Incentive provision with multiple tasks and multiple agents

Inauguraldissertation
zur
Erlangung des Doktorgrades
der
Wirtschafts- und Sozialwissenschaftlichen Fakultät der
Universität zu Köln

2014

vorgelegt
von

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aus
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Tag der Promotion:	26. Juni 2014

Acknowledgments

First and foremost, I want to thank my supervisor Patrick Schmitz for his guidance and valuable advice. I am very grateful for his continuing support and encouraging feedback at every stage of the preparation of my thesis. Writing our joint paper had a great influence shaping my thinking about economic problems and my method of working. In this regard, I am also indebted to my colleague and co-author Eva Hoppe. Our fruitful discussions lead to several research projects which are included in this thesis. I also would like to thank Oliver Gürtler for co-refereeing this thesis and Johannes Münster for chairing the defense board.

Furthermore, I am thankful to Gary Bolton for inviting me to Penn State University. Our discussions about electronic feedback systems during my research stay together with Johannes Mans lead to the paper "Leniency in feedback giving" which is not included in this thesis. I also want to thank Axel Ockenfels and the DFG research unit "Design & Behavior" for supporting this research stay, and Ben Greiner for inviting me to the University of New South Wales. Moreover, I would like to thank Achim Wambach for the valuable discussions and support not only concerning our joint paper.

I am thankful for the full scholarship by the Cologne Graduate School in Management, Economics and Social Sciences and the federal state North Rhine-Westphalia I received during 2009–2012 which allowed me to concentrate on my research, and for the financial support by the DAAD for the research stay at Penn State.

In addition, I would like to thank Dagmar Weiler and Susanne Ludewig-Greiner from the CGS for their continuing support, and our secretary Kristin Pfeiffer and the student assistants Jana Boes, Felix Meickmann and Linda Pielsticker for providing valuable assistance conducting the laboratory experiments.

I also want to thank my colleagues from the CGS and the Department of Economics for academic and non-academic discussions over lunch and between office doors: Pascal Bruno, Kristian Dicke, Christoph Feldhaus, Nicolas Fugger, Katharina Huesmann, Alexander Rasch, Andreas Pollack, Christian Waibel, and Christopher Zeppenfeld. Particularly, I want to thank my friends, colleagues and co-authors Florian Gössl and Johannes Mans. Working together with them was fun and rewarding in so many ways, both professionally and personally. I am also grateful to Tine for her support.

Finally, I thank my parents Margret and Joachim and my sisters Anne and Eva for their support and encouragement not only throughout my doctoral studies. This thesis is dedicated to them.

Cologne, July 2014 David Jakob Kusterer

Contents

Chapter One

Introduction

One of the central results of economics is that incentives matter. Contract theory, the branch of economics that is concerned with the optimal design of incentives, has seen a considerable growth in the last decades. In the most simple model, a principal wants to delegate a task he cannot conduct himself to an agent who incurs a disutility from working. Hence, the incentives of principal and agent are not aligned, and the principal has to design an appropriate incentive scheme which motivates the agent to perform the task at the lowest cost. Contracting frictions arise when the effort of the agent is not observable by the principal or when she does not know whether the agent is highly skilled or lacking ability.

Early studies on incentive provision have covered problems where the principal delegates one task to one agent.[1] However, most real-world contracting problems consist of more than one task to be carried out, and principals typically hire more than one agent. In such situations, the interactions between the agents and between the incentives for the individual tasks have to be taken into account. Since the seminal paper by Holmström and Milgrom (1991), such problems have become of great interest to the theory of incentives.[2]

This thesis consists of four self-contained chapters concerning problems where there are multiple tasks to be delegated. One study is theoretical, two combine theory and evidence from the laboratory, and one is experimental. Testing the predictions of contract-theoretical models empirically is subject to difficulties

[1]See, for example, Spence and Zeckhauser (1971), Ross (1973), Mirrlees (1976), Holmström (1979), Grossman and Hart (1983).

[2]For overviews of the multi-tasking literature, see Dewatripont et al. (2000), Laffont and Martimort (2002, Chapter 5), and Bolton and Dewatripont (2005, Chapter 6).

due to the non-observability of the agents' efforts or their types.[3] Hence, the controlled environment of laboratory experiments is very useful as a first step for testing the empirical relevance of the theoretical models.

In Chapter 2, we analyze a theoretical model where an uninformed decision-maker has to make a decision based on evidence in favor and against a proposal. The information is gathered by two biased groups, one of which searches for favorable evidence while the other searches for evidence against the proposal. Chapter 3 theoretically and experimentally considers a problem where a principal has to delegate two tasks that are in direct conflict with each other. In the theoretical and experimental study presented in Chapter 4, a government wants to provide a public service. It can delegate the two tasks of building and subsequently operating the facility either to a public-private partnership or to two independent private contractors. In our experimental studies, social preferences in the form of fairness and reciprocity influence our results. While social preferences have received considerable attention in experimental economics, there are only a few studies on the effect of cognitive abilities. We report on a short experimental study in Chapter 5 on the relationship between cognitive abilities and behavioral biases.

In *Chapter 2*,[4] we study a problem of multi-dimensional information transmission where an uninformed decision-maker receives information relevant to the decision from two biased experts. We show that reducing the dimensions on which information can be gathered—and hence reducing complexity—can increase welfare. Suppose two firms want to merge, and a judge has to decide whether to accept or to reject the merger proposal based on information provided to her by the merging firms and an antitrust authority (regulator). We assume that there is information about the effects of the merger on welfare in three dimensions. In each of the dimensions, there exists either only information in favor of the proposal, only information against the proposal, conflicting information both in

[3] See Prendergast (1999) and Chiappori and Salanié (2003) for an overview of empirical studies on the provision of incentives.

[4] This chapter is joint work with Achim Wambach and Florian Gössl. Achim Wambach suggested the idea and wrote a first draft. Florian Gössl and I extended and generalized the model, conducted the analysis, and wrote the current draft.

favor and against the proposal, or no information.[5] The firms only search for information in favor of the proposal, and the regulator only searches for evidence against it. The firms and the regulator are asymmetric in the sense that the benefit of a cleared merger for the firms exceeds the benefits of the bureaucrats of the antitrust authority in case of a blocked merger. Due to the large expected profits of a successful merger, the firms always search on all admissible dimensions. When the firms and the regulator are sufficiently asymmetric, there is an equilibrium where the regulator does not search at all. The information provided to the judge hence is biased, and she has to make her decision based on information in favor of the proposal and on the expected value of information against the proposal. In this situation, it is possible that decision errors occur, which reduce welfare. We show in a first step that in such an asymmetric situation, simplifying the decision process in that the judge only accepts evidence from two of the three dimensions enables the regulator to equal the search efforts by the firms. In a second step, we show that in this situation, the judge is able to make better decisions because the information available to her is more balanced. Compared to the situation where only the firms search, welfare can be larger.[6] This model can also be applied to the case of lobbying where, for example, big tobacco and small consumer protection groups provide politicians working on new legislation on the ban of tobacco advertising with information about the health effects of smoking, or to white collar crime trials, where big firms with large resources and understaffed prosecutors battle in court.

In the study presented in *Chapter 3*,[7] a principal wants to delegate two tasks that are in direct conflict with each other, i.e., providing effort in one task may have a negative side effect on the success probability of the other

[5]This information structure is an extension of Dewatripont and Tirole (1999) to multiple dimensions.

[6]Results where restrictions can be beneficial have also been shown in the lobbying literature where a cap on political contributions can make voters better off or lead to better policy decisions (see Prat, 2002b; Cotton, 2012), and in the literature on optimal delegation, where a restriction of the action space of the agent can increase his search incentives (see Szalay, 2005; Alonso and Matouschek, 2008).

[7]This chapter is based on Hoppe and Kusterer (2011b). Eva Hoppe suggested the idea for the paper and Eva Hoppe and I carried out the theoretical analysis. Eva Hoppe designed the experiment, while I programmed and conducted it (the data collection was part of my diploma thesis). Together, we analyzed the data and wrote the draft.

and vice versa.[8] In such situations, job design becomes a major issue and we show that implementing two efforts can be facilitated by hiring two agents instead of one agent. Consider a merchant (principal) who wants to sell two products which may be imperfect substitutes. She can either hire one or two sales representatives (agents) in order to promote the products. If the products are imperfect substitutes, then promoting one product increases its sales probability, while it reduces the sales probability of the other. If the merchant hires only one sales representative, the sales representative is reluctant to promote both products as he hurts his own efforts on the respective other product, which makes inducing two efforts very expensive for the merchant. However, if the merchant hires two sales representatives, the competition between them makes inducing two efforts cheaper for her. In case of conflict between the tasks, it depends on the parameter constellation whether hiring one or two sales representatives is better for the merchant. However, when there is no conflict, it is unambiguously better for the merchant to hire one sales representative as the rent that the merchant leaves to the sales representative to motivate him to work on one task can also be used to motivate him to work on the other task.

In order to find an answer to our research question whether the theoretical incentive problem of inducing a single agent to simultaneously exert efforts in conflicting tasks is empirically relevant, we conducted a laboratory experiment with 474 subjects. There are four treatments with a 2×2 design between the number of agents (one or two) and whether there is conflict between the tasks or not. One central finding of our experiment is that in the one-agent treatment with conflict, two efforts are chosen significantly less often than in the other three treatments. Hence, our experimental data provides strong support for the empirical relevance of the theoretically predicted incentive problem to motivate a single agent to provide efforts in conflicting tasks. However, even in the presence of conflict, a relevant fraction of agents still exerts two efforts (to reciprocate the principals' generous wage offers). This contributes to our finding that, in contrast to the theoretical prediction, in the presence of conflict, the principals' average profit is slightly larger in the one-agent treatment than in the two-agent treatment.

[8]We extend the model by Bolton and Dewatripont (2005, Section 6.2.2), which is based on the idea of agents as advocates of Dewatripont and Tirole (1999).

Chapter 4[9] contributes to the growing literature on public-private partnerships. We consider a model where a government agency wants an infrastructure-based public service to be provided.[10] The government has to decide whether to bundle the two tasks of building the infrastructure and subsequently operating it and delegate them to a public-private partnership, or to use traditional procurement and delegate each task to a single private contractor. Two kinds of cost-reducing investments can be made when building the facility, one that improves the quality of service and another that reduces service quality. The two forms of contracting differ in the investment incentives. In theory, a public-private partnership provides larger investment incentives in the building stage as the consortium reaps the benefits of the cost-reducing investments when running the facility. Under traditional procurement, the builder has no incentive to invest in cost-reducing technologies as only the operator profits from lower running costs. Hence, a public-private partnership chooses the first-best level of the quality-enhancing investment, but there is overinvestment regarding the quality-reducing investment, while under traditional procurement, the first-best level of the quality-reducing investment is taken, but there is underinvestment in the quality-enhancing investment. Which mode of service provision is desirable depends on the relative effects of both investments. Furthermore, we also open the black box of public-private partnerships and take different modes of subcontracting within the consortium into account. We consider two situations, where either the builder is the main contractor and subcontracts service provision, or where the operator is the main contractor who subcontracts the construction of the facility. Theoretically, the first situation provides the same investment incentives as a public-private partnership, whereas the incentives are as under traditional procurement in the latter situation.

In our experiment with 400 subjects, where we use a parameter constellation such that a public-private partnership is more attractive than traditional procurement, we test whether the trade-off between strong investment incentives in a public-private partnership and weak investment incentives under traditional pro-

[9]This chapter is based on Hoppe, Kusterer, and Schmitz (2013). Eva Hoppe and Patrick Schmitz provided the theory and designed the experiment. I programmed and conducted the experiment and carried out most of the statistical analyses. Eva Hoppe, Patrick Schmitz and I wrote the draft.

[10]The model is based on Hart (2003).

curement is of empirical relevance. We conducted four treatments for all different modes of public-service provision: public-private partnership, traditional procurement, subcontracting with the builder as main contractor, and subcontracting with the operator as main contractor. Our results mostly corroborate the theoretical predictions. Both investments are taken more often in the public-private partnership and in the builder-as-main-contractor treatments than in the treatments with traditional procurement and operator-as-main-contractor, which in turn creates a higher total surplus when the two tasks are bundled.

Only recently, researchers have started to investigate the impact of cognitive ability on judgment and decision making.[11] In *Chapter 5*,[12] we investigate whether the susceptibility to behavioral biases is related to cognitive ability.[13] Frederick (2005) introduced the Cognitive Reflection Test (CRT) to measure a person's mode of reasoning and cognitive ability. The CRT consists of questions that have an intuitive but wrong answer which comes to mind quickly, and a correct one which requires more deliberation. We use this test to categorize subjects into more intuitive and more deliberate decision makers in order to test whether more deliberate thinking lowers the probability of falling for a behavioral bias. In our experiment, we study the base rate fallacy (to underweight the base rate), the conservatism bias (to overweight the base rate), overconfidence, and the endowment effect. Our results show that subjects with lower cognitive abilities are more likely to fall for the base rate fallacy and for the conservatism bias. Higher cognitive ability is related to a more precise self-assessment in the overconfidence task, whereas cognitive ability does not affect the occurrence of the endowment effect which is striking in both, low and high CRT groups.

[11] The literature on heuristics and biases has shown that individuals sometimes use simple decision heuristics instead of deliberate rational thinking (see Kahneman et al., 1982).

[12] This chapter is based on Hoppe and Kusterer (2011a). Eva Hoppe and I designed the experiment. I programmed and conducted the experiment. Together, we analyzed the data and wrote the draft.

[13] For a related study, see Oechssler et al. (2009).

Chapter Two

Searching for evidence: less can be more

2.1 INTRODUCTION

Regulation and antitrust has become more complex. For example, in financial regulation in the United States, the Dodd-Frank Act which was signed into law in 2010 is "23 times longer than Glass-Steagall" (Economist, 2012), the legislation passed in the 1930s as a response to the 1929 crash of Wall Street. In the European Union, the European Commission (EC) observes increased complexity in merger cases. The EC states: "The recent trend that transactions become more complex has continued in 2013. Second phase investigations in particular generally require sophisticated quantitative and qualitative analyses involving large amounts of data." (European Commission, 2014, p. 25).

Complexity itself may not be problematic, but it becomes an issue if the firms and government agencies involved in regulation and antitrust cases cannot adjust to it in a similar fashion. While firms can presumably more easily increase their budget for legal and/or economic advice if deemed necessary, government agencies face binding budget constraints and may be unable to increase their workforce or keep enough competent staff on their payroll. This asymmetry may lead to biased decisions and welfare losses, or, as Rogoff (2012) puts it for the case of financial regulation: "The problem, at least, is simple: As finance has become more complicated, regulators have tried to keep up by adopting ever more complicated rules. It is an arms race that underfunded government agencies have no chance to win."

In a setting where a decision-maker has to decide on an issue but is uninformed and has to rely on two biased groups that may search for multiple pieces of information and submit it to her, we find that reducing complexity may increase search activity and welfare if the two groups are asymmetric in the utility they derive from a favorable decision.

We assume that the two groups derive positive utility only if the decision is made in their favor. Applied to our initial example, one group may be interpreted as a firm filing for a merger with one of its competitors while the other group is the antitrust authority attempting to prevent a potential reduction of consumer surplus due to the merger. In this situation, we argue that it is natural to assume that both groups benefit from a favorable decision only and that the (monetary) benefit of a cleared merger to the involved firm(s) by far outweighs the (potentially non-monetary) benefit of the (bureaucrats of the) antitrust authority in case of a blocked merger.

Both groups can search simultaneously for information on multiple dimensions. We interpret the number of dimensions as the complexity of a case. If the utility of the disadvantaged group is too low to engage in any search for information initially, we show in a first step that a reduction of complexity, that is, a reduction of the number of dimension available for investigation, may increase search incentives of this group holding constant full search by the other group. The reduction of complexity reduces the advantage of the privileged group which makes search more attractive to the disadvantaged group.

The decision-maker aims to maximize welfare but is neither informed about the state nor is she able to observe the search activity by the two groups. In a first-best world, the decision-maker is fully informed and does not generate welfare losses by wrong decisions. This could be reached in equilibrium if both parties search on all dimensions. In an equilibrium where one of the groups does not search on all dimensions, however, the decision-maker is not fully informed and cannot avoid decision errors. A reduction of complexity has in principle two effects: it makes it impossible to reach the first-best but it can at the same time lead to increased search activity by the disadvantaged group which translates into more and more balanced information available to the decision-maker. For an initially large enough number of dimensions, this can lead to an increase of welfare.

Our results suggest that it may be beneficial for welfare to simplify procedures in competition and regulation cases if the involved agents are asymmetric. This finding is consistent with the Regulatory Fitness and Performance program (REFIT) initiated by the EU which, regarding merger review, aims "to make the EU merger review procedures simpler and lighter for stakeholders and to save costs." (European Commission, 2014, p. 24)

The decision-maker in our model could correspond to a judge deciding on an antitrust or regulation case in the US or to a judge presiding over a white-collar-crime case. In the EU, the EC has the hybrid role of a biased group *and* the decision-maker. On the one hand, its goal is to protect consumer interests, on the other hand, it decides on whether to allow or block a merger. But because 'wrong' decisions can be reviewed and overturned by the European Court of Justice, our model also applies to the European case.

Another prominent application of our model is informational lobbying with competing interest groups.[1] Policy-makers who have to decide on whether to vote in favor of or against new legislation are potentially uninformed about the implications of the new legislation but can rely on lobby groups to feed them with (possibly biased) information. Lobby groups benefit from a policy change in their favor and can invest resources to search for arguments and information supporting their preferred outcome. If such information is discovered, the group has an incentive to inform the policy-maker about it. Examples where the benefit of a favorable decision may differ significantly between interest groups include tobacco companies competing with consumer protection groups in order to avoid sales and/or marketing restrictions or oil companies lobbying for drilling rights or the legalization of fracking against environmental protection interest groups.

[1] In informational lobbying, interest groups submit information supporting their cause to a decision-maker. A second important instrument in lobbyist activities are financial contributions. It has been argued that informational lobbying is more prevalent, especially in the EU (Chalmers, 2013; New York Times, 2013), and more important compared to contributions (Potters and van Winden, 1992; Bennedsen and Feldmann, 2002).

Our model is related to the literature on strategic information transmission started by Crawford and Sobel (1982).[2] In these models, an uninformed decision maker (receiver) makes a decision based on information presented by one or more informed expert(s) (sender). The messages in these games typically are cheap talk while in our model, messages are verifiable, and senders can only send hard information they have gathered at a cost beforehand.

In the economic literature on lobbying[3] there are two different channels through which interest groups can influence the political decision process: campaign contributions and informational lobbying.[4] Interest groups can either supply politicians with information pertinent to the policy decision (Milgrom and Roberts, 1986; Austen-Smith and Wright, 1992; Potters and van Winden, 1992) or donate money to swing policy in their favor or help the preferred candidate to get elected (Prat, 2002a,b; Coate, 2004a,b), or both (Bennedsen and Feldmann, 2006; Dahm and Porteiro, 2008; Cotton, 2012). Generally, the literature on informational lobbying shows that decision-makers can learn something about the state of the world even from biased experts and improve policy by taking their information into account. We show in this chapter that with asymmetric lobby groups and multiple searches, the decision-maker may only receive information from the stronger group and welfare-reducing decision errors can occur. Simplifying the decision process by restricting the number of dimensions where information is taken into account for the decision results in more balanced information provision and increased welfare. A similar result has been found in the literature on contribution limits. Exertion of political influence by means of contributions is seen critical by the general public which fears that wealthy groups can simply buy political favors (Prat, 2002b). In response, many countries use some form of contribution limits or try to reform campaign finance. In a model with politicians, lobbies, and voters, Prat (2002b) shows that while voters might learn valuable information from political advertising, the median voter can be better off when contributions are banned. Cotton (2012) analyzes a situation where a rich and a poor lobby group can pay contributions in order to get access

[2]A more recent overview of this literature is provided by Sobel (2013).

[3]There is also a large political science literature on this topic, for an overview see Woll (2006).

[4]For an overview, see Grossman and Helpman (2001).

to a decision-maker which is assumed to be essential for the transmission of information. Without caps on contributions, the poor group has less access but is not necessarily disadvantaged because the politician can extract a rent from the rich group. Contribution limits then make the richer group better off as they limit the rent-extraction ability of the decision-maker. In his model, limits can be beneficial and yield more information transmission and better policy when interest groups can decide whether to form a lobby or not. Our model is complementary to that literature in that it shows that welfare can be improved by simplifying the decision process when two asymmetric interest groups compete.

In our model, the interest groups are only interested in finding evidence in favor of their cause and hence are advocates in the sense of Dewatripont and Tirole (1999) who have shown that when agents receive decision-based rewards, competition between opposed agents can increase information gathering or render it cheaper for the principal (see also Austen-Smith and Wright, 1992). Similarly, Krishna and Morgan (2001) show that a decision-maker benefits from consulting two experts, but only when the experts' preferences are opposed. Bennedsen and Feldmann (2006) look at the interplay of informational lobbying and contributions and find that if contributions are available, less information is transmitted in equilibrium and competition between the groups cannot fully alleviate this result because search creates an information externality if it is unsuccessful which benefits the weaker group and thus decreases the incentives to search by the stronger group.

The positive effect of reducing the action space of the agents has also been shown in the literature on optimal delegation (e.g. Szalay, 2005; Alonso and Matouschek, 2008; Armstrong and Vickers, 2010). In these models, a principal delegates decision making authority to a self-interested agent. The principal has to decide how much liberty he wants to give to the agent. In a model of interval delegation, Szalay (2005) for example shows that removing intermediate decisions from the agent's action set can improve his incentives for information gathering. This is similar to our model where the quality of decisions can be improved by restricting the information space through deliberate exclusion of one of the dimensions.

The remainder of this chapter is organized as follows. In Section 2.2 we present the model. The analysis of the game in Section 2.3 starts in Subsection 2.3.1 with the case where search is unrestricted and proceeds with the case where search on one dimension is prohibited in Subsection 2.3.2. We then compare the search activity and the effects on welfare of the reduction in the number of dimensions in Subsection 2.3.3. A discussion follows in Section 2.4, and we conclude and provide an outlook in Section 2.5.

2.2 THE MODEL

A judge (she) has to make a decision on a case based on information available on multiple dimensions. The information is collected by two interested parties, the firm and the regulator. Information on all dimensions is weighted equally for the decision. More specifically, the judge can either accept or reject a proposal brought forward by the firm, denoted by d_f and d_r, respectively. The firm prefers decision d_f, while the regulator prefers d_r. The information on each dimension $i \in \{1,2,\ldots,n\}$ consists of the realization of two i.i.d. random variables $\theta_{i,j}$, $j \in \{f,r\}$. Each $\theta_{i,j}$ takes value 1 with probability p and value 0 with probability $1-p$ where $0<p<1$. $\theta_{i,f}=1$ can be interpreted as information in favor of the proposal while $\theta_{i,r}=1$ can be interpreted as information against the proposal in dimension i. $\theta_{i,j}=0$, $j \in \{f,r\}$ means that there is no information available either in favor or against the proposal in dimension i. The state of the world is defined as $\Theta = \{\sum_i \theta_{i,f}, \sum_i \theta_{i,r}\}$.[5]

The two parties receive benefit $w_j \geq 0$ in case $d = d_j$ and zero otherwise.[6] Both parties maximize expected profits $u(w_j,d,c) = \Pr(d = d_j | E_f, E_r) w_j - E_j c$ where $c > 0$ are the marginal search costs and E_j, $j \in \{f,r\}$ is the number of searches by each party. To account for asymmetry between the two parties, we assume $w_f > w_r$. Furthermore we assume that the benefit accruing to the firm if

[5] Qualitatively, our information structure can be interpreted as an extension of the information structure of Dewatripont and Tirole (1999) to multiple dimensions.

