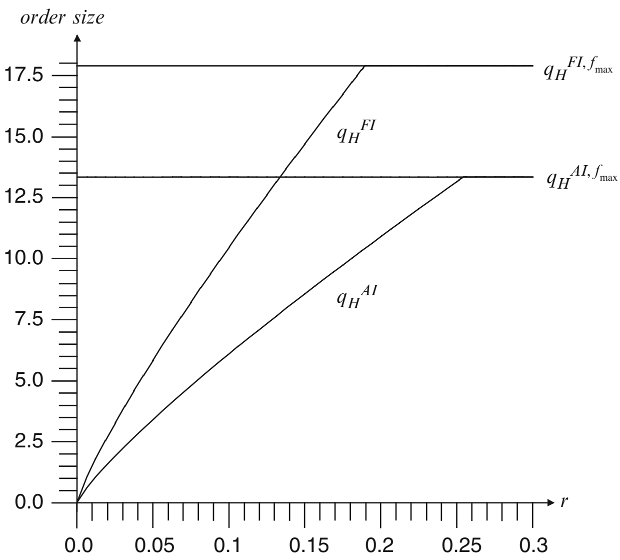


Fig. 3.12 Order sizes in dependence of the interest rate r

Chapter 4
The Impact of Information Sharing on the Effectiveness of Screening Contracts: A First Laboratory Experiment

The following section analyses, if the strategic use of private information is observable in an experimental setting, and which role communication plays for supply chain coordination. Section 4.1 briefly introduces the relevant experimental work of supply chain coordination with contracts. Section 4.2 shows how the strategic lotsizing model can be implemented in a laboratory experiment. The results of the experiments are presented in Sects. 4.3–4.6. First, Sect. 4.3 investigates the impact of information sharing on the suppliers' contract offers. Then, Sect. 4.4 analyzes the buyers' contract choice behavior, answering the question if information revelation takes place via contract choices. In contrast, Sect. 4.5 evaluates the truthfulness of the buyers' reports as well as the consistency between reports and contact choices. Afterwards, Sect. 4.6 shows the impact of the before-mentioned results on the overall supply chain performance. Finally, Sect. 4.7 summarizes the results and gives some managerial insights.

4.1 Behavioral Studies in Supply Chain Coordination with Contracts

There has been a growing interest in behavioral operations management in the recent past. Bendoly et al. (2006) give a comprehensive review on the related literature. The range of literature mentioned in this review is broad, including production control, supply chain management, quality management, and operations technology. Also, they intensively discuss the benefits of behavioral experiments. Hence, it is referred to Bendoly et al. (2006) for a widespread introduction of laboratory experiments in the operations management context.

The experiments presented in this work mainly fits into the area of supply chain coordination with contracts. The seminal study in this area stems from Schweitzer and Cachon (2000), who investigate individual ordering behavior in the newsvendor context. In this study, the newsvendor ordering behavior is analyzed under the

G. Voigt, *Supply Chain Coordination in Case of Asymmetric Information*, Lecture Notes in Economics and Mathematical Systems 650,
DOI 10.1007/978-3-642-20132-5_4,

simplest form of a contract, namely the wholesale-price contract. Yet, Schweitzer and Cachon (2000) do not analyze the interaction of supplier and buyer, as the supplier's wholesale-price decision was automated. Keser and Paleologo (2004) expand this framework to a supply chain setting, in which the supplier sets the newsboy's wholesale-price. Knowing that the simple wholesale price contract cannot coordinate the newsboy supply chain, Katok and Wu (2009) investigate the empirical efficiency of the buy-back and revenue sharing contract. However, they also do not investigate the interaction within the supply chain, as they automated the counterpart's decision. Lim and Ho (2007) experimentally investigate the coordination efficiency of the wholesale-price contract as well as the multi-block tariff in a supply chain with price-sensitive and deterministic end-customer demand in case of full information. They show that the number of price blocks influence the decision behavior although theory predicts otherwise. Finally, Özer et al. (2008) investigate the interaction of supply chain members given a simple wholesale price contract and asymmetric information. They find that there is partial truth-telling and trust although theory predicts that all communication accounts to no more than cheap talk.

4.2 Experimental Design and Implementation

A total of 117 subjects participated in five treatments in the experiment. Only the simplest form of a supply chain, consisting of one supplier and one buyer was tested (see Fig. 1.1). The groups were matched randomly at the beginning of the first round. Since long lasting relationships between suppliers and buyers are commonly assumed in supply chain management, we did not change the matching of suppliers and buyers over time. This approach was also chosen by Croson et al. (2003) who show in a repeated bargaining experiment that communication can indeed influence the decision maker's behavior although rational game theory would predict otherwise. All subjects played 20 rounds. The sessions were run at the MaxLab, Otto-von-Guericke University Magdeburg. The experimental software was implemented with the toolbox z-Tree (Fischbacher 2007). Upon arrival, each participant received written instructions (see Appendix 3). 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, every subject was paid according to a fraction of his total profits in the experiment.

The experimental design consists of five treatments. In fact, there are basically two treatment variables. First, we tested the impact of information sharing by conducting treatments with and without the possibility of information sharing. Second, we tested whether an additional punishment and reward (P&R) mechanism helps the supply chain members to coordinate their actions. Brandts and Charness (2003) report that the punishment for uncooperative actions as well as the reward for cooperative actions is prevalent in one-shot games with communication. This indicates that punishment and reward options have an even greater impact on repeated interactions, especially because there is the possibility to build up reputation. Hence, the supplier in the underlying study is allowed to reward cooperative

Table 4.1 Treatment variables

	W/o P&R	With P&R
Without information sharing	11	12
With information sharing	12	12

behavior by an additional side-payment which can be granted outside the regular contracting stage.

Table 4.1 depicts the number of supply chains (and therefore the number of independent observations) for each treatment. Finally, we tested in a setting without communication and without P&R whether the supplier's actions depend on the assessment of the buyers' sequential rationality. This was tested by automating the buyer's actions. This treatment was conducted with 12 subjects (suppliers).

4.2.1 Parameters

The experimental setting assumes that the holding costs h_i 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. In this experimental setting, there are three possible holding cost realizations $h_L = 1$, $h_M = 3$, and $h_H = 5$. The holding costs are drawn independently in every round for every subject according to the distribution function $(p_L, p_M, p_H) = (0.3, 0.4, 0.3)$. Therefore, the revelation principle holds, as the last round can be regarded as a one-shot game (see Fudenberg and Tirole 1995). The supplier's fixed costs amount to $f = 800$ and there is a constant demand of 1 unit per period. The buyers have fixed revenues of $Y_b = 85$ and the suppliers of $Y_s = 200$ per round. If the buyer chooses the alternative supplier, he faces costs of 5 and the supplier loses his revenues in the respective round.

If the buyer with holding costs $h_i, i \in L, M, H$ chooses the contract $A_j = \langle q_j^{AI}, Z_j^{AI} \rangle, j \in L, M, H$ he incurs a profit of $P_{b,i} = Y_b - h_i/2 \cdot q_j^{AI} + Z_j^{AI}$ per unit. Yet, if he chooses the alternative supplier, he incurs cost of $C_{AS} = 5$. In other words, the buyer's profit is equal to $R = Y_b - C_{AS} = 85 - 5 = 80$ if he chooses the outside option. The supplier incurs profits of $P_s = Y_s - 800/q_j^{AI} - Z_j^{AI}$ per unit if his buyer chooses the contract A_j. 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 A_i and A_j due to the indifference modeling approach. Yet, to give the buyer a strict incentive to choose the self-selection contract A_i, the problem AI was solved with a slight change of the incentive constraint (i.e., $h_i/2 \cdot q_i - Z_i \leq h_i/2 \cdot q_j - Z_j - 0.1$). Hence, the buyer faces strictly higher profits if he chooses the self-selection contract. This is the well-known ε- argument, i.e., any arbitrarily small ε in payoff difference will make the agent choose the self-selection contract A_i.

Finally, the supplier can punish and reward the buyer. The reward is an additional side-payment Z_R that can be paid from the supplier to the buyer after a contract was concluded. The supplier can punish the buyer by reducing his profits by Z_P units (see Sect. 2.3.2). Yet, the supplier faces costs of $0.2 \cdot Z_p$ when punishing the buyer. The rewards and the punishments have an upper limit of 40.

4.2.2 Decision Sequence

In the following the decision sequence for the treatment with information sharing and punishment and reward is explained (see Fig. 4.1).Obviously, some of the stages are not prevalent in some treatments.

The first decision in every round of the experiment is the buyer's signal choice $S \in (S_L, S_M, S_H, S_{No})$ where $S_i = h_i \; \forall i = L, M, H$ and $S_{No} \doteq$No Signal. Given the buyer's signal, the supplier decides upon his subjective probability distribution $p_i(S), i \in L, M, H,$ with the choice being limited to steps of 0.1, i.e., $p_i \in [0, 0.1, 0.2, ..., 1], \forall i \in L, M, H$ and $\sum_{i=L,M,H} p_i(S) = 1$. The supplier calculates his (at least subjective) optimal menu of contracts $A_i = \langle {q_i}^{AI}, Z_i^{AI} \rangle, \forall i = L, M, H$ for this distribution $p_i(S)$. Formally, the supplier's objective function (2.5) changes to

$$\max \; E(P_s) = \sum\nolimits_{i=1}^{n} p_i(S) \cdot P_{s,i} \tag{4.1}$$

The buyer, then, chooses one of the three contracts from the menu or the alternative supplier. Finally, the supplier has the option to punish or to reward the buyer. Figure 4.1 depicts the decision sequence.

4.2.3 Decision Support

A Decision Support System (DSS) was provided in order to implement the problem AI into an experimental setting. This system calculates the optimal screening contract given the subjective probability distribution $p_i(S)$, since the calculation takes some computational efforts and no behavioral insights are expected from performing this task.

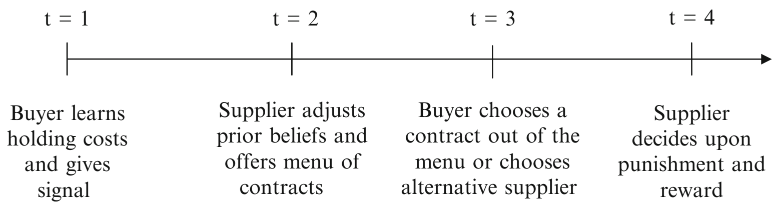


Fig. 4.1 Decision sequence

In order to facilitate the decision problem for the subjects, further material consisting of a "profit calculator" and a payoff table were provided. The profit calculator can be used by buyers and suppliers to display the relevant outcomes for any subjective probability distribution $p_i(S)$ at any stage of the experiment. Alternatively, the subjects can check the payoff table in the instruction that contains all possible payoff combinations (see Appendix 3).

It is worth to highlight, that it is not the task of the supplier to calculate the optimal menu of contracts. He only has to decide upon the probabilities for which a "black box" is solving this problem. The menu of contracts is then calculated according to problem AI in a way that the buyer strictly favors the revealing contract, i.e., the contract which corresponds to the actual holding costs. To guarantee strict preferences, an additional amount of 0.1 was given. However, even if the suppliers do not solve the optimization problem on their own, both buyers and suppliers know from the instructions, that the "black box" is creating a menu of contracts, i.e., that for the buyer with holding cost h_L, h_M, h_H the contract A_L, A_M, A_H minimizes his unit costs.

4.3 Do Suppliers React to the Shared Information?

In the following it is analyzed whether the suppliers react to the buyer's reports, or ignoring them as cheap talk as predicted in the game-theoretic equilibrium. Section 4.3.1 presents the results for the treatments without information sharing, Sect. 4.3.2 for the treatments with information sharing but without punishment and reward, and Sect. 4.3.3 for the treatments with both information sharing and punishment and reward.

4.3.1 Baseline: No Information Sharing

Figures 4.2–4.4 depict the box-plots of subjective probabilities $p_L(\cdot)$, $p_M(\cdot)$ and $p_H(\cdot)$, where $p_i(\cdot), i \in [L, M, H]$ denotes the subjective probability given a treatment in which no signal was given, i.e., in a treatment without information sharing. Figure 4.2 refers to the treatment with the automated buyer, Fig. 4.3 to the treatment w/o P&R, and Fig. 4.4 with P&R.

A closer look at the three figures reveals that there is no substantial difference in the suppliers' adjustment of believes in the three treatments. Interestingly, the median values of subjective probabilities are equal to the a priori probability distribution, i.e., $(p_L, p_M, p_H) = (0.3, 0.4, 0.3)$. However, there is also a non-negligible amount of deviations from the a priori distribution. In the following it is argued that alternating risk preferences may explain these deviations.

As an example, if the supplier offers the contract which is based on the a priori distribution, then he has expected payoffs of $E(P_s) = 121.56$ and a standard

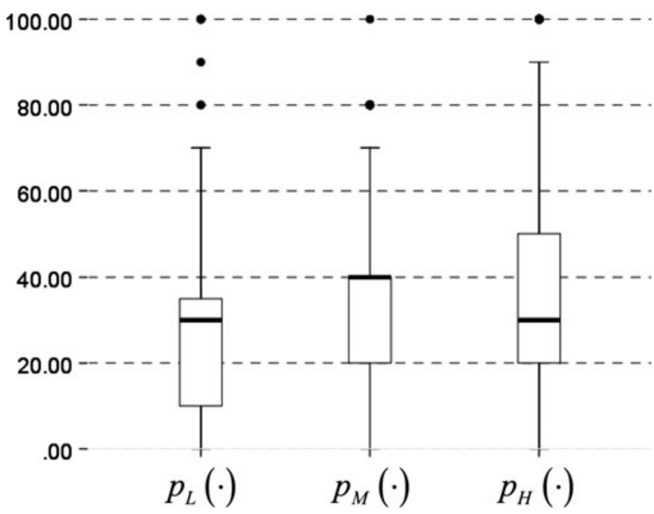


Fig. 4.2 Distribution of subjective probabilities in treatment w/o information sharing, w/o P&R, and automated buyer

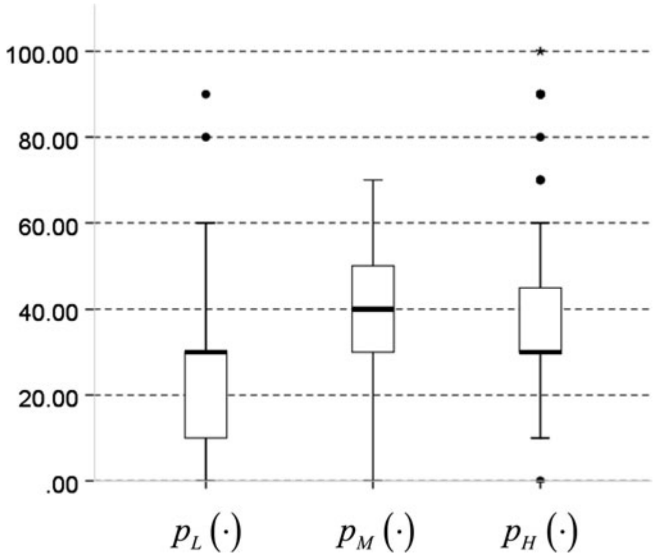


Fig. 4.3 Distribution of subjective probabilities in treatment w/o information sharing and w/o P&R

deviation of payoffs results from $\sigma = 11.21$. In contrast, if the supplier adjusts the subjective probability $p_H(\cdot)$ upwards, than he can reduce the standard deviation of his payoffs. In other words, a risk averse supplier tends to adjust $p_H(\cdot)$ upwards and $p_L(\cdot), p_M(\cdot)$ downwards. If the supplier chooses the subjective probability

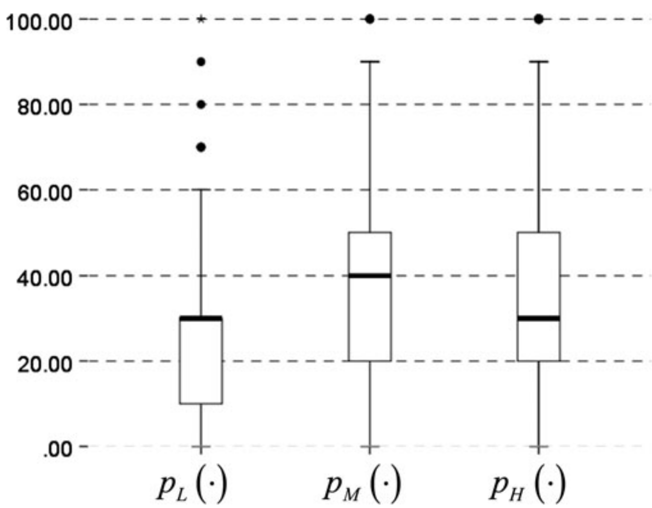


Fig. 4.4 Distribution of subjective probabilities in treatment w/o information sharing and with P&R

distribution $(p_L(\cdot), p_M(\cdot), p_H(\cdot)) = (0.1, 0.1, 0.8)$, then the supplier's expected profits would decrease to $E(P_s) = 120.01$ and the standard deviation to $\sigma = 8.08$, respectively. A closer look at Figs. 4.2–4.4 reveals that the supplier indeed tend to adjust $p_H(\cdot)$ upwards, which indicates some level of risk aversion. Note, however, that we do not consider the supplier's risk aversion by computing the optimal menu of contracts. In fact, the supplier would solve the following optimization problem:

$$\max\ EU(P_s) = \sum\nolimits_{i=1}^{n} p_i(\cdot) \cdot u\left(P_{s,i}\right) \tag{4.2}$$

s.t.

$$P_{b,i}(q_i) \geq P_{b,i}\left(q_j\right), \quad \forall i \neq j; i, j = 1, \ldots, n. \tag{4.3}$$

$$P_{b,i}(q_i) \geq R, \quad \forall i = 1, \ldots, n \tag{4.4}$$

where $u(\cdot)$ denotes the supplier's Neumann–Morgenstern utility function. It is assumed that $u(\cdot)$ is strictly increasing in P_s and twice continuously differentiable. In this case, the supplier's optimal menu of contracts in dependence of the risk preference (index RP) is equal to (see Appendix 1)

$$q_i^{RP} = \sqrt{\frac{2 \cdot f}{h_i + \frac{\sum_{t=1}^{i-1} p_t u'_{s,t}}{p_i \cdot u'_{s,i}} (h_i - h_{i-1})}} \tag{4.5}$$

$$\text{where} \quad u'_{s,i} = \frac{\partial u}{\partial(-P_{s,i})} \quad \text{and} \quad P_{s,i} = Y_s - \frac{f}{q_i} - Z_i$$

$$Z_n{}^{RP} = \frac{h_n}{2} q_n{}^{RP} - C_{AS} \tag{4.6}$$

$$Z_i{}^{RP} = \frac{h_i}{2}\left(q_i{}^{RP} - q_{i+1}{}^{RP}\right) + Z_{i+1}{}^{RP}, \quad \forall i = 1, ..., n-1 \tag{4.7}$$

Let $q_i{}^{RN}$, $q_i{}^{RS}$ and $q_i{}^{RA}$ denote the order sizes in the menu of contracts A that are offered from a risk neutral (RN), risk seeking (RS) and risk averse (RA) supplier, respectively.

Obviously, the same menu of contracts as in Sect. 2.2.4 results if the supplier is risk neutral. In this case, the first order derivative is constant regardless of the holding cost realization, i.e., $\frac{\partial u}{\partial(-P_{s,i})} = \frac{\partial u}{\partial(-P_{s,j})}, \forall i, j = 1, ..., n$. Hence, (4.5) reduces to the well-known order quantity (2.16), i.e., $q_i{}^{RN} = q_i{}^{AI}$.

Furthermore, it can be shown that the relation $q_i{}^{RS} < q_i{}^{RN} < q_i{}^{RA}$ holds (see Appendix 2). Thus, the supply chain coordination deficit increases if the supplier is risk seeking, and it decreases if he is risk averse respectively. Intuitively, the risk averse supplier prefers a lower variance in his payoffs. Yet, there is no reason to distort the order size q_1. Hence, the supplier can only induce payoff structures with less variance if he reduces the distortion of the order sizes $q_i, i > 1$.

Summing up, the suppliers in the treatments without information sharing seem to be risk averse. However, the experimental design does not account for this risk aversion. Hence, further studies are required investigating whether the coordination deficit is reduced when the supplier has the option to offer optimal contracts with respect to his risk preferences.

4.3.2 Information Sharing Without Punishment and Reward

Figure 4.5 depicts the box-plots for the treatment in which information sharing was allowed, but in which no P&R was in place. The figure depicts the subjective probabilities in dependence of the signal S. As an example, the box-plots in the upper-left of Fig. 4.5 depict the adjustment of the subjective probability $p_L(S)$ in dependence of the signal. The signals are the categories in the respective grid. As an example, the median value of $p_L(S_M)$ is equal to 20%. This is, the median supplier sets his subjective probability $p_L(S)$ to 20% when he gets the holding cost signal S_M. Figure 4.5 shows that the median of all signal probabilities are well-above the a priori probabilities. This supports the hypothesis that suppliers react at least on average to the signal. In the following the individual reaction to signal is analyzed.

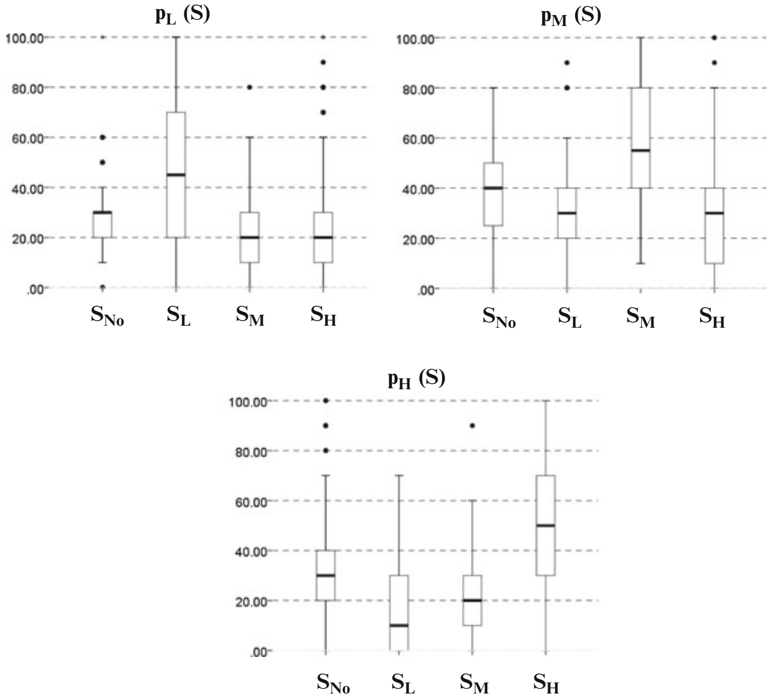


Fig. 4.5 Distribution of subjective probabilities in treatment with information sharing and w/o P&R

Let $p_i(S_i), i \in [L, M, H]$ denote the ***signal probability***. Yet, the more a supplier believes that a signal is more likely to be true than to be false, the more he adjusts the signal probability upwards. As an example, the buyer signals that he has low holding costs, i.e., S_L. Yet, if the supplier believes in the signal, then he chooses higher values of $p_L(S_L)$, and vice versa.

A closer look at Fig. 4.5 reveals that the suppliers react to signals, as all medians of the signal probabilities are higher than the a priori distribution. Additionally, the median values are highest for the signal probabilities.

To analyze, whether the 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., $\frac{p_i(S_i) - p_i}{100 - p_i}$, for $p_i(S_i) > p_i$ and $-\frac{p_i - p_i(S_i)}{p_i}$, otherwise. A perfect believer adjusts his subjective probabilities perfectly upwards (i.e., 100%) for the signaled cost level. A perfect non-believer does not adjust the probabilities at all (i.e., 0%). A perfect disbeliever adjusts his subjective probabilities perfectly downwards (i.e., -100%) for the signaled cost level.

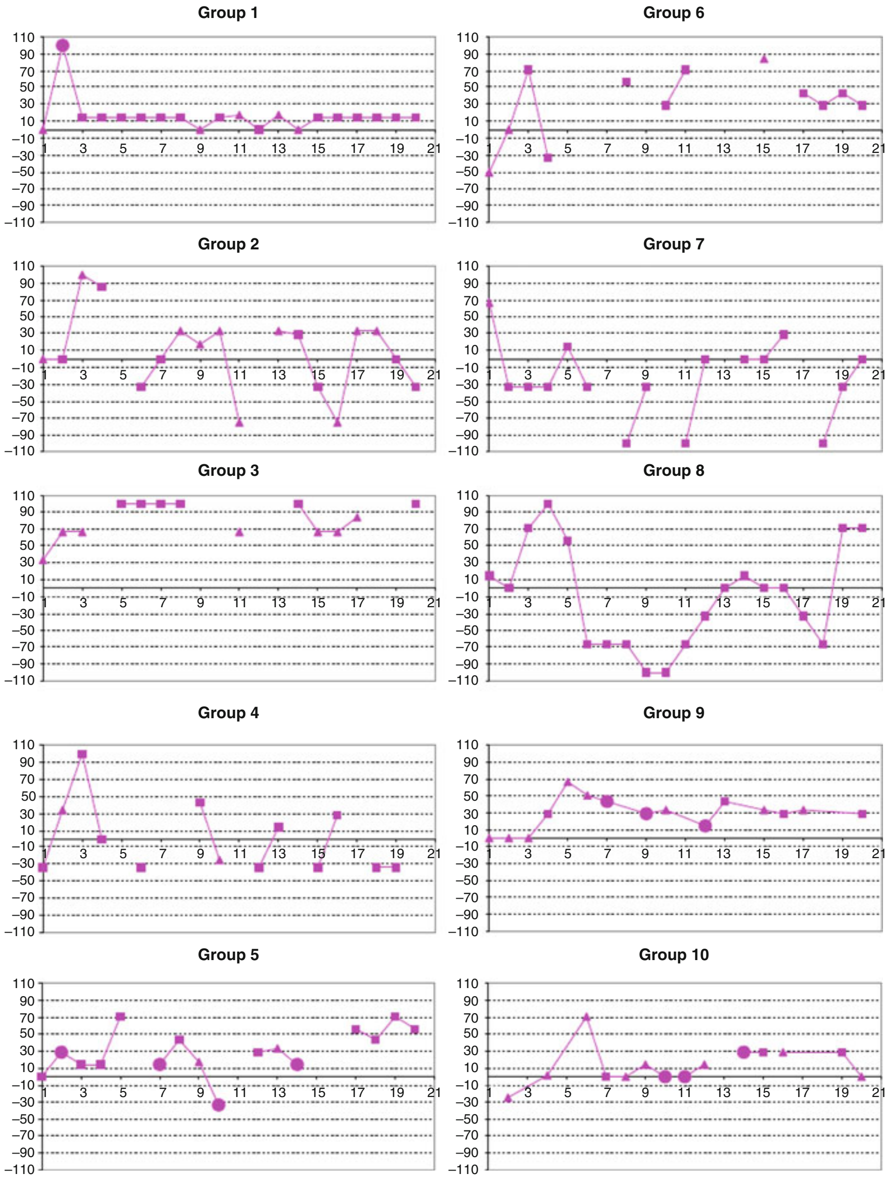


Fig. 4.6 (continued)

Figure 4.6 shows the development of the relative adjustment of signal probabilities. The different shapes of the nodes refer to the signal sent by the buyer in the corresponding 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% threshold throughout all periods. As an example, the supplier in

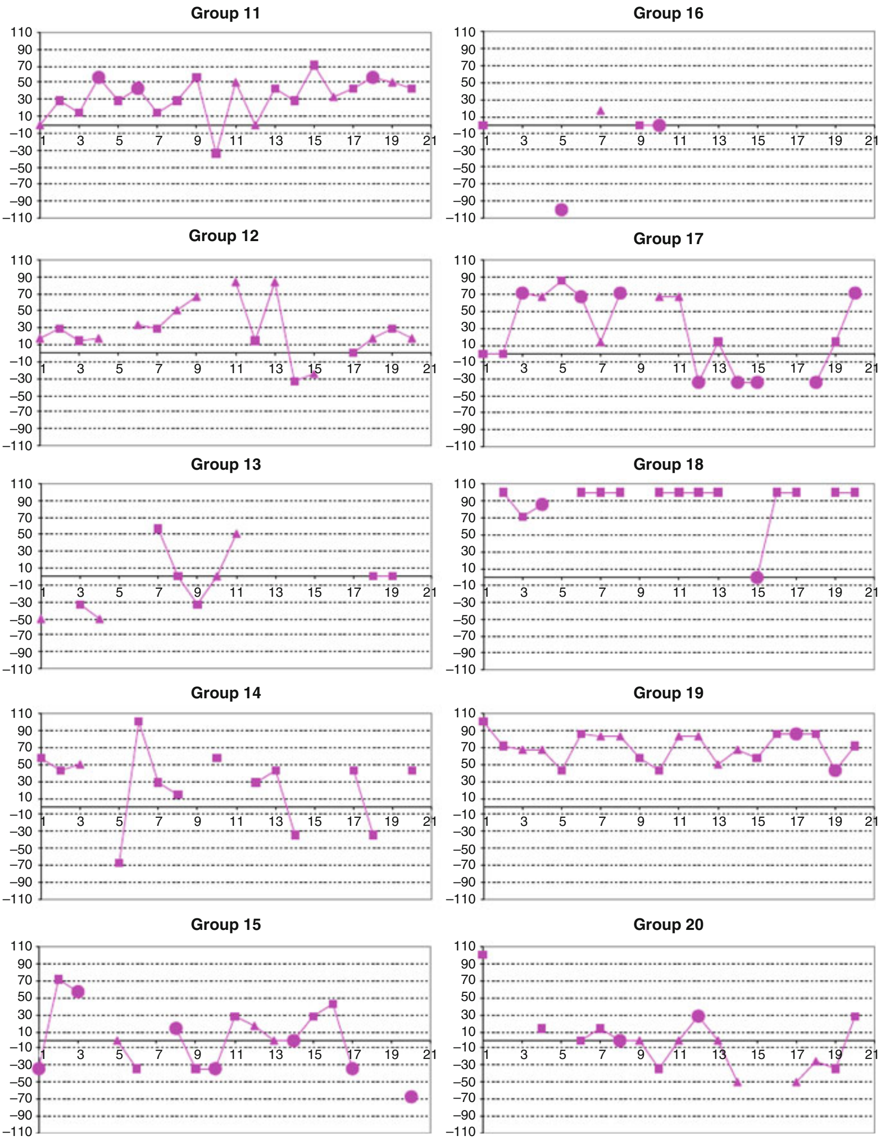


Fig. 4.6 (continued)

group 19 depicts such a case. These are the suppliers who believe that the signals are more likely to be true than to be false.[1] We also find a number of suppliers who believe at times and disbelieve at other times, e.g., the supplier in group 15.

[1]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%.

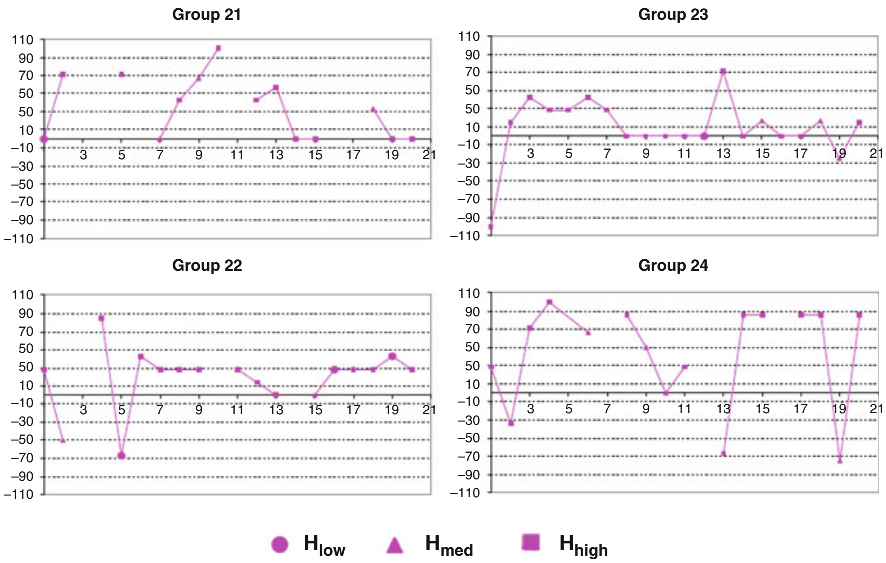


Fig. 4.6 Probability adjustment of signal probability w/o P&R across groups

Table 4.2 Categorization of believers and non-believers according to sign-test in treatment w/o P&R

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	0.759
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

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 all graphs, we find that the suppliers can basically categorized in two groups, namely 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., $p_i(S) > p_i$.

Table 4.2 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 0.05 level, one-sided, is called a believer. All believers in Table 4.2 are marked with a star (*).

Table 4.3 Regression results for "believers" w/o P&R

	$\hat{p}_L(S)$	$\hat{p}_M(S)$	$\hat{p}_H(S)$
$\hat{\alpha}$	34.5***	49.2***	16.3***
$\hat{\beta}_L$	22.8***	−12.5***	−10.2**
$\hat{\beta}_M$	−6.7**	16.9***	−10.2***
$\hat{\beta}_H$	−13.9***	−13***	26.9***
Subject 1	9.71**	−11.22**	1.52
Subject 3	−15.03***	−4.24	19.27***
Subject 5	−7.48	−7.9	15.38**
Subject 6	4.71	−17.9***	13.2**
Subject 10	0.74	−10.67**	9.92
Subject 11	0.04	−9.27*	9.22
Subject 12	−9.34*	−0.13	9.47
Subject 14	−4.69	−9.62*	14.3**
Subject 18	−14.79***	−29.51***	44.31***
Subject 19	−12.7**	−4.23	16.93***
Subject 21	−4.73	−9.63*	14.36**
Subject 22	5.54	−21.23***	15.69**
Subject 23	3.43	0.27	−3.69
Subject 24	−15.88***	−24.8***	40.68***
R^2	0.43	0.48	0.58

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

In total, 15 out of 24 suppliers are believers.[2] The remaining nine suppliers are categorized as "non-believers".[3]

So far, only the immediate impact of a signal on the subjective probability that is associated with the signaled cost level was considered. 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 following regression model, applying it to each cost level probability $p_i(S)$ separately.

$$p_i(S) = \alpha + H_L \cdot S_L + \beta_M \cdot H_M + \beta_H \cdot H_H \quad \text{for} \quad i \in [L, M, H]$$

$$\text{where} \quad H_i = \left\{ \begin{array}{l} 1,\ \text{if buyer's signal is } S = S_i,\ \forall i \in [L, M, H] \\ 0,\ \text{else} \end{array} \right\}.$$

Because the sign test presented above shows that we can expect substantial differences in the behavior of "believers" and "non-believers," separate regressions for each of the two groups were run. All regressions include a dummy-variable for each supplier to control individual fixed effects.