[6] The subscript j is dropped later in the analysis whenever it is clear to which party w refers.

the proposal is accepted is large enough such that full information collection on all dimensions always overcompensates the cost of doing so.[7]

The judge's aim is to maximize expected welfare based on the information available to her.[8] The welfare of a decision is given by $\sum_i \theta_{i,f} - \sum_i \theta_{i,r}$ if the proposal is accepted and $\sum_i \theta_{i,r} - \sum_i \theta_{i,f}$ if the proposal is rejected.[9]

Thus, in case of full information, if there is (weakly) more information in favor of the proposal, i.e., $\sum_i \theta_{i,f} \geq \sum_i \theta_{i,r}$, it is optimal to accept the proposal and reject it otherwise. Observe that in case of a tie, the proposal is accepted.[10]

In the situation we analyze there is incomplete information such that the state of the world is ex ante unknown. Without any information, the expected value of pro and contra information is the same in all dimensions and the judge accepts the proposal. In this situation, that decision reduces welfare whenever $\sum_i \theta_{i,r} > \sum_i \theta_{i,f}$. Hence, the judge is interested in gathering information. She cannot search for information herself but has to rely on information made available to her by the firm and the regulator. At the beginning of the game, the judge chooses the number of dimensions which are relevant for the decision. The firm is interested in searching information in favor of the proposal only, i.e., $\theta_{i,f}$. The regulator only searches for information against the proposal $\theta_{i,r}$. Both firm and regulator simultaneously search in each dimension at cost c. If a party searches in a given dimension i and there exists evidence in this dimension, it learns $\theta_{i,j}$ with certainty. If a party does not search, it learns nothing, which we denote by 0. Hence, finding no information and not searching for information yield the same result.

After searching, both parties send a message $m_j \in \{\sum_k \theta_{k,j}, 0\}$ to the judge, where k denotes the number of dimensions where the respective party searched for information. We assume that parties cannot withhold information. This is

[7]It is easy to verify that there are values of w_f and c such that the firm wants to search n times as long as $\Pr(d = d_f | E_f, E_r) w_f$ is increasing in E_f.

[8]We assume that the decision-maker has no leeway and has to take the ex post optimal decision given the evidence presented to her. We believe that a judge or the legislature politically cannot implement a decision rule that is not welfare-optimal (for a similar argument, see Bennedsen and Feldmann, 2006).

[9]We assume that the benefits w_j as well as the search costs c are insignificant relative to the welfare effects of each dimension and hence omit them from our welfare definition.

[10]We argue that in case of a tie, there is no conclusive evidence against the proposal and thus, there is no obvious reason to decide against it. Our results do not change qualitatively if we use a tie breaking rule where the judge rejects the proposal or where she flips a fair coin.

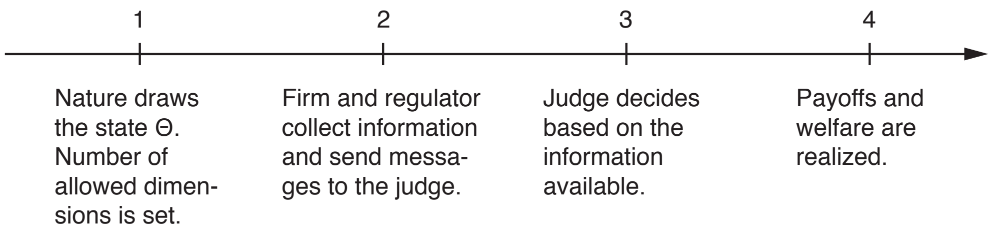


Figure 2.1: Sequence of events.

natural in our case as parties only search for information that is beneficial to them and hence have no interest in holding it back. The message either consists of the number of pieces of evidence that were found or 0. The information available to the judge therefore is $M = \{m_f, m_r\}$, which we also call outcome.

The judge holds two types of beliefs. First, the judge has an expectation $\mu_j \in \{0, 1, 2, \ldots, n\}$ about the number of searches of each party.[11,12] Second, she has a belief about the state of the world. Updating this belief not only depends on the messages received by the two parties but also on the expectation about the number of searches. Two cases are of particular interest to us. When the judge expects the regulator not to search ($\mu_r = 0$) and receives $m_r = 0$, she learns nothing about the evidence against the proposal and hence she cannot update her belief about the state. In contrast, when the judge expects a full search by the regulator on all dimensions, i.e. $\mu_r = n$, she updates her belief about the state such that the probability of the state contained in the message she receives is equal to 1. The sequence of events is summarized in Figure 2.1.

2.3 ANALYSIS

We derive perfect Bayesian equilibria of the specified game. Each of these equilibria consists of the number of searches by firm and regulator, the best response (or decision rule) by the judge, and her beliefs μ_f and μ_r about the

[11] Technically, the judge holds $n+1$ beliefs $\Pr(E_j = X)$ that a party's number of searches equals $X \in \{0, 1, 2, \ldots, n\}$. In pure-strategy equilibria, the judge expects the parties to search a specific number of times such that one of these beliefs equals 1 and all other equal zero.

[12] In what follows, we assume the judge's expectation about the number of searches by the firm μ_f to be equal to the number of admissible dimensions.

number of searches performed by the firm and regulator, respectively. In what follows, we fix the number of dimensions $n = 3$. We first analyze Situation 1, where searching in all three dimensions is allowed (the case of full complexity), and Situation 2, where the judge only accepts evidence from two of the three dimensions (reduced complexity). All proofs are relegated to the Appendix.

2.3.1 SITUATION 1: SEARCH IS POSSIBLE IN ALL THREE DIMENSIONS

It is a natural starting point to first determine the benefit such that it is in the regulator's interest to acquire information on all possible dimensions as well. Observe that in case both parties search three times, the information available to the judge M is equal to the state Θ. If the judge believes that both firm and regulator search three times ($\mu_f = \mu_r = 3$), she decides as in the case with full information according to the first-best decision rule.

The probability $\Pr(d_r|E_r)$ of a decision against the proposal when the regulator performs $E_r \in \{0,1,2,3\}$ searches is given by[13]

$$\begin{aligned}
\Pr(d_r|0) &= 0\\
\Pr(d_r|1) &= (1-p)^3 p\\
\Pr(d_r|2) &= (1-p)^3(2p(1-p)+p^2)+3p(1-p)^2p^2\\
\Pr(d_r|3) &= (1-p)^3(1-(1-p)^3)+3p(1-p)^2(3p^2(1-p)+p^3)\\
&\quad +3p^2(1-p)p^3.
\end{aligned}$$

For example, if the regulator searches three times, the decision is made in his favor in case he finds more information than the firm. Specifically, if the firm finds no information, the regulator wins if he finds any positive amount of information. If the firm reports one piece of information, the proposal is rejected if the regulator finds two or three pieces of evidence. Finally, the regulator needs to find three pieces of information if the firm has found two.

It is optimal for the regulator to search three times if the expected profit of searching three times is larger than the expected profit of searching twice (2.1),

[13] As $E_f = 3$ we omit the reference to the number of the searches by the firm.

of searching once (2.2), and of not searching (2.3).

$$\Pr(d_r|3)w - 3c \geq \Pr(d_r|2)w - 2c \tag{2.1}$$

$$\Pr(d_r|3)w - 3c \geq \Pr(d_r|1)w - c \tag{2.2}$$

$$\Pr(d_r|3)w - 3c \geq \Pr(d_r|0)w \tag{2.3}$$

The following lemma gives a condition under which these constraints hold such that the regulator matches the search efforts by the firm.

Lemma 2.1. *There exists a critical value $\tilde{p} \in [0,1]$ such that if and only if $w \geq \overline{w}$, where*

$$\overline{w} = \begin{cases} c/\left(p - 5p^2 + 16p^3 - 28p^4 + 26p^5 - 10p^6\right) & \text{for } 0 < p \leq \tilde{p} \\ c/\left(p - 4p^2 + \frac{28}{3}p^3 - 13p^4 + 10p^5 - \frac{10}{3}p^6\right) & \text{for } \tilde{p} < p \leq 1, \end{cases}$$

there exists an equilibrium in which the regulator and the firm search three times and the judge has beliefs $\mu_f = \mu_r = 3$.

Constraint (2.1) can be written as $w\Delta_{3,2} \geq c$, where $\Delta_{k,l}$ refers to the difference in success probability when searching k instead of l times. Similarly, (2.3) can be written as $w(\Delta_{3,2} + \Delta_{2,1} + \Delta_{1,0})/3 \geq c$. The binding incentive constraint is determined by the comparison of the increase in the probability of a decision against the proposal when searching three times instead of two times, $\Delta_{3,2}$, with the average probability increase for the first two efforts, $(\Delta_{2,1} + \Delta_{1,0})/2$, i.e. by comparing constraints (2.1) and (2.3). Constraint (2.2) is never relevant. For low values of p, the third search has a relatively small effect on the probability of a decision against the proposal. The reason is that the additional cases in which the decision is made in favor of the regulator due to the third search are unlikely to occur if p is small. It follows it is harder to motivate the regulator to conduct the third search than it is to conduct the first two, i.e. (2.1) is binding. For large p, the additional cases due to the third search become more relevant and increase the probability of a favorable decision. Hence, the first two searches are relatively harder to motivate and (2.3) is binding.

As a next step, we first show that there also exists an equilibrium where the regulator does not search, and second, that no search is an equilibrium for

	{0,0}	{1,0}	{2,0}	{3,0}
$0 < p \leq 1/3$	Regulator	Firm	Firm	Firm
$1/3 < p \leq 2/3$	Regulator	Regulator	Firm	Firm
$2/3 < p < 1$	Regulator	Regulator	Regulator	Firm
Exp. welfare if accepted	$0-3p$	$1-3p$	$2-3p$	$3-3p$

Table 2.1: Decision rule for $\mu_f = 3$, $\mu_r = 0$.

benefits below $\overline{w}$. In order to determine the no-search equilibrium ($\mu_r = 0$), it is sufficient to count the amount of evidence found by the firm. There are four possible outcomes M after the firm has searched for information: $\{3,0\}$, $\{2,0\}$, $\{1,0\}$, and $\{0,0\}$. In case the firm finds three pieces of evidence, the decision is made in favor of the firm, while the proposal is rejected if the firm finds no evidence.

We assume that if the judge receives a message other than 0 when expecting the regulator not to search, then she updates her (out-of-equilibrium) belief concerning the number of searches of the regulator to $\mu_r = 3$.[14] She thus updates her belief regarding the state such that the probability that it is equal to the message is equal to 1. It follows that the decision rule under full information applies out of equilibrium.

The optimal decision rule for the two intermediate cases depends on p. Note that the expected value of information against the proposal is given by $3 \times p^3 + 2 \times 3(p^2(1-p)) + 1 \times 3p(1-p^2) = 3p$. For example, if the firm finds one piece of evidence and the proposal is accepted, expected welfare is given by $1-3p$ which is positive only for $p < 1/3$ and hence the judge will reject the proposal for values of p larger than $1/3$. The judge decides according to the decision rule in Table 2.1.

With increasing probability of information existing, there are more cases in which the decision is made against the proposal, e.g. for $p > 2/3$, the firm has to find three pieces of evidence to offset the expected value of contra information.

[14]Bayes' rule does not apply in situations that occur with probability zero. We choose the out-of-equilibrium belief that is least favorable for the regulator.

It is optimal for the regulator not to search if the following constraints hold.

$$\Pr(d_r|0)w \geq \Pr(d_r|3)w - 3c \tag{2.4}$$

$$\Pr(d_r|0)w \geq \Pr(d_r|2)w - 2c \tag{2.5}$$

$$\Pr(d_r|0)w \geq \Pr(d_r|1)w - c \tag{2.6}$$

The incentive compatibility constraints (2.4), (2.5), and (2.6) ensure that the change in winning probability when not searching instead of searching three, two, or one time(s) is larger than the change in cost. These constraints can easily be satisfied by setting $w = 0$. The following lemma states a threshold on w below which it is not in the regulator's interest to search for information.

Lemma 2.2. *There exists a critical value $\hat{p} \in [0,1]$ such that if and only if $w < \hat{w}$, where*

$$\hat{w} = \begin{cases} c/\left(3p^3 - 8p^4 + 8p^5 - 3p^6\right) & \text{for } 0 < p \leq \frac{1}{3} \\ \infty & \text{for } \frac{1}{3} < p \leq \hat{p} \\ -3c/\left(9p^2 - 36p^3 + 54p^4 - 39p^5 + 12p^6\right) & \text{for } \hat{p} < p \leq \frac{2}{3} \\ \infty & \text{for } \frac{2}{3} < p \leq 1, \end{cases}$$

there exists an equilibrium where the regulator does not search, the firm searches in all three dimensions, and the judge has beliefs $\mu_f = 3$ and $\mu_r = 0$.

For values of $p \in [0, 1/3]$, if the regulator does not search, he wins only in case the firm does not find information. Searching in one dimension does not improve the chances of the regulator. This is the case because if the regulator searches in one dimension, the best he can do is find one piece of evidence. Given the decision rule, this leads to a decision in favor of the regulator only if the firm finds no evidence. In this case, however, the decision is always made in favor of the regulator. Hence, one search by the regulator can never be optimal. Searching twice leads to a decision in favor of the regulator provided that the firm does not find any information or if it finds one piece and the regulator finds two pieces and thus increases the chances of winning for the regulator compared to not searching. Finally, searching in all three dimensions leads to a decision in favor of the regulator in two additional cases (when compared to searching twice):

he also wins in case the firm finds one piece of information and the regulator finds three pieces, and in case the firm finds two pieces while the regulator finds three. This implies that either the incentive constraint preventing the regulator from searching twice instead of zero, or the incentive constraint preventing the regulator from three searches instead of zero, or both are binding. As the average increase in winning probability per search is larger with three searches compared to two, constraint (2.4) is binding and yields the relevant upper bound $\hat{w}$ for the regulator's benefit.

For $p \in [1/3, 2/3]$, when not searching, the regulator now also wins if the firm has found one piece of evidence. Searching once strictly reduces his chances of winning compared to not searching because if both he and the firm find one piece of evidence (out of equilibrium), he does not win. For the same reason, two searches also lower the winning probability. Without searching, the regulator certainly wins when the firm finds one piece of evidence, but when searching twice he only wins in this case when he finds zero or two pieces of evidence. Therefore, both conditions (2.6) and (2.5) are always satisfied. A full search on all three dimensions has an ambiguous effect on the winning probability. On the one hand it lowers the chances of winning in case the firm finds one piece of evidence for the reason outlined above, but on the other hand the regulator now also wins if he finds three pieces of evidence and the firm finds two. It turns out that for smaller values of p, $\Pr(d_r|3)$ is smaller than $\Pr(d_r|0)$ and hence (2.4) always holds for arbitrary positive values of w, while for $\hat{p} < p < 2/3$, constraint (2.4) becomes binding and determines $\hat{w}$.

When $p \in [2/3, 1]$ and the regulator does not search, the decision is also made against the proposal if the firm finds two pieces of evidence. Searching once strictly decreases the regulator's chances of winning because in case the firm finds one or two pieces of evidence, he only wins if he finds nothing. This also is the case when he searches twice. If the firm finds one piece of evidence the proposal is rejected only when the regulator finds zero or two pieces of evidence but not when he finds one, and if the firm finds two pieces, the regulator must not find anything in order to win. Finally, a similar argument establishes that when searching three times, the winning probability is also strictly lower compared to not searching. It is then obvious that there exists no positive wage inducing the regulator to search for information in this range of p.

As we are interested in a situation where the benefit of the regulator is not sufficient to make three search efforts optimal for him, we next compare the two critical values of w—$\overline{w}$ and $\hat{w}$—to show that the equilibrium in which the regulator does not search exists for benefits below $\overline{w}$, i.e. the lowest possible benefit inducing three searches by the regulator.

Lemma 2.3. *Suppose that $w < \overline{w}$. No search by the regulator is an equilibrium given three searches by the firm.*

The lemma says that the necessary benefit for three efforts by the regulator when the judge expects him to search three times ($\mu_r = 3$) is always smaller than the upper bound for the benefit such that searching is not profitable when the judge expects him not to search ($\mu_r = 0$). The reason for this lies in the different beliefs. When the judge holds the belief that the regulator does not search, then the chances of winning are comparatively high for the regulator, especially for large p. This is because the judge takes into account the expected value of information against the proposal, which can be quite high depending on p. In turn, the benefit necessary to motivate him to search is relatively large compared to the benefit needed in the situation where the judge expects the regulator to search. When $\mu_r = 3$, the decision will never be made against the proposal if the regulator does not search, and hence his intrinsic motivation to search for information is larger.

For benefits below $\overline{w}$, equilibria where the regulator searches one or two times also exist (see Appendix 2.6.1). In Lemma 2.4 we define constraints on w such that no search by the regulator is the unique equilibrium in pure strategies in Situation 1.

Lemma 2.4. *There exist critical values $\overline{w}_2$ and $\ddot{p}$ such that if and only if either (a) $w < \tilde{w}$ or (b) $\overline{w}_2 < w < \overline{w}$ and $1/2 < p < \ddot{p}$, no search by the regulator is the unique equilibrium given three searches by the firm.*

To sum up, in the situation where search is unrestricted and the judge accepts evidence from all three available dimensions, we have looked at the case where firm and regulator are asymmetric in that the benefit w for the regulator is bounded from above such that the equilibrium in which both firm and regulator conduct a full search does not exist. This leads to a situation in which search activity is one-sided: the firm gathers evidence on all dimensions whereas the regulator does not search. In consequence, the judge only learns the arguments in favor of the decision.

2.3.2 SITUATION 2: SCOPE OF SEARCH IS RESTRICTED

In this section, we analyze the situation where the scope of search is restricted in the sense that the judge accepts evidence from two dimensions only. We describe an equilibrium in which both parties search in all allowed dimensions and the reported amount of evidence is equal to the true values of the investigated dimensions. The probability that information exists in the third dimension is equal for both parties (and cases) and thus not relevant for the decision.

We proceed by specifying the decision rule by the judge given the belief that both parties search twice, $\mu_f = \mu_r = 2$. In this case, there are nine possible outcomes M: {2,2}, {2,1}, {1,2}, {2,0}, {0,2}, {1,1}, {1,0}, {0,1}, {0,0}. The judge then takes the welfare-maximizing decision where the proposal is accepted if the firm has found (weakly) more information and rejected otherwise. The regulator's chances of winning contingent on the number of searches is given by

$$\begin{aligned}
&\Pr(d_r|0) = 0 \\
&\Pr(d_r|1) = (1-p)^2 p \\
&\Pr(d_r|2) = 2p(1-p)p^2 + (1-p)^2\left(2p(1-p)+p^2\right)
\end{aligned}$$

Given the decision rule the regulator will never win if he does not search. Searching once leads to a decision in favor of the regulator only if he finds one piece of evidence while the firm does not find any information. With two searches, the regulator wins if he finds two (one or two) piece(s) of evidence and the firm one (zero). It is in the interest of the regulator to search twice if the following conditions hold.

$$\Pr(d_r|2)w - 2c \geq \Pr(d_r|1)w - c \tag{2.7}$$

$$\Pr(d_r|2)w - 2c \geq \Pr(d_r|0)w \tag{2.8}$$

The following lemma gives a condition under which an equilibrium where the regulator and the firm search two times exists.

Lemma 2.5. *Suppose that search on one dimension is prohibited. If and only if $w \geq \underline{w}$, where*

$$\underline{w} = \begin{cases} c/\left(p - 3p^2 + 5p^3 - 3p^4\right) & \text{for } 0 < p < 1/3 \\ c/\left(p - \frac{5}{2}p^2 + 3p^3 - \frac{3}{2}p^4\right) & \text{for } 1/3 \leq p < 1, \end{cases}$$

there exists an equilibrium in which the regulator and the firm search on all two admissible dimensions and the judge has beliefs $\mu_f = \mu_r = 2$.

The regulator compares the increase in winning probability for the first and for the second effort. For small p, the first increase is large because he never wins if he does not search, but he wins if $M = \{0, 1\}$ when searching once. The second increase is small as the cases in which he additionally wins require a larger amount of information, which is unlikely for small p. Hence, in this range, the necessary benefit is determined by the incentive constraint for the second effort, while for large p, the constraint for the first effort is the relevant one.

2.3.3 COMPARISON OF SITUATIONS 1 AND 2

Search activity

After solving the game separately in Situation 1, where search is unrestricted, and in Situation 2, where evidence on one dimensions is not accepted by the judge, we now combine and summarize our previous results regarding the regulator's search activity in the following proposition.

Proposition 2.1. *The minimum benefit $\overline{w}$ necessary to render three efforts optimal for the regulator when three dimensions are allowed is always larger than the minimum benefit $\underline{w}$ necessary to make two efforts optimal when only two dimensions are allowed.*

The proposition says that a range of benefits w exists where it is not in the regulator's interest to keep up with the firm's search activity when search is unrestricted, while it is in his interest to do so when the scope of search is restricted to two dimensions. The range of benefits where this is the case is depicted by the gray area in Figure 2.2.

The reason is that the net increase in winning probability relative to the cost of searching c of the regulator in Situation 2 turns out to be larger than in Situation 1. Therefore, the benefit making search worthwhile for the regulator is smaller in Situation 2. If it is unlikely that information exists (small p), in both situations the regulator compares the expected profit from full search with the expected profit of one less search. The absolute probability of winning when the regulator matches the firm's search efforts is larger in Situation 1 than in Situation 2. However, the probability of winning with two efforts is relatively large in Situation 1 while it is relatively small in Situation 2 such that the net increase in the probability of winning caused by the "catch-up" search is larger in Situation 2 and hence a smaller benefit is required.

For large probabilities that information exists, the relevant comparison is between full search and no search. In both situations, the regulator will never win when he does not search. He thus compares the average increase in winning probability per c in Situations 1 and 2 when searching fully. While again the absolute probability of winning is larger in Situation 1, the increase per search cost c is higher in Situation 2, leading to a smaller necessary benefit.[15]

The corollary follows immediately from Proposition 2.1 and Lemma 2.3.

Corollary 2.1. *If $\underline{w} < w < \overline{w}$, in Situation 1 there exists an equilibrium where the regulator does not search while the firm conducts a full search on all dimensions, whereas in Situation 2 the regulator matches the search efforts by the firm.*

Figure 2.2 shows the range of benefits described in Corollary 2.1. For benefits located in the gray area, the regulator has no incentive to search under full complexity but searches on all allowed dimensions under reduced complexity. Observe that the upper bound for the benefit $\hat{w}$ such that no search is optimal is not shown in the figure as the upper bound either does not exist or is very large.

Under the conditions of Proposition 2.1 there are two other equilibria in Situation 1 where the regulator searches once and twice, respectively. The

[15]For the small range $\tilde{p} < p < 1/3$, the regulator compares the average increase when searching fully in Situation 1 with the increase of the "catch-up" search in Situation 2 and again finds the latter increase to be larger than the former.