Table 4.3 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

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

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

Table 4.4 Regression results for "non-believers"

	$\hat{p}_L(S)$	$\hat{p}_M(S)$	$\hat{p}_H(S)$
$\hat{\alpha}$	57.4***	5.5	37.1***
$\hat{\beta}_L$	10.9*	9.3*	−20.2***
$\hat{\beta}_M$	2.9	13.2***	−16.1***
$\hat{\beta}_H$	−1.4	3.5	−2.1
Subject 2	−37.3***	37.5***	−0.2
Subject 4	−18.9***	16.8***	2.2
Subject 7	−37.5***	48.7***	−11.2*
Subject 13	−28.6***	20.8***	7.7
Subject 15	−32.7***	20.2***	12.5*
Subject 16	−39.5***	50.1***	−10.6
Subject 17	−25***	34.8***	−9.8
Subject 20	−29.9***	24.9***	5
R^2	0.26	0.45	0.24

*** $p < 0.01$, $p < 0.05$, * $p < 0.1$

subjective probabilities of the cost levels that were not signaled are significantly adjusted downwards when compared to the a priori probabilities.

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., $\hat{\beta}_H[\hat{p}_H(S)] = 26.9$ is greater than $\hat{\beta}_L[\hat{p}_L(S)] = 22.8$ and $\hat{\beta}_M[\hat{p}_M(S)] = 16.9$.

Table 4.4 summarizes the regression results for the non-believers. We see that the non-believers also tend to believe at least a bit in the signal S_L (weakly significant) and show a behavior similar to the believers given the signal S_M. However, note that the non-believers are much more cautious than the believers to adjust $p_L(S_M)$ downwards. This gives weak support for the hypothesis that the non-believers anticipate that the buyers have an incentive to exaggerate their cost position. Hence, given the signal S_M the non-believers assume that the signal is either true or an overstatement. For this reason they do not significantly adjust $p_L(S_M)$. Note, however, that supplier heterogeneity is very strong (all fixed effects are highly significant), and that this interpretation of the regression model needs therefore be handled carefully.

4.3.3 Information Sharing with Punishment and Reward

This subsection analyzes the suppliers adjustment of believes for the treatment in which the P&R mechanism was in place. A comparison of the Figs. 4.5 and 4.7 reveals that median values of the signal probabilities $p_L(S_L)$ and $p_M(S_M)$ are higher,

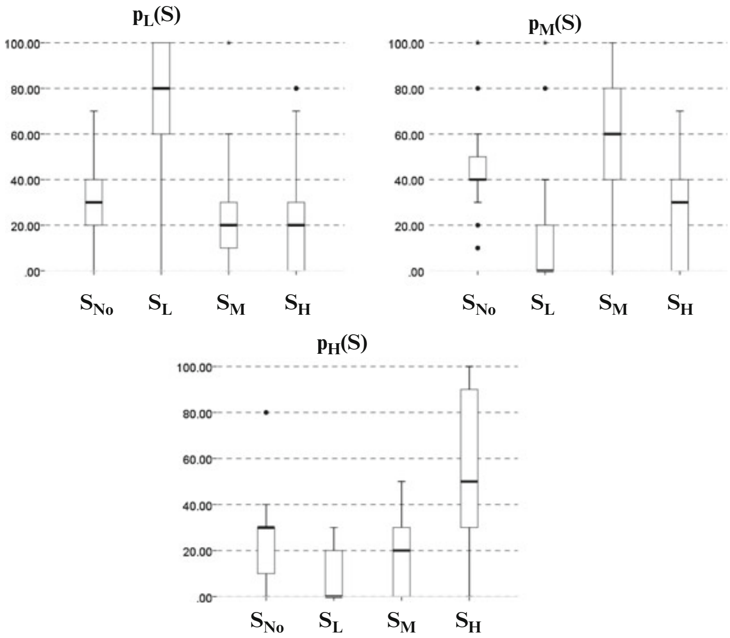


Fig. 4.7 Distribution of subjective probabilities in treatment with information sharing and with P&R

when a P&R mechanism is in place.[4] On an aggregated level, thus, the suppliers seems to believe more in the buyers' signals if a P&R mechanism is available.

However, to test whether there are actually more believers than without the P&R mechanism we analyzed the adjustment of the signal probability over time (see Fig. 4.8). A comparison of Figs. 4.6 and 4.8 reveals that there are no notable differences between the treatments with or w/o P&R. Again, the sign-test is used to categorize the subjects into believers and non-believers. Table 4.5 summarizes the p-values of the sign test. Remember that a supplier is categorized as a believer if the sign-test shows significantly that the signal probability is adjusted upwards ($p < 0.05$, two-sided).

Interestingly, the relative frequency of non-believers even increases compared to the treatment w/o P&R. 6 out of 12 suppliers (50%) show a non-believer behavior when the P&R mechanism is in place while only 9 out of 24 suppliers (37.5%) where identified as non-believers without P&R. Hence, it seems that the P&R mechanism is generally not able to increase the total number of believers. Yet, the subjective probability adjustment of believers is more rigorous when the P&R mechanism is in place.

Finally, the regression model presented for the treatment without P&R is tested on the data set with P&R (see Tables 4.6 and 4.7). Interestingly, the regression

[4]However, this effect is only significant for $p_L(S_L)$ on a disaggregate level (Mann–Whitney-U test, $p < 0.001$, two-sided).

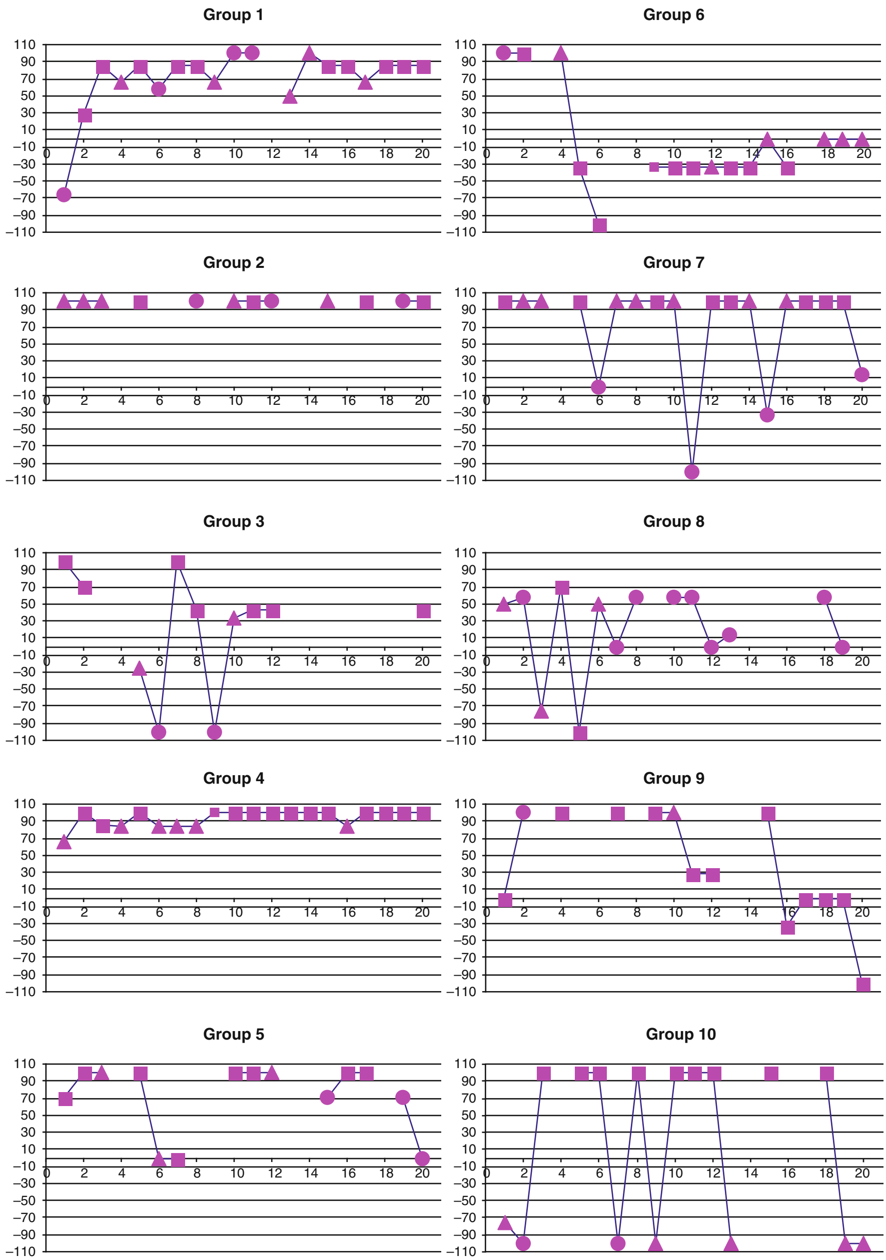


Fig. 4.8 (continued)

results shed some more light on how the believers adjust their probabilities compared to the treatment w/o P&R. The regression confirms that the adjustment given signal S_L is indeed much heavier with P&R (49.77 compared to 22.8). The same

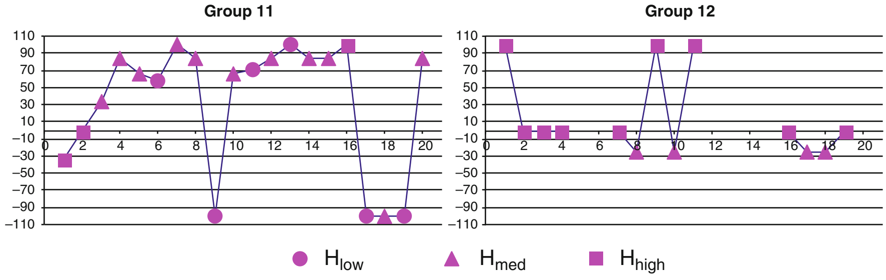


Fig. 4.8 Probability adjustment of signal probability with P&R across groups

Table 4.5 Categorization of believers and non-believers according to sign-test in treatment with P&R

Group	1	2	3	4	5	6
p-Value	0.105	0.011*	0.000*	0.002*	0.291	0.212
Group	7	8	9	10	11	12
p-Value	0.008*	0.212	0.000*	0.145	0.166	0.000*

*believer

Table 4.6 Regression results for "believers" w/o P&R

	$\hat{p}_L(S)$	$\hat{p}_M(S)$	$\hat{p}_H(S)$
$\hat{\alpha}$	32.90***	48.1***	19.00***
$\hat{\beta}_L$	49.77***	−40.77***	−9.000
$\hat{\beta}_M$	−14.33***	13.66**	0.675
$\hat{\beta}_H$	−10.1***	−39.06***	50.06***
Subject 1	2.350	0.38	−2.730
Subject 5	−3.000	8.484	−5.508
Subject 6	−8.750	3.790	4.961
Subject 8	−23.76***	13.92*	9.840
Subject 11	−8.57*	10.617	−2.052
R^2	0.680	0.569	0.624

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 4.7 Regression results for "non-believers" w/o P&R

	$\hat{p}_L(S)$	$\hat{p}_M(S)$	$\hat{p}_H(S)$
$\hat{\alpha}$	31.01***	27.48***	41.51***
$\hat{\beta}_L$	40.06***	−29.44***	−10.610
$\hat{\beta}_M$	−5.710	15.19**	−9.480
$\hat{\beta}_H$	−8.900	−3.690	12.58*
Subject 2	12.46**	15.09**	−27.55***
Subject 3	5.650	−3.690	−1.950
Subject 4	5.490	4.280	−9.770
Subject 9	4.950	22.47***	−27.42***
Subject 12	2.160	19.89***	−22.05***
R^2	0.365	0.374	0.296

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

argument holds given the signal S_H. In this case, the suppliers in the treatment with P&R adjust the probability $p_H(S_H)$ about 50.06 upwards. In contrast, w/o P&R this effect is much weaker, i.e., 26.9. However, the difference is not substantial for the medium holding cost realization.

In contrast to the treatment w/o P&R, the behavior of the non-believers seems to be more predictable. In fact, the non-believers adjust the signal probabilities $p_L(S)$ and $p_M(S)$ (highly) significantly upwards (but not as rigorously as the believers). However, the non-believers in this treatment seem to asses the signal S_H differently than the believers in the same treatment. Particularly, the adjustment given the signal S_H is only weakly significant, and the effect is considerably lower (i.e., 12.58 vs. 50.06). This indicates that the non-believers tend to believe at least in the signals that carry not too much strategic weight.

4.4 Are Buyers Screened Successfully?

The contracts that are offered to the buyers provide incentives for the buyers to self-select according to their holding cost levels. Hence, the screening of buyers is expected. Knowing this, 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, it is examined whether buyers are screened successfully, i.e., whether they choose the contract that provides them with the greatest incentives ex-post. Additionally, it is analyzed whether the option to punish or reward has an effect on the buyers' contract choice behavior. Finally, the impact of information sharing on the buyers' contract choice behavior is analyzed.[5]

In the following three different kinds of contract choices will be distinguished. First, there is the choice of the self-selection contract. This contract choice maximizes the buyer's profits once the specific menu of contract is offered. This is, the buyer with holding costs $h_L(h_M, h_H)$ chooses the contract $A_L(A_M, A_H)$ out of the menu of contracts. Second, the buyer might choose the indifference contract. Theoretically, the buyer is always indifferent between two contracts (see Sect. 2.2.4). In particular, the buyer facing holding costs h_L is indifferent between the contracts A_L and A_M, and the buyer facing holding costs h_M is indifferent between A_M and A_H. Note, however, that the experimental design gives an additional amount in the size of 0.1 to give the buyer a strict incentive to choose the self-selection contract. Hence, if the buyer decides to choose the indifference contract, then he foregoes profits of 0.1 in the respective round. However, this contract choice is nearly optimal as this amount is only small compared to the actual payoff. Finally,

[5] Note there is a perfect screening in the treatment with an automated buyer. A further discussion of this treatment is therefore omitted.

the buyer can reject the offer and choose the alternative supplier. Note that the buyer is also indifferent between choosing A_H and the alternative supplier, if he faces holding costs h_H. However, to avoid double-counting, the choice of the alternative supplier in this case is not counted as an "indifference contract" contract choice. Sects. 4.4.1 and 4.4.2 will present the results for the treatments without information sharing and with information sharing, respectively.

4.4.1 Screening Without Information Sharing

Tables 4.8 and 4.9 depict the cross tabulation of actual holding costs and contract choices in the treatments without information sharing. Table 4.8 refers to the treatment w/o P&R, and Table 4.9 with P&R, respectively. As an example, the buyers in the treatment w/o P&R faced in 35.45% of the cases the holding cost realization h_M while choosing the self-selection contract A_M. In contrast, in 5% of the observations they chose the indifference contract A_H while facing the holding cost realization h_M.

The buyers are screened rather successfully in both treatments. Without P&R, the buyers were screened in about 70.45% of all observations. Nonetheless, there is also a non-negligible amount of indifference contract choices (12.73%). Furthermore, the alternative supplier was chosen in 15.46% of all observations. However, optimal or nearly optimal contracts were chosen in 96.82% of the observations.[6]

In contrast, with the P&R mechanism in place, the buyers chose the self-selection contract in 77.5% of all observations. The indifference contract was chosen in 8.75% of all observations, and the alternative supplier was chosen in

Table 4.8 Cross tabulation of holding cost realization and contract choice in treatment w/o information sharing and w/o P&R

	h_L	h_M	h_H
A_L	23.18%	0.00%	0.00%
A_M	7.73%	35.45%	0.45%
A_H	0.91%	5.00%	11.82%
Alternative supplier	0.00%	1.82%	13.64%

Table 4.9 Cross tabulation of holding cost realization and contract choice in treatment w/o information sharing and with P&R

	h_L	h_M	h_H
A_L	22.92%	0.83%	0.00%
A_M	3.75%	36.25%	1.67%
A_H	1.25%	5.00%	18.33%
Alternative supplier	0.00%	0.00%	10.00%

[6]This is, self-selection contract, indifference contract, or alternative supplier while facing holding costs h_H.

Table 4.10 Frequency of indifference contract choices in treatments w/o information sharing disaggregated by groups

Group	1	2	3	4	5	6	7	8	9	10	11	12	Avg
w/o P&R	35%	0%	10%	0%	0%	55%	15%	10%	5%	5%	5%	–	13%
P&R	0%	20%	10%	30%	10%	10%	10%	0%	0%	10%	0%	5%	9%

Table 4.11 Frequency of alternative supplier choice in treatments w/o information sharing disaggregated by groups

Group	1	2	3	4	5	6	7	8	9	10	11	12	Avg
w/o P&R	25%	5%	20%	25%	0%	10%	0%	25%	10%	10%	20%	–	14%
P&R	0%	20%	25%	10%	0%	0%	0%	0%	15%	25%	25%	0%	10%

Table 4.12 Cross tabulation of holding cost realization and contract choice in treatment with information sharing and w/o P&R

	h_L	h_M	h_H
A_L	25.00%	0.42%	0.00%
A_M	3.33%	34.17%	0.83%
A_H	0.63%	2.92%	19.79%
Alternative supplier	0.21%	1.88%	10.93%

10% of all observations. Optimal or nearly optimal contracts were chosen in 96.25% of the observations.

Table 4.10 summarizes the relative frequency of indifference contract choices disaggregated by treatments and groups. There are no significant differences in indifference contract choices on a disaggregated level (MWU-test, $p < 0.88$, two-sided). Therefore, the P&R mechanism has no significant effect on the buyer's tendency to choose the indifference contract if there is no communication.

Additionally, Table 4.11 summarizes the frequency with which the buyers chose the outside option. One might argue that the punishment option leads to significantly more contract acceptances because the supplier can punish uncooperative behavior. However, a Mann-Whithney-U-test reveals that there are no significant differences between the treatments with and without P&R (MWU-test, $p < 0.373$, two-sided).

4.4.2 Screening with Information Sharing

The following subsection elaborates the buyers' contract choices in the treatments with information sharing.

Table 4.12 summarizes the cross tabulation of actual holding cost realizations and contract choices for the treatment with information sharing and w/o P&R. The self-selection contract was chosen in 78.96% of all observations. In contrast, the indifference contract was chosen in 6.25% of all observations. Finally, the alternative supplier was chosen in 13.02% of all observations. Optimal or nearly optimal contracts were chosen in 96.03% of the observations.

Table 4.13 summarizes the cross tabulation of actual holding cost realization and contract choice for the treatment with information sharing and with P&R. The self-selection contract was chosen in 77.08% of all observations. In contrast, the indifference contract was chosen in only 3.75% of all observations. Finally, the alternative supplier was chosen in 15.41% of all observations. Optimal or nearly optimal contracts were chosen in 91.67% of the observations.

The aggregated comparison of contract choices with and without P&R reveals that the indifference contract was chosen more often on average when there was no P&R mechanism (6.25% vs. 3.75%). Table 4.14 shows the frequencies of indifference contract choices disaggregated by groups and treatments. A Mann–Whitney-*U* test does not show any significant differences between the treatments (MWU-test, $p < 0.212$, two-sided).

Also, the MWU-test reveals no significant differences in the buyers' relative frequency of alternative supplier choices (MWU, $p < 0.251$, two-sided), which is summarized in Table 4.15. Summing up, it seems that the existence of the P&R mechanism has a minor effect on the buyer's contract choice behavior regardless of whether there is information sharing or not.

The most surprising finding, however, is that the average frequency of indifference contract choices is substantially higher when there is no information sharing

Table 4.13 Cross tabulation of holding cost realization and contract choice in treatment with information sharing and with P&R

	h_L	h_M	h_H
A_L	27.50%	2.08%	0.00%
A_M	2.08%	32.5%	1.25%
A_H	0.42%	1.67%	17.08%
Alternative supplier	0.00%	4.58%	10.83%

Table 4.14 Frequency of indifference contract choices in treatments with information sharing disaggregated by groups

Group	1	2	3	4	5	6	7	8	9	10	11	12
W/o P&R	0%	5%	0%	5%	20%	25%	5%	0%	0%	0%	0%	0%
Group	13	14	15	16	17	18	19	20	21	22	23	24
W/o P&R	5%	0%	0%	10%	5%	0%	25%	20%	10%	0%	0%	15%
Group	1	2	3	4	5	6	7	8	9	10	11	12
P&R	15%	20%	5%	0%	20%	5%	25%	10%	5%	0%	10%	0%

Table 4.15 Frequency of alternative supplier choice in treatments with information sharing disaggregated by groups

Group	1	2	3	4	5	6	7	8	9	10	11	12
W/o P&R	5%	5%	0%	15%	35%	10%	0%	5%	5%	20%	0%	5%
Group	13	14	15	16	17	18	19	20	21	22	23	24
W/o P&R	30%	0%	15%	0%	0%	30%	25%	30%	10%	20%	20%	25%
Group	1	2	3	4	5	6	7	8	9	10	11	12
P&R	5%	25%	0%	15%	50%	5%	0%	10%	0%	0%	5%	0%

(16%) compared to the treatment with information sharing (7.36%). This difference is significant on a disaggregated level (MWU,$p < 0.047$, two-sided).[7] In fact, one might argue that the frequency of indifference contract choices increases when communication is possible. This is, because the buyers can cover up their deceptive signals through the indifference contract choice. Consider, as an example, the situation in which the buyer faces holding costs h_M and gives the deceptive signal S_H. Yet, after the supplier offers the menu of contract, the buyer can simply cover up his deceptive signal by choosing the contract A_H out of the menu of contracts. This choice is nearly optimal, and causes only opportunity costs of 0.1.[8] The upside of the indifference contract choice is that the buyer is consistent with respect to his signal. However, the data presented in this subsection reveals that the frequency of indifference contract choices decreases with communication. This is because the option to cover up deceptive signals is not used very often. In fact, only two buyers (i.e., the buyer in groups 6 and 19 w/o P&R) use this option persistently. On an aggregated level, however, the effect of covering up deceptive signals is negligible.

Finally, note that optimal or nearly optimal contract choices were made on average in 95% of all observations. This indicates that the profit maximizing assumption used throughout the screening literature is not unjustifiable. Nonetheless, the buyers do not seem to react properly to small payoff differences. The following sections will analyze the effect of this finding on the supply chain performance.

4.5 Is Information Sharing Cheap Talk?

The former section showed that the buyers tend to choose the self-selection contract, the indifference contract, or the alternative supplier. However, the relation between the signal and the actual contract choice has not been addressed so far. Theoretically, one would assume that the buyers use their signals strategically, i.e., that they always claim that they have the highest holding cost realization. In the following, it is analyzed whether communication is empirically really cheap talk, or whether the buyers convey credible information with their signals.

Therefore, two measures are introduced, namely the frequency of consistent contract choices, and the frequency of truthful signals. Note that the supplier cannot judge whether a signal is truthful or not. In fact, the supplier can only observe whether the buyer choose a consistent contract for a given signal. A consistent contract choice (e.g., contract choice A_H after signal S_H) can either refer to a truthful signal (in this case the buyer faces holding costs h_H) or to a deceptive signal (e.g., the buyer faces holding costs h_L and covers up his deceptive signal by choosing A_H).

[7]In contrast, the frequency of contract rejections is not dependend on whether there is information sharing or not (MWU, $p < 0.911$, two-sided).

[8]This is the amount given to the buyers to ensure strict incentives (see Sect. 4.2).

Table 4.16 Frequencies of contract choices for a given signal in the treatment w/o P&R

	No signal	S_L	S_M	S_H
Alternative supplier	15%	21%	6%	13%
A_L	30%	43%	22%	22%
A_M	36%	21%	61%	33%
A_H	20%	14%	10%	32%

Table 4.17 Frequencies of contract choices for a given signal in the treatment with P&R

	No signal	S_L	S_M	S_H
Alternative supplier	6%	9%	4%	10%
A_L	17%	74%	19%	36%
A_M	33%	14%	70%	23%
A_H	44%	3%	7%	30%

Table 4.16 depicts the frequency of contract choices after a given signal for the treatment w/o P&R. As an example, in 43% of the cases the buyer chooses the contract A_L after sending the signal S_L. 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 (0.43 compared to $p_L = 0.3$ and 0.61 compared to $p_M = 0.4$), observing a high holding cost signal should not affect the suppliers' expectations (0.32 compared to $p_H = 0.3$). 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.

Table 4.17 summarizes the relative frequencies of contract choices for a given signal in the treatment with P&R. A comparison of Tables 4.16 and 4.17 reveals that the buyers seem to be more truthful when P&R is possible. In particular, the buyers choose A_L in 74% vs. 43% after sending S_L, and A_H in 70% vs. 61% after sending S_M. As in the treatment w/o P&R, however, the high holding cost signal is not informative.

As already mentioned, the data allows to distinguish between truthful signals (i.e., $h_i = S_i$) and consistent contract choices (i.e., choosing the contract A_i after sending the signal S_i). This differentiation is empirically relevant, because the suppliers cannot observe truthfulness, but can observe consistency. Since supply chain relationships in this 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 4.18 summarizes the frequency of truthful signals and of consistent contract choices in each supply chain for both treatments. On average the buyers give truthful signals in 36% and consistent signals in 32% of the cases in the treatment w/o P&R. A quick inspection reveals the high correlation between truthful signals and the signal-to-choice consistency.[9] While some buyers are less consistent than truthful, many are more consistent than truthful, i.e., cover up some

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

Table 4.18 Truthfulness and consistency

w/o P&R						P&R		
Group	Truthful signals	Consistent signals	Group	Truthful signals	Consistent signals	Group	Truthful signals	Consistent signals
1	20%	20%	13	20%	15%	1	30%	70%
2	25%	25%	14	25%	25%	2	25%	20%
3	65%	65%	15	50%	40%	3	50%	45%
4	20%	10%	16	15%	20%	4	30%	60%
5	20%	20%	17	25%	35%	5	30%	35%
6	30%	50%	18	15%	5%	6	60%	55%
7	10%	10%	19	55%	60%	7	80%	40%
8	30%	30%	20	60%	20%	8	29%	15%
9	45%	45%	21	20%	20%	9	50%	50%
10	35%	30%	22	45%	35%	10	80%	75%
11	100%	100%	23	45%	30%	11	75%	65%
12	40%	35%	24	45%	15%			

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 no systematic effects are observed. This stresses again that covering up deceptive signals is not a main driver of the results in the underlying experiment.

In contrast, in the treatment with P&R, the buyers give on average 52% truthful as well as consistent signals. Hence, the higher consistency between signals and contract choices (see Tables 4.16 and 4.17) can be explained by a higher degree of truthfulness. The Mann–Whitney-*U* test confirms that the buyers in the treatment with P&R are more truthful (MWU, $p < 0.05$, two-sided) and more consistent (MWU, $p < 0.01$, two-sided).

4.6 Does Information Sharing Enhance Supply Chain Performance?

The former sections stressed that there are substantial deviations from the standard screening equilibrium hypothesis. In particular, some subjects do not stick the a priori probabilities even though no communication takes place. Other subjects adjust the signal probability upwards, which indicates a believer behavior. Finally, not all buyers choose the self-selection contract consequently. The following subsection elaborates the impact of these deviations from the predicted equilibrium on supply chain performance.

The performance is measured by comparing observed outcomes to equilibrium or cooperative outcomes, given the actual realization of the holding cost parameter. This gives more exact measures than comparisons to the expected equilibrium or expected cooperative outcomes would, because the effect of stochastic cost variations is neutralized. Furthermore, all observations in which no contracts were concluded are not considered. This is, because the welfare effects of choosing the alternative supplier are solely driven by the experimental design. In contrast, all performance deviations reported in this subsection stem from the structure of screening contracts.

For every treatment the observed deviation from equilibrium and from the overall supply chain optimal solution will be reported. Additionally, the performance under the assumption that the buyer would haven chosen the self-selection contract is disclosed. The performance, in this case, only differs from the observed performance for those supply chains, in which the buyer did not always choose the (ex-post) payoff maximizing contract. Section 4.6.1 presents the results for the treatments without information sharing, Sect. 4.6.2 for the treatments with information sharing, and Sect. 4.6.3 compares the deviations from the game-theoretic equilibrium for all treatments.

4.6.1 Baseline: No Information Sharing

Tables 4.19–4.21 depict the performance deviation in the treatments without information sharing.

Table 4.19 refers to the treatment in which the buyer was automated. Obviously, there is no deviation caused by the indifference contract choice, and all contracts were concluded. The buyer's behavior is therefore perfectly predictable for the supplier, and all deviations do solely stem from variations of the subjective probabilities. In this case, the supply chains' deviations are equal to the suppliers' deviations. As mentioned before, these deviations can be explained by risk preferences different from risk neutrality. On average these adjustments of subjective probabilities cause cost of −8.77 per subject. The deviation from the supply chain optimum is on average −29.61 per subject. Seven out of 12 suppliers are

Table 4.19 Deviation from screening equilibrium in treatment w/o information sharing, w/o P&R and with automated buyer

Group	Observed	Cooperative
1	−3.36	−27.96
2	13.63	−20.14
3	−1.60	−15.35
4	−50.52	−69.53
5	2.38	−16.60
6	−39.07	−55.39
7	−2.50	−29.15
8	6.31	−15.38
9	0.66	−10.92
10	−5.89	−34.07
11	3.64	−18.07
12	−28.98	−42.79
Average	−8.77	−29.61

Table 4.20 Deviation from screening equilibrium in treatment w/o information sharing, w/o P&R

			Supplier		Buyer		Supply chain		
Subject	Contract	Indifference (%)	Observed	Self-selection	Observed	Self-selection	Observed	Self-selection	Cooperative
1	15	47	−45.59	−6.07	5.16	6.53	−40.43	0.46	−42.12
2	19	0	−4.92	−4.92	0.22	0.22	−4.70	−4.70	−6.56
3	16	13	−23.61	−15.22	18.62	18.72	−4.99	3.51	−9.53
4	15	0	−10.66	−10.66	3.04	3.04	−7.62	−7.62	−10.80
5	20	0	−15.57	−15.57	−4.04	−4.04	−19.62	−19.62	−25.81
6	18	61	−78.23	−10.16	−8.07	−6.06	−86.30	−16.22	−89.73
7	20	15	−12.8	−3.55	9.75	9.85	−3.06	6.30	−4.47
8	15	13	−29.89	−19.01	7.4	7.5	−22.49	−11.50	−28.15
9	18	6	−45.68	−42.45	47.07	47.12	1.39	4.67	−12.94
10	18	6	−10.98	−7.72	3.71	3.74	−7.27	−3.98	−10.03
11	16	6	−20.15	−13.49	0.64	0.71	−19.51	−12.78	−33.00
	Average	15	−27.1	−13.53	7.59	7.94	−19.51	−5.59	−24.83

worse off compared to the risk neutral strategy, while the performance of the remaining five suppliers even improved.

Table 4.20 depicts the performance for every buyer, supplier and the overall supply chain in the treatment w/o information sharing and w/o P&R. The supply chain performance deviates on average by −19.51 points. A closer look at Table 4.20 reveals, however, that a large portion of these deviations are solely caused by the buyers' self-selection contract choice. In fact, about 72% of the deviation can be explained by about 15% of indifference contract choices.[10]

A closer look at Table 4.20 reveals two performance effects. First, the suppliers' shift of probability mass to the highest holding cost realization (i.e., the upward adjustment of $p_H(\cdot)$) benefits the buyers, as they can improve their performance on average by 7.59 compared to the equilibrium outcome.

Second, the choice of the indifference contract has no substantial effect on the buyers' performance, as this choice is at least nearly optimal from the buyers' perspective. In contrast, the impact on the suppliers' performance is massive and about 50% of the suppliers' deviations are due to the buyers' indifference contract choice. However, it surprises that the suppliers are significantly worse compared to the treatment with an automated buyer even under the self-selection assumption (MWU,$p < 0.05$, two-sided). This indicates that the suppliers change their behavior simply because the buyer can reject the offer or because he can choose the indifference contract.

Table 4.21 summarizes the performance deviations in the treatment w/o information sharing, and with P&R. Interestingly, the results are quite similar to the treatment w/o P&R. This resembles the results from Sect. 4.4, in which no significant effect of the P&R option on the buyers' choice behavior could be identified.

[10]Note that the basis for the relative frequency of indifference contract choices is changed compared to Sect. 4.4. Here, the relative frequency refers to the number of rounds in which a contract was concluded.

Table 4.21 Deviation from screening equilibrium in treatment w/o information sharing, and with P&R

			Supplier		Buyer		Supply chain		
Group	Contracts	Indifference (%)	Observed	Self-selection	Observed	Self-selection	Observed	Self-selection	Cooperative
1	20	0	−20.33	−20.33	−5.12	−5.12	−25.45	−25.45	−38.94
2	16	25	−49.36	10.10	−22.06	−21.78	−71.42	−11.69	−85.15
3	15	13	−60.24	−53.13	47.11	47.18	−13.12	−5.95	−16.57
4	18	33	−39.95	−31.87	20.78	21.04	−19.17	−10.83	−29.69
5	20	10	−11.77	−6.89	1.49	1.56	−10.29	−5.34	−23.57
6	20	10	−20.83	−8.38	−5.80	−5.71	−26.63	−14.09	−33.00
7	20	10	−5.63	2.75	−3.53	−3.46	−9.16	−0.71	−18.72
8	20	0	7.31	7.31	−5.86	−5.86	1.45	1.45	−8.89
9	17	0	−8.13	−8.13	4.45	4.45	−3.69	−3.69	−15.56
10	15	13	−54.63	−45.42	47.09	41.71	−7.53	−3.71	−19.07
11	15	0	−55.19	−55.19	−16.72	−16.72	−71.91	−71.91	−85.56
12	20	5	−19.36	−18.34	1.12	1.95	−18.24	−16.39	−31.52
	Average	10	−28.18	−18.96	5.25	4.94	−22.93	−14.02	−33.85

Interestingly, there is no significant difference between the suppliers' performance in the treatment with automated buyer and w/o P&R and the treatment with P&R (MWU, $p < 0.539$, two-sided).[11] Recap, though, that the performance differed significantly when punishment and reward were not possible. This indicates that the suppliers only strongly react to the buyers contract choice behavior (compared to the treatment with the automated buyer) when no direct punishment and reward is possible.

4.6.2 *Information Sharing*

Table 4.22 summarizes the performance deviation in case of communication and without P&R. Observed performance is worse than predicted by theory for most suppliers, buyers, and supply chains. Only eight suppliers (33%), ten buyers (42%), and three 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. Also, it becomes evident that the indifference contract choice continues to be a major problem of the screening contract, as 68% of the supply chains' average deviation can be explained by no more than 30 (~7%) of the buyers' indifference contract choices.

Yet, even though there are three cases (groups 3, 11, and 19), in which the overall supply chain performance is improved, it seems clear that Pareto improvements

[11]In fact, there is no significant difference between the treatments with and w/o P&R for any performance measure (Mann–Whitney-*U* test).

Table 4.22 Deviation from screening equilibrium in treatment with information sharing and w/o P&R

			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

compared to the screening equilibrium are hard to achieve even with 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 behavior 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, groups 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 deteriorates. This is somehow surprising, as one might believe that either the buyers' truthful signals or the suppliers tendency to believe simply reallocate the profits within the supply chain. There are three variables, however, that interact, causing a deterioration of the performance for both the suppliers and the buyers.

First, in all of these supply chains the indifference contract is 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

Table 4.23 Deviation from screening equilibrium in treatment with information sharing, and with P&R

			Supplier		Buyer		Supply chain		
Group	Contracts	Indifference (%)	Observed	Self-selection	Observed	Self-selection	Observed	Self-selection	Cooperative
1	17	6	−1.90	−1.90	−28.41	−28.41	−30.31	−30.31	−44.79
2	16	31	−44.32	−42.02	43.40	43.43	−0.92	1.42	−9.03
3	19	0	−31.89	−31.89	0.53	0.53	−31.36	−31.36	−41.58
4	20	15	−22.75	−20.75	14.87	15.04	−7.88	−5.72	−23.83
5	16	63	−54.21	−37.78	−15.73	−15.44	−69.93	−53.22	−80.09
6	19	5	−9.15	−9.15	−2.02	−2.02	−11.16	−11.16	−36.83
7	15	0	−19.19	−19.19	−3.24	−3.24	−22.43	−22.43	−30.03
8	18	11	−8.37	−8.37	−9.51	−9.51	−17.88	−17.88	−28.93
9	19	0	−2.90	−2.90	25.68	25.68	22.78	22.78	−1.76
10	20	0	−42.05	−42.05	48.29	48.29	6.24	6.24	−16.14
11	18	6	−15.33	−15.33	−8.70	−8.70	−24.03	−24.03	−37.25
12	20	0	−5.56	−5.56	17.08	17.08	11.52	11.52	−0.79
		Average	−21.47	−19.74	6.85	6.89	−14.61	−12.85	−31.84

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 observed – do not stick to the a priori probabilities, instead trying to interpret the buyers' signals, profits are on average much lower for the buyers.

Table 4.23 summarizes the deviation from equilibrium in the treatment with information sharing and with P&R. Interestingly, the buyers benefit on average from the P&R mechanism, as they can improve their performance compared to the equilibrium benchmark. This indicates that the gains from rewards are higher than the losses from punishments. However, comparing the treatment with and w/o P&R, this performance improvement is not significant (MWU, $p < 0.327$, two-sided).

Second, the suppliers are significantly worse off, if they can use the P&R option (MWU, $p < 0.053$, two-sided). This highlights that both, punishments as well as rewards directly causes costs for the supplier. This is, every unit reward directly reduces the profits by one unit, and every unit punishment reduces the profits by 0.2, respectively. On average, thus, the P&R mechanism is not able to induce win-win situations. In fact, the supplier is worse off, even though the punishment or reward decision is made by himself.

Finally, it seems that the supply chain is more likely to loose due to the P&R option, as the average performance declines. However, this result is only weakly significant under the self-selection assumption (MWU, $p < 0.055$, one-sided).

4.6.3 Performance Comparison

Figure 4.9 breaks down the total supply chain deviations for all treatments into three parts. First, there is a deviation due to the adjustment of probabilities (black).

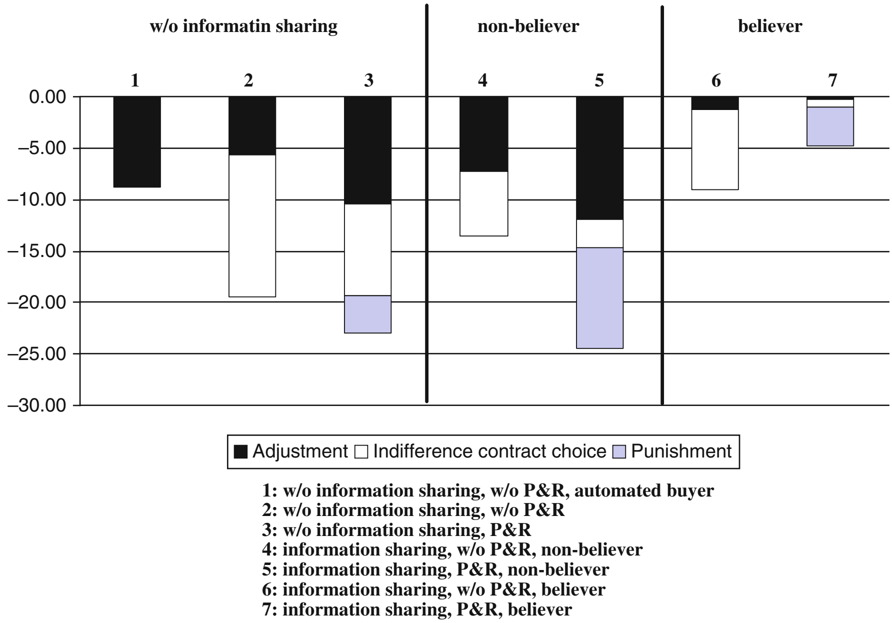


Fig. 4.9 Average performance deviations across treatments

Second, there is a deviation from the equilibrium if the buyer chooses the indifference contract instead of the self-selection contract (white). Finally, there is a direct effect of punishment, as every unit of punishment causes a supply chain deviation of 1.2 (grey).

The data for the treatments with information sharing is also disaggregated by believers and non-believers (see Sect. 4.3). In other words, the four bars on the right hand side of Fig. 4.9 refers to the treatments with information sharing disaggregated by the categories believers and non-believers. In contrast, the first three bars refer to the treatments without information sharing.

Figure 4.9 reveals that screening contracts typically perform worse than theoretically predicted. First, Fig. 4.9 stresses that there are uncontrolled factors which lead to the adjustment of probabilities even though there is no communication at all. This fact was already extensively discussed in Sect. 4.3.1. Interestingly, however, Fig. 4.9 highlights that the deviations caused by the probability adjustment are negligible as soon as communication is introduced and the suppliers tend to believe in signals. This result indicates that communication may indeed help to align the actions of the supply chain members.[12]

[12]However, the performance effects between the non-believers and believers without P&R are not significant, because the choice of the indifference contract has an even greater impact on the supply chain performance than the direct effect of the probability adjustment.

Also, Fig. 4.9 shows that the P&R mechanism in case of communication has two countervailing effects. On the one hand, there is a relatively high amount of punishment that causes almost 50% of the deviation. On the other hand, the buyers choose the indifference contract less often if they can either be rewarded for consistency or punished for inconsistency. In fact, Table 4.17 in Sect. 4.5 shows that the buyers are not only more consistent but also more truthful if punishments and rewards are possible. This highlights that the higher consistency stems from truth-telling and not from covering up deceptive signal via the indifference contract choice.

Finally, a closer look at Fig. 4.9 might lead to the conclusion that the adjustment behavior of the non-believers resembles in fact the behavior of subjects that do not get any information at all. However, remember the regression results for the non-believer in Sect. 4.3, which highlights that at least some probability adjustment of non-believers can be explained by the suppliers' signals.

4.7 Conclusion and Managerial Insights

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. The underlying laboratory experiment shows the strengths and the weaknesses 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 ($\approx 76\%$). Hence, theory predicts the buyer's contract choice behavior fairly well. However, in 7.9% 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 the experiment, for example, it can be shown that the average equilibrium deviations of supply chains would have been decreased by approximately 50% across treatments if buyers had chosen the self-selection contract every time. Note that these numbers exclude all observations, in which the buyers chose the alternative supplier. Hence, 50% of the deviation can be explained by no more than about 7.9% of the contract choices. If it is assumed 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-modeling approach can seriously harm supply chain performance. It can be therefore concluded 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 is generally not assumed that communication affects this process. Yet, the results show that communication might help to reduce the uncontrolled adjustment of subjective probabilities. In fact, 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 buyer's signals are more informative than others. The interaction of these behavioral types indicates that trusting behavior helps to align the actions and can even enhance the supply chain performance, whereas deception and mistrust leads to the ineffectiveness of communication.

Finally, the results will even be valuable to managerial decision-making if it is assumed that managers in real business operations are well informed of the circumstances under which screening contracts are reasonable. It is shown that communication influences the subjective probabilities that are key inputs of the decision support system and have a substantial impact on the recommendations made by the decision support system.

All in all, the 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 modeling and of managerial implementation of supply chain concepts.

Appendix

Appendix 1: Deviation of an Optimal Screening Contract Under Risk-Preferences

Setting up the Lagrange-function gives:

$$\begin{aligned} &\min\ L\left(q_i, Z_i, \lambda_{ij}, \mu_i \middle| i,j = 1,\dots,n \text{ and } i \neq j\right) = -Y_s + \\ &\sum\nolimits_{i=1}^{n} p_i \cdot u\left(-Y_s + \frac{f_i}{q_i} + Z_i\right) + \sum\nolimits_{i=1}^{n} \mu_i \left(\frac{h_i}{2} q_i - Z_i - C_{AS}\right) + \\ &\sum\nolimits_{j=1, j\neq i}^{n} \sum\nolimits_{i=1}^{n} \lambda_{ij} \left(\frac{h_i}{2} q_i - Z_i - \frac{h_i}{2} q_j + Z_j\right). \end{aligned} \tag{4.8}$$

The Karush-Kuhn-Tucker conditions are:

$$\frac{\partial L}{\partial q_i} = -p_i \cdot \frac{\partial u}{\partial\left(-P_{s,i}\right)} \cdot \frac{f}{q_i} + \mu_i \frac{h_i}{2} + \sum\nolimits_{j=1,j\neq i}^{n} \left(\lambda_{ij} \frac{h_i}{2} - \lambda_{ji} \frac{h_j}{2}\right) \leq 0 \tag{4.9}$$

$$\frac{\partial L}{\partial Z_i} = p_i \frac{\partial u}{\partial\left(-P_{s,i}\right)} - \mu_i + \sum\nolimits_{j=1,j\neq i}^{n} \left(\lambda_{ji} - \lambda_{ij}\right) \leq 0 \tag{4.10}$$

$$\frac{\partial L}{\partial \mu_i} = \frac{h_i}{2} q_i - C_{AS} - Z_i \leq 0 \tag{4.11}$$

$$\frac{\partial L}{\partial \lambda_{ij}} = \frac{h_i}{2} q_i - Z_i - \frac{h_i}{2} q_j + Z_j \leq 0 \tag{4.12}$$

$$\frac{\partial L}{\partial q_i} q_i = 0, \frac{\partial L}{\partial Z_i} Z_i = 0, \frac{\partial L}{\partial \mu_i} \mu_i = 0, \frac{\partial L}{\partial \lambda_{ij}} \lambda_{ij} \tag{4.13}$$

$$\mu_i \geq 0, \lambda_{ij} \geq 0 \tag{4.14}$$

Solving (4.9) for μ_i

$$\mu_i = p_i \frac{\partial u}{\partial\left(-P_{s,i}\right)} + \sum\nolimits_{j=1,j\neq i}^{n} \left(\lambda_{ji} - \lambda_{ij}\right) \tag{4.15}$$

and substituting (4.15) in (4.9) while considering $q_i > 0$ results in

$$\begin{aligned} & - p_i \cdot \frac{\partial U}{\partial\left(-P_{s,i}\right)} \cdot \frac{f}{Q_i} + \left(p_i \frac{\partial U}{\partial\left(-P_{s,i}\right)} + \sum\nolimits_{j=1,j\neq i}^{n} \left(\lambda_{ji} - \lambda_{ij}\right)\right) \frac{h_i}{2} \\ & + \sum\nolimits_{j=1,j\neq i}^{n} \left(\lambda_{ij} \frac{h_i}{2} - \lambda_{ji} \frac{h_j}{2}\right) = 0 \\ & \vdots \\ & p_i \cdot \frac{\partial U}{\partial\left(-P_{s,i}\right)} \cdot \left(\frac{h_i}{2} - \frac{f}{Q_i}\right) + \sum\nolimits_{j=1,j\neq i}^{n} \lambda_{ji} \left(\frac{h_i}{2} - \frac{h_j}{2}\right) = 0 \end{aligned} \tag{4.16}$$

From (4.10) and Sappington's (1983) results $\mu_i = 0\ \forall i = 1, \ldots, n-1$, $\mu_n > 0$ and $\lambda_{ij} = 0$, for $j < i$ and $j > i + 1$ it follows that

for i = n

$$p_n \frac{\partial u}{\partial\left(-P_{s,n}\right)} + \lambda_{n-1,n} = \mu_n \tag{4.17}$$

for i = n − 1

$$p_{n-1}\frac{\partial u}{\partial(-P_{s,n-1})}+\lambda_{n-2,n-1}-\lambda_{n-1,n}=0$$
$$\rightarrow \quad \lambda_{n-2,n-1}=\lambda_{n-1,n}-p_{n-1}\frac{\partial u}{\partial(-P_{s,n-1})}=\mu_n-p_n\frac{\partial u}{\partial(-P_{s,n})}-p_{n-1}\frac{\partial u}{\partial(-P_{s,n-1})} \tag{4.18}$$

$\vdots$

for i = 2

$$p_2\frac{\partial u}{\partial(-P_{s,2})}+\lambda_{1,2}-\lambda_{2,3}=0$$
$$\rightarrow \quad \lambda_{1,2}=\mu_n-p_n\frac{\partial u}{\partial(-P_{s,n})}-\ldots-p_2\frac{\partial u}{\partial(-P_{s,2})} \tag{4.19}$$

for i = 1

$$p_1\frac{\partial u}{\partial(-P_{s,1})}-\lambda_{1,2}=0 \rightarrow p_1\frac{\partial u}{\partial(-P_{s,1})}-\mu_n+p_n\frac{\partial u}{\partial(-P_{s,n})}+\ldots+p_2\frac{\partial u}{\partial(-P_{s,2})}=0$$
$$\rightarrow \mu_n=\sum\nolimits_{t=1}^{n}p_t\frac{\partial u}{\partial(-P_{s,t})} \tag{4.20}$$

Substituting (4.20) into (4.18) and solving for $\lambda_{i,j}$ gives:

$$\begin{aligned}\lambda_{ji}&=\mu_n-p_n\frac{\partial u}{\partial(-P_{s,n})}-\ldots-p_{n-1}\frac{\partial u}{\partial(-P_{s,i})}\\&=\sum\nolimits_{t=1}^{n}p_t\frac{\partial u}{\partial(-P_{s,t})}-p_n\frac{\partial u}{\partial(-P_{s,n})}-\ldots-p_i\frac{\partial u}{\partial(-P_{s,i})}\\&=\sum\nolimits_{t=1}^{i-1}p_t\frac{\partial u}{\partial(-P_{s,t})}\end{aligned} \tag{4.21}$$

Substituting (4.21) in (4.16) and solving for q_i gives:

$$p_i\cdot\frac{\partial u}{\partial(-P_{s,i})}\cdot\left(\frac{h_i}{2}-\frac{f}{q_i}\right)+\sum\nolimits_{j=1,j\neq i}^{n}\lambda_{ji}\left(\frac{h_i}{2}-\frac{h_j}{2}\right)=0$$
$$\vdots$$
$$q_i^{RP}=\sqrt{\frac{2\cdot f}{h_i+\frac{\sum_{t=1}^{i-1}p_t u'_{s,t}}{p_i\cdot u'_{s,i}}(h_i-h_{i-1})}} \tag{4.22}$$

where $\quad u'_{s,i}=\frac{\partial u}{\partial(-P_{s,i})}$ and $\quad P_{s,i}=Y_s-\frac{f}{q_i}-Z_i$

As $\mu_n > 0$ (4.20) it follows that

$$Z_n{}^{RP} = \frac{h_n}{2} q_n{}^{RP} - C_{AS} \tag{4.23}$$

Furthermore, $\lambda_{ij} = 0,$ for $j < i$ and $j > i + 1$ and $\lambda_{ij} > 0$ for $i = j - 1$ holds (see Sappington 1983) and it follows from (4.12)

$$Z_i{}^{RP} = \frac{h_i}{2}\left(q_i{}^{RP} - q_{i+1}{}^{RP}\right) + Z_{i+1}{}^{RP}, \forall i = 1, \ldots, n-1 \tag{4.24}$$

Appendix 2: Supply Chain Performance in Dependence of the Supplier's Risk Preference

Given risk seeking preferences, the supplier's marginal utility is higher the higher the respective profit in a lottery. Hence, it follows that $\frac{\partial u}{\partial (P_{s,t})} > \frac{\partial u}{\partial (P_{s,i})}, \forall t < i$ and $u'_{s,t} = \frac{\partial u}{\partial (-P_{s,t})} < \frac{\partial u}{\partial (-P_{s,i})} = u'_{s,i}, \forall t < i$, respectively. This, in turn, implies that

$$\sqrt{\frac{2 \cdot f}{h_i + \frac{\sum_{t=1}^{i-1} p_t u'_{s,t}}{p_i \cdot u'_{s,i}} (h_i - h_{i-1})}} < \sqrt{\frac{2 \cdot f}{h_i + \frac{\sum_{t=1}^{i-1} p_t u'_{s,i}}{p_i \cdot u'_{s,i}} (h_i - h_{i-1})}} = \sqrt{\frac{2 \cdot f}{h_i + \frac{\sum_{t=1}^{i-1} p_t}{p_i} (h_i - h_{i-1})}} \tag{4.25}$$

as $\sum_{t=1}^{i-1} p_t u'_{s,t} < \sum_{t=1}^{i-1} p_t u'_{s,i}$ holds. The downward distortion, thus, increases if the supplier faces risk seeking preferences, i.e., $q_i{}^{RS} < q_i{}^{RN}$.

In turn, if the supplier faces risk averse preferences, than his marginal utility increases with the respective profit in a lottery, i.e., $u'_{s,t} > u'_{s,i}, \ \forall t < i$. This, in turn, implies that the downward distortion decreases if the supplier is risk averse.

Appendix 3: Sample Instructions (Translation into English)

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 buyer's 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 = 2–5 or if Q = 3–7.5 (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 buyer's 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 buyer's true holding costs. Yet, the supplier knows a probability distribution over the possible holding costs realizations. In the course of the experiment, the buyer's holding costs are drawn independently from this probability distribution in every round. The buyer knows his true holding costs in every round.

There are three possible types of holding costs realizations, 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 supplier's 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 buyer's signal, the supplier can adjust his beliefs about the buyer's holding costs. On this basis, three offers are generated, from which the buyer can choose one. This offers maximize the supplier's 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

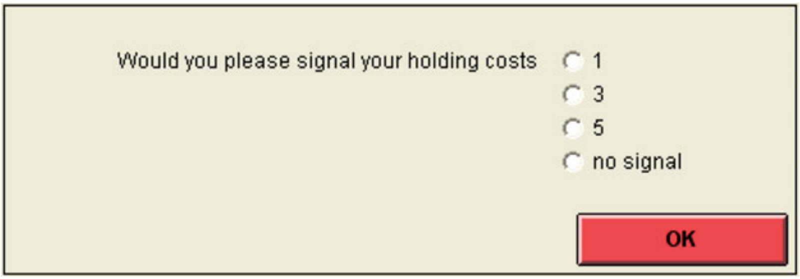
How Are the Contract Corresponding Profits Calculated?

The supplier's offers differ with his subjective beliefs regarding the buyer's 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 supplier's expectations.

The buyer's profits amount to a fixed revenue per period (85) minus the respective holding costs plus the supplier's 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 supplier's beliefs (the beneath example is basing on a holding cost of 1).

Subjective probability of holding costs			
1€	3€	5€	Profit
0	0	100	121.29
10	40	50	116.80
30	40	30	112.02

The buyer can base his signal on this information.



The supplier's 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 supplier's respective round profit amounts to 0.

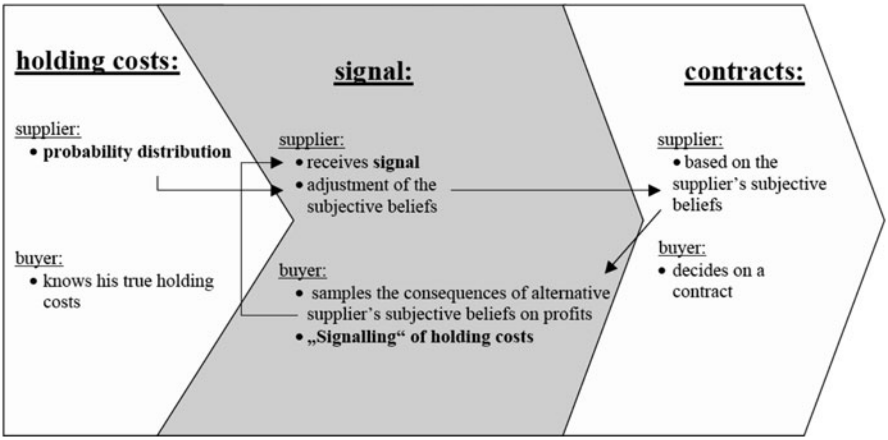
On a computer screen the supplier sees the contract specific profits dependent on his subjective beliefs. The resulting profits though depend on the buyer's actual contract choice.

			Profit maximum for buyer with holding costs of		
Subjective probability of holding costs			1€	3€	5€
1€	3€	5€	Profit contract 1	Profit contract 2	Profit contract 3
0	0	100	123.71	117.62	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?

Twenty rounds are going to be played. The buyer's 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 Payoff Calculated?

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

If there are any questions, please raise your hand.

Please leave the instructions on your place after the experiment.

Good Luck!

									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		profit maximum for buyer		profit maximum for buyer					profit maximum for buyer with holding			profit maximum for buyer with holding			profit maximum for buyer with holding		
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	15.10	no contract offer				164.90	0.00	0.00	80.1	40.1	0.1	80	80	80	80	80	80
0.9	0.1	0	40.00	25.99	8.73	8.19			154.01	100.17	0.00	90.99	50.99	10.99	88.83	80.1	71.37	80	80	80
0.8	0.2	0	40.00	29.32	12.06	13.19			150.68	120.48	0.00	94.32	54.32	14.32	92.16	80.1	68.04	80	80	80
0.7	0.3	0	40.00	31.71	14.45	16.77			148.29	127.87	0.00	96.71	56.71	16.71	94.55	80.1	65.65	80	80	80
0.6	0.4	0	40.00	33.59	16.33	19.59			146.41	131.42	0.00	98.59	58.59	18.59	96.43	80.1	63.77	80	80	80
0.5	0.5	0	40.00	35.15	17.89	21.93	no contract offer		144.85	133.35	0.00	100.15	60.15	20.15	97.99	80.1	62.21	80	80	80
0.4	0.6	0	40.00	36.48	19.22	23.93			143.52	134.45	0.00	101.48	61.48	21.48	99.32	80.1	60.88	80	80	80
0.3	0.7	0	40.00	37.63	20.37	25.65			142.37	135.08	0.00	102.63	62.63	22.63	100.47	80.1	59.73	80	80	80
0.2	0.8	0	40.00	38.64	21.38	27.17			141.36	135.41	0.00	103.64	63.64	23.64	101.48	80.1	58.72	80	80	80
0.1	0.9	0	40.00	39.54	22.28	28.52			140.46	135.57	0.00	104.54	64.54	24.54	102.38	80.1	57.82	80	80	80
0	1	0	40.00	40.36	23.09	29.73			139.64	135.62	0.00	105.36	65.36	25.36	103.19	80.1	57.01	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	46.74	23.09	38.18	8.34	15.95	133.26	127.17	88.13	111.74	71.74	31.74	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	22.82	140.27	113.69	105.04	104.73	64.73	24.73	104.63	91.3	77.97	102.28	91.19	80.1
0.5	0.3	0.2	40.00	42.29	15.89	30.14	11.09	22.82	137.71	119.51	105.04	107.29	67.29	27.29	107.2	91.31	75.42	102.28	91.19	80.1
0.4	0.4	0.2	40.00	44.28	17.89	33.13	11.09	22.82	135.72	122.15	105.04	109.28	69.28	29.28	109.19	91.3	73.41	102.28	91.19	80.1
0.3	0.5	0.2	40.00	45.91	19.52	35.57	11.09	22.82	134.09	123.45	105.04	110.91	70.91	30.91	110.81	91.29	71.77	102.28	91.19	80.1
0.2	0.6	0.2	40.00	47.28	20.89	37.63	11.09	22.82	132.72	124.07	105.04	112.28	72.28	32.28	112.19	91.3	70.41	102.28	91.19	80.1
0.1	0.7	0.2	40.00	48.46	22.07	39.39	11.09	22.82	131.54	124.36	105.04	113.46	73.46	33.46	113.36	91.29	69.22	102.28	91.19	80.1
0	0.8	0.2	40.00	49.50	23.09	40.94	11.09	22.82	130.50	124.41	105.04	114.5	74.5	34.5	114.4	91.31	68.22	102.28	91.19	80.1
0.7	0	0.3	40.00	36.63	10.77	21.91	10.57	21.52	143.37	103.81	102.79	101.63	61.63	21.63	101.53	90.76	79.99	101.24	90.67	80.1
0.6	0.1	0.3	40.00	39.52	12.21	25.53	12.01	25.12	140.48	108.95	108.27	104.52	64.52	24.52	104.43	92.22	80.01	104.12	92.11	80.1
0.5	0.2	0.3	40.00	42.31	14.14	29.28	12.87	27.27	137.69	114.14	110.57	107.31	67.31	27.31	107.21	93.07	78.93	105.84	92.97	80.1
0.4	0.3	0.3	40.00	44.97	16.80	33.27	12.87	27.27	135.03	119.11	110.57	109.97	69.97	29.97	109.87	93.07	76.27	105.84	92.97	80.1
0.3	0.4	0.3	40.00	47.02	18.86	36.35	12.87	27.27	132.98	121.23	110.57	112.02	72.02	32.02	111.92	93.06	74.2	105.84	92.97	80.1
0.2	0.5	0.3	40.00	48.68	20.52	38.84	12.87	27.27	131.32	122.17	110.57	113.68	73.68	33.68	113.58	93.06	72.54	105.84	92.97	80.1
0.1	0.6	0.3	40.00	50.07	21.91	40.93	12.87	27.27	129.93	122.56	110.57	115.07	75.07	35.07	114.98	93.07	71.16	105.84	92.97	80.1
0	0.7	0.3	40.00	51.27	23.09	42.71	12.87	27.27	128.73	122.64	110.57	116.27	76.27	36.27	116.17	93.08	69.99	105.84	92.97	80.1
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	28.32	137.91	112.00	111.48	107.09	67.09	27.09	106.99	93.49	79.99	106.68	93.39	80.1
0.4	0.2	0.4	40.00	44.56	15.12	32.02	14.14	30.45	135.44	115.07	112.97	109.56	69.56	29.56	109.46	94.34	79.22	108.38	94.24	80.1
0.3	0.3	0.4	40.00	47.33	17.89	36.17	14.14	30.45	132.67	119.11	112.97	112.33	72.33	32.33	112.23	94.34	76.45	108.38	94.24	80.1
0.2	0.4	0.4	40.00	49.44	20.00	39.34	14.14	30.45	130.56	120.66	112.97	114.44	74.44	34.44	114.34	94.34	74.34	108.38	94.24	80.1
0.1	0.5	0.4	40.00	51.14	21.69	41.88	14.14	30.45	128.86	121.24	112.97	116.14	76.14	36.14	116.04	94.35	72.66	108.38	94.24	80.1
0	0.6	0.4	40.00	52.54	23.09	43.98	14.14	30.45	127.46	121.37	112.97	117.54	77.54	37.54	117.44	94.35	71.26	108.38	94.24	80.1
0.5	0	0.5	40.00	42.17	13.53	28.83	13.33	28.42	137.83	112.04	111.56	107.17	67.17	27.17	107.07	93.54	80.01	106.76	93.43	80.1
0.4	0.1	0.5	40.00	44.32	14.61	31.53	14.41	31.12	135.68	113.71	113.36	109.32	69.32	29.32	109.23	94.62	80.01	108.92	94.51	80.1
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	53.52	23.09	44.96	15.12	32.90	126.48	120.39	114.19	118.52	78.52	38.52	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	34.82	130.92	117.35	114.83	114.08	74.08	34.08	113.99	96.1	78.21	111.88	95.99	80.1
0.1	0.3	0.6	40.00	52.08	20.89	42.43	15.89	34.82	127.92	119.27	114.83	117.08	77.08	37.08	116.99	96.1	75.21	111.88	95.99	80.1
0	0.4	0.6	40.00	54.30	23.09	45.74	15.89	34.82	125.70	119.61	114.83	119.3	79.3	39.3	119.2	96.11	73.02	111.88	95.99	80.1
0.3	0	0.7	40.00	46.37	15.64	34.09	15.44	33.70	133.63	114.76	114.49	111.37	71.37	31.37	111.27	95.63	79.99	110.98	95.54	80.1
0.2	0.1	0.7	40.00	48.11	16.51	36.26	16.31	35.87	131.89	115.28	115.08	113.11	73.11	33.11	113.01	96.5	79.99	112.72	96.41	80.1
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	54.93	23.09	46.37	16.53	36.42	125.07	118.98	115.18	119.93	79.93	39.93	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	37.75	129.76	116.19	115.36	115.24	75.24	35.24	115.15	97.26	79.37	114.22	97.16	80.1
0	0.2	0.8	40.00	55.46	23.09	46.90	17.06	37.75	124.54	118.45	115.36	120.46	80.46	40.46	120.36	97.27	74.18	114.22	97.16	80.1
0.1	0	0.9	40.00	49.79	17.34	38.36	17.14	37.95	130.21	115.50	115.38	114.79	74.79	34.79	114.69	97.35	80.01	114.38	97.24	80.1
0	0.1	0.9	40.00	55.90	23.09	47.34	17.50	38.85	124.10	118.01	115.44	120.9	80.9	40.9	120.8	97.71	74.62	115.1	97.6	80.1
0	0	1	40.00	56.29	23.09	47.73	17.89	39.82	123.71	117.62	115.46	121.29	81.29	41.29	121.19	98.1	75.01	115.88	97.99	80.1

*This table was handed out on sheets DIN A3.

Chapter 5
The Impact of Contract Complexity, Supply Chain Configuration, and Out-of-Equilibrium Behavior on the Effectiveness of Information Sharing: A Second Laboratory Experiment

The experiment presented in Chap. 4 shows a subtle way to measure the suppliers' trust in supply chain interactions by analyzing the signal probability in a screening game. In contrast to the experiment presented in the following section, the supplier could choose out of 66 distinctive screening contracts which were generated with respect to the supplier's assessment of the buyer's private information (see payoff table in the sample instructions, Appendix 2 in Chap. 4). Yet, in the following experiment the number of options was substantially reduced, as previous research states that the number of options in a game can influence the decision maker's behavior (see Ho and Weigelt 1996). Hence, the number of options was reduced to either offering a contract as if under full information or offering a screening contract. A closer look on the payoff tables used in the experiment introduced in Chap. 4 (see payoff table in the sample instructions, Appendix 3 in Chap. 4) and the underlying study (see Table 5.1) shows that the reduction of options makes the differences between the options more salient for the participants of the experiment. In other words, it is much easier for the subjects to analyze what would have happened if another contract would have been chosen, when there are only 4 options instead of 66. This approach was also chosen by Bolton and Katok (2008) who reduce the number of ordering options in a newsvendor setting. Bolton and Katok (2008) find that this reduction indeed influences the decision maker's behavior, especially because there is the possibility of a focused feedback with respect to the limited number of options.

The previous section revealed that the buyers tend to choose the indifference contract. One might think about increasing the size of the additional incentive (e.g., from 0.1 to 1) to reduce the frequency of indifference contract choices. Yet, there are two problems taking this approach. First of all, the additional incentive cannot be chosen arbitrarily high, because screening contracts turn to be suboptimal in this case, and simple wholesale-price contracts become payoff maximizing. Second, even if we find an actual value of an additional side-payment that prevents the buyer from choosing the indifference contract, we cannot be sure that the supplier does not perceive the risk of this action. Therefore, we conducted an experiment, in which we enforced self-selection by limiting the buyer's contract choice options.

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Table 5.1 Contracts and corresponding total profits

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

This allows evaluating the impact of out-of-equilibrium contract choices, and therefore an upper-bound for the benefits resulting from reducing indifference contract choices.

Moreover, the brief literature review in Sect. 2.1 showed that the screening-mechanism can be applied to both single- and multiple agent settings. Hence, the screening theory introduced for the single supplier – single buyer supply chain can theoretically be easily transferred to single supplier – multiple buyer supply chains. Yet, the behavioral impact of alternating supply chain configurations has not been addressed so far. Hence, two treatments with diverging supply chains were conducted.

Finally, Chap. 4 showed that a P&R mechanism outside the contracting stage has a substantial impact on the effectiveness of information sharing. In the following experiment the effectiveness of two punishment mechanisms is analyzed, i.e., a rather crude and a subtle punishment mechanism. The crude punishment is implemented by allowing the supplier to withdraw an offer leaving zero profits for both supply chain members. The subtle punishment mechanism, in turn, allows the supplier continuously reducing the buyer's payoffs up to a certain amount.

The remainder of this section is organized as follows: Sect. 5.1 describes the experimental design and the treatment variables. Sect. 5.2 discusses the experimental results disaggregated for buyers, suppliers and the overall supply chain. Sect. 5.3 elaborates the effect of the suppliers' and buyers' action on the overall supply chains' performance. Finally, Sect. 5.4 summarizes the results and gives some managerial insights that can be deduced from the laboratory experiment.

5.1 Experimental Design and Implementation

The overall experiment consists of five treatments, namely the baseline treatment, the diverging supply chain treatment, the diverging supply chain treatment without price-discrimination, the enforced self-selection treatment, and the punishment treatment. The treatments were run at the MaxLab, Otto-von-Guericke University Magdeburg. The experimental software was implemented with the toolbox z-Tree (Fischbacher 2007). Upon arrival, each participant received written instructions which were read out aloud (see Appendix for sample instructions). All remaining questions were answered privately. Every subject was paid according to a fraction of his total profits at the end of the experiment. In the following, the experimental design of the baseline treatment is outlined in Sect. 5.1.1, while Sect. 5.1.2 discusses the changes compared to the baseline treatment.