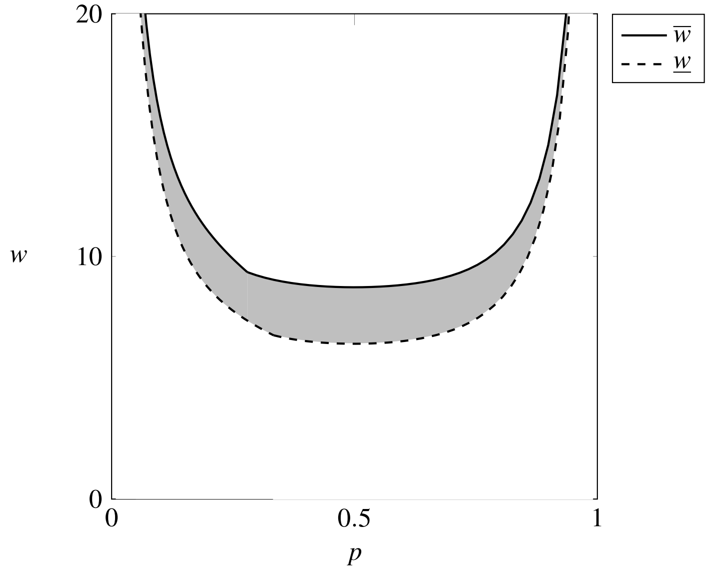


Figure 2.2: The gray area defines the range of benefits defined in Corollary 2.1 where reduced complexity increases search activity. For this figure, the value of c is set to 1 for both benefits.

following proposition shows that the main effect of Proposition 2.1 is still present also if we restrict w and p such that not searching is the unique equilibrium in Situation 1.

Proposition 2.2. *There exist critical values* $\overline{w}_2$ *and* $\ddot{p}$ *such that if and only if either (a)* $\underline{w} \leq w < \tilde{w}$ *and* $0 < p < 1/3$ *or (b)* $\max\{\overline{w}_2, \underline{w}\} < w < \overline{w}$ *and* $1/2 < p < \ddot{p}$*, the regulator searches in two dimensions if the scope of search is limited to two dimensions while he does not search if searching on all three dimension is allowed.*

Taken together, if the benefits of the regulator are bounded from above, particularly if the benefits are below $\tilde{w}$, he will not search if the scope of search is unrestricted. Prohibiting search for information on one of the three dimensions lowers the benefit that is necessary to make the regulator willing to search on all available dimensions. This levels the playing field such that the regulator is able to search on as many dimensions as the firm. Next we show that a reduction of the number of admissible dimensions can also be welfare-enhancing.

Welfare

We now determine the expected welfare losses L_i, where $i \in \{1,2\}$ refers to Situation 1 or 2, due to decision errors under incomplete information. These errors occur when the decision taken by the judge given M does not match the optimal decision given Θ. In order to facilitate the intuition, we decompose the expected welfare losses L_i in each situation into two terms: on the one hand the probability of messages in which a decision error can occur (henceforth error-prone messages or M_e) and on the other hand the expected losses conditional on having received messages in which errors can occur (henceforth conditional expected losses).

In Situation 1, where we focus on the equilibrium where the regulator does not search, welfare losses can occur in the two intermediate outcomes, that is, if the firm has found evidence in one or two dimensions.[16] Hence, the probability of error-prone messages $\{1,0\}$ and $\{2,0\}$ in Situation 1 is $\Pr\left(M_e^1\right) = 3p^2(1-p)+3p(1-p)^2$. The cases in which welfare is reduced depend on the level of p as the judge's decision rule is different for different values of p. In case of $0 < p < 1/3$, a wrong decision is made by the judge when the firm has found one piece of evidence but two or three pieces of evidence exist for the regulator, or when the firm has found two pieces but there are three pieces of evidence favoring the regulator's case. The conditional expected losses in this range of p are

$$\frac{3p(1-p)^2 \times 3p^2(1-p)(2-1)}{\Pr(M_e^1)} + \frac{3p(1-p)^2 \times p^3(3-1)}{\Pr(M_e^1)} + \frac{3p^2(1-p) \times p^3(3-2)}{\Pr(M_e^1)}$$

When $1/3 < p < 2/3$, the judge rejects the firm's proposal also when it has found one piece of evidence. This decision rule results in a welfare loss if the firm has found one piece and there exist no pieces of evidence for the regulator. Welfare is also reduced as before when the firm has found two pieces and there exist three pieces of evidence on the side of the regulator. In this case, the conditional

[16] Observe that losses do not occur in case of ties. While the actual decision might violate the specified tie-breaking rule, the value of information is the same regardless of the decision and thus cancels out so that the welfare loss is equal to zero.

expected losses are

$$\frac{3p(1-p)^2 \times (1-p)^3(1-0)}{\Pr(M_e^1)} + \frac{3p^2(1-p) \times p^3(3-2)}{\Pr(M_e^1)}$$

For $2/3 < p < 1$, the decision is additionally made in favor of the regulator when the firm has found two pieces of evidence. In this case, ex post erroneous decisions are made again in case of $\{1,0\}$, and when the firm has found two pieces but there exist zero or only one piece for the regulator. The conditional expected losses are

$$\frac{3p(1-p)^2 \times (1-p)^3(1-0)}{\Pr(M_e^1)} + \frac{3p^2(1-p) \times (1-p)^3(2-0)}{\Pr(M_e^1)} + \frac{3p^2(1-p) \times 3p(1-p)^2(2-1)}{\Pr(M_e^1)}$$

The total expected welfare loss in Situation 1 is given by

$$L_1 = \begin{cases} 9p^3 - 21p^4 + 18p^5 - 6p^6 & \text{for } 0 < p < 1/3 \\ 3p - 15p^2 + 30p^3 - 30p^4 + 18p^5 - 6p^6 & \text{for } 1/3 < p < 2/3 \\ 3p - 9p^2 + 15p^3 - 21p^4 + 18p^5 - 6p^6 & \text{for } 2/3 < p < 1. \end{cases}$$

In Situation 2, welfare losses can occur in all outcomes in which both parties have found the same amount of evidence, that is, $\{0,0\}$, $\{1,1\}$, and $\{2,2\}$. The probability of error-prone messages hence is $\Pr\left(M_e^2\right) = (1-p)^4 + 4p^2(1-p)^2 + p^4$. In these cases, it is possible that additional evidence in favor of the regulator but not in favor of the firm exists in the additional dimension but is not discovered. The expected conditional losses in this situation are

$$\frac{(1-p)^4 \times (1-p)p(1-0)}{\Pr(M_e^2)} + \frac{4p^2(1-p)^2 \times (1-p)p(2-1)}{\Pr(M_e^2)} + \frac{p^4 \times (1-p)p(3-2)}{\Pr(M_e^2)}$$

which reduces to $(1-p)p$ as all losses have value 1 and occur with equal probability. The expected welfare loss in Situation 2 is given by

$$L_2 = -5p^2 + p + 14p^3 - 22p^4 + 18p^5 - 6p^6.$$

A comparison of the losses gives the following result.

Proposition 2.3. *Under the conditions of Proposition 2.2 and for* $2-\sqrt{3} < p < \sqrt{3}-1$*, the reduction of the number of dimensions from three to two is welfare-enhancing.*

For values of p close to zero, error-prone messages are very unlikely to occur in Situation 1 because they involve at least one piece of information. Conversely, in Situation 2, errors can occur if neither party finds any information ($M = \{0,0\}$), which is very likely for small p. This makes the possibility of errors more prevalent in Situation 2.

The conditional expected loss in Situation 1 is relatively small as an erroneous decision requires more information against the proposal than in favor of it, which is unlikely for small p. Conversely, in Situation 2 errors occur when there is information against the proposal but not in favor of it in the omitted third dimension, which is relatively likely. Hence, as both the likelihood of an error-prone message and the conditional expected loss are larger in Situation 2, the welfare losses are smaller in Situation 1. For large values of p, the reasoning is analogous to the case of small p.

As p increases, cases in which errors might occur become more probable in Situation 1 and less probable in Situation 2. Error-prone messages become less likely in Situation 2 because for intermediate values of p, the probability of messages that allow for clear-cut decisions, i.e. where no decision errors are possible, increases. Thus, for values of $p > 2-\sqrt{3}$, expected welfare losses are larger in Situation 1. For intermediate values of p, the probability of error-prone messages $\{1,0\}$ and $\{2,0\}$ in Situation 1 is close to its maximum while in Situation 2, the probability of error-prone messages is close to its minimum and hence the difference in the two probabilities is largest. In contrast, the conditional expected losses are smaller in Situation 1 than in Situation 2 because in Situation 1 erroneous decisions require zero or three pieces of evidence against the proposal while in Situation 2, the likelihood that the omitted dimension contains clear-cut evidence against the proposal is largest. However, the former effect (weakly) dominates the latter and the expected losses are higher in Situation 1 where it is not in the regulator's interest to keep up with the firm's search effort. For intermediate probabilities that information exists, welfare can be enhanced by reducing the scope of search. The expected losses in Situations 1 and 2 are displayed in Figure 2.3.

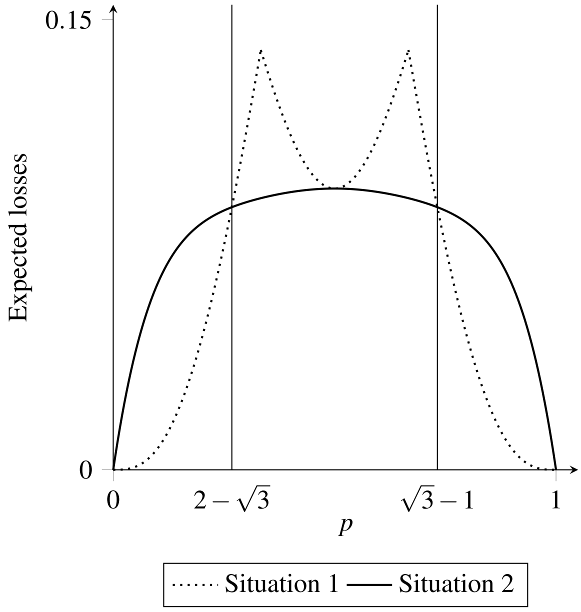


Figure 2.3: Expected losses in Situations 1 and 2.

Taken together, it can be beneficial from a welfare perspective to reduce the complexity of the case and deliberately ignore evidence from one dimension when (i) one of the two parties who can search for information is disadvantaged in the sense that its benefit from the decision is smaller than the other party's, and (ii) the probability that evidence exists in a given dimension and in a given direction is intermediate.

2.4 DISCUSSION

In the following section we examine the robustness of our results. In particular, we discuss varying the number of initial dimensions as well as allowing for asymmetry in the probabilities that information exists for either cause.

Number of dimensions

Our analysis is based on initially three dimensions. We argue that this is the smallest number of dimensions where restricting search can increase welfare. The main difference between the two situations is that if the regulator does not search, the judge learns all arguments in favor of the proposal but none against it, while if search is restricted, she learns all pro and contra arguments on all but one dimensions. When there are two or less initial dimensions, knowing all evidence in one direction is better from a welfare perspective than not knowing any evidence from the excluded dimension. This is obvious if there is only one dimension. If there are more dimensions, the judge adjusts the decision rule in case of asymmetric search according to the expected value of information in the unsearched direction which dampens welfare losses. If search is symmetric but restricted the expected value concerning the unavailable dimension is irrelevant for the decision and thus losses cannot be avoided. For two initial dimensions, the first effect dominates and welfare cannot be improved by restricting search.[17]

As the number of dimensions increases, however, making the correct decision without information from the regulator becomes more and more problematic as the number of the intermediate outcomes where errors can occur and the size of the errors increase. In contrast, the losses when being fully informed about all but one dimensions decrease because the single omitted dimension's impact on the decision becomes increasingly smaller. Thus it is plausible that the effect exists and may be even stronger for a larger number of dimensions. We leave the formal proof of this claim as an open question for future research.

Asymmetric probabilities

The probability p that information exists is equal for both evidence in favor and against the proposal in the sense that (i) the expected sum of evidence in favor and against the proposal is equal across dimensions and (ii) within one dimension, neither pro nor contra evidence is more likely. One single dimension is most relevant for the decision when $p = 0.5$ such that the most likely outcome is either information in favor or against the proposal. If $p \to 0$ or $p \to 1$, the probability

[17] Reducing complexity also does not increase overall search activity and thus does not improve welfare.

of a tie tends to one. Then there are no (or negligible) losses in welfare regardless of the decision. Across all dimensions, for intermediate values of p, states of the world implying a clear decision for one of the causes occur with the highest probability.

We now give an intuition about the effect of asymmetric probabilities in the sense that either pro or contra evidence is more likely to exist on our results. Suppose that q (p) is the probability that evidence in favor of (against) the proposal exists. In general, the initial disadvantage of the regulator is increased when the probabilities for evidence in favor of the proposal are higher and vice versa. The best response of the judge only depends on the probability of evidence against the proposal in the case of one-sided search an hence remains unaffected. The thresholds for the benefit in the cases of symmetric and asymmetric search change as expected.

When $q > p$, asymmetry between the two parties increases. We argue that this does not change our qualitative results. In both equilibria where firm and regulator search equally, the disadvantage of the regulator tends to be more pronounced because the decision is made in his favor less often. This leads to an increased benefit necessary to make search worthwhile. Furthermore, the minimum benefit in the equilibrium where both parties search twice still remains below the minimum benefit when search is unrestricted.[18] In the no-search equilibrium, the regulator wins less often without search, which makes not searching less attractive and hence decreases the upper limit $\hat{w}$.

Welfare losses with restricted search decrease if $q > p$, the main driver appears to be that in case there is an error-prone message, the probability of a wrong decision decreases unambiguously. Tentative calculations show that the effect of asymmetric probabilities on losses in Situation 1 is ambiguous but our result tends to hold.

Assuming $q < p$ leads to a more symmetric situation in that the regulator's disadvantage due to the lower benefit is compensated by a larger probability of existing evidence in his favor. Intuitively, our results tend to vanish as asymmetry decreases. As we have stressed before, we find the asymmetry between the two

[18]Note that in this equilibrium, deciding for the firm in case of a tie is now strictly optimal from a welfare perspective.

groups to be one of the defining characteristic of our model. We thus do not discuss this case any further.

2.5 CONCLUSION

In merger cases, information about the potential effects on consumer surplus is essential for the decision-making ability of the competition authority. Similarly, in lobbying cases, policy-makers need access to information in order to draft sensible legislation. We analyze a model where a decision-maker has to decide on a proposal based on information imparted to her by two interested parties, the firm and the regulator. The firm prefers the proposal to be accepted while the regulator benefits from a rejection. Information is multidimensional in the sense that there is information in favor and against the proposal in several dimensions. The basis of our analysis is the assumption that the regulator receives a smaller benefit from winning than the firm. This assumption captures that the regulator typically consists of bureaucrats with fixed wages, while the firm employs consultants and lawyers with incentive contracts to defend their case. The firm (regulator) only searches for information in favor (against) the proposal. We find that this asymmetry between the two parties can lead to biased information search where the firm searches on all dimensions and the regulator on none. We suggest to reduce complexity of the decision-making process by reducing the number of dimensions that are relevant for the decision. This allows the disadvantaged regulator to catch up with the firm's search efforts which in turn provides the decision-maker with more and more balanced information. This can result in better decisions and increased welfare.

At a first glance it is sensible to include as much relevant aspects as possible in merger cases or when new legislation is drafted. However, this aim might not be achievable when the parties who provide the decision-maker with information are very asymmetric, for example when small citizens' initiatives compete with large energy companies lobbying for fracking rights, or when an understaffed competition authority examines a proposed merger by companies who are able to pay what is necessary for legal advice. In such cases it can be beneficial to reduce the complexity of the procedure in order to level the playing field. Our findings are in line with recent efforts by the EU as part of the REFIT programme which, regarding merger review, aims "to make the EU merger review procedures simpler and lighter for stakeholders and to save costs." (European Commission, 2014, p. 24)

More research on the topic of asymmetric interested parties is needed. A natural next step would be generalize the present model to a setting including a variable number of initial dimensions. This makes it possible to study the optimal reduction of complexity depending on the number of initial dimensions and the degree of asymmetry. In a similar vein, allowing the firm to strategically choose the number of relevant dimensions could lead to interesting new results explaining the observation of asymmetric search effort.

2.6 APPENDIX

2.6.1 OTHER EQUILIBRIA IN PURE STRATEGIES

We also show that equilibria in pure strategies exist where the regulator searches once or twice given three searches by the firm.

We begin with the equilibrium where the regulator searches once. In this case, the rational judge decides according to the decision rule given in Table 2.2. If the expected value of information against the proposal on the two remaining dimensions where the regulator did not search, $2 \times p^2 + 1 \times p(1-p) = 2p$, is larger than the value of evidence on favor of the proposal, then the decision is made against the proposal. In the two cases where the firm has one more piece of information than the firm ($\{1,0\}$ and $\{2,1\}$), the expected value of contra information is large enough to tip the decision towards the regulator for $p > 1/2$. We again assume that when the regulator presents more than one piece of information out of equilibrium, the judge believes that the regulator did search in all other dimensions as well and did not discover any evidence. Hence, the decision rule under full information applies out of equilibrium.

The following conditions must hold such that searching once is optimal for the regulator, given three searches by the firm and the corresponding belief by the judge, $\mu_f = 3$, $\mu_r = 1$.

$$\Pr(d_r|1)w - c \geq \Pr(d_r|3)w - 3c \tag{2.9}$$

$$\Pr(d_r|1)w - c \geq \Pr(d_r|2)w - 2c \tag{2.10}$$

$$\Pr(d_r|1)w - c \geq \Pr(d_r|0)w \tag{2.11}$$

Lemma 2.6. *If and only if* $\underline{w}_1 \leq w \leq \overline{w}_1$ *and* $0 < p < 1/2$*, where* $\underline{w}_1 = c/(3p^2 - 6p^3 + 3p^4)$ *and* $\overline{w}_1 = c/(3p^2 - 9p^3 + 9p^4 - 3p^5)$*, there exists an equilibrium*

	{0,0}	{1,0}	{2,0}	{3,0}	{0,1}	{1,1}	{2,1}	{3,1}
$0 < p \leq 1/2$	R	F	F	F	R	R	F	F
$1/2 < p \leq 1$	R	R	F	F	R	R	R	F

Table 2.2: Decision rule for $\mu_f = 3$ and $\mu_r = 1$.

where the regulator searches once, the firm searches three times, and the judge has beliefs $\mu_f = 3$ *and* $\mu_r = 1$*. For* $1/2 \leq p < 1$*, only one search by the regulator never is optimal.*

Proof. First, for $0 < p < 1/2$, the winning probabilities for the regulator are

$$\begin{aligned}
\Pr(d_r|0) &= (1-p)^3 \\
\Pr(d_r|1) &= (1-p)^3 + 3p(1-p)^2 p \\
\Pr(d_r|2) &= (1-p)^3 + 3p(1-p)^2\left(2p(1-p)+p^2\right) \\
\Pr(d_r|3) &= (1-p)^3 + 3p(1-p)^2\left(1-(1-p)^3\right) + 3p^2(1-p)p^3.
\end{aligned}$$

The incentive constraint (2.11), which ensures that one search is better than no search, gives the lower bound for the wage $\underline{w}_1 = c/(3p^2 - 6p^3 + 3p^4)$. For the moment, ignore (2.9). Condition (2.10), which ensures that one search is more profitable than two searches, gives the upper bound for the wage, $\overline{w}_1 = c/(3p^2 - 9p^3 + 9p^4 - 3p^5)$. The upper bound $\overline{w}_1$ is above the lower bound $\underline{w}_1$ if

$$\frac{c}{3p^2 - 6p^3 + 3p^4} < \frac{c}{3p^2 - 9p^3 + 9p^4 - 3p^5}$$

or $p^3(3-(6p-3p^2)) > 0$. The term $6p - 3p^2$ has its global maximum at $p = 1$ with value 3 and is strictly concave, hence the condition is satisfied for the relevant range of p, $0 < p < 1/2$. It remains to check that (2.9) is slack. Plugging $\overline{w}_1$ into (2.9) yields

$$\frac{-6p^2 + 21p^3 - 27p^4 + 12p^5}{3p^2 - 9p^3 + 9p^4 - 3p^5} c \geq -2c$$

or $p^3\left(1-(3p-2p^2)\right) \geq 0$. The term $3p - 2p^2$ is strictly concave and has its maximum at $p = 3/4$. It is strictly increasing in the relevant range $0 < p < 1/2$ and takes on value 1 at $p = 1/2$. Hence, the condition is satisfied for that range and (2.9) is slack.

For $1/2 \leq p < 1$, the winning probabilities for the regulator are

$$\begin{aligned}
\Pr(d_r|0) &= (1-p)^3 + 3p(1-p)^2 \\
\Pr(d_r|1) &= (1-p)^3 + 3p(1-p)^2 \\
\Pr(d_r|2) &= (1-p)^3 + 3p(1-p)^2 + 3p^2(1-p)2p(1-p) \\
\Pr(d_r|3) &= (1-p)^3 + 3p(1-p)^2 + 3p^2(1-p)(3p(1-p)^2 + p^3).
\end{aligned}$$

It is obvious that for any positive value of search cost c and non-negative benefit w, the constraint (2.11) can never hold. Hence, an equilibrium with one search effort by the regulator does not exist for $1/2 \leq p < 1$. $\square$

As the next step, we characterize an equilibrium where the regulator searches twice. The judge decides in favor of the party that delivers more pieces of information. In case of a tie ({0,0}, {1,1}, {2,2}) the decision is made in favor of the regulator as the expected value of contra information on the third dimension where no search has taken place is positive.[19] We again assume that when the regulator presents more than two pieces of information out of equilibrium, the judge believes that the regulator did search in the third dimension as well and did not discover any evidence. Hence, the decision rule under full information applies out of equilibrium.

The following conditions must hold such that two searches are optimal for the regulator, given three searches by the firm and the corresponding belief by the judge, $\mu_f = 3$, $\mu_r = 2$.

$$\Pr(d_r|2)w - 2c \geq \Pr(d_r|3)w - 3c \tag{2.12}$$

$$\Pr(d_r|2)w - 2c \geq \Pr(d_r|1)w - c \tag{2.13}$$

$$\Pr(d_r|2)w - 2c \geq \Pr(d_r|0)w \tag{2.14}$$

The three conditions guarantee that the regulator prefers two searches to three, one, and zero searches.

Lemma 2.7. *If and only if $\underline{w}_2 \leq w \leq \overline{w}_2$, where*

$$\underline{w}_2 = \begin{cases} c/\left(3p^2 - 9p^3 + 12p^4 - 6p^5\right) & \text{for } 0 < p < 1/2 \\ c/\left(3p^2 - (15/2)p^3 + (15/2)p^4 - 3p^5\right) & \text{for } 1/2 \leq p < 1, \end{cases}$$

and $\overline{w}_2 = c/\left(3p^2 - 12p^3 + 24p^4 - 24p^5 + 9p^6\right)$, there exists an equilibrium where the regulator searches twice, the firm searches in all three dimensions and the judge has beliefs $\mu_f = 3$ and $\mu_r = 2$.

[19] Note that when the judge receives the information {3,3} out of equilibrium, the decision is made for the firm.

Proof. The winning probabilities for the regulator are

$$\Pr(d_r|0) = (1-p)^3$$
$$\Pr(d_r|1) = (1-p)^3 + 3p(1-p)^2 p$$
$$\Pr(d_r|2) = (1-p)^3 + 3p(1-p)^2(2p(1-p)+p^2) + 3p^2(1-p)p^2$$
$$\Pr(d_r|3) = (1-p)^3 + 3p(1-p)^2(1-(1-p)^3) + 3p^2(1-p)(3p^2(1-p)+p^3).$$

The upper bound for the wage $\overline{w}_2 = c/\left(3p^2 - 12p^3 + 24p^4 - 24p^5 + 9p^6\right)$ is given by condition (2.12).