5.1.1 Baseline Treatment

The baseline treatment considers the simplest form a supply chain consisting of one buyer and one supplier, i.e., a serial supply chain. The matching of buyers and suppliers did not change over time. All subjects played 30 rounds. The supplier is allowed to give an additional side-payment, Z_R, after the buyer chose a contract. This additional side-payment, Z_R, allows the supplier to share the benefits of coordinated actions (i.e., the benefits of increasing the order size from ${q_i}^{AI}$ to ${q_i}^{FI}$). As discussed before (see Sect. 2.3.2), the supplier would never pay an optional side-payment after the buyer's contract choice $\langle {q_i}^{FI}, {Z_i}^{FI} \rangle$, because the buyer reveals with a contract acceptance that his participation constraint is met. Thus, the game theoretic equilibrium predicts that $Z_R = 0$ holds.

Furthermore, the supplier might withdraw an offer after the buyer chose a contract. In this case both supply chain parties yield zero profits. However, in the game-theoretic equilibrium this option is never been chosen by the supplier as every contract acceptance is favorable. In other words, the withdrawal of an offer is a very rough punishment option which causes high costs for the buyer as well as the supplier.

5.1.1.1 Parameters

In the experimental setting there are three distinctive holding cost realizations $h_L = 1,\ h_M = 5$ and $h_H = 9$ that occur with the corresponding a-priori probabilities $p_L = 0.4, p_M = 0.3$ and $p_H = 0.3$. The holding costs are drawn independently in every round according to the distribution function which is common knowledge. The supplier's fixed cost are set to $f = 800$ and the buyer's cost of sourcing from the alternative supplier to $C_{AS} = 2$. Furthermore, it is assumed that the supplier generates a menu of contracts which minimizes his expected costs, i.e., the menu of contracts is generated as if the supplier is risk neutral. The buyer yields fixed revenues of $Y_b = 5$ per round and the supplier $Y_s = 155$ per round, respectively. Different parameters values than those presented in Chap. 4 were chosen in order to increase the potential gains from cooperative behavior.

5.1.1.2 Decision Sequence

(t = 1): At the beginning of every round, the buyer is able to communicate a holding cost to his supplier via a signal $S \in [S_L = h_L, S_M = h_M, S_H = h_H, S_{No} \doteq No\ Signal]$.

(t = 2): After the buyer gives his signal, S, the supplier can decide on his contract offers. His contract offers are restricted to (1) $F_L = \langle q_L{}^{FI}, Z_L{}^{FI} \rangle$, (2) $F_M = \langle q_M{}^{FI}, Z_M{}^{FI} \rangle$, (3) $F_H = \langle q_H{}^{FI}, Z_H{}^{FI} \rangle$ and (4) $A = (A_L, A_M, A_H)$ where $A_i = \langle q_i{}^{AI}, Z_i{}^{AI} \rangle$, $i \in L, M, H$. The supplier, thus, can either offer contracts as if under full information (FI), i.e., (1)–(3) or an incentive compatible screening contract that theoretically ensures the buyer's self-selection, i.e., (4).

(t = 3): If the supplier offers a contract as if under full information in t = 2, then the buyer can either accept or reject this offer. In contrast, if the supplier offers the menu of contracts A in t = 2, the buyer has to decide between choosing A_L, A_M and A_H, or rejecting the offer. Yet, if the buyer rejects the offer, he sources from the alternative supplier at cost of C_{AS}, and the supplier realizes zero profits.

(t = 4): After the buyer's contract choice, the supplier has the option to withdraw the offer. In that case the profits of both the buyer and the supplier equal zero. Nonetheless, if the supplier decides to keep the offer valid, he has the option to give an extra side-payment, Z_R. The respective profits in each round result from $P_b = Y_b - C_b(q,Z) + Z_R$ and $P_s = Y_s - C_s(q,Z) - Z_R$ where $q \in (q_i{}^{AI}, q_i{}^{FI})$ and $Z \in (Z_i^{AI}, Z_i^{FI})$.

(t = 5): A new holding cost parameter is drawn with respect to probability distribution. Thus, the supplier cannot infer the buyer's holding cost parameter of the next round even though the buyer chooses the self-selection contract in $t = 3$.

Table 5.1 depicts the resulting order sizes q and side-payments Z in the contracts $F_i, i \in (L, M, H)$ and the menu of contracts A, respectively. Furthermore, the column P_s summarizes the supplier's profits (without the additional side-payment Z_R) if the buyer accepts the respective contract. In contrast, the buyer's profits P_b do not only depend on the acceptance of the respective contract offer but also on his holding cost realization. If the buyer faces, for example, holding costs of h_L and accepts the contract F_M, he realizes a profit of $P_b = 38.88$. The buyer yields a profit of $P_b = Y_b - C_{AS} = 3$ if he chooses the alternative supplier in $t = 3$. In this case the suppliers profit equals to zero, i.e., $P_s = 0$.

Note that the participation constraint in the strategic lotsizing model formulation in Sect. 2.2.4 leaves the buyer with holding costs h_i indifferent between the outside option and the contract F_i. Yet, in the experimental design the buyer has a strict incentive of 0.1 to accept the contract. For example, the buyer with holding costs h_L accepting the contract F_L yields a profit of $P_s = 3.1$. If this buyer would choose the outside option, he would earn 0.1 less, i.e., $P_s = 3$.

The same strict incentives are given in the menu of contracts A. The buyer, thus, has a strict incentive to choose the self-selection contract, i.e., A_i given h_i. For example, if the buyer chooses the contract A_H while facing holding costs h_M, he would earn 0.1 less compared to the contract choice A_M.

5.1.2 Treatment Variables

The overall experiment consists of five treatments, namely the baseline treatment, the diverging supply chain treatment, the diverging supply chain treatment without price-discrimination, the enforced self-selection treatment, and the punishment treatment. In the following the treatment variables, i.e., the changes of treatments compared to the baseline treatment, are presented.

5.1.2.1 Diverging Supply Chain

A total of 24 subjects participated in this treatment, 8 being suppliers and 16 being buyers. In this treatment, the supplier can offer different contracts to different buyers. As an example, the buyer can offer the contract F_L to buyer 1, and the contract F_M to buyer 2. Hence, the unit prices for the respective buyers might differ, and a price discrimination is possible. Note that we do not consider the potential gains from coordinating the buyers' order sizes as discussed in Roundy (1985).

5.1.2.2 Diverging Supply Chain: No Price Discrimination

A total of 24 subjects participated in this treatment, 8 being suppliers and 16 being buyers.

In contrast to the before-mentioned treatment, the supplier was not allowed to offer two distinctive contracts to the buyers. As an example, the supplier was not allowed to offer the menu of contracts A to the first buyer, but the contract F_L to his second buyer. Note that the theoretical prediction in this case does not differ from the other treatments. This is, because both buyers are assumed to use their signals strategically. In this case, it is in the supplier's best interest to offer the screening contract.

5.1.2.3 Enforced Self-Selection

In this treatment, the buyer (in a simple serial supply chain) was forced to choose the self-selection contract, once the supplier offered the menu of contracts A. Hence, the supplier does not face the strategic risk of the buyer choosing the indifference contract. A total of 16 subjects participated in this treatment, 8 being suppliers and 8 being buyers.

5.1.2.4 Subtle Punishment

In this treatment, the supplier gets the option to directly punish the buyer. Every unit of punishment causes costs for the supplier of 0.2. Hence, the difference to the baseline treatment is, that the supplier's punishment option is not only restricted to withdraw an offer (which goes along with high opportunity costs for the supplier), but that he can utilize a more subtle mechanism to punish the buyer. The upper limit of punishment and rewards was set to 60.

5.2 Experimental Results

The following section discusses the experimental results. Section 5.2.1 starts with analyzing the buyer's signaling behavior. Then, Sect. 5.2.2 evaluates the impact of the buyer's reports on the supplier's contract offer decision. Afterwards, Sect. 5.2.3 discusses the buyer's contract choice behavior. Finally, Sect. 5.2.4 analyses to what extent punishments and rewards are used.

5.2.1 The Buyers' Information Sharing Behavior

Table 5.2 shows the cross tabulation of the buyer's holding costs and signals disaggregated by all treatments.

Obviously, there is considerable variance in the buyers' signals. Yet, screening theory assumes that signals can be even randomized in equilibrium, as the signals are ignored anyway. However, in the following it is shown that the buyers' signals do basically fit into three categories. Either, a signal is truthful (i.e., sending S_i while having holding costs h_i), consistent (i.e., sending S_i while choosing A_i), or an exaggeration of the actual cost position. Nonetheless, note that a small but non-negligible portion of signals does not fit into any of these categories. As an example, there is no rational explanation except the randomization strategy to give the signal S_L while facing holding costs h_M. In case the supplier believes the signal, the buyer's participation constraint is not satisfied, and he only gets his reservation profit. However, we observed this signal in about 1% of all observations, and no learning effects could be observed, i.e., these signals do not vanish over time.

Table 5.3 summarizes the relative frequency of truthfulness disaggregated by each supply chain for each treatment. The punishment option has obviously the most significant effect on the truthfulness of the buyers. The differences are highly significant compared to the baseline, and enforced treatment (MWU, $p < 0.05$, two-sided), and weakly significant compared to diverging supply chain treatment (MWU, $p < 0.1$, one-sided). This finding is in-line with the experiment presented

Table 5.2 Crosstabulation of the buyer's actual holding costs and signals

	h_L (%)	h_M (%)	h_H (%)	*Total* (%)
Baseline				
S_{No}	2.50	5.83	7.92	16.25
S_L	1.67	0.42	0.83	2.92
S_M	6.25	3.33	0.42	10.00
S_H	27.50	18.33	25.00	70.83
Total	37.92	27.92	34.17	100.00
No discrimination				
S_{No}	4.17	4.17	4.79	13.13
S_L	16.88	0.42	2.92	20.21
S_M	5.21	12.92	0.83	18.96
S_H	12.92	10.83	23.96	47.71
Total	39.17	28.33	32.50	100.00
Diverging				
S_{No}	12.50	9.79	7.50	29.79
S_L	4.79	0.83	1.88	7.50
S_M	1.25	5.00	0.21	6.46
S_H	18.75	13.75	23.75	56.25
Total	37.29	29.38	33.33	100.00
Enforced				
S_{No}	10.42	10.42	8.75	29.58
SL	7.92	0.83	1.67	10.42
SM	3.75	6.25	0.83	10.83
SH	21.25	13.75	14.17	49.17
Total	43.33	31.25	25.42	100.00
Punish				
S_{No}	4.58	4.17	3.75	12.50
S_L	21.25	2.08	1.67	25.00
S_M	0.42	15.83	0.00	16.25
S_H	13.75	9.58	22.92	46.25
Total	40.00	31.67	28.33	100.00

in Chap. 4, in which the buyers have been also more informative in case of a direct punishment mechanism.

Also, the truthfulness in the no discrimination treatment is significantly higher compared to the baseline treatment (MWU, $p < 0.05$, two-sided), diverging supply chain treatment (MWU, $p < 0.1$,two-sided), and the enforced self-selection treatment (MWU, $p < 0.05$, two-sided). One reason for the higher level of truthfulness in this setting is that the supplier cannot easily exploit truthfulness. This is, because

Table 5.3 Observed truthfulness disaggregated by subjects and treatments

Subject	Baseline (%)	No discrimination (%)	Diverging (%)	Enforced (%)	Punish (%)
1	53	33	33	63	50
2	20	63	45	30	97
3	33	83	33	20	37
4	27	35	30	17	97
5	30	25	35	23	80
6	10	62	33	30	23
7	33	72	37	17	47
8	33	57	22	27	50
Avg	30	54	34	28	60

Table 5.4 Observed consistency disaggregated by subjects and treatments

Subject	Baseline (%)	No discrimination (%)	Diverging (%)	Enforced (%)	Punish (%)
1	80	52	55	53	53
2	47	37	72	20	87
3	37	97	27	20	83
4	67	27	37	37	83
5	77	25	38	27	90
6	23	67	50	23	40
7	10	53	45	13	53
8	40	73	17	13	40
Avg	48	54	43	26	66

an F_i-contract is typically only profit maximizing if the supplier believes that both buyers have the same holding cost realization.

Finally, the MWU-test reveals that the truthfulness in the enforced self-selection treatment is significantly lower than in the no discrimination, diverging supply chain and punishment treatment.

Table 5.4 summarizes the consistency of each buyer disaggregated by subjects. The buyers in the punishment treatment were significantly more consistent compared to the baseline (MWU, $p < 0.1$, two-sided), diverging supply chain (MWU, $p < 0.05$, two-sided), and enforced self-selection (MWU, $p < 0.01$, two-sided) treatment. Additionally, the Mann-Whitney-U test confirms that the subjects in the enforced self-selection treatment are by far the less consistent (all MWU tests are at least significant on the 0.1 level, two-sided).

To analyze the informativeness of a distinctive holding cost signal, the portion of truthful signals for a respective holding cost realization is computed. For example, the buyers in the baseline treatment gave the signal S_M in 10% of all cases. However, only in 3.33% of these cases, their signal was truthful. Hence, the observed frequency of a truthful signal given the signal S_M results from $3.33/10 = 0.333$, i.e., 33.3%. Table 5.5 summarizes these observed frequencies of truthful signals. The analysis reveals that the strategic most relevant signal S_H does carry hardly information, as the frequency of truthful signals given S_H is on average only slightly different from the a-priori probability (0.41 vs.$p_H = 0.3$).

Table 5.5 Observed frequencies of truthful signaling given the respective signal

	h_L (%)	h_M (%)	h_H (%)
Baseline	57	33	35
No discrimination	84	68	50
Diverging	64	77	42
Enforced	76	58	29
Punish	85	97	50
Avg	73	67	41

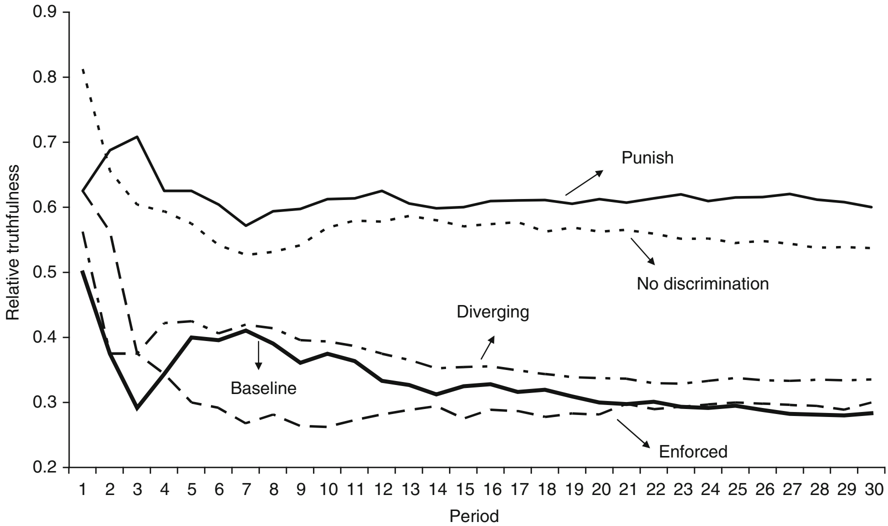

Fig. 5.1 Relative cumulated truthfulness

Yet, the low and medium cost signals are well-above the a-priori probabilities (0.73 vs. $p_L = 0.4$ and 0.67 vs. $p_M = 0.3$) and carry therefore on average at least some information. This result is in-line with the results from the experiment discussed in Chap. 4.

Finally, the relative cumulated frequency of truthfulness and consistency per period were computed. i.e.,

$$\frac{\sum_{i=1}^{8}\sum_{t=1}^{Period} T_{i,t}}{8 \cdot Period},$$

$$\text{where } T_{i,t} = \left\{ \begin{array}{ll} 1, & \text{if subject i reports truthfully (or consistent) in period t} \\ 0, & \text{else} \end{array} \right\},$$

and where "*Period*" is the respective point in time in the respective figure.

Figure 5.1 depicts the relative cumulated truthfulness over time. A Wilcoxon-ranked sign-test gives a weak support for the hypothesis that the buyers' in the

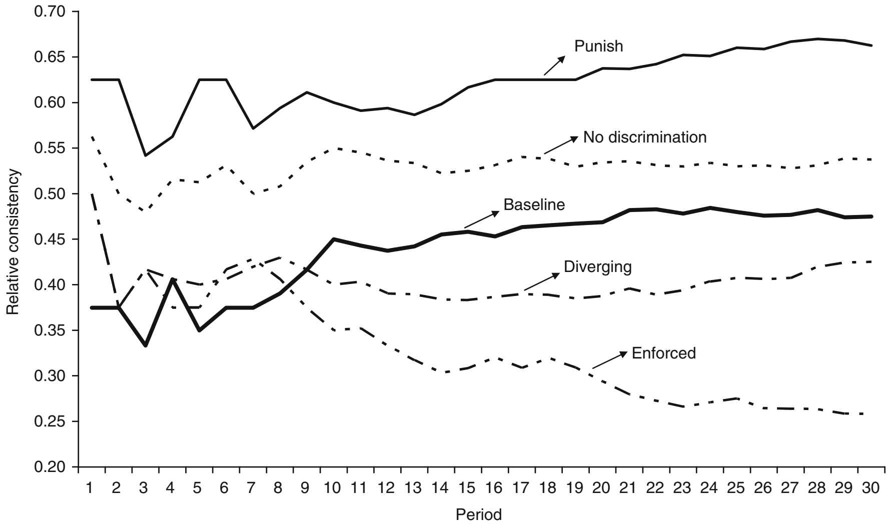

Fig. 5.2 Relative cumulated consistency

enforced self-selection treatment were more informative in the first 15 periods ($p < 0.1$, one-sided).

Figure 5.2 depicts the relative cumulated frequency of consistency over time. The Wilcoxon test gives weak support for the hypothesis that the buyers in the punishment and diverging supply chain were more consistent in the last 15 periods. Furthermore, the buyers in the enforced self-selection treatment were more consistent in the first 15 periods ($p < 0.1$, one-sided). As Figs. 5.1 and 5.2 show relatively homogenous patterns over time, and because all before-mentioned Wilcoxon tests are only weakly significant, it is concluded that the main findings with respect to truthfulness and consistency hold over time.

5.2.2 Do Suppliers React to the Buyers' Shared Information?

In the previous section, it was shown that the buyer's truthfulness can be influenced, e.g., by the installation of a punishment mechanism. Yet, even if all buyers report constantly truthful, this would have no impact on the supply chain performance if the supplier ignores the signals. Table 5.6 shows the cross tabulation of the supplier's received signals and contract offers disaggregated by the respective treatments. Theory predicts that the risk neutral supplier will offer the screening contract, regardless of the signal he receives. However, Table 5.6 shows substantial deviations from this prediction. In the following three reasons beside "white-noise" are listed that might explain why the menu of contract is not offered constantly.

Table 5.6 Cross tabulation of received signals and contract offers disaggregated by treatments

	F_L (%)	F_M (%)	F_H (%)	Menu (%)	*Total* (%)
Baseline treatment					
S_{No}	0.83	1.67	1.67	12.08	16.25
S_L	1.67	0.00	0.42	0.83	2.92
S_M	0.83	3.33	0.00	5.83	10.00
S_H	1.25	4.58	31.67	33.33	70.83
Total	4.58	9.58	33.75	52.08	100.00
Diverging					
S_{No}	3.75	6.88	0.42	18.75	29.79
S_L	1.46	0.83	0.83	4.38	7.50
S_M	0.00	2.50	0.83	3.13	6.46
S_H	1.25	2.50	21.25	31.25	56.25
Total	6.46	12.71	23.33	57.50	100.00
Enforced					
S_{No}	1.25	3.33	0.83	24.17	29.58
S_L	2.08	1.67	0.83	5.83	10.42
S_M	0.00	2.92	0.00	7.92	10.83
S_H	0.00	4.58	8.33	36.25	49.17
Total	3.33	12.50	10.00	74.17	100.00
Punish					
S_{No}	0.42	2.92	0.42	8.75	12.50
S_L	3.33	1.67	0.00	20.00	25.00
S_M	0.00	7.08	4.58	4.58	16.25
S_H	1.25	5.42	27.92	11.67	46.25
Total	5.00	17.08	32.92	45.00	100.00
No discrimination					
	4.58	4.58	17.50	73.33	100.00

Table 5.7 Mean and standard deviation of the contract offers

	F_{low}	F_{med}	F_{high}	A
$E[P_s]$	46.76	47.22	36.90	50.83
σ	67.49	38.95	0.00	22.49

5.2.2.1 Risk Preferences

Risk preferences that are different from risk neutrality might explain the high frequency of F_i- contracts across treatments. This is, because the screening menu A maximizes the utility for a risk neutral supplier but not necessarily for a supplier with other risk preferences.

Table 5.7 summarizes the expected payoffs and the standard deviation of payoffs of the respective contract offers given that the buyer chooses the profit maximizing contract. As an example, the buyer accepts the contract F_L with a probability $p_L = 0.4$. Hence, the expected payoff of offering F_L results from $E[P_s] = 0.4 \cdot 116.9 = 46.76$ and the standard deviation results from $\sigma = 67.49$. The screening contract A obviously yields the highest expected profits. However, assuming risk aversion for the supplier, he could prefer F_H. A risk seeking supplier, in contrast, could prefer the contracts F_L or F_M. It is referred to Sect. 4.3.1 for an extensive discussion on how risk preferences can be considered by designing an optimal menu of contracts. Yet, next it will be shown that risk preferences that are linked to the payoff variations can only partly organize the data.

5.2.2.2 Strategic Risk

On average, the buyers tend to choose the indifference contract in 9% of all observations.[1] In this case, the supplier faces high (opportunity) costs while the profit impact for the buyer is negligible.

Consider a buyer who faces holding costs h_M and gives the deceptive signal S_H. In case the supplier offers the menu of contract, the buyer can easily pretend to be honest by choosing A_H. In this case, however, the buyer would not choose the contract that fits to his holding cost, but the contract that fits to his signal. As the supplier knows that this action causes almost no cost for the buyer, the supplier might offer the F_i – contract not because he believes in the signal, but because he believes that the buyer would choose the signaled contract anyway. In this case, the supplier would be cautious to offer the screening contract and offer simpler F_i-contracts instead. In the following the suppliers' risk of the buyer choosing the indifference contract is denoted strategic risk, as it might be linked to the strategy of uncovering deceptive signals.

Obviously, there does not exist such a strategy in the enforced self-selection contract as the buyer cannot cover up a deceptive signal once the screening contract is offered. Furthermore, the strategic risk is lower in the treatments with two buyers, i.e., in the diverging supply chain and no discrimination treatments. The following example might make this point clear. Let I denote the relative frequency of indifference contract choices. Table 5.8 summarizes the expected costs that arise due to the buyer choosing the indifference contract. Note that these are in fact opportunity costs, as they compare the cost differences to the situation in which the buyer perfectly self-selects.

As an example, the relative frequency of indifference choices is set to $I = 9\%$ (which is the actual ex-post value across all treatments). In this case, the suppliers'

Table 5.8 Expected payoffs given a serial supply chain in the presence of indifference contract choices

Contract choice	h_L	h_M	h_H
Probability	$p_L \cdot I$	$p_M \cdot I$	$p_H \cdot I$
Payoff	$(P_{s,L} - P_{s,M}) = 30.41$	$(P_{s,M} - P_{s,H}) = 13.49$	$P_{s,H} = 29.23$

[1]This is, in 9% of all observations the buyers chose the contract A_M (A_H) while facing holding costs $h_L(h_M)$.

Table 5.9 Expected costs in case both buyers choose indifference contract

Contract choice and probability			*Buyer 2* h_L $p_L \cdot I$	h_M $p_M \cdot I$	h_H $p_H \cdot I$
	h_L	$p_L \cdot I$	30.41	21.95	29.82
	h_M	$p_M \cdot I$	21.95	13.49	21.36
Buyer 1	h_H	$p_H \cdot I$	29.82	21.36	29.23

Table 5.10 Expected costs in case one out of two buyers chooses the indifference contract

Contract choice and probability			*Buyer 2* h_L $p_L \cdot (1 - I)$	h_M $p_M \cdot (1 - I)$	h_H $p_H \cdot (1 - I)$
	h_L	$p_L \cdot I$	15.21	15.21	15.21
	h_M	$p_M \cdot I$	6.75	6.75	6.75
Buyer 1	h_H	$p_H \cdot I$	14.62	14.62	14.62

expected (opportunity) costs are equal to $\mu_1 = 2.25$ and the standard deviation is equal to $\sigma_1 = 7.18$. The index depict that there is only one buyer. In contrast, when there are two buyers, then the probability that both suppliers chooses the indifference contract is only $I^2 = 0.09 \cdot 0.09 = 0.008$, that one supplier chooses the indifference contract is $2 \cdot I \cdot (1 - I) = 2 \cdot 0.09 \cdot 0.91 = 0.164$, and that no supplier choose the indifference contract is $(1 - I)^2 = 0.91^2 = 0.828$, respectively. In case both buyers choose the indifference contract, the following average opportunity costs per buyer arise (see Table 5.9). For notational convenience, the payoff numbers $P_{s,i}, i \in L, M, H$ are directly inserted.[2]

In contrast, Table 5.10 depicts the case in which only buyer 1 chooses the indifference contract. The expected opportunity costs in the diverging supply chain are obviously not different from the expected costs in the serial supply chain, as the independence of both buyers is assumed. It follows that $\mu_2 = \mu_1 = 2.25$. Yet, the standard deviation drops to $\sigma_2 = 5.57 < \sigma_1$. Hence, the risk that is associated with the buyer choosing the indifference contract is smaller if the number of buyers increases. Hence, if the suppliers are really cautious to offer the screening contracts because of the strategic risk, than the frequency of screening contract offers should be higher in the enforced self-selection treatment (as there is no strategic risk at all), followed by the diverging supply chain and no discrimination treatment.

Figure 5.3 shows the relative cumulated frequency of screening contract offers which is calculated by

[2] As an example, the average opportunity costs per buyer in case of one buyer having holding costs h_L and the other buyer h_H results from $\left(P_{s,L} - P_{s,M} + P_{s,H}\right)/2 = 29.82$.

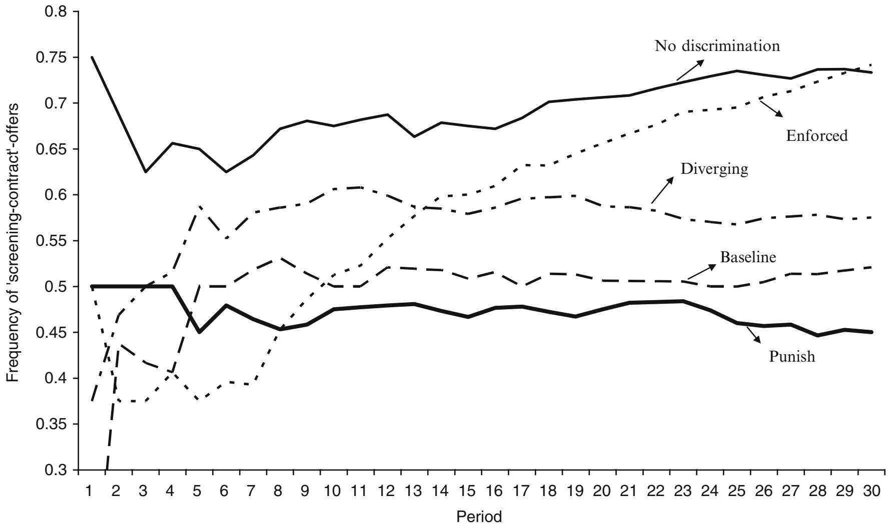

Fig. 5.3 Cumulated relative frequency of "screening-contract" offers disaggregated by treatment and period

$$\frac{\sum_{i=1}^{8}\sum_{t=1}^{Period} T_{i,t}}{8 \cdot Period}, \text{where } T_{i,t} = \left\{ \begin{array}{l} 1, \text{ if subject i offers Menu in period t} \\ 0, \text{ else} \end{array} \right\},$$

and where "*Period*" the respective point in time in the figure.

Obviously, there is a difference in how often subjects tend to use the screening contracts in the respective treatments. The above-mentioned strategic risk seems to organize the data quite well. In the last period, the treatments with the highest cumulated relative frequency of screening contract offers are the treatments with the least strategic risk, i.e., the diverging supply chain with and without price discrimination, and the enforced self-selection treatment (in which no strategic risk exists). This stresses that the subjects seem to anticipate the buyers' strategic scope to choose the indifference contract. In other words, the suppliers anticipate that the incentive constraint used in screening contracts does sometimes simply fail.

Note, however, that the frequencies of screening contract offers are significantly different in the diverging supply chain and no discrimination framework, although there is the same level of strategic risk. Yet, this difference is basically due to the fact that the supplier is restricted to offer only one contract in the no discrimination framework.

The comparison of the baseline- and the enforced self-selection treatment clarifies that the tendency towards simpler F_i-contracts in the baseline-treatment cannot be simply explained by risk-aversion that is associated with predicted payoff variations that are model inherent due to the stochastic nature of asymmetric information, as this risk is constant across these both treatments. In contrast, if suppliers totally trusted in the incentive mechanism used in screening contracts, there would be no difference at all between those two treatments. Yet, even though it cannot be ruled out that risk aversion influences the decisions of the suppliers, the comparison of the baseline and enforced self-selection treatment shows that the incentive constraint used in screening contracts is empirically problematic.

Finally, a series of Wilcoxon test were run to test whether the frequency of screening-contract offers are significantly different in the first 15 and last 15 periods. The screening contract in the enforced self-selection ($p < 0.01$, wo-sided) as well as no discrimination treatment ($p < 0.1$, two-sided) was offered significantly more often in the last 15 periods ($p < 0.01$, two-sided). Hence, it seems that the low level of screening contract offers in the beginning of the experiment does partly stem from the fact that the suppliers react to the signals (this point is discussed and analyzed more intensively in the next section). All remaining Wilcoxon-tests show no significant results.

5.2.2.3 Trust

Note that the suppliers' contract offers in dependence of the signal are hardly interpretable in terms of trust in the no discrimination treatment. This is because the supplier gets two signals, but is only allowed two offer one contract. Hence, it is possible that it is profit maximizing to offer the menu of contracts even though he totally trusts both signals. In turn, it might even be optimal for the supplier to offer a contract to the buyer which does not satisfy the participation constraint of this buyer. Consider the supplier getting the signals S_L and S_M, respectively. If he perfectly believes in both signals, it is profit maximizing to offer F_L although he knows that the buyer with the signal S_M will apparently reject the offer. This highlights that a reliable interpretation with respect to trust is not possible for the no-discrimination treatment.

Figure 5.4 depicts the relative cumulated frequency of contract offers F_i after receiving signal S_i per period, i.e., $\frac{\sum_{i=1}^{8}\sum_{t=1}^{Period} T_{i,t}}{8 \cdot Period}$, where $T_{i,t} = \left\{ \begin{array}{ll} 1, & \text{if subject i trusts in period t} \\ 0, & \text{else} \end{array} \right\}$, and "*Period*" is the respective point in time in the figure.

Note that this metric does not necessarily depict trust. Also, this action can be due to strategic risk (see Sect. 5.2.2.2), or due to risk aversion (see Sect. 5.2.2.1). Yet, the strategic risk can be ruled out in the enforced self-selection treatment. However, also risk-preferences alone cannot explain the contract offers in this treatment.

Table 5.11 depicts the cross tabulation of signals and contract offers for the supplier in the second supply chain in the enforced self-selection treatment. Obviously, the data cannot be explained by risk preferences alone, since risk preferences should not be dependent on the signal. In other words, if a subject is for example risk averse, then he should offer the F_H-contract throughout the experiment.

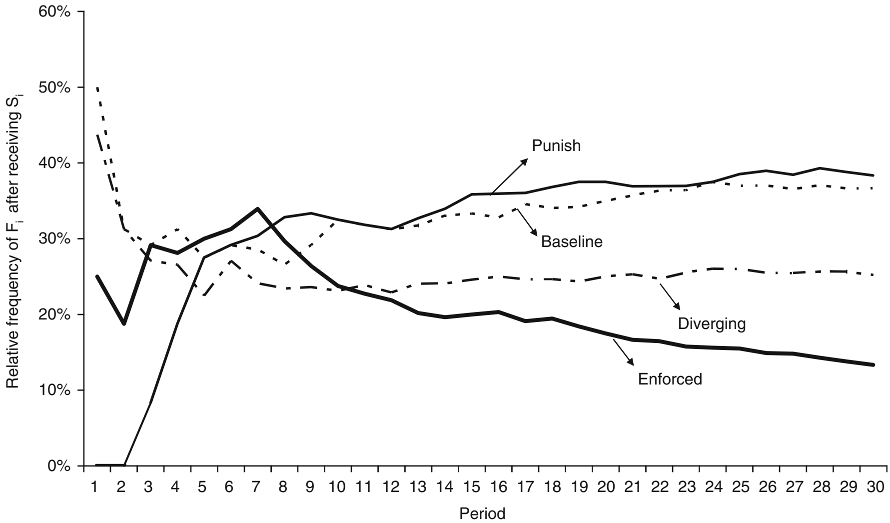

Fig. 5.4 Cumulated relative frequency of contract offers F_i after receiving signal S_i per period

Table 5.11 Cross tabulation of signal and contract offer for subject 10 in enforced self-selection treatment

	F_L	F_M	F_H	Menu
S_{No}	0	1	0	11
S_L	3	0	0	3
S_M	0	2	0	1
S_H	0	1	1	7

However, Table 5.11 shows that all possible F_i-contracts were offered, and that most of these offers match the signal. Yet, such a behavior can be found for some subjects in every treatment. Hence, it is concluded that at least some of the F_i-offers can be explained by trusting behavior.

Interestingly, the Wilcoxon test with the alternative hypothesis that there is a difference between the actions in the first and last 15 rounds (see Fig. 5.4) is only significant in the enforced self-selection treatment ($p < 0.05$, two-sided). Hence, it seems that the subjects in this treatment tend to believe in the beginning, but loose their faith in the signals later on. That is why they choose the screening contracts more frequently later on.

However, the Wilcoxon test is not significant for the other treatments. This is, because mistrusting in later rounds does not necessarily mean to offer the screening contract. In fact, taking the strategic risk into account, it might be better to offer simple F_i-contracts, which seem to resemble trusting behavior. Hence, the seemingly constant level of trust seems to stem from partial trusting in the beginning, and coping with the strategic risk in the end. Hence, the metric of trust used in Fig. 5.4 overestimates the level of trust in all treatments in which the strategic risk is not ruled out.