Conditions (2.13) and (2.14) can be written as

$$w \geq \frac{c}{3p^2 - 9p^3 + 12p^4 - 6p^5}$$

and

$$w \geq \frac{c}{3p^2 - (15/2)p^3 + (15/2)p^4 - 3p^5},$$

respectively. (2.13) is binding if

$$\frac{c}{3p^2 - 9p^3 + 12p^4 - 6p^5} < \frac{c}{3p^2 - (15/2)p^3 + (15/2)p^4 - 3p^5} \tag{2.15}$$

or $p^3\left(-\frac{3}{2} + \frac{9}{2}p - 3p^2\right) > 0$. The polynomial in parentheses is negative at $p = 1$ and equal to zero at $p = 1$. It can easily be verified that it has another root at $p = 1/2$ and hence is negative for values of p below $1/2$ and positive for values of p above. Taken together with the root at $p = 0$ from the term p^3, the condition (2.15) does not hold for $0 < p \leq 1/2$ and holds for $1/2 < p < 1$. Hence, constraint (2.14) is binding for smaller p and (2.13) for larger p.

It remains to show that the upper bound $\overline{w}_2$ lies above the lower bound $\underline{w}_2$. For $0 < p \leq 1/2$, we need to check whether

$$\frac{c}{3p^2 - 9p^3 + 12p^4 - 6p^5} < \frac{c}{3p^2 - 12p^3 + 24p^4 - 24p^5 + 9p^6},$$

which is equivalent to $p^3(3 - 12p + 18p^2 - 9p^3) > 0$. Define the term in parentheses as $g(p) = 3 - 12p + 18p^2 - 9p^3$. The second derivative $g''(p) = 36 - 54p$ is positive for $p = 0$ and negative for $p = 1$ and has one root at $p = 2/3$. Hence, $g'(p) = -12 + 36p - 27p^2$ is strictly concave and takes on value 0 at its global maximum. The original function $g(p)$ is positive for $p = 0$ and zero for $p = 1$. It is non-increasing throughout $[0,1]$, convex up to the root of $g'(p)$ and concave thereafter. Hence it cannot have another root in the relevant range. Taken together, the condition is above satisfied and $\overline{w}_2$ lies above $\underline{w}_2$ for $0 < p \leq 1/2$. For $1/2 < p < 1$, the comparison is

$$\frac{c}{3p^2 - (15/2)p^3 + (15/2)p^4 - 3p^5} < \frac{c}{3p^2 - 12p^3 + 24p^4 - 24p^5 + 9p^6}$$

or $p^3(3 - 11p + 14p^2 - 6p^3) > 0$. Let $g(p) = 3 - 11p + 14p^2 - 6p^3$. The second derivative $g''(p) = 36 - 54p$ crosses the abscissa once from above. Hence, $g'(p) = -12 + 36p - 27p^2$ is concave and has its global maximum at $p = 7/9$ with a value of $-1/3$. Thus, the original function $g(p)$ is falling in the interval $[0,1]$, is positive at $p = 0$ and equal to 0 at $p = 1$, and therefore cannot have another root in that interval. Taken together, the condition above is also satisfied for values of p between $1/2$ and 1 and the proof concludes. □

2.6.2 PROOFS

Proof of Lemma 2.1. For the moment, ignore (2.2). Rearranging (2.1) and (2.3) gives

$$\frac{c}{w} \leq p - 5p^2 + 16p^3 - 28p^4 + 26p^5 - 10p^6 \tag{2.16}$$

and

$$\frac{c}{w} \leq p - 4p^2 + \frac{28}{3}p^3 - 13p^4 + 10p^5 - \frac{10}{3}p^6, \tag{2.17}$$

respectively. The binding constraint is the stricter one, i.e., the one with the smaller RHS. Constraint (2.16) is the binding one if the RHS of (2.17) minus the RHS of (2.16) is positive, or $3 - 20p + 45p^2 - 48p^3 + 20p^4 \geq 0$. Define the LHS as $g(p)$. The third derivative $g'''(p) = -288 + 480p$ is increasing and crosses the abscissa once from below. Hence, $g''(p) = 90 - 288p + 240p^2$ is convex and has a local minimum at $p = 288/480$. As its value is positive at this local minimum, it is positive throughout the range of p. This implies that $g'(p) = -20 + 90p - 144p^2 + 80p^3$ has a positive slope, and it crosses the abscissa once from below as $g'(0) < 0$ and $g'(1) > 0$. Therefore, $g(p)$ is convex and has a local minimum, and because $g(0) > 0$ but $g(1) = 0$ and $g'(1) > 0$, its local minimum must be negative. Hence, $g(p)$ has a root, and it can be shown that it lies at

$$\tilde{p} = -\frac{1}{30}(586+45\sqrt{271})^{1/3} + \frac{59}{30(586+45\sqrt{271})^{1/3}} + \frac{7}{15} \approx 0.2794.$$

Hence, for $0 < p < \tilde{p}$, the condition above is satisfied and (2.1) is binding. For $\tilde{p} < p < 1$, (2.3) is the relevant constraint.

It remains to be shown that (2.2) is slack. Rearranging gives

$$\frac{c}{w} \leq p - \frac{9}{2}p^2 + \frac{25}{2}p^3 - 19p^4 + 15p^5 - 5p^6 \tag{2.18}$$

It suffices to show that the RHS of (2.18) is larger than the RHS (2.16), which is equivalent to $g_a(p) := 1 - 7p + 18p^2 - 22p^3 + 10p^4 \geq 0$ for $0 < p \leq \tilde{p}$ and larger than the RHS of (2.17) for $\tilde{p} < p < 1$, which is equivalent to $g_b(p) := -3 + 19p - 36p^2 + 30p^3 - 10p^4 \geq 0$.

The third derivative $g_a'''(p) = -132 + 240p$ is increasing and negative in the relevant range as $g_a'''(\tilde{p}) < 0$. It follows that $g_a''(p) = 36 - 132p + 120p^2$ has a negative slope and is positive as $g_a''(\tilde{p}) > 0$. Therefore, $g_a'(p) = -7 + 36p - 66p^2 + 40p^3$ is increasing and negative because $g_a'(\tilde{p}) < 0$. The original function $g_a(p)$ is decreasing but positive, as $g_a(\tilde{p}) > 0$. Hence, the condition above holds and (2.2) is slack for $0 < p < \tilde{p}$.

For $\tilde{p} < p < 1$, the third derivative $g_b'''(p) = 180 - 240p$ is decreasing and crosses the abscissa once from above because $g_b'''(\tilde{p}) > 0$ and $g_b'''(1) < 0$. The second derivative $g_b''(p) = -72 + 180p - 120p^2$ hence is concave and has a local maximum at $p = 3/4$. As it is negative at its local maximum it is negative throughout the relevant range of p and therefore $g_b'(p) = 19 - 72p + 90p^2 - 40p^3$ has a negative slope. From $g_b'(\tilde{p}) > 0$ and $g_b'(1) < 0$ follows that it crosses the abscissa once from above and that $g_b(p)$ is concave and has a local maximum in the range of interest. As $g_b(\tilde{p}) > 0$ and $g_b(1) = 0$ (and $g_b'(1) < 0$) we can infer that it is positive in the range of interest, the condition above holds and (2.2) is also slack for $\tilde{p} < p < 1$. □

Proof of Lemma 2.2. The proof is divided in three parts according to the three ranges of p which differ in the decision rule—and hence in the $\Pr(d_r|E_r)$s—as outlined in Table 2.1.

For $p \leq 1/3$,

$$\begin{aligned}
\Pr(d_r|0) &= (1-p)^3 \\
\Pr(d_r|1) &= (1-p)^3 \\
\Pr(d_r|2) &= (1-p)^3 + 3p(1-p)^2 p^2 \\
\Pr(d_r|3) &= (1-p)^3 + 3p(1-p)^2(3p^2(1-p) + p^3) + 3p^2(1-p)p^3.
\end{aligned}$$

Observe that (2.6) holds as long as $c \geq 0$, which is given by definition. Plugging in the relevant probabilities $\Pr(d_r|E_r)$ in (2.4) and (2.5) and rearranging gives

$$\frac{c}{w} \geq 3p^3 - 8p^4 + 8p^5 - 3p^6 \tag{2.19}$$

and

$$\frac{c}{w} \geq \frac{3}{2}p^3 - 3p^4 + \frac{3}{2}p^5, \tag{2.20}$$

respectively. (2.4) is the binding constraint if the RHS of (2.19) is larger than the RHS of (2.20), which is equivalent to $\frac{3}{2} - 5p + \frac{13}{2}p^2 - 3p^3 > 0$. Define the LHS of this inequality as $g(p)$ where $g'(p) = -5 + 13p - 9p^2$. $g'(p)$ is strictly concave and takes a global maximum of $-11/36$ at $p = 13/18$. Hence $g(p)$ is decreasing, and with $g(0) > 0$ and $g(1) = 0$ we have shown that the sign of $g(p)$ is nonnegative in the relevant range of p. The wage in that range of p hence is given by (2.4), the incentive constraint preventing the regulator to conduct three instead of zero searches.

For $1/3 < p \leq 2/3$,

$$\begin{aligned}
\Pr(d_r|0) &= (1-p)^3 + 3p(1-p)^2 \\
\Pr(d_r|1) &= (1-p)^3 + 3p(1-p)^2(1-p) \\
\Pr(d_r|2) &= (1-p)^3 + 3p(1-p)^2((1-p)^2 + p^2) \\
\Pr(d_r|3) &= (1-p)^3 + 3p(1-p)^2((1-p)^3 + 3p^2(1-p) + p^3) + 3p^2(1-p)p^3.
\end{aligned}$$

We show that both incentive constraints (2.5) and (2.6) are always slack as the probability difference on the LHS is positive for all values of p. Observe that compared to zero searches, searching twice strictly reduces the winning probability and the regulator has to incur effort costs of $2c$. Searching twice hence can never be optimal. The same holds for searching once, which also never is optimal. It remains to be shown that (2.4) is slack for values of p below $\hat{p}$ and binding otherwise. Using the relevant winning probabilities in (2.4) and rearranging yields

$$\frac{c}{w} \geq -3p^2 + 12p^3 - 18p^4 + 13p^5 - 4p^6. \tag{2.21}$$

Define as $g(p) = -3 + 12p - 18p^2 + 13p^3 - 4p^4$, which is the RHS of (2.21) with p^2 factored out. The value of $g(0)$ is negative and the value of $g(1)$ is zero, so there can be at most three real roots in the range of p. We determine the actual number of roots between 0 and 1 by analyzing the derivatives of $g(p)$. $g'''(p) = 78 - 96p$ is a linear decreasing function with a positive value at $p = 0$ and a negative value at $p = 1$ and one root in between. Hence, $g''(p) = -36 + 78p - 48p^2$ is a concave function with one maximum in the relevant range. As $g''(p)$ is negative at the root of $g'''(p)$, its maximum, the second derivative of $g(p)$ is strictly negative in the domain from 0 to 1. Therefore, the first derivative $g'(p) = 12 - 36p + 39p^2 - 16p^3$ is decreasing in this range and has one root as $g'(0)$ is positive and $g'(1)$ is negative. Finally, this implies that $g(p)$ is concave and has a maximum in the domain from 0 to 1. Accordingly, there is one root at $p = \hat{p}$ where

$$\hat{p} = \frac{1}{4}3^{\frac{1}{3}} - \frac{1}{4}3^{\frac{2}{3}} + \frac{3}{4} \approx 0.5905$$

in that interval as the value of $g(1)$ is zero. Taken together, the RHS of (2.21) has roots at 0, $\hat{p}$, and 1, is negative for $0 < p < \hat{p}$ and positive for $\hat{p} < p < 1$. Since both c and w are positive numbers, (2.21) is slack for $0 < p < \hat{p}$ and no positive wage induces the regulator to search three times. For $\hat{p} < p < 1$, this constraint is binding and yields the upper bound for the wage in the lemma.

For $p > 2/3$,

$$\begin{aligned}
\Pr(d_r|0) &= (1-p)^3 + 3p(1-p)^2 + 3p^2(1-p) \\
\Pr(d_r|1) &= (1-p)^3 + 3p(1-p)^2(1-p) + 3p^2(1-p)(1-p) \\
\Pr(d_r|2) &= (1-p)^3 + 3p(1-p)^2((1-p)^2 + p^2) + 3p^2(1-p)(1-p)^2 \\
\Pr(d_r|3) &= (1-p)^3 + 3p(1-p)^2((1-p)^3 + 3p^2(1-p) + p^3) \\
&\quad + 3p^2(1-p)((1-p)^3 + p^3).
\end{aligned}$$

The probability of winning when not exerting effort $\Pr(d_r|0)$ consists of the probabilities that the firm finds zero, one, or two pieces of information. Searching once reduces the chances of winning because given one or two pieces of information found by the firm, the decision is now made against the proposal only if the regulator does not find information. A similar argument establishes that $\Pr(d_r|2)$ and $\Pr(d_r|3)$ are also smaller than $\Pr(d_r|0)$. Hence, all constraints (2.4), (2.5), and (2.6) are slack and no positive wage induces the regulator to search for evidence. This concludes the proof. $\square$

Proof of Lemma 2.3. We need to show that $\hat{w} \geq \overline{w}$. There are several cases along the range of p. For $0 < p \leq \tilde{p}$, $\hat{w} \geq \overline{w}$ is equivalent to

$$\frac{c}{3p^3 - 8p^4 + 8p^5 - 3p^6} \geq \frac{c}{p - 5p^2 + 16p^3 - 28p^4 + 26p^5 - 10p^6}$$
$$\Leftrightarrow 1 - 5p + 13p^2 - 20p^3 + 18p^4 - 7p^5 \geq 0 \tag{2.22}$$

Define the LHS of (2.22) as $g(p)$. The fourth derivative $g''''(p) = 432 - 840p$ is decreasing and positive in the relevant range as $g''''(\tilde{p}) > 0$. Hence, $g'''(p) = -120 + 432p - 420p^2$ is increasing and negative as $g'''(\tilde{p}) < 0$. It follows that $g''(p) = 26 - 120p + 216p^2 - 140p^3$ has a negative slope and is positive throughout the range of interest as $g''(\tilde{p}) > 0$. The first derivative $g'(p) = -5 + 26p - 60p^2 + 72p^3 - 35p^4$ therefore increases but is negative as $g'(\tilde{p}) < 0$. From this we know that the original function $g(p)$ is decreasing and positive as $g(\tilde{p}) > 0$ and the LHS of (2.22) is positive in the relevant range.

For $p > \tilde{p}$, the relevant comparison is

$$\frac{c}{3p^3 - 8p^4 + 8p^5 - 3p^6} \geq \frac{c}{p - 4p^2 + \frac{28}{3}p^3 - 13p^4 + 10p^5 - \frac{10}{3}p^6}$$
$$\Leftrightarrow 1 - 4p + (19/3)p^2 - 5p^3 + 2p^4 - (1/3)p^5 \geq 0 \tag{2.23}$$

Define the LHS of (2.23) as $g(p)$. The fourth derivative $g''''(p) = 48 - 40p$ is decreasing and positive. Hence, $g'''(p) = -30 + 48p - 20p^2$ is increasing and negative as $g'''(1) < 0$. Therefore, $g''(p) = 38/3 - 30p + 24p^2 - (20/3)p^3$ is decreasing and positive as $g''(1) = 0$. The first derivative $g'(p) = -4 + (38/3)p - 15p^2 + 8p^3 - (5/3)p^4$ hence is increasing and negative as $g'(1) = 0$. It follows that the original function $g(p)$ is decreasing and positive as $g(1) = 0$, which implies that the LHS of (2.23) is positive in the relevant range.

For $1/3 < p \leq \hat{p}$, the regulator will not search for information for any positive value of w and hence, $\hat{w} \geq \overline{w}$ is satisfied trivially. For $\hat{p} < p \leq 2/3$, the relevant comparison is

$$\frac{-3c}{9p^2-36p^3+54p^4-39p^5+12p^6} \geq \frac{c}{p-4p^2+\frac{28}{3}p^3-13p^4+10p^5-\frac{10}{3}p^6}$$
$$\Leftrightarrow 1-p-(8/3)p^2+5p^3-3p^4+(2/3)p^5 \geq 0. \tag{2.24}$$

Define as $g(p)$ the LHS of (2.24). The fourth derivative $g''''(p) = -72+80p$ is increasing and negative in the relevant range as $g''''(2/3) < 0$. Hence, $g'''(p) = 30-72p+40p^2$ has a negative slope and crosses the abscissa once as $g'''(\hat{p}) > 0$ and $g'''(2/3) < 0$. It follows that $g''(p) = -16/3+30p-36p^2+(40/3)p^3$ is concave with a local maximum. As both $g''(\hat{p})$ and $g''(2/3)$ are positive, the second derivative is positive throughout the range of interest. The first derivative $g'(p) = -1-(16/3)p+15p^2-12p^3+(10/3)p^4$ therefore is increasing and negative because $g'(2/3) < 0$. From this we know that the original function $g(p)$ is decreasing and positive as $g(2/3) > 0$. This implies that inequality (2.24) strictly holds.

In the remaining interval $2/3 < p < 1$, the regulator will not search for any positive value of w and hence $\hat{w} \geq \overline{w}$ is satisfied. □

Proof of Lemma 2.4. We show that $\overline{w}$ is either smaller than the lower bound or larger than the upper bound of the wage necessary for the other two equilibria where the regulator searches once or twice.

We start by showing that for $0 < p < 1/2$, where there are equilibria in which the regulator searches once or twice, $\underline{w}_1$ is smaller than $\underline{w}_2$ and hence is the relevant wage to be compared with $\overline{w}$ in order to determine $\min\{\overline{w}, \underline{w}_1, \underline{w}_2\}$. The comparison

$$\underline{w}_1 = \frac{c}{3p^2-6p^3+3p^4} \leq \frac{c}{3p^2-9p^3+12p^4-6p^5} = \underline{w}_2$$

can be simplified to $1-3p+2p^2 \geq 0$. The LHS is falling in the relevant range as the derivative $-3+4p$ is negative for $0 < p < 1/2$. At $1/2$, the LHS is zero, and hence, the condition above holds.

The relevant upper bound is given by $\overline{w}_2$ if

$$\overline{w}_2 = \frac{c}{3p^2-12p^3+24p^4-24p^5+9p^6} \geq \frac{c}{3p^2-9p^3+9p^4-3p^5} = \overline{w}_1$$

or $3p^3(1-5p+7p^2-3p^3) \geq 0$. Define the term in parentheses as $g(p)$. The second derivative $g''(p) = 14-18p$ is positive and decreasing in the relevant range as $g''(0.5)$ is positive. Hence, $g'(p) = -5+14p-9p^2$ is increasing in the negative domain because $g'(0.5)$ is negative. This implies that $g(p)$ is falling, and we know further that it must have one root as $g(0)$ is positive but $g(0.5)$ is negative. It can be shown that $g(p)$ crosses the abscissa at $p = 1/3$. Hence, for $0 < p < 1/3$, the relevant upper bound is given by $\overline{w}_2$ and by $\overline{w}_1$ for $1/3 < p < 1/2$.

For $0 < p \leq \tilde{p}$, we start by determining the relevant lower bound below which no search by the regulator is the unique equilibrium. The relevant comparison is

$$\overline{w} = \frac{c}{p-5p^2+16p^3-28p^4+26p^5-10p^6} \leq \frac{c}{3p^2-6p^3+3p^4} = \underline{w}_1$$

or $p(1-8p+22p^2-31p^3+26p^4-10p^5) \geq 0$. Define the term in parentheses as $g(p)$. The fourth derivative $g''''(p) = 624-1200p$ is positive in the relevant range $[0,\tilde{p}]$. Therefore, $g'''(p) = -186+624p-600p^2$ is increasing in this range and negative for both $p = 0$ and $p = \tilde{p}$ and hence has no root. The second derivative $g''(p) = 44-186p+312p^2-200p^3$ is strictly falling in that interval and takes on a positive value both at $p = 0$ and at $p = \tilde{p}$, and thus has no root in the relevant interval. The first derivative $g'(p) = -8+44p-93p^2+104p^3-50p^4$ is negative for both $p = 0$ and $p = \tilde{p}$ and thus has no root as it is strictly increasing in that range of p. Hence, $g(p)$ is strictly falling in that interval and has one root as $g(0)$ is positive and $g(\tilde{p})$ is negative. It can be shown that the root lies at

$$\begin{aligned} \dot{p} = \frac{2}{5} &+ \frac{1}{10\sqrt{\frac{6}{-54+5\left(486-27\sqrt{323}\right)^{1/3}+15\left(18+\sqrt{323}\right)^{1/3}}}} \\ &-\frac{1}{2}\Bigg[-\frac{18}{25}-\frac{1}{30}\left(486-27\sqrt{323}\right)^{1/3}-\frac{1}{10}\left(18+\sqrt{323}\right)^{1/3} \\ &+\frac{3}{25}\sqrt{\frac{6}{-54+5\left(486-27\sqrt{323}\right)^{1/3}+15\left(18+\sqrt{323}\right)^{1/3}}}\Bigg]^{1/2} \approx 0.23802. \end{aligned}$$

It follows that $\overline{w}$ is smaller than $\underline{w}_1$ up to that root. This implies that the relevant lower bound is given by $\overline{w}$ from $p = 0$ up to the root and then by $\underline{w}_1$ until $p = \tilde{p}$.

Next, we show that $\overline{w}$ lies below the relevant upper bound in this range given by $\overline{w}_2$. The comparison

$$\overline{w} = \frac{c}{p - 5p^2 + 16p^3 - 28p^4 + 26p^5 - 10p^6} \leq \frac{c}{3p^2 - 12p^3 + 24p^4 - 24p^5 + 9p^6} = \overline{w}_2$$

can be simplified to $1 - 8p + 28p^2 - 52p^3 + 50p^4 - 19p^5 \geq 0$. Define the LHS of the last inequality as $g(p)$. The fourth derivative $g''''(p) = 1200 - 1140p$ is positive throughout the relevant range and hence, $g'''(p) = -312 + 1200p - 1140p^2$ is increasing. Observe that $g'''(\tilde{p})$ is negative which implies that the third derivative is negative throughout the range. Therefore, $g''(p) = 56 - 312p + 600p^2 - 380p^3$ is decreasing and positive, as $g''(\tilde{p})$ is positive. This indicates that $g'(p) = -8 + 56p - 156p^2 + 200p^3 - 95p^4$ increases in that range of p, and as $g'(\tilde{p})$ is negative, the first derivative is negative throughout. Taken together, we now know that $g(p)$ is decreasing, and as $g(\tilde{p})$ is positive, that it has no root in that range. The condition above holds.

For $\tilde{p} < p < 1/2$ we show first that

$$\underline{w}_1 = \frac{c}{3p^2 - 6p^3 + 3p^4} \leq \frac{c}{p - 4p^2 + \frac{28}{3}p^3 - 13p^4 + 10p^5 - \frac{10}{3}p^6} = \overline{w}$$

or $-3 + 21p - 46p^2 + 48p^3 - 30p^4 + 10p^5 \geq 0$. Define the LHS as $g(p)$. The fourth derivative $g''''(p) = -720 + 1200p$ is increasing and negative in the relevant range as $g''''(1/2) < 0$, implying a negative slope of $g'''(p) = 288 - 720p + 600p^2$. The positive value of $g'''(1/2)$ shows that the third derivative is positive throughout. Hence, $g''(p) = -92 + 288p - 360p^2 + 200p^3$ increases and is negative as $g''(1/2) < 0$, also implying that $g'(p) = 21 - 92p + 144p^2 - 120p^3 + 50p^4$ is decreasing. As $g'(\tilde{p}) > 0$ but $g'(1/2) < 0$ the first derivative has one root in the range of interest. The function $g(p)$ hence first is increasing and then decreasing, and because both $g(\tilde{p})$ and $g(1/2)$ are positive, it is positive throughout the range of interest and hence the condition above holds. Therefore, $\underline{w}_1$ is the relevant lower bound for this range.

Second, for the same range of p we show that

$$\overline{w} = \frac{c}{p - 4p^2 + \frac{28}{3}p^3 - 13p^4 + 10p^5 - \frac{10}{3}p^6} \leq \frac{c}{3p^2 - 9p^3 + 9p^4 - 3p^5} = \overline{w}_1$$

or $3-21p+55p^2-66p^3+39p^4-10p^5 \geq 0$. Define the LHS as $g(p)$. The fourth derivative $g''''(p) = 936-1200p$ is decreasing in the positive domain, and hence $g'''(p) = -396+936p+-600p^2$ is increasing. Because $g'''(1/2) < 0$ the third derivative is negative throughout, implying a negative slope of $g''(p) = 110-396p+468p^2-200p^3$. Observe that the second derivative is positive throughout as $g''(1/2) > 0$, and thus $g'(p) = -21+110p-198p^2+156p^3-50p^4$ is increasing. Since $g'(\tilde{p}) < 0$ and $g'(1/2) > 0$, the first derivative has one root, and hence $g(p)$ is decreasing first and then increasing. It can be easily verified that $g(p)$ is positive at this root of $g'(p)$ and hence is positive throughout, satisfying the condition above. Therefore, there is no range of p and w below $\overline{w}$ where not searching is the unique equilibrium.

Taken together, we can now define

$$\tilde{w} = \begin{cases} \overline{w} & \text{for} \quad 0 < p < \dot{p} \\ \underline{w}_1 & \text{for} \quad \dot{p} < p < 1/2 \\ \underline{w}_2 & \text{for} \quad 1/2 < p < 1 \end{cases}$$

as used in the statement of the proposition.

For $1/2 < p < 1$, where the equilibrium in which the regulator searches twice also exists, we now show that the lower bound is given by $\underline{w}_2$ and that there also exists an area below $\overline{w}$ and above $\underline{w}_2$ where not searching is the unique equilibrium. The first condition is

$$\begin{aligned} \underline{w}_2 = & \frac{c}{3p^2-(15/2)p^3+(15/2)p^4-3p^5} \\ & \leq \frac{c}{p-4p^2+\frac{28}{3}p^3-13p^4+10p^5-\frac{10}{3}p^6} = \overline{w} \end{aligned}$$

or $-12+84p-202p^2+246p^3-156p^4+40p^5 \geq 0$. Define the LHS as $g(p)$. The fourth derivative $g''''(p) = -3744+4800p$ is increasing and crosses the abscissa once from below. This implies that $g'''(p) = 1476-3744p+2400p^2$ first has a decreasing and then an increasing slope, and as it is positive at the root of $g''''(p)$, it is positive throughout the relevant range. From this fact we know that $g''(p) = -404+1476p-1872p^2+800p^3$ is increasing, and it is negative and has no root in the relevant range as $g''(1) = 0$. Hence, $g'(p) = 84-404p+738p^2-$

$624p^3 + 200p^4$ is decreasing, and has one zero as $g'(1/2) > 0$ but $g'(1) < 0$. The original function $g'(p)$ thus has a local maximum at this root and is positive throughout as both $g(1/2)$ and $g(1)$ are positive, and the condition above is satisfied.

Lastly, we show that

$$\overline{w}_2 = \frac{c}{3p^2 - 12p^3 + 24p^4 - 24p^5 + 9p^6} \leq \frac{c}{p - 4p^2 + \frac{28}{3}p^3 - 13p^4 + 10p^5 - \frac{10}{3}p^6} = \overline{w}$$

or $-3+21p-64p^2+111p^3-102p^4+37p^5 \geq 0$ for some values of p. Define the LHS as $g(p)$. The fourth derivative $g''''(p) = -2448+4440p$ crosses the abscissa once from below, implying a local minimum of $g'''(p) = 666-2448p+2220p^2$. As $g'''(1/2) < 0$ and $g'''(1) > 0$, the third derivative has one root in the range of interest. Hence, $g''(p) = -128+666p-1224p^2+740p^3$ also has a local minimum in the relevant range. Similarly, $g''(1/2) < 0$ and $g''(1) > 0$, such that $g''(p)$ also crosses the abscissa once from below, implying one local minimum of $g'(p) = 21-128p+333p^2-408p^3+185p^4$. As both $g'(1/2)$ and $g'(1)$ are positive but there are negative values of $g'(p)$ in between, the first derivative first crosses the abscissa from above and then again from below. Hence, $g(p)$ first has a local maximum and then a local minimum. As $g(1/2)$ is positive, the local maximum must be in the positive domain, and because $g(1) = 0$ and $g'(1) > 0$, the graph crosses the abscissa from below at $p = 1$ and hence the local minimum is in the negative domain. This implies that there must be a zero in between. It can be shown that this root lies at

$$\ddot{p} = \frac{65}{148} + \frac{1}{148\sqrt{\frac{3}{-941-9176\left(\frac{2}{8561+9\sqrt{916593}}\right)^{1/3}+74\times 2^{2/3}\left(8561+9\sqrt{916593}\right)^{1/3}}}}$$
$$+\frac{1}{2}\left[-\frac{941}{8214}+\frac{62}{111}\left(\frac{2}{8561+9\sqrt{916593}}\right)^{1/3}-\frac{1}{111}\left(\frac{1}{2}\left(8561+9\sqrt{916593}\right)\right)^{1/3}\right.$$
$$\left.+\frac{29241\sqrt{\frac{3}{-941-9176\left(2/(8561+9\sqrt{916593})\right)^{1/3}+74\times 2^{2/3}\left(8561+9\sqrt{916593}\right)^{1/3}}}}{2738}\right],$$

which is ≈ 0.81216. Therefore, $\overline{w}_2$ is smaller than $\overline{w}$ for $1/2 < p < \ddot{p}$ and there are levels of w between $\overline{w}_2$ and $\overline{w}$ for which not searching is the unique equilibrium. □

Proof of Lemma 2.5. Rearranging (2.7) and (2.8) gives

$$\frac{c}{w} \leq p - 3p^2 + 5p^3 - 3p^4 \tag{2.25}$$

and

$$\frac{c}{w} \leq p - \frac{5}{2}p^2 + 3p^3 - \frac{3}{2}p^4, \tag{2.26}$$

respectively. (2.7) is the relevant constraint if the RHS of (2.25) is smaller than the RHS of (2.26) or $p^2 g(p) \geq 0$ where $g(p) = 1/2 - 2p + (3/2)p^2$. The first derivative $g'(p) = -2 + 3p$ crosses the abscissa once from below and hence, $g(p)$ is convex. It is easy to verify that $g(p)$ has roots at $p^* = 1/3$ and $p = 1$ and hence is positive for values of p below p^* and negative for values above. Thus, (2.7) is binding for small p while (2.8) is relevant for large p and the lemma follows. □

Proof of Proposition 2.1. We have to show that $\overline{w} > \underline{w}$ for all p. For $0 < p < \tilde{p}$, the relevant comparison is

$$\overline{w} = \frac{c}{p - 5p^2 + 16p^3 - 28p^4 + 26p^5 - 10p^6} \geq \frac{c}{p - 3p^2 + 5p^3 - 3p^4} = \underline{w}$$

or $2 - 11p + 25p^2 - 26p^3 + 10p^4 \geq 0$. Define the LHS as $g(p)$. The third derivative $g'''(p) = -156 + 240p$ is increasing and negative in the relevant range as $g'''(\tilde{p}) < 0$. This implies that $g''(p) = 50 - 156p + 120p^2$ is decreasing, and it is positive as its value at $\tilde{p}$ is positive. Hence, $g'(p) = -11 + 50p - 78p^2 + 40p^3$ is increasing, and from $g'(\tilde{p}) < 0$ we know that it is negative. Due to this fact, $g(p)$ is decreasing, and as $g(\tilde{p}) > 0$, it is positive and the condition above holds.

For $\tilde{p} < p < 1/3$, the relevant comparison is

$$\overline{w} = \frac{c}{p - 4p^2 + \frac{28}{3}p^3 - 13p^4 + 10p^5 - \frac{10}{3}p^6} \geq \frac{c}{p - 3p^2 + 5p^3 - 3p^4} = \underline{w}$$

or $3 - 13p + 30p^2 - 30p^3 + 10p^4 \geq 0$. Define the LHS as $g(p)$. The third derivative $g'''(p) = -180 + 240p$ is increasing and negative in the range of interest as $g'''(1/3) < 0$. Hence, $g''(p) = 60 - 180p + 120p^2$ is decreasing and positive as $g''(1/3) > 0$. The slope of $g'(p) = -13 + 60p - 90p^2 + 40p^3$ thus is positive, and the first derivative is negative because $g'(1/3) < 0$. From this we know that $g(p)$ is decreasing. As $g(1/3) > 0$, the LHS is positive throughout the range of interest and the above condition is satisfied.

For $1/3 < p < 1$, the relevant comparison is

$$\overline{w} = \frac{c}{p - 4p^2 + \frac{28}{3}p^3 - 13p^4 + 10p^5 - \frac{10}{3}p^6} \geq \frac{c}{p - \frac{5}{2}p^2 + 3p^3 - \frac{3}{2}p^4} = \underline{w}$$

or $9 - 38p + 69p^2 - 60p^3 + 20p^4 \geq 0$. Define the LHS as $g(p)$. The third derivative $g'''(p) = -360 + 480p$ is increasing and crosses the abscissa once from below as $g'''(1/3) < 0$ and $g'''(1) > 0$. Hence $g''(p) = 138 - 360p + 240p^2$ is convex and has a local minimum at $p = 3/4$. As its value is positive at the local minimum it is positive throughout the range of interest. Therefore, $g'(p) = -38 + 138p - 180p^2 + 80p^3$ is increasing and negative as $g'(1/3) < 0$ and $g'(1) = 0$. That being the case, the LHS decreases in p and is positive as $g(1/3) > 0$ and $g(1) = 0$. The above condition holds and the proof concludes. $\square$

Proof of Proposition 2.2. First, we show that $\underline{w}$ is smaller than $\tilde{w}$ for $p < 1/3$. For $0 < p < \dot{p}$ where the relevant upper bound is $\overline{w}$, we check whether

$$\underline{w} = \frac{c}{p - 3p^2 + 5p^3 - 3p^4} \leq \frac{c}{p - 5p^2 + 16p^3 - 28p^4 + 26p^5 - 10p^6} = \overline{w}$$

or $2 - 11p + 25p^2 - 26p^3 + 10p^4 \geq 0$. Define the LHS as $g(p)$. Observe that $g'''(p) = -156 + 240p$ is increasing and negative throughout the relevant range, which means that $g''(p) = 50 - 156p + 120p^2$ is decreasing. As $g''(\dot{p}) > 0$, the second derivative is positive, which implies a positive slope for $g'(p) = -11 + 50p - 78p^2 + 40p^3$. As $g'(\dot{p}) < 0$ we know that the first derivative is negative and by that we know that $g(p)$ is decreasing. The fact that $g(\dot{p}) > 0$ implies that the LHS is positive throughout the relevant range and that the conditions above holds.

For $\dot{p} < p < 1/3$, the relevant upper bound for the wage is $\underline{w}_1$ and hence, the relevant comparison is

$$\underline{w} = \frac{c}{p - 3p^2 + 5p^3 - 3p^4} \leq \frac{c}{3p^2 - 6p^3 + 3p^4} = \underline{w}_1$$

or $1 - 6p + 11p^2 - 6p^3 \geq 0$. Define the LHS as $g(p)$. The second derivative $g''(p) = 22 - 36p$ is decreasing and positive for $p = 1/3$ and thus positive in the relevant range so that $g'(p) = -6+22p-18p^2$ is increasing. As $g'(1/3) < 0$, the first derivative is negative which implies a negative slope of $g(p)$. Together with the facts that $g(\dot{p}) > 0$ and $g(1/3) = 0$ we know that $g(p)$ is positive in the relevant range and the condition above holds.

Next we show that for values of p above $1/3$, $\underline{w}$ is never below $\tilde{w}$. First, for $1/3 < p < 1/2$, the relevant comparison is

$$\underline{w} = \frac{c}{p - \frac{5}{2}p^2 + 3p^3 - \frac{3}{2}p^4} \geq \frac{c}{3p^2 - 6p^3 + 3p^4} = \underline{w}_1$$

or $-2+11p-18p^2+9p^3 \geq 0$. Define the LHS as $g(p)$. The second derivative $g''(p) = -36+54p$ is increasing and negative for $p = 1/2$ and thus negative in the relevant range, implying a negative slope of $g'(p) = 11-36p+27p^2$. As $g'(1/3) > 0$ and $g'(1/2) < 0$, there must be one root of the first derivative in the relevant range. This implies that $g(p)$ is concave and has a local maximum in that range, and because $g(1/3) = 0$ and $g(1/2) > 0$, it is positive throughout the range and the condition above holds. Second, for $1/2 < p < 1$, the relevant comparison is

$$\underline{w} = \frac{c}{p - \frac{5}{2}p^2 + 3p^3 - \frac{3}{2}p^4} \geq \frac{c}{3p^2 - \frac{15}{2}p^3 + \frac{15}{2}p^4 - 3p^5} = \underline{w}_2$$

or $-2+11p-21p^2+18p^3-6p^4 \geq 0$. Define the LHS as $g(p)$. The third derivative $g'''(p) = 108-144p$ is decreasing and crosses the abscissa once because $g'''(1/2) > 0$ and $g'''(1) < 0$. This implies that $g''(p) = -42+108p-72p^2$ is concave and has a local maximum at $p = 108/144$ in that range. As $g''(108/144) < 0$, the second derivative is negative throughout. The first derivative $g'(p) = 11-42p+54p^2-24p^3$ hence is decreasing in the relevant range. As $g'(1/2) > 0$ and $g'(1) < 0$ the first derivative has one root and $g(p)$ is concave and has a local maximum. From $g(1/2) > 0$ and $g(1) = 0$ we can infer that $g(p)$ is positive in the relevant range and the condition above holds.

The second part of the proof follows from the earlier analysis. For $1/2 < p < \ddot{p}$, $\overline{w}_2 < \overline{w}$ from Lemma 2.4 and $\underline{w} < \overline{w}$ from Proposition 2.1. Hence, whenever $w > \max\{\overline{w}_2, \underline{w}\}$ it is below $\overline{w}$ and the unique equilibrium exists for this range of p. $\square$

Proof of Proposition 2.3. There are three cases. For $0 < p < 1/3$, the losses in Situation 1 L_1 are larger than the losses in Situation 2 L_2 if

$$L_1 = 9p^3 - 21p^4 + 18p^5 - 6p^6 \geq p - 5p^2 + 14p^3 - 22p^4 + 18p^5 - 6p^6 = L_2$$

or $-1 + 5p - 5p^2 + p^3 \geq 0$. Define the LHS as $g(p)$. The second derivative $g''(p) = -10 + 6p$ is increasing and negative throughout the relevant range as $g''(1/3) < 0$. Hence $g'(p) = 5 - 10p + 3p^2$ is decreasing, and it is positive because $g'(1/3) > 0$. It follows that $g(p)$ has a positive slope. As $g(0) < 0$ but $g(1/3) > 0$ it crosses the abscissa once from below in the range of interest. It can be shown that this root lies at $p = 2 - \sqrt{3}$, and hence the condition above holds for values of p larger than that.

For $1/3 < p < 2/3$, the relevant comparison is

$$\begin{aligned} L_1 = 3p - 15p^2 + 30p^3 - 30p^4 + 18p^5 - 6p^6 \\ \geq p - 5p^2 + 14p^3 - 22p^4 + 18p^5 - 6p^6 = L_2 \end{aligned}$$

or $1 - 5p + 8p^2 - 4p^3 \geq 0$. Define the LHS as $g(p)$. The second derivative $g''(p) = 16 - 24p$ is decreasing and positive as $g''(2/3) = 0$. Thus, $g'(p) = -5 + 16p - 12p^2$ is increasing and crosses the abscissa once from below as $g'(1/3) < 0$ and $g'(2/3) > 0$. It can be shown that $g'(1/2) = 0$. From this we can infer that $g(p)$ is convex and has a local minimum. Its value at the local minimum is zero, so the condition above weakly holds in the relevant range of p.

Lastly, for $2/3 < p < 1$, the relevant condition is

$$\begin{aligned} L_1 = 3p - 9p^2 + 15p^3 - 21p^4 + 18p^5 - 6p^6 \\ \geq p - 5p^2 + 14p^3 - 22p^4 + 18p^5 - 6p^6 = L_2 \end{aligned}$$

or $2 - 4p + p^2 + p^3 \geq 0$. Define the LHS as $g(p)$. The second derivative $g''(p) = 2 + 6p$ is increasing and positive throughout the whole range of interest, implying a positive slope for $g'(p) = -4 + 2p + 3p^2$. As $g'(2/3) < 0$ and $g'(1) > 0$, the first derivative crosses the abscissa once from below. From this we can infer that $g(p)$ is convex and has a local minimum. We know that this local minimum is negative as $g(2/3) > 0$, $g(1) = 0$, and $g'(1) > 0$, and therefore, $g(p)$ crosses the abscissa once from above. It can be shown that this root lies at $p = \sqrt{3} - 1$, and the condition above holds for values of p smaller than that. $\square$

Chapter Three

Conflicting tasks and moral hazard: theory and experimental evidence

3.1 INTRODUCTION

In real-world agency problems, it is often the case that principals have to delegate not just one but several tasks. In this chapter we focus on situations in which two different tasks to be delegated may be in direct conflict with each other; i.e., providing effort in one task may have a negative side effect on the success probability of the other task.[1] In such situations, job design becomes a major issue. In particular, it might be the case that implementing effort in both tasks may be facilitated by hiring two different agents each in charge of one task instead of letting one agent be responsible for both tasks. In the present chapter we investigate these incentive problems in a theoretical model and provide first experimental evidence that also in the laboratory, where fairness and reciprocity considerations matter, agents are indeed reluctant to perform different tasks when they are in conflict with each other.

To fix ideas, consider a merchant (principal) who wants to sell two products which may be imperfect substitutes. The merchant may hire either one or two sales representatives (agents) who can exert effort to promote the products. The effort decisions are assumed to be non-contractible, but the wages can depend on which products are sold. The agents are risk-neutral and have no wealth, so

[1]Examples of conflicting tasks abound in the real world. For instance, franchise companies that decide to open a new branch store in close proximity to their existing stores have to investigate carefully to which extent the opening of the new store will affect sales in the existing stores and whether overall company sales will increase. Moreover, when producers of consumer goods have related and competing products in their portfolio, they always have to consider that an advertising campaign for one product may cannibalize the sales levels of their related products.

that the wages must be non-negative. There are no technological (dis-)economies of scope, so that in the absence of incentive problems, the principal would be indifferent between hiring one or two agents.

Suppose first that the merchant has only one sales representative in charge of both products. If the products are imperfect substitutes, then promotion effort in one task increases the probability of sale of the promoted product, but at the same time it lowers the probability of sale of the other product (i.e., there is conflict between the tasks). In contrast, if there is no relation between the products, promotion of one product has no effect on the probability of sale of the other product. We consider a symmetric situation such that in theory, when the products are unrelated (so that there is no conflict), the principal induces either effort in both tasks or no effort at all. However, when there is conflict between the tasks, then it may be optimal for the principal to induce the agent to invest effort in only one task. Intuitively, if there is conflict between the two tasks, a single sales representative is very reluctant to exert effort in both tasks, because he knows that promotion effort does not only increase the probability of sale of the promoted product, but at the same time it also lowers the probability of sale of the other product he is supposed to sell. This makes it very expensive for the principal to induce two efforts.

Suppose next that there are two (identical) sales representatives, each of them responsible for promoting one product. Due to symmetry, in theory the principal induces either effort in both tasks or no effort at all, regardless of whether or not there is conflict.

In general, if there is conflict, it depends on the parameter constellation whether the principal's expected profit is larger with one or with two agents. Yet, if there is no conflict, then the principal's expected profit is unambiguously larger when only one agent is in charge of both tasks. Intuitively, when the tasks are not in conflict with each other, the rent that the principal leaves to the agent to motivate him to work on one task can also be used to motivate him to work on the other task.

In order to find an answer to our research question whether the theoretical incentive problem of inducing a single agent to simultaneously exert efforts in conflicting tasks is empirically relevant, we conducted a laboratory experiment with 474 subjects. There are two treatments with conflict; one where the principal has only a single agent and another one where she has two agents. We have chosen a parameter constellation such that according to standard theory, a merchant who has only one sales representative would induce him to invest effort in only one task, while a merchant with two sales representatives would induce each one to promote his respective product. Moreover, there are two treatments without conflict, one with a single agent and another one with two agents. The theoretical prediction for our parameter constellation is that in the absence of conflict, a merchant would always induce two efforts, regardless of whether she has only one or two sales representatives to perform these tasks.

One central finding of our experiment is that in the one-agent treatment with conflict, two efforts are chosen significantly less often than in the other three treatments. Hence, our experimental data provides strong support for the empirical relevance of the theoretically predicted incentive problem to motivate a single agent to provide efforts in conflicting tasks. However, even in the presence of conflict, a relevant fraction of agents still exerts two efforts. This happens mostly when a principal's wage offer is very generous. Thus, fairness and reciprocity may mitigate the incentive problem. Moreover, in contrast to the theoretical prediction, in the presence of conflict, the principals' average profit is slightly larger in the one-agent treatment than in the two-agent treatment. Two facts contribute to this result. First, the fraction of two efforts in the one-agent treatment with conflict is larger than theoretically predicted, and second, in the two-agent treatment, in sum the principal offers the agents more than in the one-agent treatment. Yet, with regard to the no-conflict treatments, we find significant support for the theoretical prediction that the principals' profits are larger in the case of one agent than in the case of two agents.

Since the seminal work of Holmström and Milgrom (1991), multi-task principal-agent problems have played a prominent role in the contract theoretic literature.[2] However, most of these papers have focused on effort substitution and the trade-off between insurance and incentives when agents are risk-averse. More recently, many authors have studied moral hazard models with risk-neutral but

[2]For surveys, see e.g. Dewatripont, Jewitt, and Tirole (2000), Laffont and Martimort (2002, ch. 5), and Bolton and Dewatripont (2005, ch. 6).

wealth-constrained agents.[3] In the latter framework, several authors have shown that a principal can save agency costs if she lets one agent be in charge of several tasks (see e.g. Hirao, 1993, Che and Yoo, 2001, Laux, 2001, and Mylovanov and Schmitz, 2008).[4] The potential benefits of separating tasks in sequential agency problems have been discussed by Hirao (1993), Schmitz (2005), and Khalil, Kim, and Shin (2006). The fact that conflicts between different tasks may explain why they are delegated to different agents ("advocates") has first been studied by Dewatripont and Tirole (1999). They analyze the optimality of organizing the judicial system in an incomplete contracting framework. This chapter is most closely related to a complete contracting variant of their model which is discussed in Bolton and Dewatripont (2005, Section 6.2.2). To the best of our knowledge, only a few experiments on multi-task principal-agent problems have been conducted so far. In particular, Fehr and Schmidt (2004) study a problem where one task is contractible and they focus on the pros and cons of piece-rate versus bonus contracts. Brüggen and Moers (2007) investigate the role of financial and social incentives in multi-task settings where agents choose an effort level and an effort allocation.