Table 5.12 Ratio of F_i-contract and screening contract given signal S_i

	F_L	F_M	F_H
Baseline	0.572	0.571	0.950
Diverging	0.195	0.799	0.680
Enforced	0.200	0.369	0.230
Punish	0.133	1.546	2.392

Nonetheless, even though the measure in Fig. 5.4 does not perfectly measure trust, it seems that the level of trust seems to be highest in the punishment treatment. A closer look at the cross tabulations in Table 5.2 reveals that the suppliers assess the signal S_H quite differently across treatments. As an example, in the baseline treatment the ratio between F_H and menu contract offers given the signal S_H is equal to 0.95.[3] A ratio smaller than one indicates that the suppliers offered more often the menu of contracts than F_H-contract after receiving the high cost signal, and vice versa. The data shows ratios smaller than one except for the punishment treatment. In these treatments the suppliers tend to offer relatively more often the F_i-contracts than the menu after receiving medium or high cost signals, respectively. Assuming that the strategic risk of the indifference contract choice is equal or smaller in the punishment treatment compared to the baseline treatment, the ratios indicate that there is a higher level of trust in the punishment treatment.

Table 5.12 summarizes these ratios for every treatment and signal, respectively. The data shows ratios smaller than one except for the punishment treatment. In this treatments the suppliers tend to offer relatively more often the F_M and F_H-contracts than the menu after receiving medium or high cost signals, respectively. Assuming, that the strategic risk of the indifference contract choice is equal or smaller in the punishment treatment compared to the baseline treatment,[4] the ratios indicate a higher level of trust in the punishment treatment.

5.2.3 The Buyers' Contract Choice Behavior

In Sect. 4.4 the distinction between the "indifference"- and the "self-selection" contract was already discussed. Theory assumes that all buyers choose the "self-selection"-contract and accept an offer as long as the participation constraint is

[3]That is, 31.67%/33.33%.

[4]This assumption is supported by two findings. First, the data in Sect. 5.2.3 reveals that the buyers choose on average substantially less often the indifference contract in the punishment treatment. Yet, it is likely that the supplier's assessment of the strategic risk is dependent upon the observed contract choices. This is, if the supplier observes considerably more often contract choices which might be indifference contract choices, then he is likely to perceive a higher strategic risk, and vice versa. Second, given this observation, the supplier has an instrument to punish the buyer for the perceived strategic risk. Therefore, it is concluded that the strategic risk is at worst equal to the baseline treatment, but likely to be smaller.

satisfied. However, the data shows substantial deviations from these predictions. Basically, the buyers' contract choices can be divided into five categories. First, the buyer can choose the profit maximizing contract in each round, i.e., he accepts an offer as long as the participation constraint is satisfied and chooses the self-selection contract in case a screening contract was offered. Second, the buyer chooses the indifference-contract, i.e., he chooses A_M (A_H) although he faces holding costs of $h_L(h_M)$. Third, the buyer chooses the alternative supplier when being indifferent, i.e., if he faces holding costs h_H or if $F_i = h_i, i \in (L, M, H)$ holds. Fourth, the buyer chooses the alternative supplier because his participation constraint is not satisfied, which is only possible if the supplier offers F_L or F_M. Finally, the buyer can bear a profit loss higher than 0.1, i.e., higher than the amount that ensures strict incentives. Table 5.13 summarizes all the buyers' contract choices given the above classifications disaggregated by treatments.

Interestingly, the buyers chose on average in 98% of observations optimal or nearly optimal contracts. Only in 2% of the observations the buyers choose a contract which causes a loss higher than 0.1 compared to the next alternative. However, we observe that the indifference-contract was chosen in 9% of all contract choices.

A series of Mann-Whitney U test reveals that the buyers in the punishment treatment choose significantly more often the profit maximizing contract compared to the baseline treatment ($p < 0.01$, two-sided), diverging supply chain treatment ($p < 0.05$, two-sided), and enforced self-selection treatment ($p < 0.05$, two-sided). Furthermore, the buyers in the punishment treatment choose significantly less often the alternative supplier compared to the diverging supply chain treatment ($p < 0.05$, two-sided) and the enforced self-selection treatment ($p < 0.01$, two-sided). This highlights that the punishment option makes the buyers acting more like theory predicts, because deviating behavior that deteriorates the supplier's performance can be punished. There are no more significant differences than reported above. In particular, even the comparison of indifference contract choices in the punishment treatment compared to the other treatments is not significant, even though the average of indifference contract choices is substantially lower, i.e., 3% vs. 11%.

5.2.4 Do the Suppliers' Rewards Facilitate Supply Chain Coordination?

The previous analysis showed that the buyers' signals are hardly informative in all treatments except the punishment treatment. Obviously, truthful information sharing does only benefit both supply chain parties, as long as the additional side-payment Z_R is sufficiently large.

Table 5.14 summarizes the minimum additional side-payment, $Z_R^{\min}$, for which the buyer would be indifferent between reporting truthfully and accepting

Table 5.13 Buyers' contract choices

Treatment	Subject (%)	Profit maximum (%)	Indifference contract A_M or A_H (%)	Indifference contract – alternative supplier (%)	Profit loss > 0.1 (%)	Participation constraint not satisfied (%)
	1	80	0	10	0	10
	2	53	30	13	0	3
	3	67	10	17	0	7
	4	57	10	13	10	10
	5	80	3	3	10	3
	6	90	3	0	0	7
	7	63	0	33	0	3
Baseline	8	97	0	0	0	3
	1	60	23	10	0	7
	2	27	40	33	0	0
	3	90	3	3	3	0
	4	83	0	7	0	10
	5	100	0	0	0	0
	6	60	17	13	7	3
	7	20	37	43	0	0
	8	83	13	3	0	0
	9	67	7	27	0	0
	10	63	10	17	10	0
	11	100	0	0	0	0
	12	70	0	17	0	13
	13	100	0	0	0	0
	14	73	3	7	7	10
	15	100	0	0	0	0
No discrimination	16	33	27	37	0	3
	1	57	13	27	0	3
	2	67	3	13	7	10
	3	97	0	0	0	3
	4	90	0	3	0	7
	5	53	17	30	0	0
	6	67	0	20	0	13
	7	97	0	3	0	0
	8	37	23	23	0	17
	9	57	10	23	10	0
	10	87	0	10	0	3
	11	63	23	13	0	0
	12	70	20	3	0	7
	13	33	43	23	0	0
	14	67	13	7	0	13
	15	17	43	27	13	0
Diverging	16	60	0	27	0	13
	1	77	0	13	3	7
	2	73	0	17	0	10
	3	90	0	7	0	3
	4	80	0	17	0	3
	5	83	0	13	3	0
	6	63	0	30	0	7
	7	80	0	13	0	7
Enforced	8	77	0	23	0	0

(continued)

Table 5.13 (continued)

Treatment	Subject (%)	Profit maximum (%)	Indifference contract A_M or A_H (%)	Indifference contract – alternative supplier (%)	Profit loss > 0.1 (%)	Participation constraint not satisfied (%)
	1	97	0	0	0	3
	2	87	3	10	0	0
	3	83	7	3	3	3
	4	87	3	10	0	0
	5	93	0	0	0	7
	6	77	0	7	10	7
	7	97	0	3	0	0
	8	80	7	7	0	7
Punish	Avg	72	9	13	2	4

Table 5.14 Side-payments Z_R^{min} that lead to win–win situations

	F_{low}	F_{med}	F_{high}
Z_R^{min}	43.77	18.78	0

a F_i-contract. For example, if the buyer faces the holding cost h_M he would be indifferent between the contracts F_M and A_M given the additional side-payment $Z_R^{min} = 21.88 - 3.1 = 18.78$.

Figure 5.5 shows the box-plots of side-payments Z_R disaggregated by treatments and contract acceptance (i.e., A_i- or F_i-contracts). Surprisingly, no side-payments (except one outlier) suffice to ensure win-win situations given the contract choices F_L or F_M in all treatments except the punishment treatment. Thus, it does not surprise that the supply chain parties do not coordinate to the supply chain optimum and communication does not show the favorable impact.

Table 5.15 summarizes the total size of rewards disaggregated by subjects and treatments. A Mann-Whitney-U test reveals only significant differences between the no discrimination and diverging supply chain treatment ($p < 0.01$). As the total size of rewards is higher in the no discrimination treatment, it seems that the suppliers reward the buyers for more consistency (see Sect. 5.2.1).

Finally, the Spearman-correlation coefficient was computed to test whether the total size of the side-payment has a significant impact on the buyers' contract choice or signaling behavior. It was tested whether there is an impact on the frequency of alternative supplier choices (see Table 5.13), indifference contract choices (see Table 5.13), or on the buyers' consistency or truthfulness (see Tables 5.3 and 5.4). However, none of the correlation coefficients are significant, which highlights that the rewards are too low to have a significant impact on the buyers' choice and signaling behavior.

Finally, it is worth to mention that the punishment option was used rather seldom. Table 5.16 summarizes the absolute frequency and total size of punishments disaggregated by supply chains (in the punishment treatment). Only in 14 out of 240 observations the punishment option was used. In 6 out of these 14 cases, the supplier punished the buyer for choosing the alternative supplier.

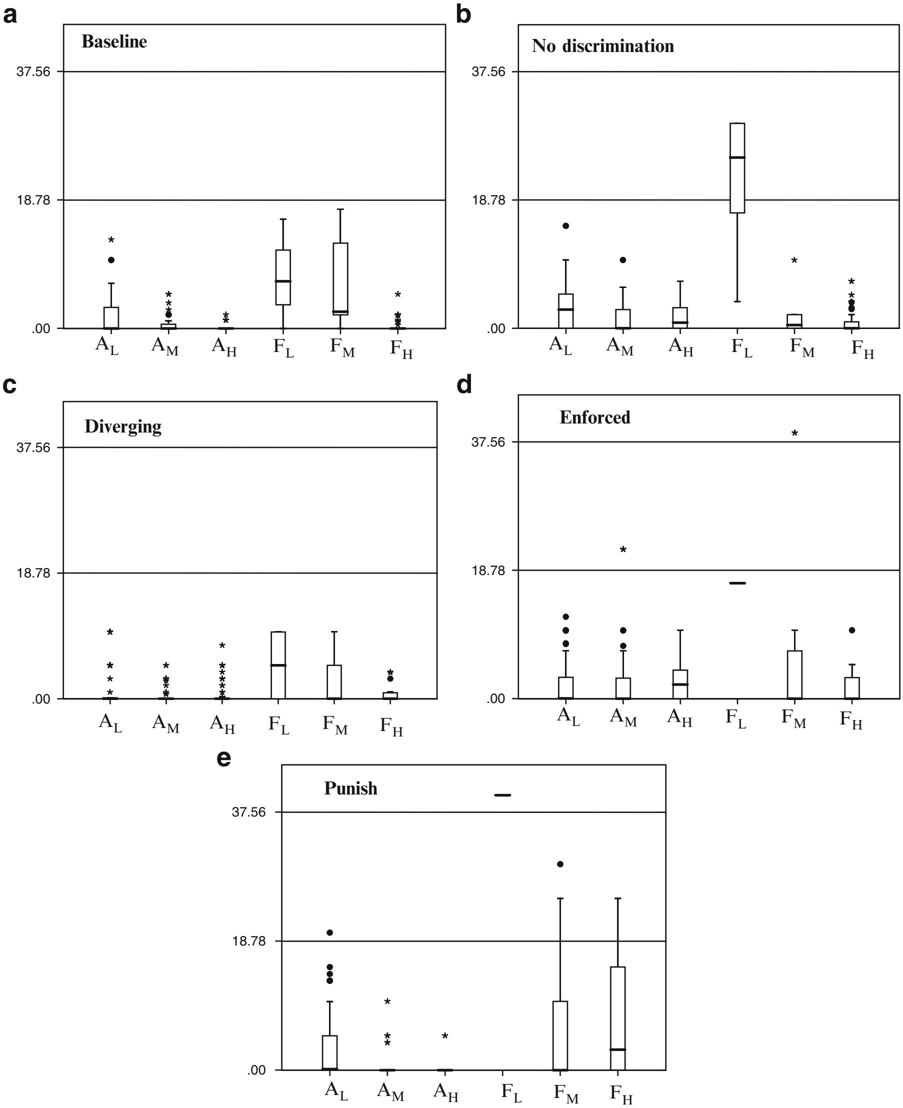

Fig. 5.5 Box-plots of side-payments Z_R disaggregated by treatments and contract acceptance Box-plots of side-payments Z_R: (a) Baseline treatment. (b) No-discrimination treatment. (c) Diverging supply chain treatment. (d) Enforced self-selection treatment. (e) Subtle punishment treatment

Interestingly, there is also no significant Spearman rank correlation between the total size of the punishment and the buyers' contract choice behavior, consistency or truthfulness. This highlights that the mere presence of the punishment option helps to align the actions of the supply chain parties.

Table 5.15 Total size of additional side-payment disaggregated by subjects and treatments

Subject	Baseline	No discrimination	Diverging	Enforced	Punish
1	35.82	3	9.95	0.8	64
2	5	67.5	0.17	42.15	202
3	38.42	15.94	36.5	35	0
4	3.92	12.14	29.5	49.96	117
5	0	55	0	9	474
6	0	75.6	9	16	0
7	40	41.68	2.5	92	0
8	0	14.3	0	0	0
Avg	15.395	35.645	10.9525	30.61375	107.125

Table 5.16 Total size and absolute frequency of punishment

Supply chain	1	2	3	4	5	6	7	8
Total size	0	0	0	81	40	100	0	180
Absolute frequency	0	0	0	3	1	5	0	5

5.3 Performance Impact

The previous analysis of the suppliers' and buyers' decision behavior shows substantial deviations from the theory's prediction. Two benchmarks are introduced to elaborate the influence of the suppliers' contract offers on the profits of buyers, suppliers and the overall supply chains. Note that the performance is measured by comparing observed outcomes to the benchmark given the actual realization of the holding cost parameters. This gives more exact measures than comparisons to the expected benchmark, because the effect of stochastic cost variations is neutralized.

The first benchmark captures the situation in which no menu of contracts is available and the participation constraint must not be violated. In this case the supplier offers constantly F_H. In the following, this benchmark will be denoted as F_{high}. As the participation constraint is always satisfied for F_H, the buyer should theoretically accept all contracts in this benchmark. However, a non negligible portion of buyers chose the alternative supplier although the participation constraint was satisfied. Yet, these observations are excluded from the following analysis since additional assumptions are required to evaluate the welfare effects of choosing the alternative supplier.

The second benchmark is the theoretical equilibrium under asymmetric information, i.e., the supplier offers the menu of contracts A while the buyers choose the self-selection contracts. Again, all observations in which the buyers chose the alternative supplier are excluded. This benchmark is called the "Screening-benchmark".

From a supply chain perspective, the screening benchmark lies above the F_{high} benchmark.

Note, however, that the F_{high} benchmark can theoretically lie above the screening benchmark, as observed outcomes (ex-post) instead of expected outcomes (ex-ante) are evaluated. As an example, this would happen if the buyer constantly faces the holding costs h_H. From $q_H^{FI} > q_H^{AI}$ follows directly that offering F_H would be ex-post superior to offering the menu of contracts A. However, this was not observed in the underlying experiments. Hence, offering screening contracts under the self-selection assumption was ex-post superior compared to constantly offering F_H.

Nonetheless, in case of trust and trustworthiness even the screening benchmark can be outperformed. The following analysis therefore allows to evaluate whether screening contracts outperform the simple compensation scheme as theoretically predicted, or whether the supply chain members engage in truth-telling and trust. In this case, the screening contracts would be empirically unnecessary, as the actors coordinate to the supply chain optimum even though there is no ex-ante incentive alignment by the compensation scheme. Sections 5.3.1 and 5.3.2 summarize the performance for the buyer and supplier, respectively, while Sect. 5.3.3 presents the performance for the overall supply chain.

5.3.1 Buyer

Figures 5.6–5.10 compare the observed performance with the screening and F_{high} benchmarks for every buyer in every treatment.

The buyers in all treatments do significantly perform worse than in the benchmark F_{high}. This highlights that the buyers were not able to constantly deceive the suppliers with high cost signals. Furthermore, some buyers improved the performance compared to the screening benchmark while others are worse off. Furthermore, a series of Mann-Whitney-U tests were run on the alternative hypothesis that the observed deviations from the screening benchmark differ across treatments. However, none of these tests was significant. In other words, there are no significant effects of treatment variables on the buyers' payoffs. This shows that the payoffs of the buyers are relatively robust. On the one hand, this is due to the fact that the buyers strategic scope of contract choices has hardly an effect on the performance, as payoff differences between the alternatives are negligible in most situations. Nonetheless, an inspection of the Figs. 5.6 and 5.9 leads to the suggestion that the buyers in the baseline treatment are more likely to improve their performance compared to the screening benchmark, while there is no such tendency in the enforced self-selection contract. The reason is that the suppliers tend to offer more often F_H in the baseline treatment because of the strategic risk. Yet, the sample size is probably too small in the baseline treatment to get a significant result that the buyers improve their performance compared to the screening benchmark.[5]

[5]The sign-test (two-sided) reveals no significant results for the hypothesis that buyers improve their performance compared to the screening benchmark: Baseline ($p < 0.289$), No discrimination ($p < 0.581$), Diverging supply chain ($p < 0.607$), Enforced self-selection ($p < 1.00$), Punishment ($p < 0.727$). Also, a Wilcoxon test gives no significant results: Baseline ($p < 0.674$), No discrimination ($p < 0.650$), Diverging supply chain ($p < 0.532$), Enforced self-selection ($p < 0.326$), Punishment ($p < 0.674$).

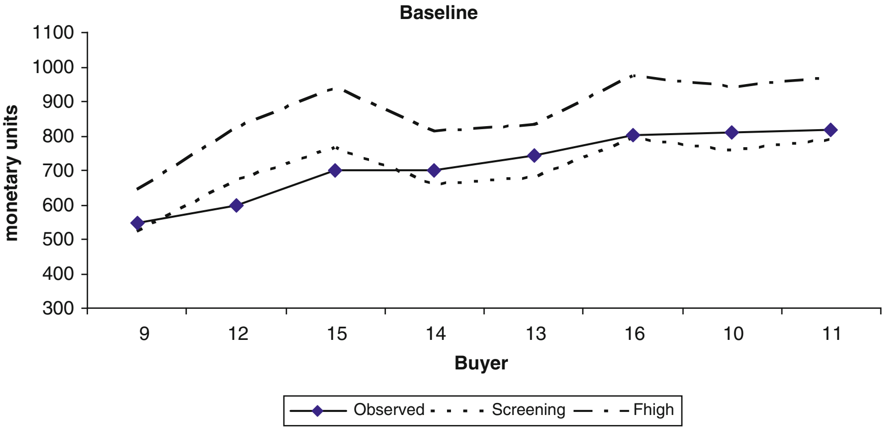

Fig. 5.6 Buyers' observed performance compared to benchmarks in the baseline treatment

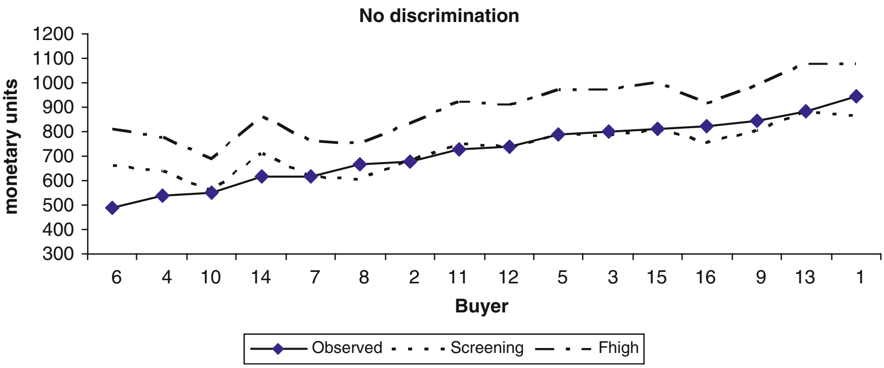

Fig. 5.7 Buyers' observed performance compared to benchmarks in the no discrimination treatment

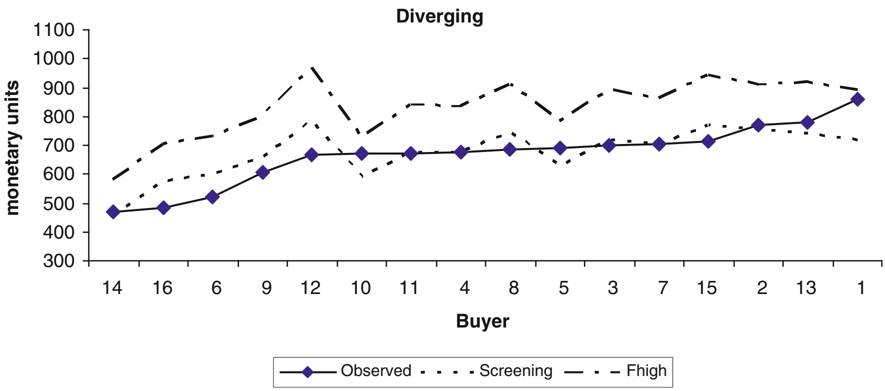

Fig. 5.8 Buyers' observed performance compared to benchmarks in the diverging supply chain treatment

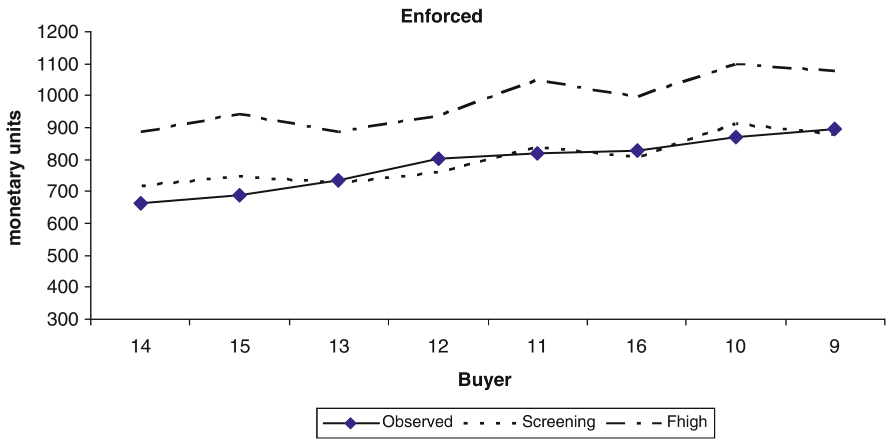

Fig. 5.9 Buyers' observed performance compared to benchmarks in the enforced self-selection treatment

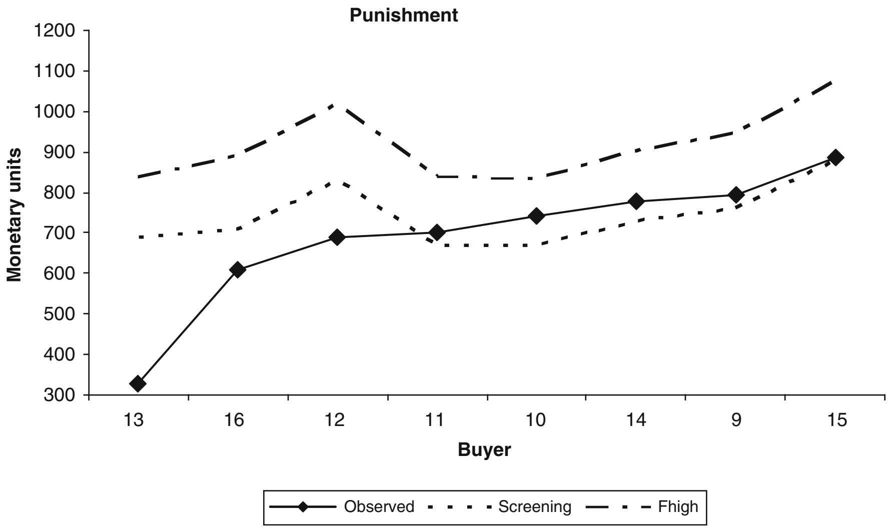

Fig. 5.10 Buyers' observed performance compared to benchmarks in the punishment treatment

5.3.2 *Supplier*

Figures 5.11–5.15 compare the observed performance with the screening and F_{high} benchmarks for every supplier in every treatment.

The suppliers' performance is significantly better in all treatments than the F_{high} benchmark. The screening contracts, thus, which have been used on average in 54% of all observations, are a useful instrument for the suppliers to improve their own

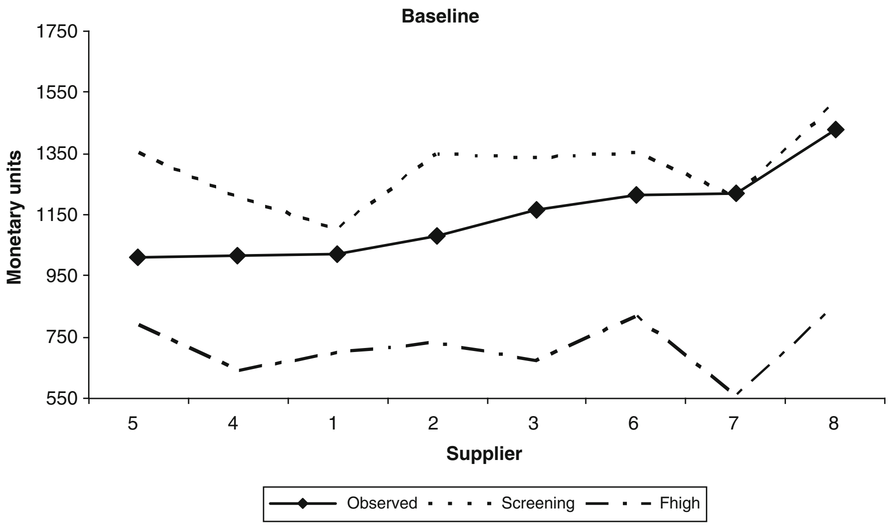

Fig. 5.11 Suppliers' observed performance compared to benchmarks in the baseline treatment

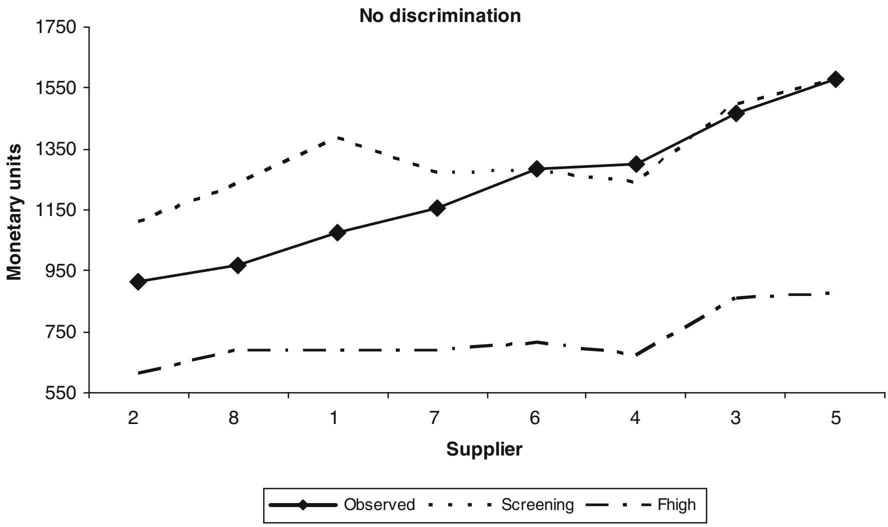

Fig. 5.12 Suppliers' observed performance compared to benchmarks in the no discrimination treatment

performance. Nonetheless, in the Baseline treatment as well as the diverging supply chain treatment, the performance deviates significantly from the screening benchmark (Wilcoxon, $p < 0.017$ for both treatments, two-sided), and weakly significant in the no discrimination treatment (Wilcoxon, $p < 0.091$, two-sided). The Wilcoxon-ranked sign test is neither significant for the enforced self-selection

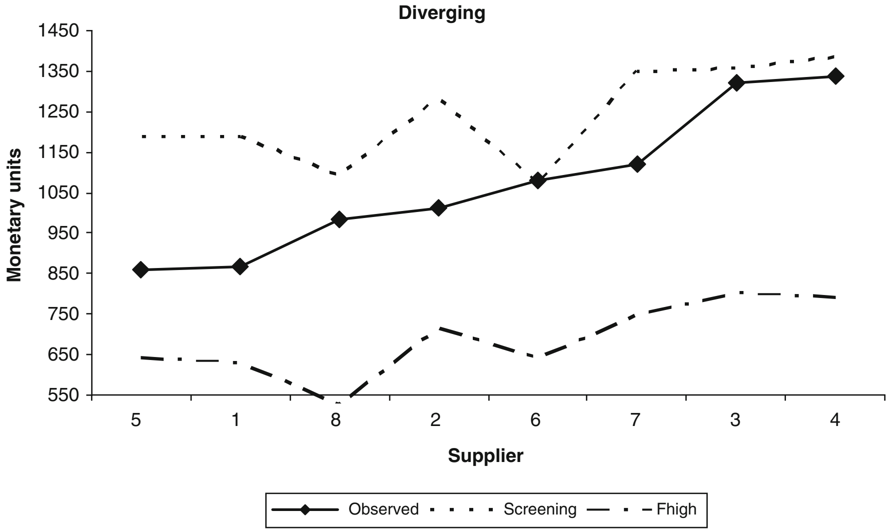

Fig. 5.13 Suppliers' observed performance compared to benchmarks in the diverging supply chain treatment

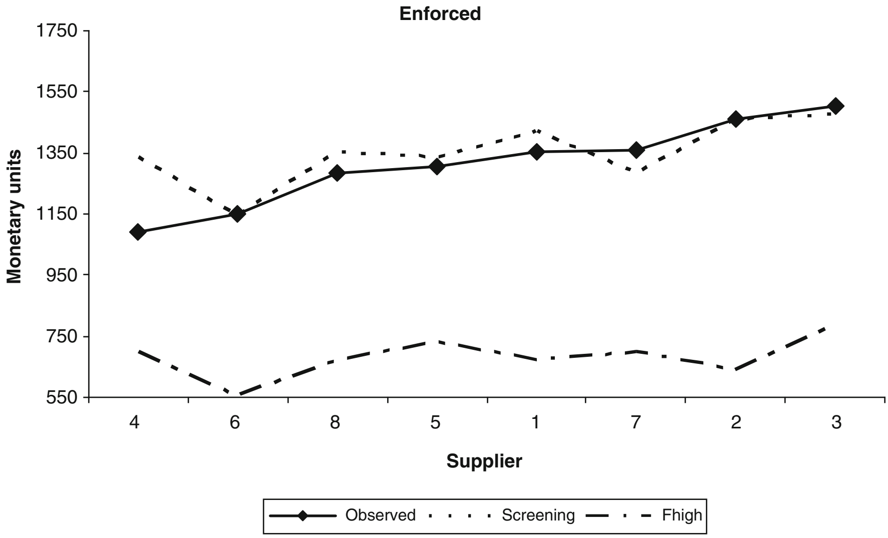

Fig. 5.14 Suppliers' observed performance compared to benchmarks in the enforced self-selection treatment

treatment ($p < 0.484$, two-sided) nor for the punishment treatment ($p < 0.866$, two-sided).

A comparison of the baseline and the enforced self-selection treatment (see Figs. 5.11 and 5.14), thus, highlights that the strategic risk, which leads towards

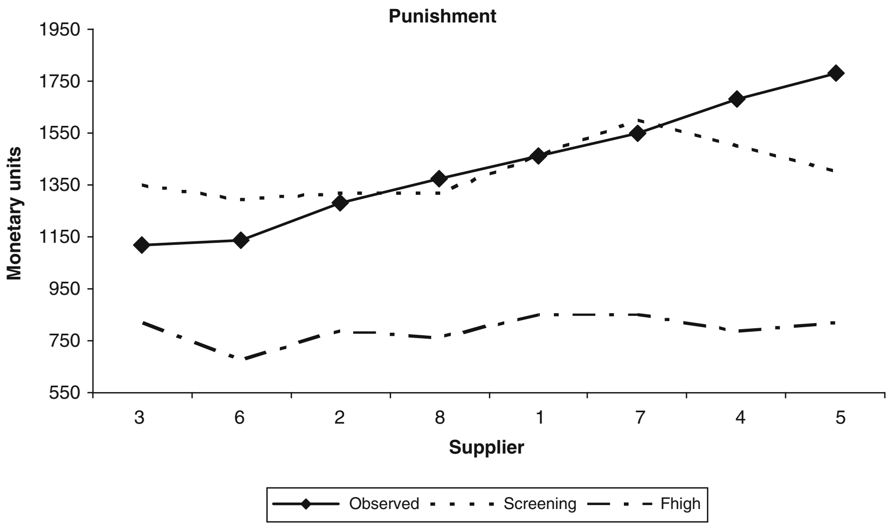

Fig. 5.15 Suppliers' observed performance compared to benchmarks in the punishment treatment

more frequent F_H-offers, is costly for the suppliers. Also, a reduction of the strategic risk, as in the diverging supply chain does not eliminate this effect (see Figs. 5.13 and 5.14).

Also, a series of Mann-Whitney-U test reveals that the suppliers in the baseline treatment perform significantly worse than in the enforced self-selection ($p < 0.038$, two-sided) and punishment ($p < 0.021$, two-sided) treatment. The same result holds for the diverging supply chain treatment in which the performance deteriorates compared to the enforced self-selection ($p < 0.015$, two-sided) and punishment ($p < 0.007$, two-sided) treatment.

This highlights that the indifference contract choice (and therefore the strategic risk) is the main source of performance deterioration for the supplier. If the indifference contract choice can be ruled out, as in the enforced self-selection treatment, or if the frequency of indifference contract choices can be limited, such as in the punishment treatment, then the suppliers performance does significantly improve.

Finally, it is worth to mention that the suppliers' performance in the punishment treatment is not significantly lower than the screening benchmark, although the frequency of screening contract offers is relatively low in this treatment (see Fig. 5.15). This highlights that the punishment option helps on average to offer F_i-contracts that fit to the respective holding costs. This is especially due to the fact that the punishment option leads to more trust (see Sect. 5.2.2.3) as well as more trustworthiness (see Sect. 5.2.1).

5.3.3 Supply Chain

Figures 5.16–5.20 compare the observed performance with the screening and F_{high} benchmarks for every supply chain in every treatment. All observations in the diverging supply chain setting (with and without price-discrimination) were averaged over both buyers.