The remainder of the chapter is organized as follows. The theoretical model which is based on Bolton and Dewatripont (2005) is analyzed in Section 3.2 and serves as a motivation for our experimental study. The experimental design is introduced in Section 3.3 and qualitative hypotheses are derived in Section 3.4. The experimental results are presented and discussed in Sections 3.5 and 3.6. Finally, concluding remarks follow in Section 3.7. All proofs are relegated to Appendix A.

3.2 THE THEORETICAL FRAMEWORK

Consider a principal who wants to sell a single unit of a product 1 and a single unit of a product 2. The sales level for a given product $i \in \{1,2\}$ is denoted by $q_i \in \{0,1\}$. If product i is sold, the principal obtains revenue $R > 0$. We consider

[3] See e.g. Innes (1990), Pitchford (1998), and Tirole (2001).

[4] See also Dana (1993) and Gilbert and Riordan (1995) who have found related results in other frameworks.

two different scenarios. In the first scenario the principal employs a single agent to sell products 1 and 2, while she employs two agents in the other scenario. All parties are risk-neutral. An agent has no wealth and his reservation utility is zero. If there is only a single agent, he can exert effort $a_i \in \{0,1\}$ to promote product $i \in \{1,2\}$. In case that there are two agents, agent A can promote product 1 and agent B can promote product 2; i.e., A chooses $a_1 \in \{0,1\}$ and B chooses $a_2 \in \{0,1\}$. The effort levels are non-contractible.

Effort to promote product i *increases* the probability of sale of product i but (weakly) *lowers* the probability of sale of product $j \neq i$. In other words, there may be a direct conflict between the effort tasks when the products are imperfect substitutes. Formally, let the probability of sale of product i be given by $\Pr(q_i = 1) = \alpha + \rho a_i - \gamma a_j$. The base rate of sale of product i is $\alpha > 0$. If product i is promoted (i.e., $a_i = 1$), the probability of sale of product i increases by $\rho > 0$. If the other product $j \neq i$ is promoted (i.e., $a_j = 1$) and the products are imperfect substitutes, the probability of sale of product i decreases by $\gamma > 0$. When the products are unrelated ($\gamma = 0$), effort to promote one product has no effect on the probability of sale of the other product.

Throughout we assume that $\gamma \leq \alpha \leq 1-\rho$ to ensure that $0 \leq \alpha + \rho a_i - \gamma a_j \leq 1$ for any combinations of effort decisions a_1 and a_2. An agent has to incur effort costs ψ if he promotes a product i. Hence, product i generates an expected net surplus of $(\alpha + \rho a_i - \gamma a_j)R - a_i\psi$. Due to the symmetry of the model it is either efficient to promote both or no products. We assume $(\rho - \gamma) > \psi/R$ such that $(\alpha + \rho - \gamma)R - \psi > \alpha R$ which implies that the expected total surplus is maximized when both products are promoted (i.e., $a_1 = a_2 = 1$). Hence, if effort were verifiable, the principal would always implement two efforts. Yet, since in our setup effort is not contractible, to induce an agent to exert effort the principal can offer a wage scheme $w_{q_1 q_2} := w(q_1, q_2)$ that is contingent only on which products have been sold.

One-agent scenario. Given that the principal has only one agent, she has to decide whether to induce promotion effort in both tasks, in only one task, or in no task.

Let us first consider the case where the principal wishes to induce effort in both tasks. The principal's problem is to minimize the expected compensation $E\left[w_{q_1q_2} \mid a_1 = a_2 = 1\right]$ she has to pay to her agent subject to the constraints $w_{q_1q_2} \geq 0$,

$$E\left[w_{q_1q_2} \mid a_1 = a_2 = 1\right] - 2\psi \geq E\left[w_{q_1q_2} \mid a_1 = 1, a_2 = 0\right] - \psi, \qquad \text{(IC 1)}$$

$$E\left[w_{q_1q_2} \mid a_1 = a_2 = 1\right] - 2\psi \geq E\left[w_{q_1q_2} \mid a_1 = 0, a_2 = 1\right] - \psi, \qquad \text{(IC 2)}$$

$$E\left[w_{q_1q_2} \mid a_1 = a_2 = 1\right] - 2\psi \geq E\left[w_{q_1q_2} \mid a_1 = a_2 = 0\right], \qquad \text{(IC 3)}$$

$$E\left[w_{q_1q_2} \mid a_1 = a_2 = 1\right] - 2\psi \geq 0. \qquad \text{(PC)}$$

The first two incentive compatibility constraints ensure that the agent prefers exerting two efforts to exerting only one effort and the third one ensures that the agent prefers exerting two efforts to exerting no effort. The last constraint ensures that the agent participates.

Lemma 3.1. *Suppose the principal wants to induce $a_1 = a_2 = 1$. Then she sets $w_{11} = \frac{2\psi}{(\alpha+\rho-\gamma)^2-\alpha^2}$ and $w_{10} = w_{01} = w_{00} = 0$. Given this wage scheme, the principal's expected profit is $\Pi_{hh} = (\alpha+\rho-\gamma)^2(2R - w_{11}) + 2(\alpha+\rho-\gamma)(1-\alpha-\rho+\gamma)R$.*

Suppose next the principal wants to induce effort in only one task. Let us assume w.l.o.g. that the principal wants to induce effort with regard to product 1; i.e., the principal wishes to implement $a_1 = 1, a_2 = 0$. In this case the principal's problem is to minimize $E\left[w_{q_1q_2} \mid a_1 = 1, a_2 = 0\right]$ subject to the constraints $w_{q_1q_2} \geq 0$,

$$E\left[w_{q_1q_2} \mid a_1 = 1, a_2 = 0\right] - \psi \geq E\left[w_{q_1q_2} \mid a_1 = a_2 = 1\right] - 2\psi, \qquad \text{(IC 1)}$$

$$E\left[w_{q_1q_2} \mid a_1 = 1, a_2 = 0\right] - \psi \geq E\left[w_{q_1q_2} \mid a_1 = 0, a_2 = 1\right] - \psi, \qquad \text{(IC 2)}$$

$$E\left[w_{q_1q_2} \mid a_1 = 1, a_2 = 0\right] - \psi \geq E\left[w_{q_1q_2} \mid a_1 = a_2 = 0\right], \qquad \text{(IC 3)}$$

$$E\left[w_{q_1q_2} \mid a_1 = 1, a_2 = 0\right] - \psi \geq 0. \qquad \text{(PC)}$$

Lemma 3.2. *Suppose the principal wants to induce $a_1 = 1$ and $a_2 = 0$.*[5] *Then it is optimal for her to set $w_{10} = \frac{\psi}{\alpha\gamma+\rho(1-\alpha+\gamma)}$ and $w_{11} = w_{01} = w_{00} = 0$. Given this wage scheme, the principal's expected profit is $\Pi_{hl} = (\alpha+\rho)(\alpha-\gamma)2R + (\alpha+\rho)(1-\alpha+\gamma)(R-w_{10}) + (1-\alpha-\rho)(\alpha-\gamma)R$.*

Observe that if there is conflict and the principal wants the agent to promote product 1 only, then it is strictly optimal to pay the agent no wage in case that also product 2 is sold. The reason is that effort in task 1 reduces the probability of sale of product 2 and hence the sale of this product can be seen as a signal that the agent may not have promoted product 1. In contrast, if there is no conflict, a wage scheme with $w_{11} = 0$ is not the only solution. This is because then the sale of product 2 provides no signal for the effort level in task 1. Therefore, a positive wage w_{11} can be optimal as long as it does not induce the agent to promote product 2 as well. Specifically, it is easy to show that if $\gamma = 0$, then any wage scheme $0 \le w_{11} \le \frac{1+\rho}{\rho(\alpha+\rho)}\psi, w_{10} \ge 0, w_{01} = w_{00} = 0$ which satisfies $\alpha w_{11} + (1-\alpha)w_{10} = \frac{\psi}{\rho}$ is optimal.

Finally the principal could induce no effort at all. It is immediate to see that for this case the optimal wage scheme is simply given by $w_{11} = w_{10} = w_{01} = w_{00} = 0$. Then the principal's expected profit is $\Pi_{ll} = 2\alpha R$.

The preceding discussion immediately implies the following result.

Proposition 3.1. *(i) If $R > \frac{\psi(\alpha+\rho-\gamma)^2}{\left[(\alpha+\rho-\gamma)^2-\alpha^2\right](\rho-\gamma)}$ and $R > \frac{2\psi(\alpha+\rho-\gamma)^2}{\left[(\alpha+\rho-\gamma)^2-\alpha^2\right](\rho-\gamma)} - \frac{(\alpha+\rho)(1-\alpha+\gamma)\psi}{[\alpha\gamma+\rho(1-\alpha+\gamma)](\rho-\gamma)}$, then the principal induces effort in both tasks.*

(ii) If $\frac{(\alpha+\rho)(1-\alpha+\gamma)\psi}{[\alpha\gamma+\rho(1-\alpha+\gamma)](\rho-\gamma)} < R < \frac{2\psi(\alpha+\rho-\gamma)^2}{\left[(\alpha+\rho-\gamma)^2-\alpha^2\right](\rho-\gamma)} - \frac{(\alpha+\rho)(1-\alpha+\gamma)\psi}{[\alpha\gamma+\rho(1-\alpha+\gamma)](\rho-\gamma)}$, then the principal induces effort in only one task.

(iii) Otherwise the principal induces no effort.

It is obvious that the principal will induce promotion for both products if the return is sufficiently large. However for intermediate values of R, if there is conflict, the principal may prefer to induce effort in only one task. The reason is as follows. If the adverse effects of promotion efforts increase, the sale of two products provides weaker evidence that the agent has chosen to exert effort in

[5] Note that due to the symmetry of the problem the principal's expected profit is the same if she implements $a_1 = 0$ and $a_2 = 1$.

both tasks, while the sale of only one product provides stronger evidence that the agent has exerted effort to promote this product. As a consequence, if the conflict between tasks increases, it becomes more expensive for the principal to induce the agent to promote both products, while it becomes less expensive to implement effort in only one task.

In contrast, if γ is sufficiently small (in particular, if there is no conflict), the principal will never implement effort in only one task; i.e., the condition in part (ii) cannot be satisfied.

Two-agent scenario. Given that the principal can employ two agents, she has to decide whether to induce both agents to exert effort, whether to provide only one agent with incentives or whether she prefers to induce no efforts at all. The principal will now offer a wage schedule $w^k_{q_1q_2} := w^k(q_1,q_2)$ with $k \in \{A,B\}$ to the agents. This means she will offer each agent one wage for each possible combination of q_1 and q_2.

Let us first assume the principal wishes to induce agent A to exert effort to promote product 1 and agent B to exert effort to promote product 2. The principal's problem is to minimize the sum of the expected compensation $E\left[w^A_{q_1q_2} + w^B_{q_1q_2} \mid a_1 = a_2 = 1\right]$ she has to pay to the agents subject to the constraints $w^k_{q_1q_2} \geq 0$,

$$E\left[w^A_{q_1q_2} \mid a_1 = a_2 = 1\right] - \psi \geq E\left[w^A_{q_1q_2} \mid a_1 = 0, a_2 = 1\right], \tag{IC A}$$

$$E\left[w^B_{q_1q_2} \mid a_1 = a_2 = 1\right] - \psi \geq E\left[w^B_{q_1q_2} \mid a_1 = 1, a_2 = 0\right], \tag{IC B}$$

$$E\left[w^A_{q_1q_2} \mid a_1 = a_2 = 1\right] - \psi \geq 0, \tag{PC A}$$

$$E\left[w^B_{q_1q_2} \mid a_1 = a_2 = 1\right] - \psi \geq 0. \tag{PC B}$$

The two incentive compatibility constraints ensure that each agent prefers to exert effort to promote his product and the participation constraints ensure that both agents will accept the offered wage scheme.

Lemma 3.3. *Suppose the principal wants to induce $a_1 = a_2 = 1$. Then she sets $w^A_{10} = w^B_{01} = \frac{\psi}{(\alpha+\rho-\gamma)(1-\alpha-\rho+\gamma)-(\alpha-\gamma)(1-\alpha-\rho)}$ and $w^k_{11} = w^k_{00} = w^A_{01} = w^B_{10} = 0$. Given this wage scheme, the principal's expected profit is $\Pi^{AB}_{hh} = (\alpha+\rho-\gamma)^2 2R + 2(\alpha+\rho-\gamma)(1-\alpha-\rho+\gamma)(R-w^A_{10})$.*

Observe that if there is conflict, then the principal pays an agent a positive wage if and only if the agent was successful in selling his product while the other agent failed. The reason is that in the case of conflict, the failure of an agent to sell his product can be seen as an indication that the other agent has promoted his product, since promotion decreases the probability of sale of the competing agent's product. In contrast, if there is no conflict, a wage scheme with $w_{11}^k = 0$ is not the only one that can be optimal. This is because in the case of no conflict, the success or failure of one agent indicates nothing about the other agent's effort decision. In particular, if $\gamma = 0$, then any wage scheme with $w_{00}^k = w_{01}^A = w_{10}^B = 0$ such that $(1-\alpha-\rho)w_{10}^A + (\alpha+\rho)w_{11}^A = \frac{\psi}{\rho}$ and $(1-\alpha-\rho)w_{01}^B + (\alpha+\rho)w_{11}^B = \frac{\psi}{\rho}$ is optimal.

Suppose next the principal wants to induce effort in only one task. Let us assume w.l.o.g. that the principal wants to induce effort with regard to product 1; i.e., the principal wishes to implement $a_1 = 1, a_2 = 0$. It is obvious that in this case the principal will set $w_{q_1 q_2}^B = 0$ for all possible combinations of q_1 and q_2 such that agent B will not exert effort. Hence, the principal's problem is to minimize $E\left[w_{q_1 q_2}^A \mid a_1 = 1, a_2 = 0\right]$ subject to the constraints $w_{q_1 q_2}^A \geq 0$,

$$E\left[w_{q_1 q_2}^A \mid a_1 = 1, a_2 = 0\right] - \psi \geq E\left[w_{q_1 q_2}^A \mid a_1 = a_2 = 0\right], \tag{IC A}$$

$$E\left[w_{q_1 q_2}^A \mid a_1 = 1, a_2 = 0\right] - \psi \geq 0. \tag{PC A}$$

Lemma 3.4. *Suppose the principal wants to induce $a_1 = 1$ and $a_2 = 0$. Then it is optimal for her to set $w_{10}^A = \frac{\psi}{\alpha\gamma + \rho(1-\alpha+\gamma)}$ and $w_{11}^A = w_{01}^A = w_{00}^A = w_{q_1 q_2}^B = 0$. Given this wage scheme, the principal's expected profit is $\Pi_{hl}^{AB} = (\alpha+\rho)(\alpha-\gamma)2R + (\alpha+\rho)(1-\alpha+\gamma)(R - w_{10}^A) + (1-\alpha-\rho)(\alpha-\gamma)R$.*

Also with two agents the principal could induce no efforts at all and as in the one-agent case this yields an expected profit of $\Pi_{ll}^{AB} = 2\alpha R$.

It is now straightforward to show that the following result holds.

Proposition 3.2. *(i) If $R > \frac{\psi(\alpha+\rho-\gamma)(1-\alpha-\rho+\gamma)}{[\rho(1-\alpha-\rho)+\gamma(\alpha+\rho-\gamma)](\rho-\gamma)}$, then the principal induces effort in both tasks.*

(ii) Otherwise the principal induces no effort.

Note that if the principal has two agents, then she will never induce only one agent to exert effort. This is obvious in the absence of conflict, because then there is no interaction between the agents, and hence she induces both agents to choose the effort level that she would implement if there were only one agent in charge of one task. If there is conflict, consider a situation where the principal prefers inducing only one effort to inducing no efforts. In such a situation, the principal can always increase her profit further by inducing two efforts. The reason is that if only one agent is induced to exert effort, then even if he deviates, the probability of sale of his product is still relatively large, which makes it expensive for the principal to induce effort. In contrast, if both agents are induced to exert effort, then if an agent chooses low effort, the probability of sale of his product is small due to the adverse effect of the other agent's promotion effort, which makes it less expensive for the principal to induce effort.

Proposition 3.1 and Proposition 3.2 imply the following result.

Proposition 3.3. *There exists a unique* $\hat{\gamma} \in (0, \min\{\alpha, \rho\})$ *such that* $\Pi_{hh}(\hat{\gamma}) = \Pi_{hh}^{AB}(\hat{\gamma})$.

(i) Consider the case $\gamma \leq \hat{\gamma}$. *If* $R > \frac{\psi(\alpha+\rho-\gamma)^2}{\left[(\alpha+\rho-\gamma)^2-\alpha^2\right](\rho-\gamma)}$, *then it is optimal for the principal to have one agent and to induce effort in both tasks.*

(ii) Next consider $\gamma > \hat{\gamma}$. *If* $R > \frac{\psi(\alpha+\rho-\gamma)(1-\alpha-\rho+\gamma)}{[\rho(1-\alpha-\rho)+\gamma(\alpha+\rho-\gamma)](\rho-\gamma)}$, *then it is optimal for the principal to have two agents and to induce effort in both tasks.*

(iii) Otherwise it is optimal to induce no efforts and it makes no difference whether the principal has one or two agents.

Observe that if the conflict between the tasks is weak ($\gamma \leq \hat{\gamma}$), then the principal prefers to employ one agent, provided that the return R is sufficiently large such that she wants to induce effort in both tasks.[6] This observation generalizes the well-known result that in the absence of conflict, a principal who wants to delegate several tasks may prefer to assign them to a single agent, because this gives her the possibility to save rents. Specifically, if there are two agents each in charge of one task, then even when there is only one success, the

[6]Note that it is never optimal to hire only one agent and implement only one effort, since this yields the same expected profit as hiring two agents and implementing only one effort, which cannot be optimal according to Proposition 3.2.

principal has to leave a rent to the successful agent. In contrast, if there is only one agent in charge of both tasks, the principal has to leave a rent to the agent only if he was successful in both tasks.

Now consider the case where the conflict is strong ($\gamma > \hat{\gamma}$). In this case, inducing two efforts is less expensive for the principal when she hires two agents. Intuitively, consider the limiting case where γ approaches α, so that if only one product is promoted, the probability of sale of the other product approaches zero. This means that in the two-agent case, an agent will almost never sell his product if he shirks, provided that the other agent exerts effort. Hence, the agents' rents tend to zero. In contrast, in the one-agent case, when the agent exerts no effort at all, both products will still be sold with probability α^2. This implies that the principal has to deter the agent from doing so by leaving him a non-negligible rent.

3.3 DESIGN

Our experiment consists of four different treatments. Each treatment was run in four sessions. Each session had 30 participants, except for one session with 28 subjects and one session with 26 subjects (due to no-shows). No subject was allowed to participate in more than one session. In total, 474 subjects participated in the experiment. All subjects were students of the University of Cologne from a wide variety of fields of study. The computerized experiment was programmed and conducted with z-Tree (Fischbacher, 2007) and subjects were recruited using ORSEE (Greiner, 2004). A session lasted between 30 and 40 minutes. Subjects were paid on average 11.03€.[7]

In order to give subjects a monetary incentive to take their decisions seriously and to ensure a large number of independent observations, each session consisted of only one round; i.e., there were no repetitions and this was known to the subjects. In each session there were subjects in the role of principals (merchants) and other subjects in the role of agents (sales representatives). Each principal could sell one single unit of a product 1 and one single unit of a product 2 via

[7] The average payment includes the show-up fee which was 4€.

a single agent in the one-agent treatments and via two agents in the two-agent treatments. If a product was sold, the principal obtained a revenue of $R = 15€$. All interactions were anonymous; i.e., the participants did not know the identity of the subject(s) they were playing with. At the beginning of each session, written instructions were handed out to the subjects. Then they were given 20 minutes to read the instructions and afterwards all participants had to answer some questions to check that they had understood the instructions.

One-agent treatments. In each session, half of the participants are randomly assigned to the role of principals and the others to the role of agents. Each principal is randomly matched with one agent. There are two stages. In the first stage, each principal offers her agent a wage scheme that can be contingent on which products the agent has sold. In particular, the principal sets w_{11}, w_{10} and w_{01}. For w_{11} the principal could choose any number between 0 and 30, while for w_{10} and w_{01}, any numbers between 0 and 15 could be chosen.[8] Since the principal obtains no revenue in the case that no product is sold, the wage w_{00} is set to zero. In the second stage each agent learns the wage scheme his principal has set. Then the agent can exert promotion effort for each of the two products. In particular, the agent can decide whether to promote no product, only one product, or both products. If the agent promotes a product, he has to incur promotion costs $\psi = 2€$. The principal cannot observe the effort decision of her agent. The effect of promotion effort is as follows. If no product is promoted, then each product is sold with a probability of $\alpha = 0.4$. If only one product is promoted, the probability of sale of this product increases by $\rho = 0.5$, while the probability of sale of the other product decreases by γ. If both products are promoted, then each product is sold with probability $\alpha + \rho - \gamma = 0.9 - \gamma$. There is one treatment with $\gamma = 0.3$, which implies that there is conflict between the two promotion tasks. In another treatment we have $\gamma = 0$, such that there is no conflict between the two tasks. Once the agent has taken the effort decisions with regard to both

[8]All wages could be specified with up to one decimal place. In the experiment, to avoid unlimited losses, the feasible wage offers had to be bounded from above. The stated upper bounds are the ones that arise naturally if also the principal is subject to limited liability. It is easy to show that given the parameter constellations in the experiment, the principal's limited liability constraint will never affect the equilibrium payoffs obtained in Section 3.2.

tasks, the probabilities of sale of the two products are fixed. According to these probabilities the computer decides randomly, whether no, exactly one, or both products are sold. Depending on the wage scheme and on which products are sold, the principal's profit is $15€(q_1 + q_2) - w_{q_1q_2}$. The agent's profit is given by $w_{q_1q_2} - 2€(a_1 + a_2)$ and it depends on the wage scheme, on the number of products sold and on the effort decisions regarding both tasks.

Two-agent treatments. In each session, one third of the participants are randomly assigned to the role of principals, another third of the participants are randomly assigned to the role of agents A, and the others are assigned to the role of agents B. Each principal is randomly matched with one agent A and one agent B. The principal pays both agents according to a wage scheme that can be contingent on which products have been sold.