The Wilcoxon-ranked signed test reveals that the supply chain performance deteriorates compared to the screening benchmark in the baseline treatment ($p < 0.012$, two-sided), no discrimination treatment ($p < 0.028$, two-sided), diverging supply chain ($p < 0.018$), and the enforced self-selection treatment ($p < 0.036$, two-sided). This highlights that the interaction of strategic risk, indifference contract choices, communication and trust leads to a significant performance deterioration of the supply chain compared to the screening benchmark. However, the performance deterioration is no longer observable as soon as an appropriate punishment mechanism is introduced. This punishment mechanism seems to be effective to reduce the frequency of indifference contract choices, and establish a cooperative environment in which the level of trust and trustworthiness is significantly higher than in other treatments. Also, the supply chain performance is relatively close to the equilibrium in the enforced self-selection treatment (see Fig. 5.19). Hence, managers should be aware that proper incentives should be given in case a punishment mechanism cannot be easily implemented.

A Mann-Whitney-U test confirms that the supply chain in the punishment and the enforced self-selection treatment perform significantly better than in the

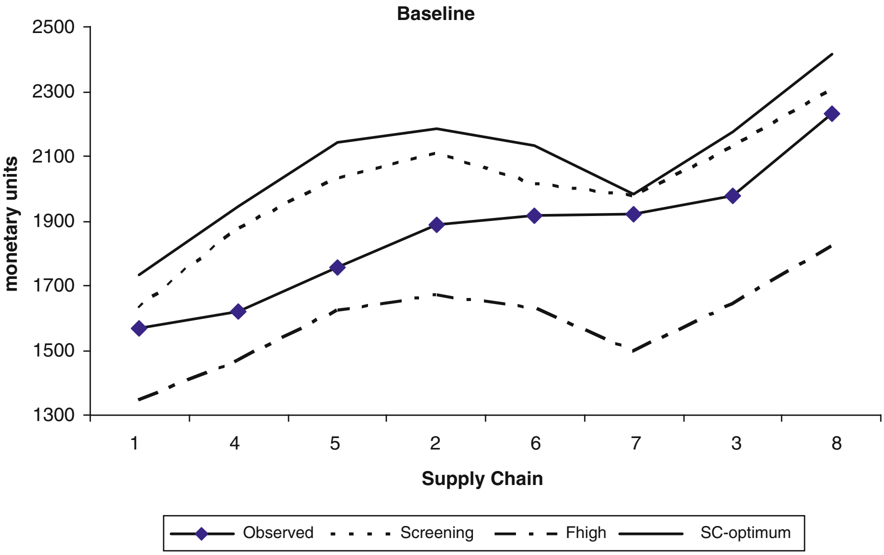

Fig. 5.16 Supply chains' observed performance compared to benchmarks in the baseline treatment

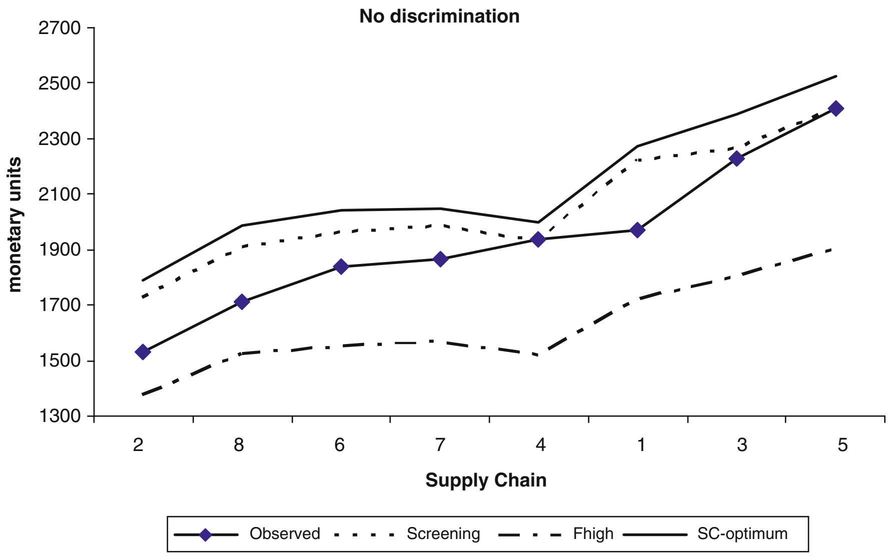

Fig. 5.17 Supply chains' observed performance compared to benchmarks in the no discrimination treatment

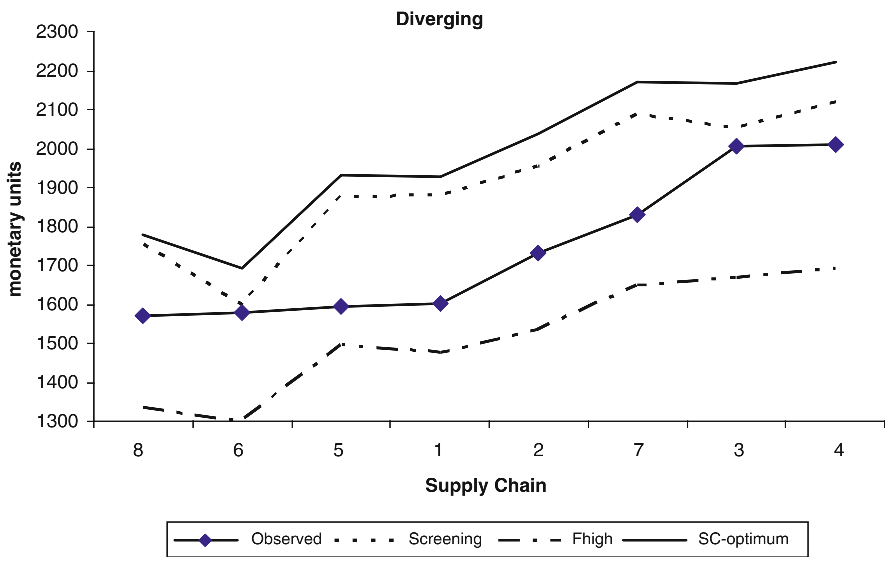

Fig. 5.18 Supply chains' observed performance compared to benchmarks in the diverging supply chain treatment

baseline treatment ($p < 0.038$ for both treatments, two-sided) and in the diverging supply chain treatment ($p < 0.006$ and $p < 0.014$, respectively, two-sided). Yet, the test is not significant for the no discrimination treatment. Limiting the supplier's

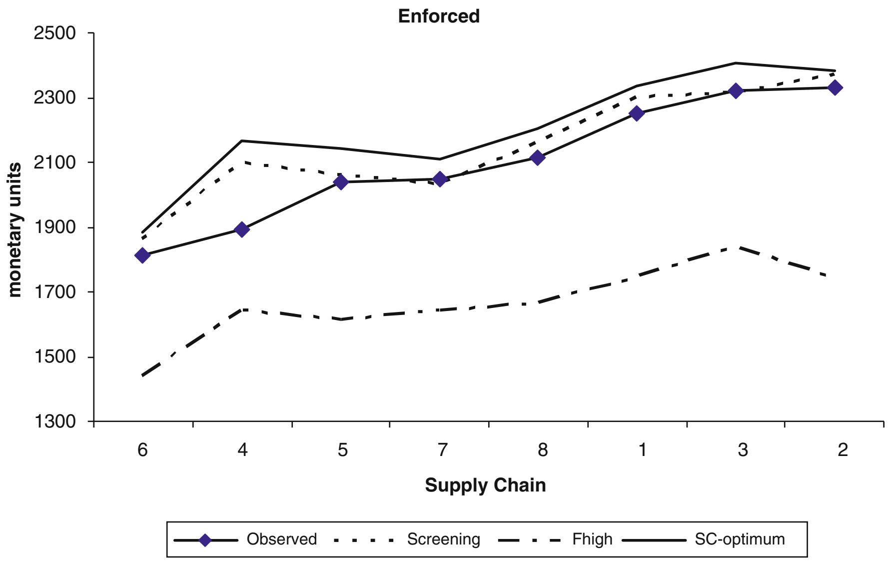

Fig. 5.19 Suppliers' observed performance compared to benchmarks in the enforced self-selection treatment

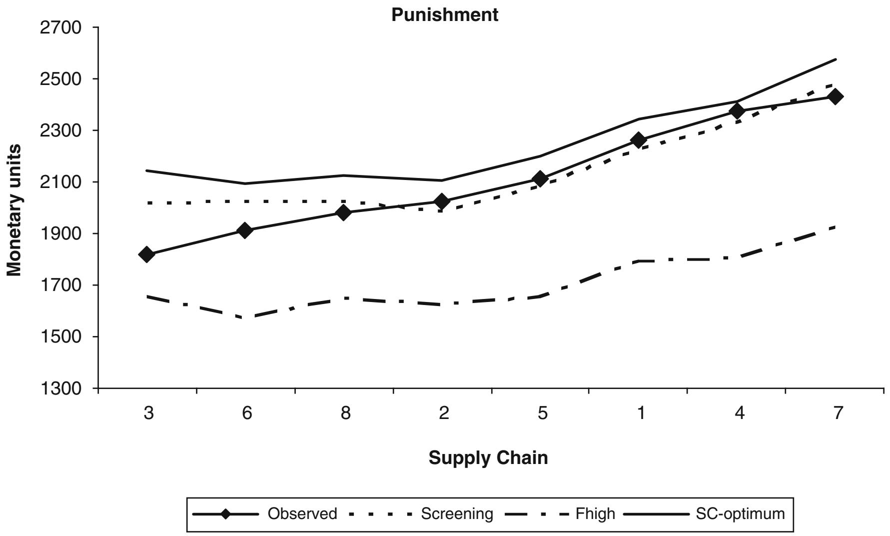

Fig. 5.20 Supply chains' observed performance compared to benchmarks in punishment treatment

flexibility to react to signals can therefore improve the supplier's performance on average. This is, because the limited flexibility leads towards a natural tendency to offer the screening contract more often, even though the strategic risk is not eliminated.[6] Nonetheless, the inefficiencies that arise out of the indifference contract choice continue to be substantial. If the buyer chose continuously the self-selection contract in the no discrimination treatment, the average performance would have been increased by 8%.

5.4 Conclusion and Managerial Insights

This experiment shows that screening contracts are empirically highly relevant, although a lot of the coordinational power is lost by the behavioral inrobustness of this contract type.

In particular, the supply chain performance significantly improved compared to the benchmark in which only the simplest contract format is allowed. This highlights that screening contracts are able to coordinate the supply chain at least to some extent. However, the analysis does also show that the incentive mechanism used throughout the screening literature does only work if an appropriate punishment option is available. Otherwise, there is a substantial level of indifference contract choices. The effect is twofold. There is a direct effect on the efficiency of the supply chain, as the order size is even more downward distorted. Additionally, the suppliers perceive a strategic risk which leads towards a tendency to offer simpler contracts. Not surprisingly, the analysis reveals that the strategic risk has a minor impact on the supplier's contract offer behavior, if he is restricted in offering only one contract in a diverging supply chain. Nevertheless, the direct inefficiencies that occur due to indifference contract choices are still substantial.

Furthermore, the analysis reveals that the buyers tend to be more truthful if they can either be punished for inconsistency, or if truthful reporting cannot easily be exploited because of the suppliers' limited flexibility to offer contracts. In contrast, it seems that there is low quality communication which conveys hardly any information, if the self-selection of the buyer can be somehow ensured. Yet, in case of ensured self-selection, communication is less important as suppliers prefer to offer the screening contract more frequently anyway.

Moreover, the analysis shows that the suppliers' and buyers' behavior is quite robust over time. The data show that the rewards, which can be given from the supplier to the buyer to enable win-win situations, are way too low to coordinate the supply chain members to Pareto-improvement. Hence, one might conjecture that the repeated interaction is not the main driver of the underlying results, and that similar results would be obtained in supply chain configurations without repeated interaction. However, this point is left out for future research.

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[6]The strategic risk might lead to F_i – contract offers, because the supplier believes that the buyer chooses the signaled contract regardless of the actual holding cost realization. Nonetheless, even in this case it can be optimal to offer the screening contract in the no discrimination treatment when the buyers' signals are not identical. Hence, there is a natural tendency towards the screening contracts even though the strategic risk is not eliminated.

Also, the study shows that the performance of buyers does not significantly depend on the treatments or on their tendency to be truthful or consistent. This is, because the screening theory works with small payoff differences between alternatives. However, the suppliers' performance is significantly dependent on whether they have an appropriate punishment option, or whether the self-selection can be somehow ensured. More theoretical and experimental research is required to develop and test behavioral robust incentive mechanisms that ensure the self-selection of buyers.

Appendix: Sample Instruction (Translation into English)

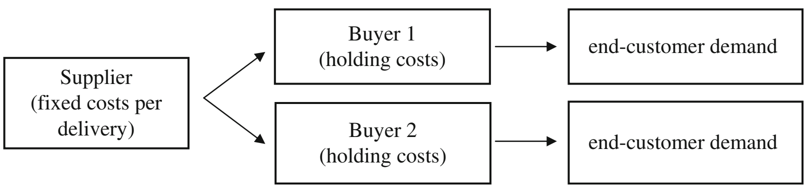
Read the instructions carefully and raise your hands if you have any questions. If there are questions during the experiment, please raise your hand as well.

Starting Position

You are in a supply chain consisting of one supplier and two buyers. The supplier offers a contract to each buyer in order to deliver a certain product at the market price. Every buyer can decide on his own whether he accepts the offer or not. Hence, the supplier's profits can differ between buyer 1 and buyer 2.

If a buyer rejects the supplier's contract offer, he can source the product from an alternative supplier. In that case, the buyer yields a profit of 3 and the supplier yields zero profits. Nevertheless, the other supplier–buyer relationship is not influenced by the contract rejection.

If a buyer accepts the supplier's contract offer, the supplier has the opportunity to withdraw the offer. In that case, both, the supplier and the buyer, yield zero profits. Nonetheless, the other supplier–buyer relationship is not influenced by the withdrawal.



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

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

Your Task: Agree Upon New Supply Conditions!

Information Availability

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

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

Holding costs (€)	1	5	9
Probability (%)	40	30	30

Contract Type

The buyers know their true holding costs realizations before the supplier's contract offer. The supplier does not know these holding cost realizations. Yet, the buyers can independently signal their realizations to the supplier. This signal can – but does not necessarily needs to – be truthful.

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

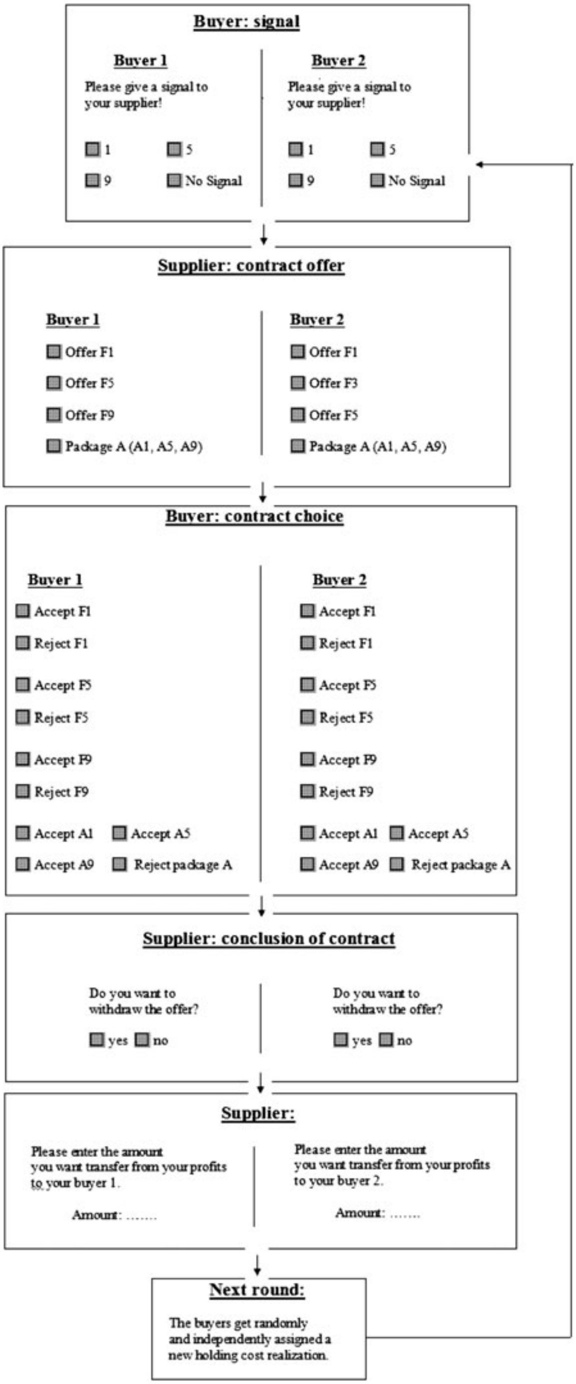
The contract offers F1, F5 and F9 maximize the supplier profits if the respective buyer faces holding costs of 1, 5 or 9.

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

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

After the contract is concluded, the supplier can transfer an amount between 0 and his profits of the respective round to one or both buyers. The transferred amounts can differ between buyer 1 and buyer 2.

The following figure depicts the decision sequence:


Buyer: signal
Buyer 1
Please give a signal to your supplier!
1
5
9
No Signal
Buyer 2
Please give a signal to your supplier!
1
5
9
No Signal
Supplier: contract offer
Buyer 1
Offer F1
Offer F5
Offer F9
Package A (A1, A5, A9)
Buyer 2
Offer F1
Offer F3
Offer F5
Package A (A1, A5, A9)
Buyer: contract choice
Buyer 1
Accept F1
Reject F1
Accept F5
Reject F5
Accept F9
Reject F9
Accept A1
Accept A5
Accept A9
Reject package A
Buyer 2
Accept F1
Reject F1
Accept F5
Reject F5
Accept F9
Reject F9
Accept A1
Accept A5
Accept A9
Reject package A
Supplier: conclusion of contract
Do you want to withdraw the offer?
yes
no
Do you want to withdraw the offer?
yes
no
Supplier:
Please enter the amount you want transfer from your profits to your buyer 1.
Amount: ....
Please enter the amount you want transfer from your profits to your buyer 2.
Amount: ....
Next round:
The buyers get randomly and independently assigned a new holding cost realization.

How Are the Contract Corresponding Profits Calculated?

The following table summarizes the profits of the supplier and the respective buyer in dependence of the contract offer and the holding cost realization. Negative amounts depict a loss.

Example. The supplier offers the package A to both buyers. If buyer 1 faces holding costs of 5 per item and period and if he accepts A5, he yields a profit of 21.88. Yet, if buyer 2 faces holding costs of 1 per item and period and if he accepts A1, he yields a profit of 46.87. The supplier, thus yields a profit from the contract with buyer 1 of 42.27 and form the contract with buyer 2 of 73.13, i.e., the supplier yields a profit of 42.27 + 73.13 = 115.85.

If a buyer rejects the offer, the respective buyer yields profits of 3. In this case the supplier yields zero profit from the respective supplier-buyer relationship.

Example. The supplier offers F1 to buyer 1 and F5 to buyer 2. If buyer 1 accepts the offer and buyer 2 rejects the offer, the supplier's profits result from 116.9 + 0 = 116.9. The profit of buyer 1 is dependent from his holding cost realization while buyer 2 yields a profit of 3.

If the supplier withdraws the offer, the supplier as well as the buyer yields zero profits.

Example. The supplier offers both buyers contract F9. Both buyers accept. The supplier decides to withdraw the offer from buyer 1. In this case, the supplier yields a profit of 0 + 36.9 = 36.9, buyer 1 yields zero profits, and the profits of buyer 2 depend on his holding cost realization.

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

	Profit supplier	Profit buyer with holding costs		
		1	5	9
F1	116.9	3.1	−76.9	−156.9

	Profit supplier	Profit buyer with holding costs		
		1	5	9
F5	67.46	38.88	3.10	−32.68

	Profit supplier	Profit buyer with holding costs		
		1	5	9
F9	36.90	56.43	29.77	3.10

	Profit supplier	Profit buyer with holding costs		
		1	5	9
A1	73.13	46.87	−33.13	−113.13
A5	42.72	46.77	21.88	−3.00
A9	29.23	40.47	21.78	3.10

How Many Rounds Are Going to Be Played?

Thirty rounds are going to be played. In every round the holding costs realizations are drawn independently from previous rounds and independently between buyers.

Who Are My Team-Mates?

Your role as supplier/buyer is the same in every round. Your team-mates do not change in the course of the experiment. The identity of your team-mates is confidential throughout – and after – the experiment.

How Is the Experimental Payoff Calculated?

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

If there are any questions, please raise your hand.

Good luck.

Chapter 6
A Behavioral Model on the Effects of Information Sharing on Supply Chain Performance

This section investigates the impact of information sharing in a behavioral model assuming that a certain fraction of buyers give honest reports, and the supplier reacts to these reports by adjusting his beliefs according to Bayes' rule. First, Sect. 6.1 briefly summarizes the principal–agent literature assuming that not all agents (here: buyers) use their private information entirely strategically, while showing that this assumption is supported by experimental results. Afterwards, Sect. 6.2 depicts how communication, trust, and trustworthiness can be formalized in the strategic lotsizing framework. Then, Sect. 6.3 evaluates the impact of information sharing assuming that the deceptive buyer gives his signals without considering his actual cost position, while Sect. 6.4 discusses the impact of strategic reporting. Finally, Sect. 6.5 summarizes the results and gives some managerial insights.

6.1 Honesty in Principal–Agent Models

The experimental results in Chaps. 4 and 5 show that communication does not necessarily improve the supply chain performance, especially if no efficient punishment and reward mechanism is in place. The experiment presented in Chap. 4 highlights that there are substantial deviations from the game-theoretic equilibrium supply chain performance, because the subjects adjust the a priori probabilities with respect to the signal. Also, both experiments show that the level of trustworthiness differs across subjects.

The following section provides a behavioral model that highlights that the effect of communication does heavily depend on the interaction of trust and trustworthiness. In particular, the behavioral model assumes that there are two types of agents (buyers), see Fig. 6.1. One group includes those agents who always communicate their private information truthfully. One explanation for this is, for example, that the honest agent faces intrinsic costs of lying (see Minkler and Miceli 2004). In the following, these agents are denoted as "honest agents". On the other hand there are

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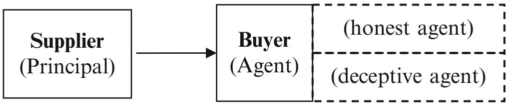

Fig. 6.1 Supply chain configuration

the agents who misrepresent their private information at least sometimes. Figure 6.1 depicts the supply chain consisting of the supplier and the buyer, who is either honest or deceptive. The behavior of these "deceptive agents" may have different explanations. In the first part of the analysis it is assumed that the deceptive agent does not consider that the principal might take the signals into account while offering the contracts. In this case the "deceptive agent" is assumed to give signals which do not depend on the private information. This is the well-known "cheap-talk" hypothesis. In the second part of the analysis it is assumed that the deceptive agent follows a strategy which is conditioned on his specific private information.

Hence, one of the main assumptions of this study is the division of agents into two subclasses. This assumption has already been made in a similar principal–agent framework from Severinov and Deneckere (2006). In this study, it is assumed that one subclass of agents is fully rational and opportunistic. They claim, for example, the highest compensation regardless of their true holding cost parameter. On the other hand there is a second subclass of agents who will always communicate their true holding cost, even though they are aware of losing money by doing this.

Severinov and Deneckere (2006) assume that the deceptive agents can be detected, as they will give always the same signal, e.g., they will always claim the highest possible compensation. On the other hand, the "honest agents" can be easily identified by a deviation from this behavior. Every agent who does not claim the highest compensation is therefore identified as an honest agent. Severinov and Deneckere (2006) propose a "password"-mechanism, where the password is the signal, which are the deceptive agents supposed to give. Thus, the agent who knows the password (i.e., the deceptive agent) is offered a more favorable contract than the honest agent, who does not know the password. However, previous research from Özer et al. (2008) as well as the experiments presented in the very underlying work show that even this division in two subgroups may not be sufficient.

Özer et al. (2008) investigate whether information sharing enhances supply chain performance in a supplier-manufacturer supply chain with uncertain end-customer demand. A simple wholesale price contract determines the financial payments in the relationship. In this study, the supplier's capacity reservation for the manufacturer relies on a demand forecast. However, as the manufacturer is closer to the market, he has more accurate forecast information than the supplier. Under these circumstances, the supply chain optimal solution is achieved, if the manufacturer reports the demand forecast truthfully. Yet, rational game theory predicts that the manufacturer exaggerates the demand forecast to influence the supplier's capacity reservation decision. In turn, the supplier treats the manufacturer's information about the demand forecast as cheap talk. Interestingly, Özer et al. show in their experiment that the manufacturers inflate the superior forecast information indeed, but they do not exaggerate to the maximum extent.

Particularly, the report does linearly depend on the private forecast information. The supplier, in turn, does not treat the report as cheap talk but conditions his capacity decision on the report instead. Özer et al., thus, find partially trust and trustworthiness in their supply chain setting. This leads to a higher supply chain performance than theoretically predicted.

Also, the underlying work shows that buyers either tend to exaggerate their holding costs or to report them truthfully. However, the buyers do not always exaggerate to the maximum extent, and there is also a non-negligible portion of reports that understated the respective holding cost. Finally, the experiments stress that the effect of communication on the overall supply chain performance is ambiguous. Particularly, the supply chains which manage to build up trust and trustworthiness performed significantly better than the supply chains in which deception and strategic interpretation of reports were prevalent.

Taking these behavioral findings into account, the password-mechanism from Severinov and Deneckere is not applicable as the deceptive agents do not constantly give the same signal (i.e., always exaggerating to the maximum extent). Hence, the underlying study does not assume that the deceptive agents are completely strategic. In fact, the deceptive agents are characterized by signals which are not constantly truthful.

Summarizing the above arguments, the underlying section proposes a behavioral model that evaluates the impact of trust and communication in a standard principal–agent setting where the deceptive agents cannot be easily identified by their signals.

Other studies that incorporate the idea of honest and deceptive agents can be found in Alger and Renault (2006, 2007). However, in contrast to the underlying study there is no direct communication between the principal and the agent.

Finally, note that definitions of trust, trustworthiness, and information sharing apply as defined in Sect. 2.3.

6.2 The Impact of Communication, Trust, and Trustworthiness on Supply Chain Performance

In the following it is assumed that the supplier receives a signal from the buyer before he offers the menu of contract. The following sequence of events results: the buyer first learns his holding cost $\tilde{h} \in [h_1, ..., h_n]$. Then, the buyer communicates a holding cost to the supplier. The buyer is restricted to signals S that are possible holding cost realizations or he can refuse to give a signal, i.e., $S \in (S_1 = h_1, \ldots, S_i = h_i, \ldots, S_n = h_n, S_{n+1} =$ "*No signal*"). Then, the supplier decides to adjust the a priori probabilities p_i to the perceived a posteriori probability distribution $\hat{p}_i(h_i|S_k)(\forall\, i = 1, ..., n; k = 1, ..., n+1)$, which is conditioned on the buyer's signal. Then, the supplier calculates the menu of contracts with respect to the perceived a posteriori distribution and offers this screening contract to the buyer.

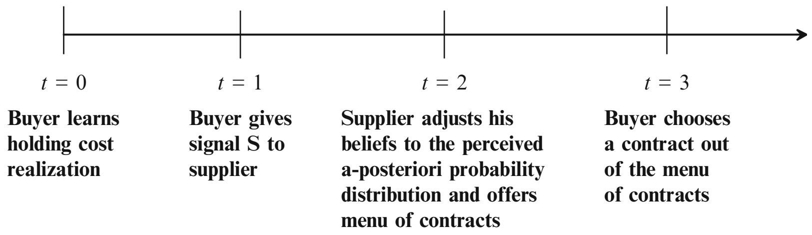

Fig. 6.2 Sequence of events

Finally, the buyer chooses one contract out of the menu of contracts. Figure 6.2 depicts the sequence of events.

Next the key factors that influence the buyer's signaling behavior ($t = 1$, see Sect. 6.2.1) as well as the supplier's adjustment of beliefs ($t = 2$, see Sect. 6.2.2), and the buyer's contract choice ($t = 3$, see Sect. 6.2.3) are analyzed.

6.2.1 The Buyer's Information Sharing Behavior

6.2.1.1 Truthful Signals

As mentioned in the introduction, it is assumed that some buyers report their holding costs truthfully, i.e., $S = \tilde{h}$. It is assumed that a fraction $\alpha \in [0, 1]$ of the buyers show this behavior. Therefore, the probability that the supplier interacts with an honest buyer is α.

6.2.1.2 Unconditioned Signals

All buyers that do not report their holding cost truthfully are called "deceptive" buyers. As a fraction α of the buyers are honest, it follows directly that a fraction $(1 - \alpha)$ of the buyers are deceptive. As mentioned in the introduction, two different types of signaling behavior are analyzed. On the one hand, the buyer is assumed to simply ignore that the supplier processes the communicated signal. In this case, the buyer gives signals regardless of his holding cost learned at $t = 0$. This behavior is formalized with unconditioned signaling variables $\phi_i, i = 1, \ldots, n + 1$, $\phi_i \in [0, 1], \sum_{i=1}^{n+1} \phi_i = 1$. The variable ϕ_i is therefore the probability of the buyer giving the signal S_i. Note that this signal is independent of the buyer's respective holding cost parameter $\tilde{h}$. Particularly, the signal can either be true, an overstatement or an understatement. Nonetheless, unconditioned signaling also includes the standard hypothesis of the buyer giving the signal S_n constantly, i.e., $\phi_n = 1$. In this case, the buyer always exaggerates to the maximum extent.

6.2.1.3 Conditioned Signals

A deceptive buyer uses his signal strategically, if he conditions the signal on the holding cost realization. This behavior is formalized with conditioned signaling variables $\phi_i(h_k), i = 1, ..., n+1, k = 1, ..., n,\ \phi_i(h_k) \in [0, 1]$. A complete strategy profile requires that $\sum_{i=1}^{n+1} \phi_i(h_k) = 1, \forall k = 1, ..., n$ holds. As an example, the buyer who always exaggerate his holding cost by one (possible) unit and gives no signal if he faces the highest holding cost realization has the strategy profile $\phi_i(h_k) = 1, \forall i = k+1, k = 1, ..., n$ and $\phi_i(h_k) = 0, \forall i \neq k+1, k = 1, ..., n$.

6.2.2 The Supplier's Probability Adjustment

The supplier is aware of the fact that there are some honest buyers. However, as there are also deceptive buyers, he has to estimate the probability that he is interacting with an honest buyer. This subjective probability is denoted by $\hat{\alpha} \in [0, 1]$. Furthermore, the supplier needs to estimate the unconditioned signaling variables $\hat{\phi}_i$, $\forall i = 1, ..., n+1$ or the conditioned signaling variables $\hat{\phi}_i(h_k)$, $\forall i = 1, ..., n+1; k = 1, ..., n$, respectively. It is assumed that the supplier can observe whether the buyer conditions his signals or not.[1] In the following we will only present the supplier's adjustment of beliefs in case of a buyer who gives unconditioned signals. The analysis, however, can be easily transferred to the case where the buyer uses conditioned signaling variables instead.

If the supplier assumes that the buyer gives unconditioned signals, he expects the following conjoint probability distribution $\widehat{p_i}(h_i \cap S_k), \forall i = 1, ..., n; k = 1, ..., n+1$ (see Table 6.1). The actual conjoint probability distribution $p_i(h_i \cap S_k)$, $\forall i = 1, ..., n; k = 1, ..., n+1$, in contrast, can be easily obtained by replacing the estimations $\hat{\alpha}, \hat{\phi}_i$ by their actual counterparts α, ϕ_i.

Let $\widehat{p_i}(h_i|S_k), i = 1, ..., n; k = 1, ..., n+1$ denote the perceived a posteriori probability that the buyer giving signal S_k faces holding cost h_i. These perceived a posteriori probabilities result from:

Table 6.1 Estimated (perceived) conjoint probability distribution $\widehat{p_i}(h_i \cap S_k)$

$0 \leq \hat{\alpha} \leq 1$	S_1	S_i	S_{n+1}	$\sum$
h_1	$\hat{\alpha}p_1 + (1-\hat{\alpha})p_1\hat{\phi}_1$	$(1-\hat{\alpha})p_1\hat{\phi}_i$	$(1-\hat{\alpha})p_1\hat{\phi}_{n+1}$	p_1
h_i	$(1-\hat{\alpha})p_i\hat{\phi}_1$	$\hat{\alpha}p_i + (1-\hat{\alpha})p_i\hat{\phi}_i$	$(1-\hat{\alpha})p_i\hat{\phi}_{n+1}$	p_i
h_n	$(1-\hat{\alpha})p_n\hat{\phi}_1$	$(1-\hat{\alpha})p_n\hat{\phi}_i$	$(1-\hat{\alpha})p_n\hat{\phi}_{n+1}$	p_n
$\sum$	$\hat{\alpha}p_1 + (1-\hat{\alpha})\hat{\phi}_1 = \widetilde{\phi_1}$	$\hat{\alpha}p_i + (1-\hat{\alpha})\hat{\phi}_i = \tilde{\phi}_i$	$(1-\hat{\alpha})\hat{\phi}_{n+1} = \tilde{\phi}_{n+1}$	1

[1]This assumption can be easily relaxed by introducing a variable that denotes the probability that the buyer gives unconditioned signals.

$$\hat{p}_i(h_i|S_i) = \frac{\hat{\alpha}p_i + (1-\hat{\alpha})p_i\hat{\phi}_i}{\tilde{\phi}_i}, \ \forall i = 1, ..., n$$

$$\hat{p}_i(h_i|S_k) = \frac{(1-\hat{\alpha})p_i\hat{\phi}_k}{\tilde{\phi}_k}, \ \forall i = 1, ..., n; k = 1, ..., n+1; i \neq k$$

This distribution is utilized to calculate the menu of contracts, i.e., the supplier solves the problem AI (see Sect. 2.2) with respect to $\widehat{p_i}(h_i|S_k), i = 1, ..., n;$ $k = 1, ..., n+1$.

The resulting optimal side-payments given the signal S_k are denoted by Z_i^k and the respective order sizes are denoted by q_i^k, $\forall i = 1, ..., n; k = 1, ..., n+1$. Throughout this study it is assumed that the supplier will always offer the "full" menu of contracts, i.e., he always offers n contracts which satisfy the incentive- and participation constraint in problem AI. This ensures that the supplier offers the contract $\langle q_i^k, Z_i^k \rangle$ even though he adjusts his beliefs to $\widehat{p_i}(h_i|S_k) = 0$. Skipping this assumption might lead to situations in which the buyer's participation constraint is not satisfied.

Summing up, the supplier forms a perceived conjoint probability distribution, $\hat{p}_i(h_i \cap S_k)$, which is used to generate a menu of contracts ($t = 2$). Yet, the actual conjoint probability distribution,$p_i(h_i \cap S_k)$, determines the relative frequency of contract choices out of the menu of contracts generated in $t = 2$. The effect of changes in this actual conjoint probability distribution is outlined in the next section.

6.2.3 The Buyer's Contract Choice and the Impact on the Overall Supply Chain Deficit

The buyer's expected contract choice ($t = 3$) is determined by the actual conjoint probability distribution $p_i(h_i \cap S_k), \forall i = 1, ..., n; k = 1, ..., n+1$. In the following the deviation from standard-theory's predictions (i.e., without communication or trust) is analyzed. The main focus of this analysis, thus, is to investigate whether communication enhances or deteriorates supply chain performance compared to the game theoretic equilibrium without communication.

The expected change of the supplier's costs, $E(\Delta C_s)$, results from the cost difference between the screening menu based on the perceived a posteriori distribution, $\langle q_i^k, Z_i^k \rangle, \forall i = 1, ..., n; k = 1, ..., n+1$, and the screening menu based on the a priori distribution, $\langle q_i^{AI}, Z_i^{AI} \rangle, \forall i = 1, ..., n$. All of these differences are weighted by the respective actual conjoint probability distribution, i.e., these cost differences are weighted by the probability that a buyer faces holding cost h_i while signaling S_k. Hence, the expected change of the supplier's expected costs results from:

$$E(\Delta C_s) = \sum_{i=1}^{n} \sum_{k=1}^{n+1} p_i(h_i \cap S_k) \Delta C_{s,i}{}^k \quad \text{where}$$

$$\Delta \mathrm{C_{s,i}}^{\mathrm{k}} = \left(\frac{\mathrm{f}}{\mathrm{q_i}^{\mathrm{k}}} + \mathrm{Z_i}^{\mathrm{k}} \right) - \left(\frac{\mathrm{f}}{\mathrm{q_i}^{\mathrm{AI}}} + \mathrm{Z_i}^{\mathrm{AI}} \right)$$

The same calculation can be done for the buyer with respect to his cost function. Then, the expected difference of the honest buyer's expected costs results from

$$E\left(\Delta C_{b,honest}\right) = \alpha \sum_{i=1}^{n} p_i \left(\frac{h_i}{2} q_i{}^i - Z_i{}^i - \frac{h_i}{2} q_i{}^{AI} + Z_i{}^{AI} \right),$$

and the expected difference of the deceptive buyer's expected costs results from

$$E\left(\Delta C_{b,deceptive}\right) = (1-\alpha) \sum_{k=1}^{n+1} \sum_{i=1}^{n} p_i \phi_k \left(\frac{h_i}{2} q_i{}^k - Z_i{}^k - \frac{h_i}{2} q_i{}^{AI} + Z_i{}^{AI} \right).$$

Hence, the total expected difference of the honest as well as the deceptive buyer's expected costs results from:

$$E(\Delta C_b) = E\left(\Delta C_{b,honest}\right) + E(\Delta C_{b,deceptive}) = \sum_{i=1}^{n} \sum_{k=1}^{n+1} p_i(h_i \cap S_k) \Delta C_{b,i}{}^k \cdot$$

where $\Delta \mathrm{C_{b,i}}^{\mathrm{k}} = \frac{h_i}{2} q_i{}^k - Z_i{}^k - \frac{h_i}{2} q_i{}^{AI} + Z_i{}^{AI}$.

Finally, the expected change of the supply chain performance results from:

$$\Delta CD = E(\Delta C_b) + E(\Delta C_s) = \sum_{i=1}^{n} \sum_{k=1}^{n+1} p_i(h_i \cap S_k) \Delta CD_i{}^k \cdot$$

where

$$\Delta CD_i{}^k = C_i{}^{SC}\left(q_i{}^k\right) - C_i{}^{SC}\left(q_i{}^{AI}\right)$$

$$C_i{}^{SC}\left(q_i{}^k\right) = \frac{f}{q_i{}^k} + \frac{h_i}{2} q_i{}^k$$

$\Delta CD_i{}^k = C_i{}^{SC}\left(q_i{}^k\right) - C_i{}^{SC}\left(q_i{}^{AI}\right)$ denotes the supply chain cost differences that arise due to the adjustment of the a priori probabilities. For $\Delta CD \leq 0$ the supply chain deficit decreases due to communication, which is identical to an improvement of the overall supply chain performance. In this case, communication is an appropriate coordination mechanism. Otherwise, it is not.

Note that the signaling behavior, ϕ_i, and the buyer's trustworthiness, α, are implicitly considered in the actual conjoint probability distribution $p_i(h_i \cap H_k)$.

Hence, these parameters actually determine the probabilities with which the buyer actually chooses a contract. In contrast, the supplier's trust as well as the perceived signaling behavior, $\hat{\phi}_i$ and $\hat{\alpha}$, are implicitly considered in the change of the coordination deficit, $\Delta CD_i{}^k$. In other words, the supplier's perceived values of trustworthiness and signaling behavior determine the contract parameters that lead to a change of the coordination deficit once this specific contract was chosen. The actual values of trustworthiness and signaling behavior, in contrast, determine the frequency with which these contracts are chosen.

6.3 The Impact of Unconditioned Information Sharing

This section elaborates the impact of communication assuming that the deceptive buyer gives his reports without considering his actual cost position. Section 6.3.1 gives some general insights, while Sects. 6.3.2 and 6.3.3 present a numerical example and a sensitivity analysis, respectively.

6.3.1 General Analysis

If the buyer believes that the supplier ignores the signal, he is assumed to use unconditioned signals. In this case the following general predictions regarding the supplier's and buyer's expected costs, and the supply chain's deficit can be derived. All proofs can be found in the Appendix.

Theorem 1. *The supplier's expected costs do not increase due to the adjustment of the a priori distribution as long as* $\hat{\alpha} \leq \min_i \left[\frac{\hat{\phi}_i \cdot \alpha}{\hat{\phi}_i \cdot \alpha + \phi_i - \phi_i \alpha}\right], i = 1, \ldots, n$ *holds.*

Theorem 1 shows that the supplier should be cautious to believe too much in the buyer's signal. This means, that he should rather underestimate the number of buyers who are honest than to overestimate this number. Yet, on the other hand the supplier cannot enhance his performance in spite of truthful signals if he chooses $\hat{\alpha}$ too low because the probability adjustment is not rigorously enough. As an example, the supplier will not adjust his probabilities at all if $\hat{\alpha} = 0$ holds although all buyers are honest, i.e., $\alpha = 1$. In this case communication has no effect, simply because the supplier does not react to the signals.

Note that the condition in Theorem 1 is always satisfied if $\hat{\alpha} \leq \alpha$ and $\hat{\phi}_i = \phi_i$, $i = 1, \ldots, n + 1$ hold. Thus, if the supplier can perfectly observe the buyer's unconditioned signals, and if his estimation with respect to the buyer's trustworthiness is equal or lower than the buyer's actual trustworthiness, the supplier will always gain from communication. Decreasing expected costs for the above parameter combinations can be observed, since the supplier is always closer to the actual a posteriori distribution than if he would stick to the a priori distribution, i.e., $p_i \leq \hat{p}_i(h_i|S_i) \leq p_i(h_i|S_i)$ and $p_i(h_i|S_k) \leq \hat{p}_i(h_i|S_k) \leq p_i, \ \forall\ i \neq k$ hold. In fact, if $\hat{\alpha} = \left(\hat{\phi}_i \cdot \alpha\right)/\left(\hat{\phi}_i \cdot \alpha + \phi_i - \phi_i\alpha\right)$ holds for a specific signal S_i, then the supplier accurately estimates the actual a posteriori distribution with respect to the signal S_i whereas the accuracy decreases with decreasing $\hat{\alpha}$.

If the above condition is not satisfied, the supplier's expected costs can decrease nonetheless. In fact, he overestimates the probability which corresponds to the respective signal, i.e., $p_i \leq p_i(h_i|S_i) \ \leq \hat{p}_i(h_i|S_i)$, and underestimates all other probabilities, i.e., $\hat{p}_i(h_i|S_k) \leq p_i(h_i|S_k) \leq p_i, \forall\ i \neq k$. In this case, the change in the supplier's expected costs is dependent on the specific parameter values.

Theorem 2.1. *The honest buyer's expected costs increase due to truthful signaling.*

The supplier will decrease all order sizes corresponding to the holding costs that are higher than the signal, i.e., ${q_i}^k \leq {q_i}^{AI}, \forall i > k$ given signal S_k. The expected cost, thus, will increase due to the "indifference"-condition (3) (see Sect. 2.2.4).

Theorem 2.2. *The expected costs of the deceptive buyer can either increase or decrease due to communication.*

The deceptive buyer can be worse off due to communication, if he reports (accidentally) truthful or if he understates his actual holding costs. The argumentation is equal to Theorem 2.1. If the deceptive buyer exaggerates his holding cost constantly to the maximum extent (i.e., $\phi_n = 1$), however, then he cannot be worse off due to communication. If the deceptive buyer exaggerates not to the maximum extent, though, his expected costs changes are dependent on the specific parameters values.

Theorem 3.1. *The supply chain optimum is achieved if $\alpha = \hat{\alpha} = 1$ holds. The supply chain performance is worst if $\phi_1 = 1, \alpha = 0$ and $\hat{\alpha} = 1$ holds.*

For $\alpha = \hat{\alpha} = 1$ the supply chain faces a decision problem as if under full information. This results in the supply chain optimum.

For $\phi_1 = 1, \alpha = 0$ *and* $\hat{\alpha} = 1$ it follows that all buyers are deceptive and constantly claim that they have the lowest possible holding costs. The supplier will, in turn, decrease all order sizes ${q_i}^1 \leq {q_i}^{AI}, \forall i = 2, ..., n$. As the order size ${q_1}^k = {q_1}^{AI}, \forall k = 1, ..., n+1$ does not change due to an adjustment of the probabilities (see Sect. 2.2.4, condition (3)) the downward distortion increases for all order sizes.

Theorem 3.2. *As long as* $\alpha \geq \frac{\sum_i \sum_{k,i \neq k} p_i \phi_k \Delta C{D_i}^k + \sum_i p_i \phi_i \Delta C{D_i}^i}{\sum_i \sum_{k,i \neq k} p_i \phi_k \Delta C{D_i}^k - \sum_i (1-\phi_i) p_i \Delta C{D_i}^i} = \alpha_{crit}\left(\hat{\alpha}, \hat{\phi}_i\right)$ *holds, communication enhances the supply chain performance, and vice versa.*

This theorem points out that there are regions of parameter values in which communication improves supply chain performance, but that there are also parameters values for which the supply chain performance deteriorates. Intuitively, from a supply chain perspective communication becomes the more attractive the higher the fraction of honest buyers, α. However, as soon as this fraction α decreases below the critical level $\alpha_{crit}(\hat{\alpha}, \hat{\phi}_i)$, the more likely are situations in which a deceptive buyer unconditionally misrepresents her holding cost realization, while the supplier reacts to this signal. From $\alpha_{crit}(\hat{\alpha}, \hat{\phi}_i) \leq 1$ it follows directly that communication can always be an appropriate coordination mechanism as long as the number of honest buyers is sufficiently large.

Theorem 3.3. *The range of levels of trustworthiness for which communication is an appropriate coordination mechanism decreases with increasing levels of supplier's trust.*

This theorem gives an interesting insight into the interaction between trust ($\hat{\alpha}$) and trustworthiness (α) and the impact of this interaction on supply chain performance. Particularly, this theorem shows that more trust does not necessarily increase the supply chain performance. In contrary, the more the supplier trusts the buyer's signal, the more likely is a deterioration of supply performance. The effectiveness of communication decreases on the other hand, if the supplier's trust decreases because he simply does not adjust the probabilities rigorously enough. Hence, it is an important challenge of supply chain management to identify an appropriate level of trust.

6.3.2 Numerical Example

In the following the previous analysis for the case of two possible holding cost realizations, i.e., $h \in [h_L, h_H]$, is illustrated. Suppose that $(\phi_L, \phi_H, \phi_{No}) = \left(\hat{\phi}_L, \hat{\phi}_H, \hat{\phi}_{No}\right) = (1/3; 1/3; 1/3)$, $(p_L; p_H) = (0.5; 0.5)$, $(h_L; h_H) = (1; 5)$, $C_{AS} = 2.5$, $\hat{\alpha} = 0.5$, $\alpha = 0.6$, and $f = 800$. The following perceived and actual conjoint and a posteriori probability distribution result (Table 6.2):

On the basis of the perceived a posteriori distribution (see Table 6.3), the supplier will offer the following order sizes and unit prices and given a respective signal (see Table 6.4) and the following changes of the supplier's costs, the buyer's cost and the supply chain's coordination deficit result: $\Delta CD = 0.04$, $E(\Delta C_s) = -2.92$, $E(\Delta C_b) = 2.96$, $E\left(\Delta C_{b,honest}\right) = 2.76$ and $E\left(\Delta C_{b,deceptive}\right) = 0.22$. The supply chain deficit increases if the buyer chooses the even further downwards distorted

Table 6.2 Perceived and actual conjoint probability distribution for $\hat{\alpha} = 0.5$ and $\alpha = 0.6$

$\hat{\alpha} = 0.5$	S_L	S_H	S_{No}
h_L	0.33	0.08	0.08
h_H	0.08	0.33	0.08
$\sum$	0.42	0.42	0.17
$\alpha = 0.6$	S_L	S_H	S_{No}
h_L	0.37	0.07	0.07
h_H	0.07	0.37	0.07
$\sum$	0.43	0.43	0.13

Table 6.3 Perceived and actual a posteriori distribution for $\hat{\alpha} = 0.5$ and $\alpha = 0.6$

$\hat{\alpha} = 0.5$	S_L	S_H	S_{No}
$p_L(h_L \vert S)$	0.80	0.20	0.50
$p_H(h_H \vert S)$	0.20	0.80	0.50
$\alpha = 0.6$	S_L	S_H	S_{No}
$\hat{p}_L(h_L \vert S)$	0.85	0.15	0.50
$\hat{p}_H(h_H \vert S)$	0.15	0.85	0.50

Table 6.4 Order sizes and unit prices in the menu of contracts

					Signal		
A priori		Supply chain optimum		A posteriori	S_L	S_H	S_{No}
${q_L}^{AI}$	40	${q_L}^{FI}$	40.00	${q_L}^k$	40	40	40
${q_H}^{AI}$	13.33	${q_H}^{FI}$	17.89	${q_H}^k$	8.73	16.33	13.33
${Z_L}^{AI}$	44.17	–	–	${Z_L}^k$	34.96	50.16	44.17
${Z_H}^{AI}$	30.83	–	–	${Z_H}^k$	19.32	38.32	30.83

order size ${q_H}^L = 8.73$ while the supply chain deficit decreases if the buyer chooses the upwards adjusted order size ${q_H}^H = 16.33$. The expected effect on the supply chain deficit, thus, depends on the frequency with which these order sizes are chosen, i.e., $p_H(h_H \cap S_L)$ and $p_H(h_H \cap S_H)$. The total coordination deficit without communication is equal to $CD = 1.95$. The supply chain deficit increases therefore by 2%. This, in turn, questions the frequent claim of information sharing within the supply chain. Even though 60% of all buyers actually are trustworthy, and the supplier underestimates this ratio, the supply chain deficit increases. In fact, the supply chain deficit would only decrease due to communication if $\alpha > \alpha_{crit} = 0.62$ holds (see Theorem 3.2).

The supplier's expected costs decrease due to communication, which is in line with Theorem 1 (as the condition in Theorem 1 holds). The buyer, in turn, is worse off, independent of whether he is honest or deceptive. This stresses that unconditioned signals can substantially deteriorate the performance even of the deceptive buyer (see Theorem 2.2).

An example in which communication is effective can be easily constructed by setting $\alpha > \alpha_{crit}$. In this case, it is more likely that the performance improving order size ${q_H}^H$ instead of the performance deteriorating order size ${q_H}^L$ is chosen. Hence, the previous analysis showed that the effect of communication on supply chain performance is ambiguous. To test the impact of the several parameters and variables, a comparative static analysis is conducted in the next section.

6.3.3 Comparative Static Analysis

Figure 6.3 depicts the changes in the coordination deficit, ΔCD, the supplier's change in expected costs, $E(\Delta C_s)$, as well as the buyer's change in expected

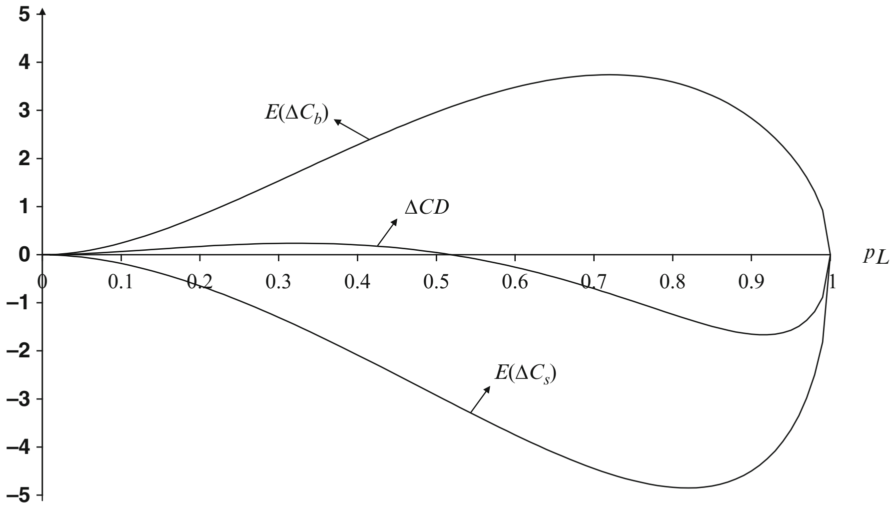

Fig. 6.3 Variation of the a priori probability p_L

costs, $E(\Delta C_b)$, in dependence of the a priori probability $p_L, p_H = 1 - p_L$. Figure 6.3 is in line with Theorem 1, i.e., the expected costs of the supplier do not increase since the relation in Theorem 1 holds. The supplier, thus, cannot be worse off due to the adjustment of beliefs as long as the condition in Theorem 1 holds. The coordination deficit decreases in this example for relatively high a priori probabilities $p_L (p_L > 0,52)$. Intuitively, in this case it is more likely that the buyer chooses the undistorted order size ${q_L}^L$ instead of the distorted order size ${q_H}^L$. Furthermore, from ${q_H}^{AI} = \sqrt{\frac{2 \cdot f}{h_H + \gamma_H}}$ and $\gamma_H = \frac{p_L}{p_H}(h_H - h_L)$ (see Sect. 2.2) it follows directly that there is a comparably stronger adjustment of the order size ${q_H}^k, k = L, H, No$ if the a priori probability p_H is low, since $\frac{\partial \gamma_H}{\partial p_H} = -\frac{1}{{p_H}^2}$ holds. As coordination potentials are only used through an upward adjustment of ${q_H}^H$, the coordination deficit decreases for low values p_H or high values p_L respectively. As an example, the supplier adjusts the order sizes from ${q_H}^{AI} = 6.25$ to ${q_H}^L = 3.28$ and ${q_H}^H = 10.69$ when $p_L = 0.9$ holds.

Additionally, Fig. 6.3 shows that the supply chain performance does not automatically increase if the supplier's estimation of the a posteriori distribution is more accurate (which is always the case if the condition in Theorem 1 holds). As the supplier minimizes his own expected costs instead of minimizing the overall expected supply chain costs, the supply chain deficit can increase even though the supplier estimates the buyer's holding costs more accurately through communication.

Figure 6.4 shows that the honest buyer cannot decrease his expected costs, regardless of the a priori distribution (see Theorem 2.1). The deceptive buyer, though, can either increase or decrease his expected costs (see Theorem 2.2).

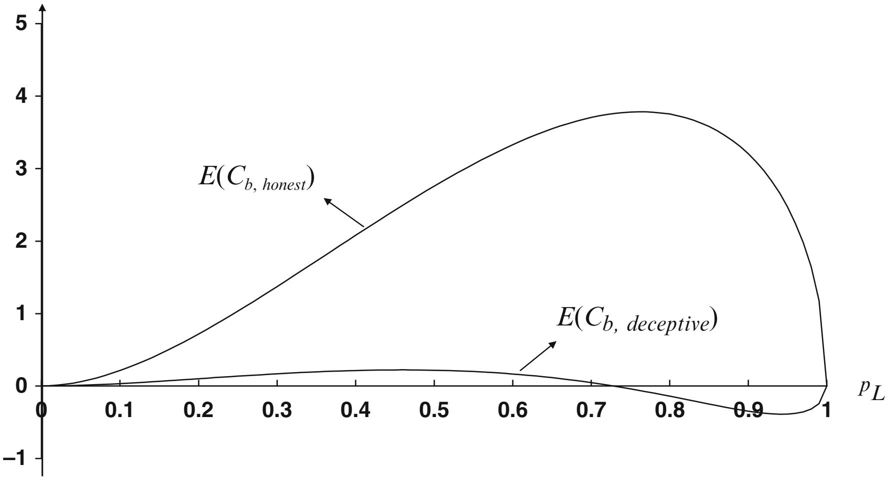

Fig. 6.4 Variation of a priori probabilities

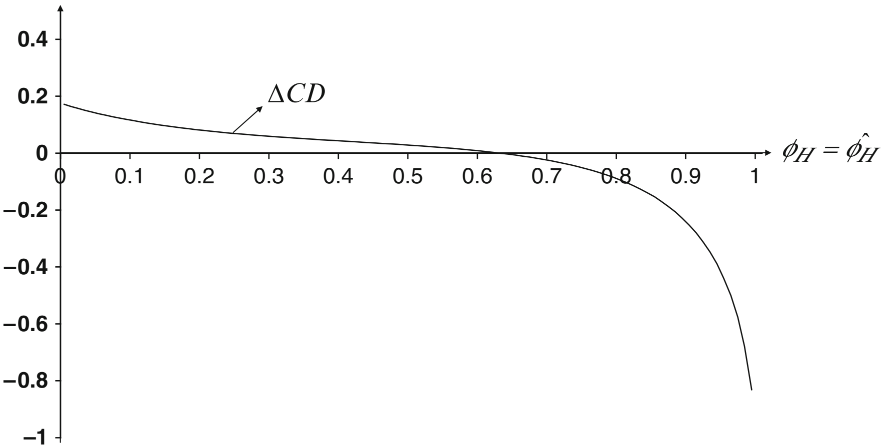

Fig. 6.5 Impact of the unconditioned signals on the buyer's costs, supplier's costs and the coordination deficit

Figure 6.5 depicts the robustness of the results in dependence of the buyer's randomization variables $\phi_i = \hat{\phi}_i, i = L, H, No$. The variation of ϕ_H is considered by setting $\phi_L = \phi_{No} = \frac{(1-\phi_H)}{2}$.

Figure 6.5 depicts that an increase of the coordination deficit is observable for a broad range of parameter values, i.e., as long as $\phi_H < 0.63$. However, communication becomes more effective in terms of coordinating the supply chain, when the deceptive buyers tend to choose the high cost signal with a high probability.

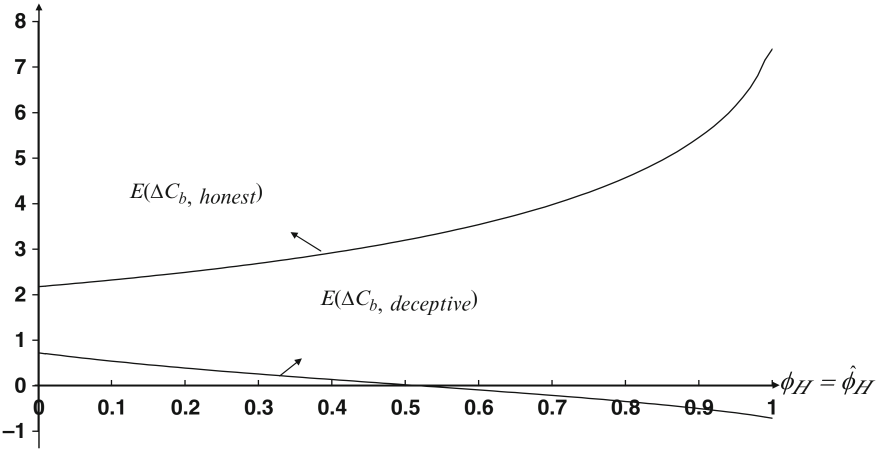

Fig. 6.6 Impact of unconditional signals on the honest and deceptive buyer's expected costs

Figure 6.6 again stresses that the rationally deceptive buyer would choose the unconditional signal $\phi_H = 1$ if he assumes that the supplier updates his beliefs with respect to the signal. An honest buyer, however, benefits from a deviating behavior, as the increase in expected costs is lower for lower values of $\phi_H = \hat{\phi}_H$. This effect is prevalent, because in this case it is harder for the supplier to distinguish whether signal S_L was given by an honest or by a dishonest buyer.

In the following, the impact of the supplier's trust as well as the buyer's trustworthiness is investigated. For this purpose, the level of the supplier's trust is fixed at $\hat{\alpha} = 0,5$ (as in the numerical example) while the buyer's trustworthiness, α, varies.

Figure 6.7 shows that the expected costs of the supplier can increase, if the overestimation of the buyer's trustworthiness is relatively high (see Theorem 1). In the numerical example the suppliers expected costs would increase for $\alpha < 0.25$. In turn, the coordination deficit decreases for $\alpha_{crit} > 0.62$.[2]

Figure 6.8 depicts the critical levels of trustworthiness, α_{crit}, in dependence of the supplier's trust, $\hat{\alpha}$, for which the supply chain performance does not change compared to the benchmark without communication. Furthermore, the arrows depicts in which regions the supply chain deficit would increase and decrease. These regions directly follow from Theorem 3.3. Figure 6.8 shows that communication becomes less attractive from a coordinational point of view, the higher the supplier's trust in the buyers signals, because α_{crit} is monotonically increasing with increasing $\hat{\alpha}$. This counterintuitive result highlights that the unilateral claim for more trust in supplier-buyer relationships might not always be justifiable. However, note that Fig. 6.8 does not depict the size of the changes in the coordination deficit.

[2]Surprisingly, if it is assumed that the supplier can perfectly observe the buyers trustworthiness, i.e., $\alpha = \hat{\alpha}$, then the coordination deficit would only decrease for $\alpha = \hat{\alpha} > 0.95$.

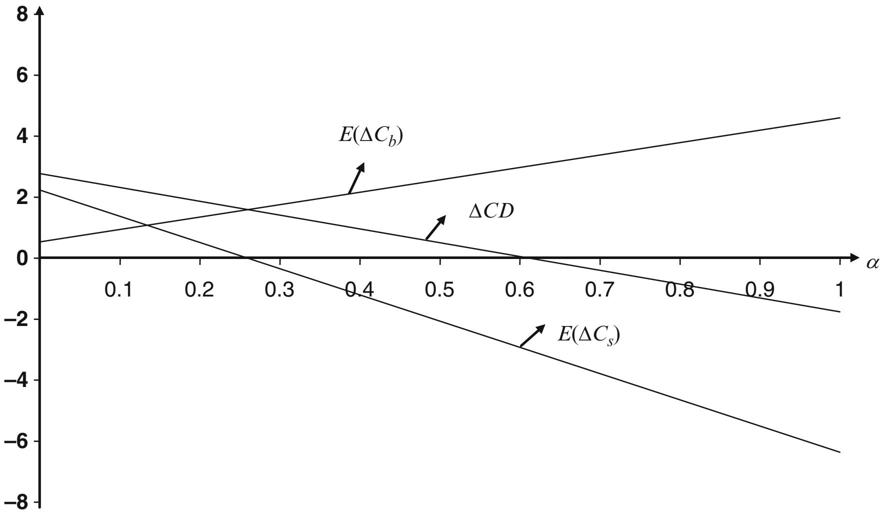

Fig. 6.7 Variation α for $\hat{\alpha} = 0.5$

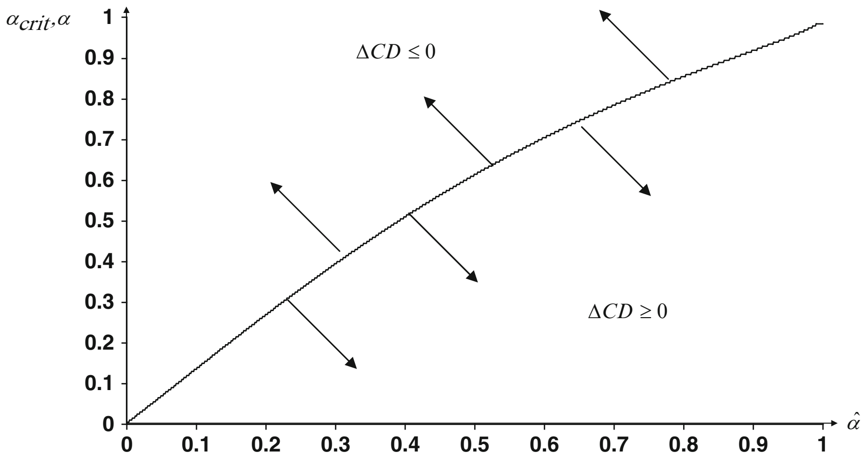

Fig. 6.8 Critical level of trustworthiness (α_{crit}) in dependence of trust $(\hat{\alpha})$

Obviously, if the supplier totally mistrusts the buyers signals, i.e., $\hat{\alpha} = 0$, then communication would have no impact on supply chain coordination and $\alpha_{crit} = 0$ would hold. In this case, though, neither the supplier nor the supply chain could benefit from trustworthy signals. The same analysis could be conducted for changes of ϕ_i. However, it can be shown that a variation of α and ϕ_i have a similar impact on the supply chain performance. Hence, this analysis is omitted.

6.4 Impact of Strategic Information Sharing

The previous analysis concentrated on unconditioned signals, i.e., the buyer who chooses his signal independently from his actual holding cost realization. Now, it is assumed that the buyer conditions his signals on the actual holding cost realization. Therefore, conditioned signaling variables,$\phi_i(h_k)\ \forall i, k,$ are defined. These variables denote the probability that the deceptive buyer facing holding cost h_k gives the signal S_i. The deceptive buyer might, for example, exaggerate his holding cost to the maximum extent, i.e., $\phi_n(h_i) = 1\ \forall i = 1, ..., n$. Alternatively, he might always exaggerate his actual holding cost realization by one (possible) unit, i.e., $\phi_i(h_k) = 1\ \forall\ i = k + 1$.

Please note, that the buyer might convey information (i.e., signals may not be cheap talk) if he uses strategic signaling variables and the supplier correctly anticipates this behavior. If the buyer always exaggerates by one unit, and the supplier anticipates this correctly, the supplier could infer the holding cost from the signal. In this case, the supplier has actually full information, which in turn leaves no information rent to the deceptive buyer.

Again, it is assumed that the supplier estimates the buyer's conditioned signaling variables. This estimation is denoted by $\widehat{\phi}_i(h_k)$.

The conditioned signaling variables are obviously a generalization of the assumption that the buyer gives unconditioned signals. Particularly, if $\phi_i = \phi_i(h_k)$ and $\hat{\phi}_i = \hat{\phi}_i(h_k), \forall k = 1, ..., n$ hold, the same results apply. Hence, it is not surprising that the analysis becomes more complex. Especially the previous theorems cannot be easily transferred. For this reason a numerical example combined with a comparative static analysis demonstrates the differences that emerge in contrast to the previous section, i.e., in contrast to unconditioned signals.

Numerical example and comparative static analysis: As a starting point, it is assumed that the supplier can perfectly observe the buyer's conditioned signaling variables. As an example, it is assumed that $\phi_L(h_L) = \hat{\phi}_L(h_L) = 0$, $\phi_H(h_L) = \hat{\phi}_H(h_L) = 1$, $\phi_{No}(h_L) = \hat{\phi}_{No}(h_L) = 0$, $\phi_L(h_H) = \hat{\phi}_L(h_H) = 1/3$, $\phi_H(h_H) = \hat{\phi}_H(h_H) = 1/3$ and $\phi_{No}(h_H) = \hat{\phi}_{No}(h_H) = 1/3$. All remaining parameter values from Chap. 5 apply. The buyer, thus, follows the strategy to always exaggerate his holding cost to the maximum extent (i.e., by one unit) if he faces holding costs h_L. Yet, if he faces the holding costs h_H he gives all signals with the same frequency of 33%.

Note that the buyer's costs do never change if he faces the highest possible holding cost realization (see Chap. 3, condition 2). Truthful reporting as well as an over- and understatement, thus, has no impact on his performance. In contrast to the previous Sect. 6.3,[3] unconditional signals given the highest possible holding cost realization h_H can indeed reflect the buyer's signaling behavior even though he

[3]In the previous section it was assumed that the buyer gives unconditional signals as he simple ignores that the supplier updates his beliefs with respect to the signal.

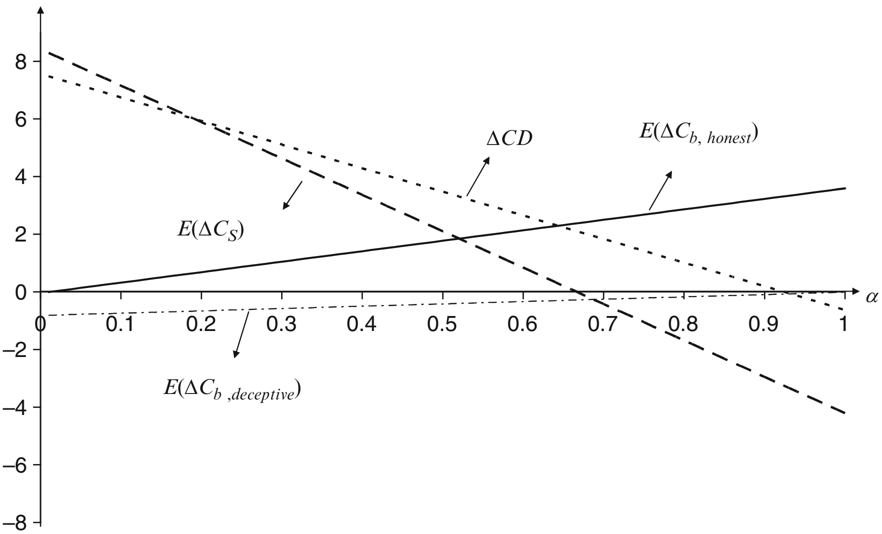

Fig. 6.9 Variation of α under conditional signaling

anticipates the supplier's adjustment of beliefs. Figure 6.9 depicts the expected changes of the supplier's costs, $E(\Delta C_s)$, the buyer's costs disaggregated by honest and deceptive buyers, $E(\Delta C_{b,honest})$, $E(\Delta C_{b,deceptive})$, and the overall supply chain deficit, ΔCD, in dependence of the buyer's trustworthiness, α.