There are two stages. In the first stage, each principal offers her agents A and B a wage scheme that can be contingent on which products are sold. In particular, each principal sets non-negative wages w^A_{11}, w^A_{10}, and w^A_{01} for agent A and w^B_{11}, w^B_{10}, and w^B_{01} for agent B. For the same reasons as explained above, the wages w^A_{00} and w^B_{00} are set to zero, while $w^A_{11} + w^B_{11}$ (resp., $w^A_{10} + w^B_{10}$ and $w^A_{01} + w^B_{01}$) had to be weakly smaller than 30 (resp., 15). In the second stage, each agent learns the wage scheme which the principal has designed. In particular, each agent does not only learn his wage scheme, but he also learns the other agent's wage scheme. Then agent A can decide whether or not to promote product 1 and agent B can decide whether or not to promote product 2. Each agent has to incur promotion costs $\psi = 2€$ if he decides to promote his product. The effect of promotion effort is exactly as in the one-agent treatments. There are again two treatments, one with conflict (where $\gamma = 0.3$) and another one without conflict ($\gamma = 0$). When both agents have taken their effort decision, the probabilities of sale of the two products are fixed. According to these probabilities the computer decides randomly, whether no, exactly one, or both products are sold. Depending on the wage scheme and on how many products have been sold, the principal's profit is $15€(q_1 + q_2) - w^A_{q_1q_2} - w^B_{q_1q_2}$. The agents' profits $w^A_{q_1q_2} - 2€a_1$ and $w^B_{q_1q_2} - 2€a_2$ depend on the wage scheme, on the number of products that have been sold, and on their respective effort decision.

3.4 QUALITATIVE HYPOTHESES

One agent - Conflict ($\gamma = 0.3$). According to Proposition 3.1 and Lemma 3.2, under standard theory assumptions, the agent would be induced to exert only one effort. He would get a wage of 3.51€ if only the product he is supposed to promote is sold, and zero otherwise. As a result, the expected wage payment would be 2.84€ and the principal's expected profit would be $\Pi_{hl} \approx 12.16$€. With regard to their structures, we did not expect the wage schemes observed in the experiment to be very close to the theoretical prediction. Taking into consideration the results from many previous experiments,[9] we anticipated that in the laboratory, principals will leave the agents more of the surplus than what in theory would be necessary to induce effort. Specifically, we expected that in our experiment, the principals would set the wages such that an agent obtains a substantial fraction of the revenue if at least one product is sold.[10] This implies that an agent who has exerted effort would not make a loss if at least one product is sold. Yet, we thought that even these more generous wage offers would not induce the majority of agents to exert two efforts. The reason is that agents may be very reluctant to exert two costly efforts because of the adverse effect that effort in one task has on the success probability of the other task. Hence, we hypothesized that indeed many agents would exert only one effort and that there would also be a non-negligible fraction of agents exerting no effort at all.

One agent - No conflict ($\gamma = 0$). As we can see from Proposition 3.1 and Lemma 3.1, according to theory the agent would be induced to exert two efforts. The theoretically predicted wage scheme is such that he would get a wage of 6.15€ if both products are sold and nothing otherwise, leading to an expected wage payment of 4.98€ and to an expected profit of $\Pi_{hh} \approx 22.02$€ for the principal. For similar reasons as explained above, we expected the wage offers in the experiment to be larger than in theory. In the absence of conflict, exerting effort in one task has no adverse effect on the agent's prospects to be successful

[9]For recent surveys on fairness and other-regarding preferences in experiments, see e.g. Camerer (2003) and Fehr and Schmidt (2006).

[10]See also Keser and Willinger (2007) who investigate how principals set wages when confronted with a moral hazard problem.

in the other task. This means, provided that an offer is generous, the probability to sell both products and thus to obtain a relevant share of the revenue of 30€ becomes very likely if the agent exerts two efforts. Hence, in this treatment we actually hypothesized the wage offers to be very effective in inducing two efforts.

Two agents - Conflict ($\gamma = 0.3$). According to Proposition 3.2 and Lemma 3.3, the theoretical prediction is that both agents would be induced to exert effort. Moreover, an agent would get a wage of 8.70€ whenever only his product is sold and zero otherwise, such that the expected wage payment is 4.17€ and the principal's expected profit is $\Pi_{hh}^{AB} \approx 13.83$€. While we thought again that the wages in the laboratory would be larger, we hypothesized that in line with theory, the vast majority of agents would indeed exert effort. The reason is that in this treatment, the agents might be very inclined to exert effort, since it increases the probability of sale of their own product, while the adverse side effect has an impact only on the probability of sale of the other agent's product. Moreover, if an agent believes that the other agent will exert effort, then his own probability of success would be very low if he shirked.

Two agents - No conflict ($\gamma = 0$). As we can see from Proposition 3.2 and Lemma 3.3, according to theory, both agents will exert effort. Any wage scheme with $w_{00}^k = w_{01}^A = w_{10}^B = 0$€ such that $0.1w_{10}^A + 0.9w_{11}^A = 4$€ and $0.1w_{01}^B + 0.9w_{11}^B = 4$€ would be optimal, yielding an expected wage payment of 7.20€. The principal's expected profit would be $\Pi_{hh}^{AB} \approx 19.80$€. We expected again that in the experiment the offered wages would be larger and that most agents would indeed exert effort. If an offer is generous, the agent's prospect to get a relevant fraction of the revenue increases considerably if he exerts effort.

The preceding discussion leads us to the following qualitative hypotheses.

Hypothesis 1. In the one-agent treatment with conflict, the relative frequency of two efforts will be much lower than in the other three treatments.

Hypothesis 2. (i) In the absence of conflict, the principals' average profit will be larger in the one-agent treatment than in the two-agent treatment. (ii) If there is conflict, the principals' average profit will be larger in the two-agent treatment than in the one-agent treatment.

	Percentage of two efforts		p-value
One agent - Conflict vs. Two agents - Conflict	36.7%	75%	0.000
One agent - Conflict vs. One agent - No conflict	36.7%	87.7%	0.000
One agent - Conflict vs. Two agents - No conflict	36.7%	70%	0.002
One agent - No conflict vs. Two agents - Conflict	87.7%	75%	0.174
Two agents - Conflict vs. Two agents - No conflict	75%	70%	0.803
One agent - No conflict vs. Two agents - No conflict	87.7%	70%	0.039

Table 3.1: Significance levels for pairwise comparisons of the shares of two efforts between the treatments. The table reports p-values according to two-sided Fisher exact tests.

3.5 DATA ANALYSIS

3.5.1 EXPERIMENTAL RESULTS

Figure 3.1 shows the frequencies of zero, one, and two efforts per treatment.[11] The figure concisely illustrates the central finding of our experiment. It is striking that in the one-agent treatment with conflict, two efforts were chosen considerably less often than in the other three treatments. Note that in the other three treatments, two efforts were chosen in the vast majority of the cases, while zero efforts were hardly ever observed. In contrast, in the one-agent case with conflict, two efforts were chosen less often than one effort, and zero efforts were observed in quite a relevant number of cases.

As can be seen in Table 3.1, it is highly significant that in the one-agent treatment with conflict, two efforts were chosen less often than in the other treatments, which provides strong support for Hypothesis 1.

The principals' average profits in the four treatments are shown in Figure 3.2. Observe that in the absence of conflict, the principals' average profit was notably larger if they had only one agent instead of two. The difference is highly signifi-

[11] In the one-agent treatments, the average numbers of efforts are 1.13 (conflict) and 1.81 (no conflict). In the two-agent treatments, the average numbers of efforts are 1.73 (conflict) and 1.65 (no conflict).

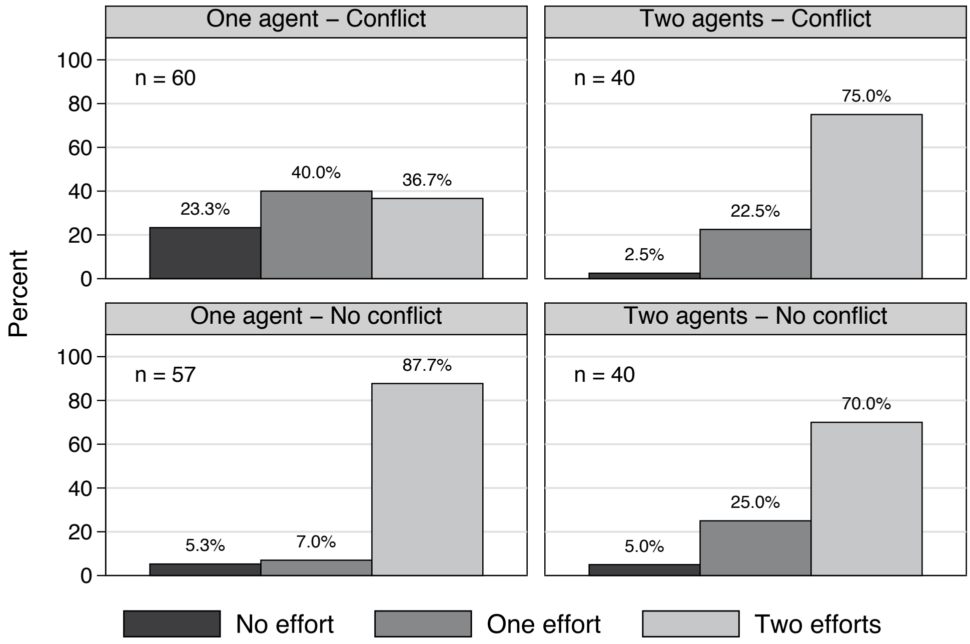


Figure 3.1: Effort levels per treatment (n denotes the number of principal-agent(s) groups per treatment). In the two-agent treatments, 86.3% (resp., 82.5%) of the agents exerted effort if there was conflict (resp., no conflict).

cant (see Table 3.2). In line with Hypothesis 2(i), this finding provides empirical support for the well-known result that if there is no conflict, then delegation of several tasks to a single agent is profitable, since it gives the principal the possibility to save agency costs. Next observe that, contrary to the theoretical prediction, in the treatments with conflict the principals' average profit was slightly larger if only one agent instead of two was assigned to them. The difference is not statistically significant, though. Note also that the theoretically predicted difference between the expected profits is very small, which made it quite difficult to find support for Hypothesis 2(ii).

Finally, the average wage payments that were made to the agents in the four treatments are displayed in Table 3.3. As anticipated, the average payments were larger than the expected wage payments according to standard theory. Yet, the relative order of the magnitudes is exactly as predicted by theory. In particular,

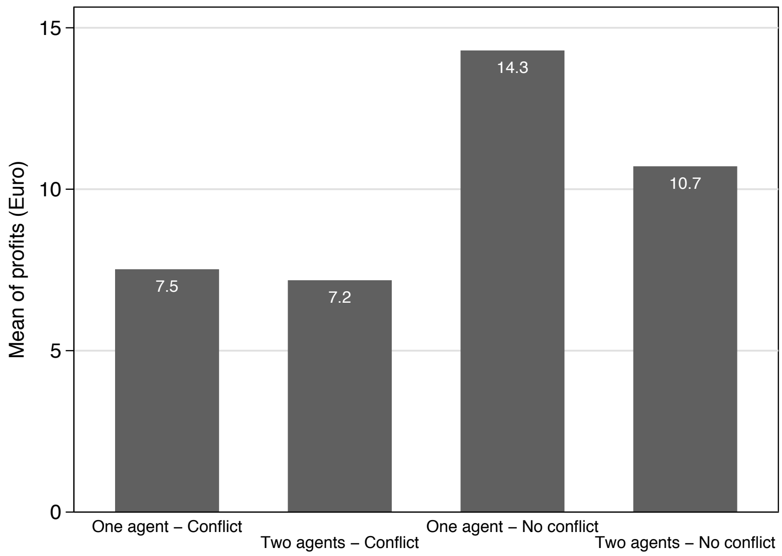


Figure 3.2: The principals' average profits. Recall that the theoretically predicted expected profits are 12.16€, 13.83€, 22.02€, and 19.80€, respectively.

	Principals' average profit (in €)		p-value	n_1	n_2	U
One agent - Conflict vs. Two agents - Conflict	7.50	7.20	0.713	60	40	1147.5
One agent - Conflict vs. One agent - No conflict	7.50	14.30	0.000	60	57	503
One agent - Conflict vs. Two agents - No conflict	7.50	10.70	0.006	60	40	813
One agent - No conflict vs. Two agents - Conflict	14.30	7.20	0.000	57	40	270
Two agents - Conflict vs. Two agents - No conflict	7.20	10.70	0.007	40	40	518.5
One agent - No conflict vs. Two agents - No conflict	14.30	10.70	0.000	57	40	629.5

Table 3.2: Significance levels for pairwise comparisons of the principals' profits between the treatments. The table reports p-values according to two-sided Mann-Whitney-U tests.

the average wage payment in the one-agent treatment with conflict is the smallest one, which is in line with the fact that the average number of efforts and thus also the average number of products a principal sold were smallest in this treatment.

	One agent - Conflict	Two agents - Conflict	One agent - No conflict	Two agents - No conflict
Average wage payment	7.20	8.60	11.80	12.90
Theoretical prediction	2.84	4.17	4.98	7.20

Table 3.3: Average wage payments in Euro.

3.5.2 INDIVIDUAL WAGE OFFERS AND RESULTING EFFORTS

One-agent treatments. First of all, it is noteworthy that nearly all wage offers are symmetric.[12] Let us now have a closer look at the symmetric wage offers which for both treatments are illustrated in Figure 3.3. For each offer, the figure also shows the resulting effort choices and the optimal effort choice according to standard theory. The three principles of contract design identified by Keser and Willinger (2000, 2007) are very useful to give an excellent description of the observed wage offers in our experiment. In both treatments, the wage for an agent is always strictly larger when he sells two products than when he sells only one product. This means that principals apply the principle of appropriateness which requires that the payment in case of a high gain is not lower than the payment in case of a low gain. Moreover, most of the principals offer wage schemes that ensure non-negative payoffs to the agent in case that at least one product is sold. For our experiment, this principle of loss avoidance means that principals are reluctant to make wage offers smaller than 4€.[13]

In the treatment with (without) conflict, 85.7% (79.2%) of the wage offers are such that w_{10}, w_{01}, and w_{11} are (weakly) larger than 4€. Finally, nearly all wages offers are such that the profit of the principal equals at least 50% of the net surplus. For our experiment, this requires w_{10} and w_{01} to be smaller than 9.50€

[12] In the treatment with conflict, only 4 out of 60 offers were asymmetric, and in the treatment without conflict, 4 out of 57 offers were asymmetric. Specifically, the wage offers (w_{10}, w_{01}, w_{11}) were $(8.5, 0, 0)$, $(8.5, 6.5, 18.5)$, $(13, 6, 6)$, and $(4, 2, 9)$ in the treatment with conflict, and $(9, 5, 13)$, $(7, 8, 14)$, $(10, 12, 29)$, and $(4, 7.5, 7.5)$ in the treatment without conflict.

[13] Observe that principals were not able to fully insure agents against losses, since w_{00} was set equal to 0€. Note, however, that this design is natural for our experiment, since in case that no product is sold, the principal obtains no revenue which she could share with the agent.

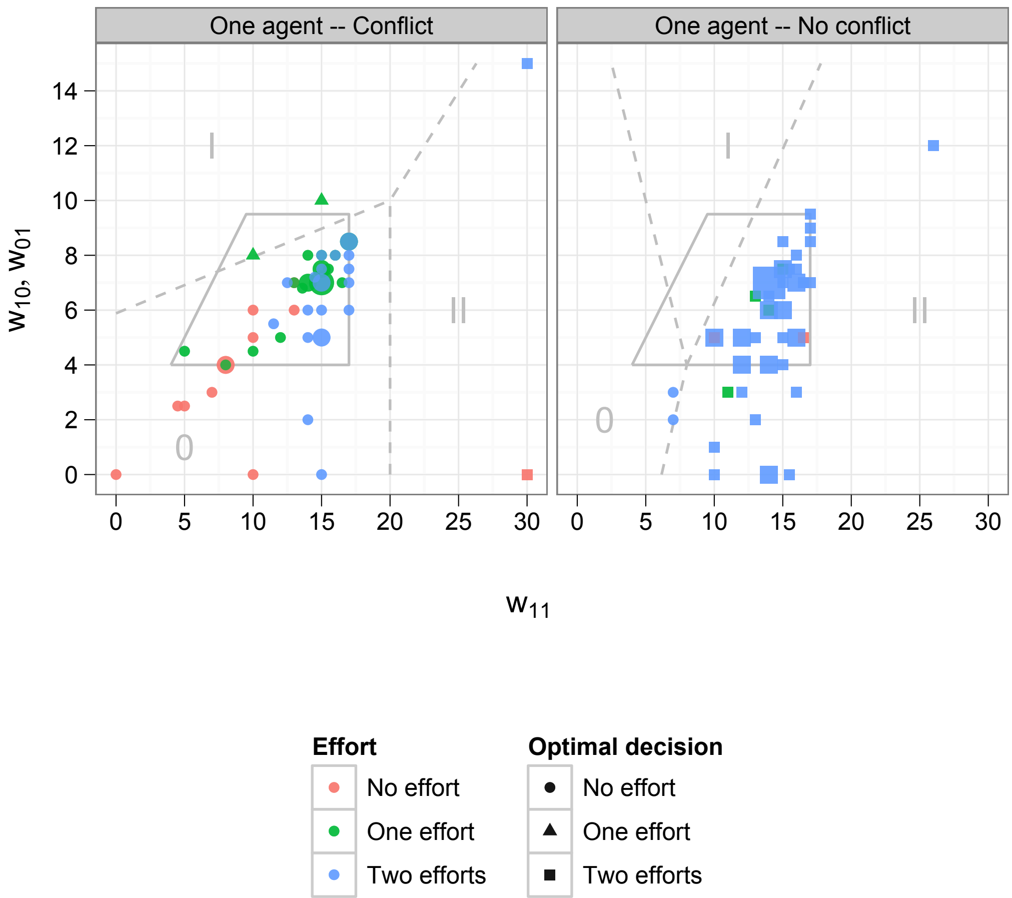


Figure 3.3: Symmetric wage schemes and resulting effort decisions in the one-agent treatments. The actually observed effort decisions are indicated by different colors, while the theoretically optimal effort decisions for given wage offers are indicated by different symbols. The size of the symbols represents the number of observations. The solid line indicates the fair-offers area. The dashed lines divide the panels into three parts where 0, I, or II efforts are optimal given symmetric offers.

and w_{11} to be smaller than 17€.[14] In the treatment with (without) conflict, 94.6% (98.1%) of the wage offers are in line with this principle of sharing power. The figure illustrates that the combination of these three principles characterizes a relatively small subset of all possible wage schemes. It is remarkable that in the treatment with (without) conflict, 82.1% (77.4%) of the symmetric wage schemes satisfy all three principles and thus belong to this small subset of possible wage schemes. In the wording of Keser and Willinger (2000), we will refer to this subset of offers as the "fair-offers area."

Now consider the treatment with conflict. Figure 3.3 makes it obvious that if principals intended to make offers in the fair-offers area, then (according to standard contract-theoretic reasoning) it was hardly possible to induce one effort and it was even impossible to induce two efforts. Indeed, taking into account all offers in the fair-offers area, no effort was the best response in 45 out of 46 cases.[15] However, contrary to standard-theoretic reasoning, only six of these 45 agents exerted no effort at all, while 21 agents exerted one effort and 18 agents exerted even two efforts. Hence, we observe that principals make generous wage offers that theoretically do not generate incentives to exert effort, but the vast majority of agents responds to such offers with one or even two efforts. Given offers in the fair-offers area, agents might actually decide to exert effort because they do not risk making a loss and they regard the offer as generous since in case of success, they receive a relevant share of the net surplus. Agents might thus reciprocate the principals' generous offers by effort levels above the theoretical predictions.[16] It is also interesting to compare offers in the fair-offers area that led to one effort with those that led to two efforts. Strikingly, when two efforts were chosen, the difference between w_{11} and $w_{10} = w_{01}$ is 8.74€, while it is only 6.60€ when one effort was chosen ($p = 0.001$, $U = 94$, $n_1 = 20$, $n_2 = 22$, two-sided Mann-Whitney-U test). It seems that the stronger principals rewarded the sale of two products compared to the sale of one product, the more inclined

[14] In case one product is sold, the net surplus is minimally 11€ such that the principal does not want to leave more than 5.50€ + 4€ to the agent. Similarly, the principal offers not more than $(30€-4€)/2+4€$ when two products are sold.

[15] There was only one offer for which it was the agent's best response to exert one effort. Indeed, in this case the agent exerted one effort.

[16] Although the agents did not face fixed wages, note that the situation is related to the gift exchange settings studied by Akerlof (1982) and Fehr, Kirchsteiger, and Riedl (1993).

were agents to choose two efforts. To sum up, in the fair-offers area, agents rewarded the principals for relatively generous offers by exerting one or even two efforts, while the few low wage offers outside of the fair-offers area were reciprocated with no effort.

Next consider the treatment with one agent and no conflict. Figure 3.3 illustrates that all 41 offers in the fair-offers area (77.4% of all 57 offers) were such that it would have been the agent's best response to exert two efforts. Indeed, 36 out of 41 agents that received an offer belonging to the fair-offers area decided to exert two efforts. This result is robust also when we take into account all 57 offers. It was then optimal to exert two efforts in 54 cases, and 48 agents actually decided to do so. In this treatment, it was relatively easy to make offers that belong to the fair-offers area and at the same time create incentives to exert two efforts. The analysis of our data shows that indeed, in the absence of conflict, the majority of principals made such generous and also incentive-compatible offers. The fact that the vast majority of agents exerted two efforts is not very surprising. As can be seen in Table 3.4 in Appendix B, in the absence of conflict, exerting two efforts led to an appreciable profit with a probability of 81% while the probability of making a loss was only 1%. Hence, the majority of agents seemed to perceive this strategy as promising and almost riskless and preferred it to other strategies.

Two-agent treatments. Again we observe that nearly all wage offers are symmetric.[17] Let us first explain Figure 3.4 which shows the symmetric wage offers. Generally, a wage scheme consists of six single wages but since the figure is restricted to symmetric offers, a wage offer is fully characterized by only three wages $w_{11} := w^A_{11} = w^B_{11}$, $w_1 := w^A_{10} = w^B_{01}$, and $w_0 := w^A_{01} = w^B_{10}$. A pair (w_{11}, w_1) appears in a darker shade while each corresponding pair (w_{11}, w_0) is plotted in a lighter shade; so each single wage scheme is represented by two points in the figure. Furthermore, a single offer is shown as a circle if – according to standard

[17] While in the treatment without conflict all wage offers are symmetric, there are four asymmetric wage offers in the treatment with conflict, namely, the asymmetric offers $(w^A_{10}, w^A_{01}, w^A_{11}, w^B_{01}, w^B_{10}, w^B_{11})$ are $(1, 1.5, 2, 1.5, 1, 2)$, $(5, 4, 10, 6, 4, 10)$, $(4, 2, 7, 4, 0, 7)$, and $(0, 0, 0, 5, 0, 5)$.

theory – both agents had a dominant strategy to exert effort, while it is shown as a triangle if both agents had a dominant strategy not to exert effort.

Cases in which agents had no dominant strategy (indicated by a square) are observed very rarely. The figure illustrates that for exerting effort to be a dominant strategy, the difference between w_1 and w_0 had to be relatively large.[18]

Let us now analyze the symmetric wage offers in the treatment with conflict. The principals made wage offers such that for 52.8% of the agent pairs, it was a dominant strategy to exert effort, while for 36.1%, it was a dominant strategy not to exert effort. The remaining 11.1% of offers were such that there existed no dominant strategy. How did the agents react to these offers? The large majority of agents exerted effort regardless of whether this was a dominant strategy or not. Specifically, 35 out of 38 agents with the dominant strategy to exert effort actually promoted their product.[19] Moreover, when it was the optimal strategy not to provide effort, 23 out of 26 agents still decided to promote their product.[20] How may the agents' behavior be explained? Observe that wage offers for which exerting effort was a dominant strategy were characterized by w_0 being very small or 0€. Hence, an agent facing such an offer may have been very reluctant not to exert effort if he feared that the other agent might exert effort. The reason is that if an agent exerts no effort, the probability of sale of the own product becomes very small (10%, see Table 3.5 in Appendix B) given that the other agent exerts effort. Hence, with a probability of 90%, the shirking agent's gain would be 0€ or very small. In contrast, exerting effort might be considered an attractive strategy since the probability of selling the own product and thereby making a reasonable profit increases regardless of the other agent's decision. Next observe that nearly all wage offers for which not exerting effort was a dominant strategy were characterized by w_0 equal to 2€ or even larger. This observation may help to explain why most of the agents exerted effort even if the dominant strategy

[18]This becomes apparent by the fact that the vertical distance between the dark and light circles (indicating a dominant strategy to exert effort) is relatively large, while the vertical distance between the dark and light triangles (indicating a dominant strategy not to exert effort) is relatively small.