Again, the supply chain deficit is vulnerable if communication takes place, i.e., if the supplier adjusts his probabilities with respect to the buyer's signal. The expected coordination deficit does only decrease if the buyers trustworthiness is relatively high, i.e., if $\alpha > 0.92$ holds. The disaggregated view on the honest and deceptive buyers point out that the deceptive buyers cannot be worse off if they choose a suitable signaling strategy. The honest agents, however, are always worse off due to reporting truthfully. This example shows, that even a buyer's rational signaling strategy, i.e., always exaggerating to maximum extent if he faces a holding cost realization that is lower than h_n, while randomizing signals if he faces the holding cost realization h_n, can significantly harm the overall supply chain performance. To highlight the impact of the buyer's randomized signals while facing the holding cost realization h_n, the buyers signaling strategy given h_n is varied. Figure 6.10 captures the changes of the respective expected costs for a change of $\phi_H(h_H)$. The variation of $\phi_H(h_H)$ is considered by setting $\phi_{No}(h_H) = 0$ and $\phi_L(h_H) = 1 - \phi_H(h_H)$. Furthermore, it is assumed that the supplier expects that the buyer always exaggerates to the maximum extent, i.e., $\hat{\phi}_H(h_L) = \hat{\phi}_H(h_H) = 1$. All other values from the previous example apply.

Figure 6.10 displays that the supply chain performance is dependent on the supplier's perception of the buyer's signaling strategy and the signaling strategy itself. As an example, for $\phi_H(h_H) = 0.2$ the supply chain deficit increases by $\Delta CD = 1.54$, i.e., the coordination deficit increases about 79% compared to the

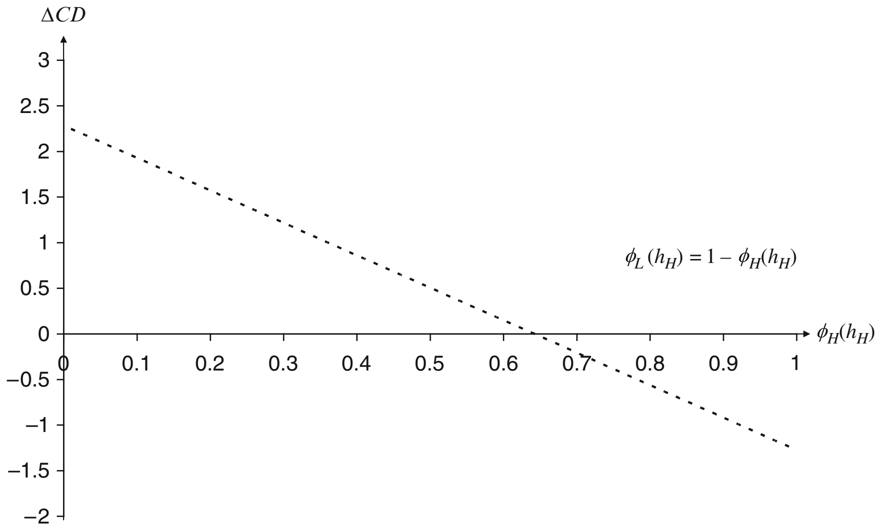

Fig. 6.10 Variation of the conditional signaling strategy

benchmark without communication, although the supplier expects the deceptive buyer to give constantly the high cost signal. In contrary, the deceptive buyer's expected costs do not change through a change of $\phi_H(h_H)$ (see Chap. 3, condition 2).[4] The supplier, thus, should carefully estimate the buyer's unconditioned signaling variables. However, if this is not possible he should be cautious to adjust the a priori probabilities at all.

6.5 Conclusion and Managerial Insights

Traditionally, it is assumed that the principal has an a priori probability distribution over the agent's private information. However, there is usually little said on how the principal obtains this distribution. Moreover, it is stressed that the assessment of the a priori distribution is not influenced by communication, as information sharing is treated as cheap talk.

This study shows that the introduction of communication in the presence of trust and trustworthiness can substantially affect the predictions of principal–agent models under asymmetric information. The behavioral model introduced in this study therefore provides a general framework which allows investigating the

[4] In fact, the deceptive buyer's expected cost change stays constant at $E(\Delta C_{b,deceptive}) = -0.02$, and the honest buyer's expected cost change stays constant at $E(\Delta C_{b,deceptive}) = -12.19$. Hence, all variation of the coordination deficit does directly benefit or harm the supplier.

impact of different information processing and information sharing behavior in a general principal–agent framework.

The underlying work shows that the effect of information processing on the supplier's performance is ambiguous. Particularly, if the supplier manages to assess the buyer's information sharing behavior accurately while underestimating the probability of receiving credible signals, the supplier can indeed improve his performance. However, if the supplier does not anticipate the buyer's information sharing behavior accurately while being overconfident in receiving credible information, a decrease in the supplier's performance level is likely.

Surprisingly, the results show that the overall supply chain performance can seriously deteriorate, even though the supplier can utilize the shared information to assess a more accurate estimation of the buyer's private information. This fact stresses the basic conflict in supply chain management, i.e., the supplier's optimization attempts do not automatically lead to supply chain optimal solutions. Therefore, communication cannot be regarded as an appropriate coordination instrument without considering the specific supply chain environment. Managers should carefully evaluate whether their respective supply chain is more likely to gain or to loose from information sharing. The suppliers, on the one hand, should carefully process the shared information and evaluate the potential losses from believing in deceptive signals. The buyers, in turn, should account for the fact that their signals might influence the supplier's contract offers, and that the randomization of signals especially in case of high holding costs can seriously harm the supply chain performance. Hence, the ever increasing unilateral claim for trust in supplier–buyer relationships needs to be handled carefully.

The behavioral model introduced in the underlying work is subject to some limitations. First, it is assumed that communication, trust and trustworthiness are exogenously determined. Yet, another approach might treat these variables endogenously by incorporating reputational effects in recurring interactions.

A further direction for research might be the extensive testing of this behavioral model according to methods presented in Chap. 4. This research might give valuable empirical data which allows for an estimation of the behavioral parameters of the model.

Appendix: Proof of Theorems

Theorem 1. *The suppliers expected costs do not increase due to the adjustment of the a priori distribution as long as* $\hat{\alpha} \leq \min_i \left[\frac{\hat{\phi}_i \cdot \alpha}{\hat{\phi}_i \cdot \alpha + \phi_i - \phi_i \alpha}\right]$, $i = 1, ..., n$ *holds.*

Proof. In the following it is shown that the supplier estimates the actual a posteriori distribution $p_i(h_i|S_i)$ more accurately if the condition in Theorem 1 holds.
(a) Adjustment of the probability that corresponds to the signal: $\hat{p}_i(h_i|S_i)$, $\forall i = 1, ..., n$

First, it is shown that the perceived a posteriori probability is always lower than the actual a posteriori probability if $\hat{\alpha} \leq \frac{\hat{\phi}_i \alpha}{\hat{\phi}_i \alpha + \phi_i - \phi_i \alpha}$ holds.

$$\hat{p}_i(h_i|S_i) = \frac{\hat{\alpha}p_i + (1-\hat{\alpha})p_i\hat{\phi}_i}{\hat{\alpha}p_i + (1-\hat{\alpha})\hat{\phi}_i} \leq \frac{\alpha p_i + (1-\alpha)p_i\phi_i}{\alpha p_i + (1-\alpha)\phi_i} = p_i(h_i|S_i)$$

$$\rightarrow -\frac{p_i\left(-\alpha\hat{\phi}_i + \alpha\hat{\phi}_i\hat{\alpha} - \phi_i\hat{\alpha}p_i + \phi_i\alpha\hat{\alpha}p_i + \hat{\alpha}\phi_i - \hat{\alpha}\phi_i\alpha + \hat{\phi}_i\alpha p_i - \hat{\phi}_i\hat{\alpha}\alpha p_i\right)}{(\alpha p_i + (1-\alpha)\phi_i)\left(\hat{\alpha}p_i + (1-\hat{\alpha})\hat{\phi}_i\right)} \geq 0$$

$$\vdots$$

$$\rightarrow \hat{\alpha} \leq \frac{\hat{\phi}_i\alpha}{\hat{\phi}_i\alpha + \phi_i - \phi_i\alpha}$$

As the supplier's estimation needs to be more accurately for every signal $S_i, i = 1, ..., n$ (note that there is no adjustment for S_{n+1}), it follows:

$$\hat{\alpha} \leq \min_i \left[\frac{\hat{\phi}_i \cdot \alpha}{\hat{\phi}_i \cdot \alpha + \phi_i - \phi_i\alpha}\right], i = 1, ..., n.$$

Second, it needs to be shown that $\hat{p}_i(h_i|S_i) \geq p_i$ holds:

$$p_i \leq \frac{\hat{\alpha}p_i + (1-\hat{\alpha})p_i\hat{\phi}_i}{\hat{\alpha}p_i + (1-\hat{\alpha})\hat{\phi}_i}$$

$$\hat{\alpha}p_i + (1-\hat{\alpha})\hat{\phi}_i \leq \hat{\alpha} + (1-\hat{\alpha})\hat{\phi}_i$$

$$\rightarrow p_i \leq 1$$

Hence, it follows that

$$\boxed{p_i \leq \hat{p}_i(h_i|S_i) \leq p_i(h_i|S_i),\ \forall i = 1, ..., n.}$$

(b) Adjustment of probabilities that do not correspond to the signal, i.e., $\hat{p}_k(h_k|S_i), \forall k = 1, ..., n; i = 1, ..., n+1; i \neq k$

$$\hat{p}_k(h_k|S_i) = \frac{(1-\hat{\alpha})p_k\hat{\phi}_i}{\hat{\alpha}p_i + (1-\hat{\alpha})\hat{\phi}_i} \geq \frac{(1-\alpha)p_k\phi_i}{\alpha p_i + (1-\alpha)\phi_i} = p_k(h_k|S_i)$$

$$\rightarrow -\frac{p_k p_i(-\hat{\alpha}\phi_i + \hat{\alpha}\phi_i\alpha + \alpha\hat{\phi}_i - \alpha\hat{\alpha}\hat{\phi}_i)}{(\alpha p_i + (1-\alpha)\phi_i)\left(\hat{\alpha}p_i + (1-\hat{\alpha})\hat{\phi}_i\right)} \leq 0$$

$$\vdots$$

$$\rightarrow \hat{\alpha} \leq \frac{\hat{\phi}_i\alpha}{\hat{\phi}_i\alpha + \phi_i - \phi_i\alpha}$$

Hence, it follows:

$$\hat{\alpha} \leq \min_i \left[\frac{\hat{\phi}_i \cdot \alpha}{\hat{\phi}_i \cdot \alpha + \phi_i - \phi_i \alpha} \right], i = 1, ..., n$$

Furthermore, it needs to be shown that $\hat{p}_k(h_k|S_i) \leq p_k$ holds:

$$p_k \geq \frac{(1-\hat{\alpha})p_k\hat{\phi}_i}{\hat{\alpha}p_i + (1-\hat{\alpha})\hat{\phi}_i}$$
$$\hat{\alpha}p_i + (1-\hat{\alpha})\hat{\phi} \geq (1-\hat{\alpha})\hat{\phi}_i$$
$$\vdots$$
$$\rightarrow p_i \geq 0$$

Hence it follows that

$$\boxed{p_k(h_k|S_i) \leq \hat{p}_k(h_k|S_i) \leq p_k, \ \forall i = 1, ..., n+1; k = 1, ..., n; i \neq k}$$

The same argumentation follows for $\hat{\alpha} \geq \min_i \left[\frac{\hat{\phi}_i \cdot \alpha}{\hat{\phi}_i \cdot \alpha + \phi_i - \phi_i \alpha} \right], i = 1, ..., n$:

$$p_i \leq p_i(h_i|S_i) \leq \hat{p}_i(h_i|S_i) \ \forall i = 1, ..., n$$
$$\hat{p}_k(h_k|S_i) \leq p_k(h_k|S_i) \leq p_k, \ \forall i = 1, ..., n+1; k = 1, ..., n; i \neq k$$

In this case, however, the change of the supplier's expected costs depends on the specific cost structure.

Theorem 2.1. *The honest buyer's expected costs increase due to truthful signaling.*

The informational rent denotes the costs savings that occur for the buyer in comparison to the outside option, i.e., the alternative supplier. Let IR_i denote informational rent of the buyer who faces holding costs of h_i. From condition 2 (see Chap. 3) it follows:

$$\frac{h_n}{2}q_n - Z_n = C_{AS}$$
$$\rightarrow IR_n = C_{AS} + Z_n - \frac{h_n}{2}q_n = 0$$
$$\frac{h_{n-1}}{2}q_{n-1} - Z_{n-1} = \frac{h_{n-1}}{2}q_n - Z_n$$
$$\rightarrow IR_{n-1} = C_{AS} + Z_{n-1} - \frac{h_{n-1}}{2}q_{n-1} = ... = IR_n + \frac{q_n}{2}(h_n - h_{n-1}) > 0, \text{ as } \mathrm{h_{n-1}} < \mathrm{h_n}$$
$$\vdots$$
$$IR_i = ... = C_{AS} + Z_{i+1} - \frac{h_i}{2}q_{i+1} = IR_{i+1} + \frac{q_{i+1}}{2}(h_{i+1} - h_i)$$

Hence, if all ${q_{i+1}}^k, ..., {q_{n-1}}^k, {q_n}^k$ decrease given a signal S_k, then the informational rent IR_i decreases as well.

The impact on the order sizes ${q_m}^k, m = i+1, ..., n$ is analyzed by computing the change of ${\gamma_m}^k$ given the changes of $\hat{p}_t(h_t|S_k), t = i+1, ..., n$. From $\frac{\partial {\gamma_m}^k}{\partial \hat{p}_t(h_t|S_k)} \leq 0, \forall t = i+1, ..., n$ it follows directly that ${q_m}^k \leq {q_m}^{AI}$ as long as $p_t \geq \hat{p}_t(h_t|S_k)$. The condition $p_t \geq \hat{p}_t(h_t|S_k)$ holds for all $H \leq \tilde{h}$ (see Theorem 1), i.e., as long as the buyer reports truthfully or understates his holding costs.

Theorem 2.2. *The expected costs of the deceptive buyer can either increase or decrease due to communication.*

The deceptive buyer may either (a) report accidentally truthful, i.e., $S = \hat{h}$, or (b) misreport his holding cost, i.e., $S \neq \hat{h}$.

Case (a): Accidental Truthful Reporting

$S = \hat{h}$ may occur if $\phi_i > 0$ holds.

From Theorem 2.1 it follows directly that the deceptive buyer is worse off if he reports truthfully.

Case (b): Deceptive Reporting

Deceptive reporting is formalized by $S \neq \hat{h}$. The case of the deceptive reporting is divided into three subclasses, (b1) an understatement of holding cost, (b2) an overstatement of holding cost, but not to the maximum extent and (b3) an overstatement to the maximum extent.

Case (b1): $S < \hat{h}$ (understatement of holding costs)

From Theorem 2.1 it follows that the deceptive buyer can only be worse off if he understates his holding cost.

Case (b2): $\hat{h} < S < h_n$ (overstatement, not to the maximum extent)

In this case, the deceptive buyer can either be better off or worse off. If the reduction of the informational rents $IR_k, ..., IR_n$ given S_k and $\hat{h} = h_i$ is compensated by the increase of the informational rents $IR_i, ..., IR_{k-1}$, then he is better off. Otherwise, he is not. However, this depends on the specific cost structure.

Case (b3): $h_n = S \geq \hat{h}$ (overstatement to the maximum extent)

From Theorem 2.1 and condition (1) (see Chap. 3) it follows directly that the deceptive buyer can only be better off if he constantly signals S_n. In this case, the supplier adjusts the order quantity ${q_n}^n$ upwards, i.e., ${q_n}^n > {q_n}^{AI}$. This leads to an increase of all informational rents $IR_i, i = 1, ..., n-1$.

Theorem 3.2. *As long as* $\alpha \geq \dfrac{\sum_i \sum_{k,i \neq k} p_i \phi_k \Delta {CD_i}^k + \sum_i p_i \phi_i \Delta {CD_i}^i}{\sum_i \sum_{k,i \neq k} p_i \phi_k \Delta {CD_i}^k - \sum_i (1-\phi_i) p_i \Delta {CD_i}^i} = \alpha_{crit}\left(\hat{\alpha}, \hat{\phi}_i\right)$ *holds, communication enhances the supply chain performance, and vice versa.*

$$\Delta CD = (1-\alpha)\sum_i \sum_{k,i\neq k} p_i \phi_k \Delta CD_i^{\,k} + \alpha \sum_i p_i \Delta CD_i^{\,i} + (1-\alpha)\sum_i p_i \phi_i \Delta CD_i^{\,i} \leq 0$$

$$\vdots$$

$$\sum_i \sum_{k,i\neq k} p_i \phi_k \Delta CD_i^k + \sum_i p_i \phi_i \Delta CD_i^i \leq \alpha \sum_i \sum_{k,i\neq k} p_i \phi_k \Delta CD_i^k - \alpha \sum_i (1-\phi_i) p_i \Delta CD_i^i$$

$$\vdots$$

$$\alpha \geq \frac{\sum_i \sum_{k,i\neq k} p_i \phi_k \Delta CD_i^k + \sum_i p_i \phi_i \Delta CD_i^i}{\sum_i \sum_{k,i\neq k} p_i \phi_k \Delta CD_i^k - \sum_i (1-\phi_i) p_i \Delta CD_i^i} = \alpha_{crit}\left(\hat{\alpha}, \hat{\phi}_i\right)$$

As $\Delta CD_i^{\,i} \leq 0$ it can be easily shown that $\alpha_{crit} \leq 1$ holds.

Theorem 3.3. *The range of levels of trustworthiness for which communication is an appropriate coordination mechanism decreases with increasing levels of supplier's trust.*

Let $\alpha_{\min}$ denote the level of trustworthiness for which the coordination deficit reaches its minimum for a given a certain level of trust $\hat{\alpha}_{\min}$.

$\alpha_{\min}$ follows from:

$$\Delta CD = (1-\alpha)\sum_i \sum_{k,i\neq k} p_i \phi_k \Delta CD_i^{\,k} + \alpha \sum_i p_i \Delta CD_i^i + (1-\alpha)\sum_i p_i \phi_i \Delta CD_i^{\,i} = 0$$

$$\rightarrow$$

$$\frac{\partial \Delta CD}{\partial \hat{\alpha}} = (1-\alpha)\sum_i \sum_{k,i\neq k} p_i \phi_k \frac{\partial \Delta CD_i^{\,k}}{\partial \hat{\alpha}} + \alpha \sum_i p_i \frac{\partial \Delta CD_i^{\,i}}{\partial \hat{\alpha}} + (1-\alpha)\sum_i p_i \phi_i \frac{\partial \Delta CD_i^{\,i}}{\partial \hat{\alpha}} = 0$$

$$\rightarrow$$

$$\alpha_{\min} = \frac{\sum_i p_i \phi_i \left.\frac{\partial \Delta CD_i^i}{\partial \hat{\alpha}}\right|_{\hat{\alpha}=\hat{\alpha}_{\min}} + \sum_i \sum_{k,i\neq k} p_i \phi_k \left.\frac{\partial \Delta CD_i^k}{\partial \hat{\alpha}}\right|_{\hat{\alpha}=\hat{\alpha}_{\min}}}{\sum_i p_i (\phi_i - 1) \left.\frac{\partial \Delta CD_i^i}{\partial \hat{\alpha}}\right|_{\hat{\alpha}=\hat{\alpha}_{\min}} + \sum_i \sum_{k,i\neq k} p_i \phi_k \left.\frac{\partial \Delta CD_i^k}{\partial \hat{\alpha}}\right|_{\hat{\alpha}=\hat{\alpha}_{\min}}} < 1$$

It follows that $\frac{\partial \Delta CD}{\partial \hat{\alpha}} \leq 0$, if $\alpha \geq \alpha_{\min}$, and vice versa.

Additionally, $\frac{\partial \Delta CD}{\partial \alpha} \leq 0$ holds:

$$\Delta CD = (1-\alpha)\sum_i \sum_{k,i\neq k} p_i \phi_k \Delta CD_i{}^k + \alpha \sum_i p_i \Delta CD_i{}^i + (1-\alpha)\sum_i p_i \phi_i \Delta CD_i{}^i$$

$$\frac{\partial \Delta CD}{\partial \alpha} = -\sum_i \sum_{k,i\neq k} p_i \phi_k \Delta CD_i{}^k + \sum_i p_i \Delta CD_i{}^i - \sum_i p_i \phi_i \Delta CD_i{}^i \leq 0$$

$$\vdots$$

$$\sum_i p_i (1-\phi_i) \Delta CD_i{}^i \leq \sum_i \sum_{k,i\neq k} p_i \phi_k \Delta CD_i{}^k$$

As $\Delta CD_i{}^i \leq 0 \; \forall i = 1,\ldots,n$ and $\Delta CD_i{}^k \geq 0, \forall i,k = 1,\ldots,n; i \neq k$ (see Theorem 2.1) it follows directly that $\frac{\partial \Delta CD}{\partial \alpha} \leq 0$ is true.

If $\alpha = \alpha_{crit}$ holds, it follows that $\Delta CD = 0$ (see Theorem 3.2). Hence, it follows that $\alpha < \alpha_{crit} \;\rightarrow\; \Delta CD > 0$ and $\alpha > \alpha_{crit} \;\rightarrow\; \Delta CD < 0$, respectively.

Hence, it follows directly that $\alpha_{\min} > \alpha_{crit}$. Since $\frac{\partial \Delta CD}{\partial \hat{\alpha}} \geq 0$ if $\alpha_{\min} \geq \alpha$, it follows directly that $\frac{\partial \alpha_{crit}}{\partial \hat{\alpha}} \geq 0$.

Chapter 7
Conclusion and Outlook

The research objective of the underlying thesis is to improve existing approaches of supply chain coordination under asymmetric information. Section 2.1 gave a brief and general introduction into principal–agent models under asymmetric information. These models were classified into moral hazard and adverse selection problem. Afterwards, one approach to solve adverse selection problems, namely screening contracts, was discussed in a strategic lotsizing framework. One of the main assumptions in this framework is that the privately informed agent uses his superior information strategically. The principal, in turn, anticipates this strategic use and offers a screening contract which is independent of any communication between the principal and the agent. Yet, these screening contracts are inefficient, and recent experimental research has shown that the assumptions of rational- and fully opportunistic behavior have to be treated with caution. Hence, Sect. 2.3 analyzes the potential benefits and pitfalls of information sharing in case of (non rational) trust and trustworthiness. Finally, Sect. 2.4 closes with a comprehensive review of adverse selection models in supply chain management.

Chapter 3 analyzes, if investments in process-improvements, such as setup cost reduction, can help to strengthen the coordinational power of screening contracts in the strategic-lotsizing framework. Interestingly, it is shown that the supplier's expected performance cannot decrease due to the investment option, but that the impact on supply chain coordination is ambiguous. Two countervailing effects, namely the fixed-cost and overinvestment effect are identified.

The basic insight is that the downward distortion of order sizes leads also to a distortion of the supplier's investment decision. This is, because the marginal revenues increase due to the downward distortion of the order size. Consecutively, there is an overinvestment in fixed cost reduction. On the other hand, the (over)-investment in fixed-cost lessens the impact of the imbalance between fixed-costs and holding costs per period. Hence, the total effect on supply chain coordination is not clear. If the overinvestment effect is predominant, then the supply chain performance is likely to decrease. In case the fixed-cost effect is predominant, thus, process-improvements seem appropriate particularly under asymmetric information.

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Chapter 4 presented a laboratory experiment of the strategic lotsizing model introduced in Sect. 2.2. The results show that some of the main assumptions in the screening theory have to be handled cautiously. First, theory assumes that the supplier ignores all shared information. Yet, the experimental results give highly significant evidence that this is not the case. It is shown that there are some suppliers who tend to believe shared information, while other suppliers ignore or interpret shared information. Second, we find that communication is not used entirely strategically. In fact, the strategic most relevant signal is hardly informative, while other signals convey at least some information. Third, it is observed that the contract choice behavior of the buyer can seriously harm the supplier's and supply chain's performance. In particular, it is shown that the buyer may have an incentive to cover up deceptive signals by his contract choice. This strategic scope arises as the supplier can only observe if a signal was consistent but not if it was truthful. As screening contracts are designed in a way that the payoff differences between two alternatives are very small, the strategy of covering up deceptive signals has almost no payoff effects for the buyer, but a substantial payoff effect for the supplier. In fact, the choice of the so-called "indifference"-contract was observed in only 7.9% of all observations, but causes almost 50% of the deviations from the game theoretic equilibrium. These findings imply that the indifference-modeling approach can seriously harm the supply chain performance.

Finally, the results show that communication limits the misalignment losses that result from the supplier's adjustment of subjective probabilities. In fact, 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' signals, 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 trusting behavior helps to align the actions and can even enhance the supply chain performance, whereas deception and mistrust leads to the ineffectiveness of communication.

Chapter 5 directly compares the effectiveness of the screening contract compared to simple wholesale-price contracts. In this experiment, the supplier's options to offer different kinds of contracts were substantially reduced. In fact, the supplier was only allowed to offer either the screening contracts or a contract as if under full information, i.e., a simple wholesale-price contract. Furthermore, this experimental design was used to analyze whether the supply chain configuration, i.e., serial or diverging, has an impact on the effectiveness of the screening contracts.

The experimental results show that screening contracts help to coordinate the supply chain at least to some extent, as the supply chain performance significantly improved compared to the wholesale-price benchmark. However, some empirical difficulties were identified that mitigate the effectiveness of this contract type.

In particular, the experiment resembles the finding from the experiment in Chap. 4, i.e., a tendency to choose the indifference-contract. This contract choice heavily deteriorates the supply chain performance. We find that the suppliers anticipate the risk of the buyer choosing the indifference-contract and are therefore reluctant to offer the screening contract. Hence, they tend to choose the simpler wholesale-price contract, which deteriorates the supply chain performance. Not surprisingly, however, the analysis reveals that the supplier's perceived risk has a minor impact on the contract offer behavior, if he is restricted to offer only one contract in a diverging supply chain. In this case, the supplier tends to offer screening contracts. Nonetheless, the direct inefficiencies that occur due to indifference contract choices are still substantial.

Moreover, the experiments show that the mere presence of a punishment option can enhance truthfulness, consistency and trust within the supply chain. Yet, the punishment option needs to be designed properly, and must not be too expensive for the supplier himself (which is the case if his only punishment option is to withdraw the offer).

Chapter 6 develops a model based on the main assumption that not all buyers use their private information entirely strategically. This assumption is supported by the experimental results from Chaps. 4 and 5. Assuming that there is a supplier who updates his beliefs according to the shared information, it is shown that the effect of communication on supply chain performance is ambiguous. The model identifies three main determinants that are crucial for analyzing the impact of communication on supply chain performance, i.e., trust, trustworthiness, and the buyer's signaling behavior. In particular, the model identifies critical levels of trust- and trustworthiness that are necessary to improve supply chain performance when the deceptive buyers' signals cannot be easily identified.

Particularly, if the supplier manages to assess the buyer's information sharing behavior accurately while underestimating the probability of receiving credible signals, then the supplier can indeed improve his performance. However, if the supplier does not anticipate the buyer's information sharing behavior accurately while being overconfident in receiving credible information, a decrease in the supplier's performance level is likely.

Furthermore, the model highlights that more accurate information can indeed harm the supply chain performance, when the supplier exploits this more accurate information. This fact highlights one of the main difficulties in supply chain coordination: pursuing individual goals instead of supply chain goals can alter the predictions of recommended strategies, such as information sharing. The following subsections conjecture how the results can be applied to other frameworks.

7.1 Different Kinds of Asymmetric Information and Supply Chain Interactions

Section 2.4 gives a comprehensive review of supply chain interactions, in which screening contracts are used to align the incentives of the supply chain members. Since all the experiments in the underlying thesis were designed as repeated games, it is likely that the experimental results are easily transferable to those supply chain interactions in which the private information (e.g., cost or demand parameters) changes over time. Hence, the experimental results are closest to supply chain setting with long lasting relationships, in which contracts are renegotiated over time. In these cases, reputational effects seem to have a substantial impact on supply chain outcomes, and punishment and reward mechanisms outside the contracting stage facilitate supply chain coordination. This is, because the truthfulness and the consistency of the reports increases, and reward considerations are decoupled from the actual screening-contract offer. Yet, more experimental work should investigate the impact of punishment and reward considerations when screening- and simple wholesale-price contracts are used under repeated interaction. As an example, a subtle punishment and reward mechanism might also be available for the buyer. In our experiment, though, the buyer was only allowed to directly affect the supplier's payoffs with the contract choice, e.g., indifference contract or alternative supplier. Yet, the indifference contract choice causes almost no costs for the buyer, but has a significant payoff effect for the supplier. A more subtle punishment mechanism might decrease the frequency of out-of-equilibrium contract choices while increasing the overall efficiency of the supply chain.

Yet, if there is only a short term relationship, the results from the behavioral model in Chapter 6 can be applied, and communication has an (positive or negative) impact on supply chain outcomes as long as there is an initial level of trust. Moreover, the optimal screening contracts for different risk preferences were derived (see Sect. 4.3), since the experimental data indicate some level of risk aversion. Yet, this analysis is also transferable to short term supply chain relationships, since risk aversion should not depend on the frequency of the respective interaction. Nonetheless, additional experiments in which suppliers and buyers interact only once seem to be an interesting focus for future research, since the benefits of long term relationships could be evaluated.

7.2 Signaling Contracts and Other Mechanisms

So far, only the effectiveness of screening contracts and/or simple wholesale-price contracts was tested in the strategic lotsizing model. However, other solution methods, such as signaling contracts could be used to mitigate incentive conflicts in adverse selection models.

The distinctive feature between screening- and signaling contracts is whether the holder of the private information makes or receives the contract offer. As discussed intensively, in screening contracts the ill-informed party offers the contract while ensuring that the private information is revealed with the contract choice. In contrast, in signaling contracts the holder of the private information offers the contract. The basic idea is briefly demonstrated on a supply chain model introduced by Desai and Srinivasan (1995). In order to stick to the notation used throughout the underlying work, it is assumed that the supplier is franchisor (principal) and the buyer is franchisee (agent). The franchisor is privately informed about the market potential for a product that is sold by a franchisee. Furthermore, the franchisee also can influence the product's demand with promotional effort which is observable by the franchisor. The franchisee's promotional effort is costly. Under these circumstances, the buyer is willing to accept a higher franchise fee and a higher promotional effort (dictated by the supplier) if the market potential of the franchise concept is high. Hence, the supplier has an incentive to state that there is high market potential in all states of nature, i.e., regardless whether he faces low- or high market potential. The buyer, in turn, anticipates this behavior and will only accept a franchise fee – promotional effort combination if the expected outcome (weighted by the a-priori probability that there is a low- and high type supplier) leaves him at least his reservation profit. Because the buyer can only base his decision on expectations, the low-type supplier's profits increase (i.e., he can enforce a better franchise fee – promotional effort combination), and the high-type supplier's profits decrease. This gives the supplier with high market potential an incentive to "signal" his potential, by offering a contract a low-type supplier would never offer.

Interestingly, the contract parameters in such signaling contracts do not depend on the a-priori distribution of types, and a subtle measurement of trust via the adjustment of subjective beliefs (see Chap. 4) is therefore not possible. However, even though the adjustment of believes is not directly observable, it might be possible observing that buyers accept contracts even though the expected outcome is smaller than the reservation profit. In this case, communication could enhance supply chain performance since the high-type supplier could offer efficient contracts which are accepted by the buyer. Moreover, it would be interesting to analyze whether low-type suppliers really mimic high-type supplier if they have the chance, and how a punishment and reward mechanism influences the subjects behavior in such an environment. Finally, note that there is no incentive to cover-up deceptive signals, because there is no indirect feedback with respect to the truthfulness and/or consistency as in screening-contracts. This fact might have a substantial impact on the effectiveness of communication.

Another direction for future research is to test mechanisms that are simpler to derive and implement than screening or signaling contracts, but which are not optimal from the principal's perspective. Cachon and Lariviere (1999), for example, analyze allocation mechanisms in case of scarce capacities within the supply chain. These allocation mechanisms define how much capacity is allocated to a buyer in dependence of his forecast report. Interestingly, one of their main results is that allocations mechanisms that theoretically lead to a misrepresentation of private information can improve the supply chain performance. Given this result, it would be interesting to investigate on the one hand, if the private information is really used strategically (which is in this case favorable) and, on the other hand, how the ill-informed party interprets the information. This experimental setting allows testing the empirical effectiveness of allocation mechanisms (in contrast to screening contracts as a coordination device).

7.3 Model Extensions

Chapter 6 introduced a behavioral model which captures the impact of communication if a certain fraction of agents reports their private information truthfully. Yet, this model can be extended in two dimensions.

First, the model does not capture the impact of repeated interaction, and therefore the development of trust, trustworthiness and reputational effect. Yet, an extension of the model could account for the dynamics arising under repeated interaction by endogenizing the fraction of honest buyers and/or the suppliers' level of trust. In such an environment, it would be interesting to analyze or simulate different information sharing and processing strategies (e.g., tit-for-tat or grim-type strategies).

Second, the experimental results show that there is a substantial tendency to choose indifference contracts. Varying the size of additional incentives to ensure self-selection is likely to be effective in reducing the frequency of indifference contract choices. Note that the decision situation is somewhat similar to an ultimatum game, i.e., the buyer rejects an offer (or chooses the indifference contract) unless the additional incentive is not high enough. A rigorous theoretical model that accounts for the underlying ultimatum structure could develop upper and lower bounds of these additional incentives, for which the screening contracts are still in the supplier's best interest. Note that such analysis is not trivial, since an additional incentive that is given to high-type buyer needs at least to be paid to the medium- and low-type buyer as well. Hence, if the additional incentive that is claimed by buyer exceeds a certain level, the informational rents become prohibitively high and the supplier tends to offer simpler wholesale-price contracts.

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