[19]This led to two efforts in 84.2% and to one effort in 15.8% of the principal-agent triads.

[20]This led to two efforts in 76.9% and to one effort in 23.1% of the principal-agent triads. With regard to the eight agents that had no dominant strategy, we observe four agents that promoted their product.

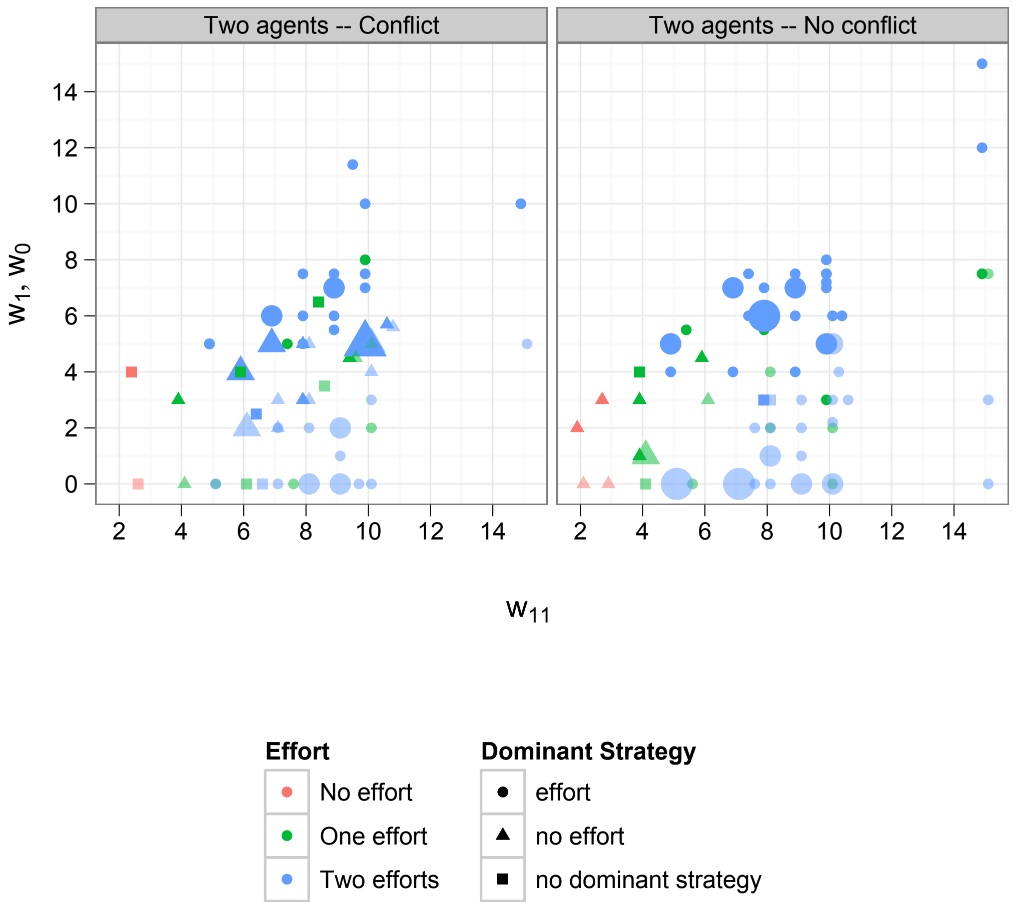


Figure 3.4: Symmetric wage schemes and resulting effort decisions in the two-agent treatments. Symmetric offers are fully characterized by three wages $w_{11} := w^A_{11} = w^B_{11}$, $w_1 := w^A_{10} = w^B_{01}$, and $w_0 := w^A_{01} = w^B_{10}$. A pair (w_{11}, w_1) appears in a darker shade (shifted 0.1 units to the left) while each corresponding pair (w_{11}, w_0) is plotted in a lighter shade (shifted 0.1 units to the right), so each single offer is represented by two points. The actually observed effort decisions are indicated by different colors, while the theoretically optimal effort decisions for given wage offers are indicated by different symbols. The size of the symbols represents the number of observations.

was not to exert effort. By promoting their product, agents could reciprocate these generous wage offers that insured them against making losses and at the same time, they further increased their chance to obtain a reasonable share of the revenue.

Taking a look at the treatment without conflict, wage offers were such that 82.5% of the agent pairs had the dominant strategy to promote their product, 12.5% had the dominant strategy not to promote their product, and the remaining 5% had no dominant strategy. A telling number of 60 agents (out of 66) with a dominant strategy to provide effort actually promoted their product. There were only ten agents with a dominant strategy not to promote their product, and seven of them decided not to exert effort. Also in this treatment, the decision to exert effort seemed to be an attractive strategy, because it promised a reasonable profit, the probability of a loss was very small, and the agents could again reward the principal for making fair wage offers.[21]

3.6 DISCUSSION

In theoretical principal-agent models, inducing a single agent to invest effort in two conflicting tasks is difficult for the principal, because the agent anticipates that exerting effort in one task directly undermines the probability of success regarding the other task. This has led us to formulate Hypothesis 1 according to which in the one-agent treatment with conflict, the relative frequency of two efforts should be much lower than in the other treatments. Indeed, our experimental results provide strong support for this hypothesis: in the one-agent treatment with conflict, only 36.7% of the agents chose two efforts while in all other treatments, two efforts were observed in at least 70% of the cases. This shows that the theoretically predicted incentive problem is of high relevance in the laboratory. Nevertheless, a relevant share of agents decides to exert two efforts even in the presence of conflict. Our analysis in Section 3.5.2 has shown that agents that chose two

[21] As can be seen in Figure 3.4, in this treatment w_0 is more often equal to zero than in the treatment with conflict. This might be due to the fact that in the absence of conflict, an agent's probability of not selling his product was very small when he exerted effort.

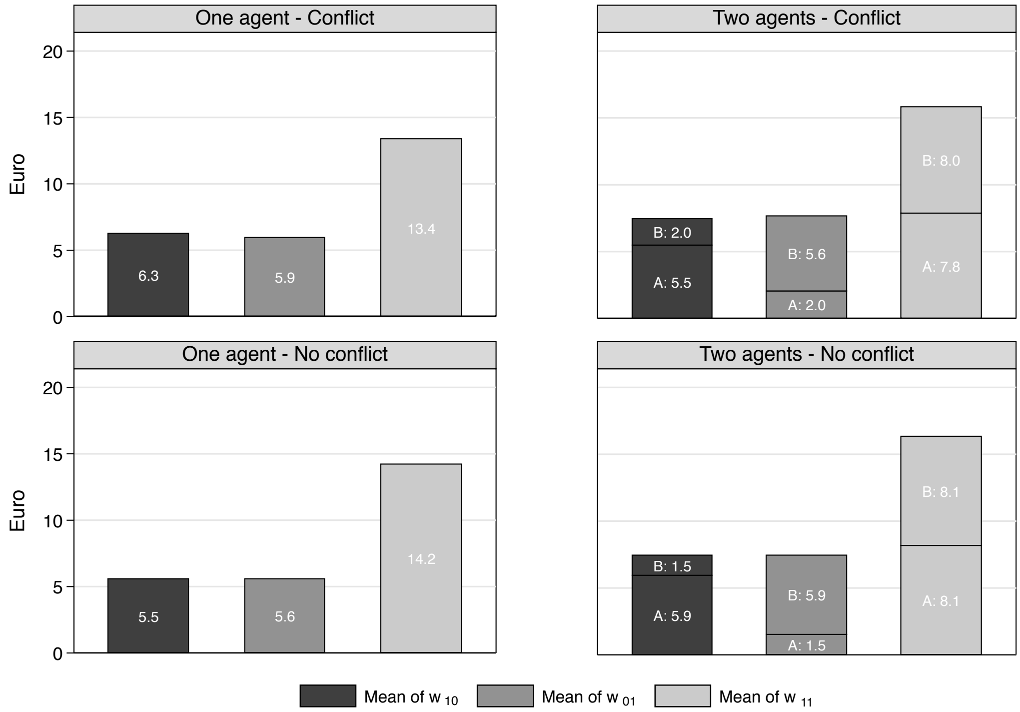


Figure 3.5: Average wage offers. In the two-agent treatments, the mean of w_{10} consists of the sum of the means of w_{10}^A and w_{10}^B, the mean of w_{01} consists of the sum of the means of w_{01}^A and w_{01}^B and the mean of w_{11} consists of the sum of the means of w_{11}^A and w_{11}^B.

efforts were those who were offered very generous wage schemes. While offers that led to two efforts were mostly very generous offers in the fair-offers area, they did not satisfy the incentive constraints for choosing two efforts. This means that in the experiment, agents often reciprocated generous offers by exerting two efforts although their best reply according to the incentive constraints would have been different. To sum up, incentive problems due to conflicting tasks are also prevalent in the lab, but the strength of this problem seems to be weaker when principals try to trigger reciprocity by very fair and generous offers.

The observation that in the lab, the incentive problem seems not to be as strong as in theory can help to explain why we cannot find support for Hypothesis 2(ii). For our parameter constellation, theory predicts that in the presence of conflict, the principal's expected profit is larger when she employs two agents instead of one. The fact that this result is not supported by our data can be attributed to two reasons. Given the parameter constellation of our experiment and conflicting tasks, in theory the principal will never induce two efforts with one agent, while in the experiment, two efforts are observed in 36.7% of the cases. Moreover, as illustrated in Figure 3.5, when two agents are assigned to the principal, in sum she pays the agents more and thus gives up a larger share of the total surplus.[22] In fact, when there are two agents, due to fairness considerations the principal tends to give up considerably more than half of the net surplus while if she has only one agent, she tends to keep at least half of the net surplus for herself. These two facts may explain why in contrast to the theoretical prediction, in the treatments with conflict the principal is better off with one agent than with two agents.

3.7 CONCLUDING REMARKS

While multi-task principal-agent models have attracted considerable attention by contract theorists in recent years, there is scarce experimental evidence on the problems involved. In this chapter we focus on incentive problems that arise when tasks are in direct conflict with each other. In theory, inducing a single agent to invest effort in two conflicting tasks is difficult for the principal, because the agent anticipates that exerting effort in one task directly undermines the probability of success regarding the other task.

Our experimental results provide strong support for the relevance of this incentive problem. Subjects in the experiment were indeed reluctant to invest simultaneously in two different tasks that are in conflict with each other. While efforts in both conflicting tasks were observed significantly more often when the tasks were assigned to two different agents, some principals even succeeded in inducing a single agent to exert efforts in both tasks by making very generous wage offers. In contrast, if the tasks were unrelated, two efforts were observed in the vast majority of cases, regardless of whether a single agent or two different agents were in charge of the tasks.

[22] Note that in the two-agent treatments, for any state of nature (one or two products sold), the sum of the wages offered to the agents is on average larger than the respective wage offered to a single agent. The differences are statistically significant on the 5% level according to one-sided Mann-Whitney-U tests.

It might be a promising avenue for future research to conduct experiments in which principals can choose how many agents they want to employ to perform different tasks that may be in conflict with each other. It would then be interesting to see whether agents perceive a principal's choice to employ two agents when the tasks are conflicting as an unfriendly act. An agent may be demotivated if he knows that the principal intentionally employs another agent whose effort frustrates his own effort. Moreover, it would be interesting to investigate whether our results remain robust when agents face real effort tasks.[23]

[23]Note that Brüggen and Strobel (2007) investigate experimentally real effort and chosen effort where participants choose increasingly costly effort levels. They find that the results support equivalence between real and chosen effort.

3.8 APPENDIX A: PROOFS

Proof of Lemma 3.1. First observe that given that the wages cannot be negative, the agent's participation constraint is redundant as it is implied by (IC 3). It is immediate to verify that given the symmetry of the problem, it is optimal for the principal to set $w_{10} = w_{01} = w_1$. Then it is straightforward to show that w_{00} must be equal to zero. Thus, the reduced problem is to minimize $E\left[w_{q_1 q_2} \mid a_1 = a_2 = 1\right] = (\alpha+\rho-\gamma)^2 w_{11} + 2(\alpha+\rho-\gamma)(1-\alpha-\rho+\gamma)w_1$ subject to the constraints $w_{11} \geq 0, w_1 \geq 0$,

$$\begin{aligned}(\alpha+\rho-\gamma)^2 w_{11} + 2(\alpha+\rho-\gamma)(1-\alpha-\rho+\gamma)w_1 - 2\psi \geq& \\ (\alpha+\rho)(\alpha-\gamma)w_{11} + (\alpha+\rho)(1-\alpha+\gamma)w_1 +& \\ (\alpha-\gamma)(1-\alpha-\rho)w_1 - \psi,&\end{aligned} \tag{IC 1}$$

$$\begin{aligned}(\alpha+\rho-\gamma)^2 w_{11} + 2(\alpha+\rho-\gamma)(1-\alpha-\rho+\gamma)w_1 - 2\psi \geq& \\ \alpha^2 w_{11} + 2\alpha(1-\alpha)w_1.&\end{aligned} \tag{IC 3}$$

Now it is easy to see that $w_1 = 0$ is optimal. To show this, consider a wage scheme $w_{11}, w_1 > 0$. Then the LHS of the two incentive constraints are unchanged if we change this wage scheme such that $\Delta w_1 = -\Delta w_{11} \frac{\alpha+\rho-\gamma}{2(1-\alpha-\rho+\gamma)} < 0$. But now the RHS of both incentive constraints are relaxed which enables the principal to reduce the expected compensation by reducing w_1. She can do so until $w_1 = 0$. Then it turns out that (IC 3) is binding which implies $w_{11} = \frac{2\psi}{(\alpha+\rho-\gamma)^2-\alpha^2}$. □

Proof of Lemma 3.2. In analogy to Lemma 3.1, it turns out that the participation constraint is redundant and that $w_{00} = 0$ is optimal. In what follows, we can ignore (IC 2). Let us verify that $w_{01} = 0$ is optimal. Consider a wage scheme with $w_{11}, w_{10}, w_{01} > 0$. If we change this wage scheme such that $\Delta w_{01} = -\Delta w_{10} \frac{(\alpha+\rho)(1-\alpha+\gamma)}{(1-\alpha-\rho)(\alpha-\gamma)} < 0$, the LHS of the two remaining incentive constraints are unchanged, while both RHS are relaxed. So the principal can increase her expected profit by lowering w_{01} until $w_{01} = 0$. In the same way it is straightforward to show that it is optimal to set $w_{11} = 0$. To see this, consider a wage scheme with $w_{11} > 0, w_{10}$. Then the LHS of the two incentive constraints remain unchanged if we change this wage scheme such that $\Delta w_{11} = -\Delta w_{10} \frac{1-\alpha+\gamma}{\alpha-\gamma} < 0$.

Given this new wage scheme, the RHS of the two incentive constraints are relaxed which implies that the principal can increase her expected profit by lowering w_{11}. She can do so until $w_{11} = 0$. It is then immediate to see that the claimed solution satisfies all the constraints. □

Proof of Lemma 3.3. Observe that given the wages cannot be negative, each agent's participation constraint is redundant as it is implied by the agent's incentive compatibility constraint. It is straightforward to show that $w_{00}^A = w_{00}^B = 0$. Moreover it is immediate to verify that given the symmetry of the problem, we can solve the problem for one agent and the other agent will receive the same incentive scheme; i.e., $w_{11}^A = w_{11}^B$, $w_{10}^A = w_{01}^B$, and $w_{01}^A = w_{10}^B$. Let us w.l.o.g. derive the optimal incentive scheme for agent A. The reduced problem is to minimize $(\alpha+\rho-\gamma)^2 w_{11}^A + (\alpha+\rho-\gamma)(1-\alpha-\rho+\gamma)(w_{10}^A + w_{01}^A)$ subject to $w_{q_1q_2}^A \geq 0$ and

$$\begin{aligned}&(\alpha+\rho-\gamma)^2 w_{11}^A + (\alpha+\rho-\gamma)(1-\alpha-\rho+\gamma)(w_{10}^A + w_{01}^A) - \psi \geq \\ &(\alpha-\gamma)(\alpha+\rho)w_{11}^A + (\alpha-\gamma)(1-\alpha-\rho)w_{10}^A + (\alpha+\rho)(1-\alpha+\gamma)w_{01}^A.\end{aligned} \tag{IC A}$$

It is immediate to verify that in the optimal incentive scheme $w_{01}^A = 0$ must hold. To see this consider a wage scheme $w_{11}^A, w_{10}^A, w_{01}^A > 0$. The LHS of the incentive constraint remains unchanged if we change this wage scheme in the following way: $\Delta w_{01}^A = -\Delta w_{10}^A < 0$. But this relaxes the RHS of the incentive constraint and hence enables us to lower the expected compensation by reducing w_{01}^A until $w_{01}^A = 0$. In the next step we can show that $w_{11}^A = 0$ is optimal. To see this consider a wage scheme $w_{11}^A > 0, w_{10}^A$. The LHS of the incentive constraint remains unchanged if we change this wage scheme such that $\Delta w_{11}^A = -\Delta w_{10}^A \frac{1-\alpha-\rho+\gamma}{\alpha+\rho-\gamma} < 0$. This relaxes the RHS of the incentive constraint and thus makes it possible to lower the expected compensation by reducing w_{11}^A. This can be done until $w_{11}^A = 0$. Then the result follows immediately. □

Proof of Lemma 3.4. In analogy to Lemma 3.3, the participation constraint is redundant and $w_{00}^A = 0$. To verify that $w_{01}^A = 0$ is optimal, consider a wage scheme with $w_{11}^A, w_{10}^A, w_{01}^A > 0$. If we change this wage scheme such that $\Delta w_{01}^A = -\Delta w_{10}^A \frac{(\alpha+\rho)(1-\alpha+\gamma)}{(1-\alpha-\rho)(\alpha-\gamma)} < 0$, the LHS of the incentive constraint remains unchanged, while the RHS of the incentive constraint is relaxed. So the principal can increase her expected profit by lowering w_{01}^A until $w_{01}^A = 0$. Next, let us show that $w_{11}^A =$

0. To see this, consider a wage scheme with $w_{11}^A > 0, w_{10}^A$. The LHS of the incentive constraint remains unchanged if we change this wage scheme such that $\Delta w_{11}^A = -\Delta w_{10}^A \frac{1-\alpha+\gamma}{\alpha-\gamma} < 0$. Given this new wage scheme, the RHS of the incentive constraint is relaxed which means that the principal can increase her expected profit by lowering w_{11}^A. She can do so until $w_{11}^A = 0$. The lemma follows immediately. □

Proof of Proposition 3.2. We have to show that it cannot be optimal for the principal to induce only one effort. To show this, assume the contrary. This means the two conditions $\Pi_{hl}^{AB} > \Pi_{hh}^{AB}$ and $\Pi_{hl}^{AB} > \Pi_{ll}^{AB}$ must be satisfied. The former condition can be rewritten as $R < \frac{2\psi(\alpha+\rho-\gamma)(1-\alpha-\rho+\gamma)}{[(\alpha+\rho-\gamma)(1-\alpha-\rho+\gamma)-(\alpha-\gamma)(1-\alpha-\rho)](\rho-\gamma)} - \frac{\psi(\alpha+\rho)(1-\alpha+\gamma)}{[\alpha\gamma+\rho(1-\alpha+\gamma)](\rho-\gamma)}$ and the latter can be rewritten as $R > \frac{\psi(\alpha+\rho)(1-\alpha+\gamma)}{[\alpha\gamma+\rho(1-\alpha+\gamma)](\rho-\gamma)}$. This implies that the RHS of the former condition must be larger than the RHS of the latter, which is equivalent to $(1-\alpha)^2+\alpha^2+\alpha(\rho-\gamma)+(1-\alpha-\rho)\gamma < (1-\alpha)\rho$. But this inequality cannot hold under our assumptions. Hence, the two conditions $\Pi_{hl}^{AB} > \Pi_{hh}^{AB}$ and $\Pi_{hl}^{AB} > \Pi_{ll}^{AB}$ cannot be satisfied simultaneously. Then the proposition follows immediately. □

Proof of Proposition 3.3. If the principal implements $a_i = 1$ and $a_{j\neq i} = 0$ in the one-agent scenario, then she would prefer to have two agents and to implement $a_1 = a_2 = 1$. To see this, suppose it is optimal for the principal to implement $a_i = 1$ and $a_{j\neq i} = 0$ in the one-agent scenario. Then $\Pi_{hl} > \Pi_{ll}$ holds. But this means that in the two-agent scenario $\Pi_{hl}^{AB} > \Pi_{ll}^{AB}$ must be satisfied, since $\Pi_{hl} = \Pi_{hl}^{AB}$ and $\Pi_{ll} = \Pi_{ll}^{AB}$. But we know from Proposition 3.2 that if $\Pi_{hl}^{AB} > \Pi_{ll}^{AB}$, then $\Pi_{hh}^{AB} > \Pi_{hl}^{AB} = \Pi_{hl}$.

It remains to be shown that there exists a unique $\hat{\gamma} \in (0, \min\{\alpha,\rho\})$ such that $\Pi_{hh}(\hat{\gamma}) = \Pi_{hh}^{AB}(\hat{\gamma})$. Observe that $\Pi_{hh} - \Pi_{hh}^{AB} > 0$ if $\gamma = 0$ and $\Pi_{hh} - \Pi_{hh}^{AB} < 0$ if $\gamma = \min\{\alpha,\rho\}$. Moreover, the condition $\Pi_{hh} - \Pi_{hh}^{AB} > 0$ is equivalent to $f(\cdot) := \gamma(3\alpha\rho+\rho^2+\alpha^2-\rho-2\alpha)+\gamma^2(1-\alpha-\rho)+\rho\alpha-\rho\alpha^2-\rho^2\alpha > 0$. The derivative of $f(\cdot)$ with respect to γ is given by $\frac{df(\cdot)}{d\gamma} = (2\gamma-\alpha-\rho)(1-\alpha-\rho)-(1-\rho)\alpha < 0$. Hence, a simple intermediate value argument implies that there exists a unique $\hat{\gamma} \in (0, \min\{\alpha,\rho\})$ such that $\Pi_{hh}(\hat{\gamma}) = \Pi_{hh}^{AB}(\hat{\gamma})$. The remainder of the proposition follows immediately from Proposition 3.1 and Proposition 3.2. □

3.9 APPENDIX B: PROBABILITIES OF SALE

	No effort	Effort in task 1	Effort in task 2	Efforts in both tasks
No product sold	36%	6%	6%	1%
Only product A sold	24%	54%	4%	9%
Only product B sold	24%	4%	54%	9%
Both products sold	16%	36%	36%	81%

Table 3.4: Probabilities of sale in the no-conflict treatments.

	No effort	Effort in task 1	Effort in task 2	Efforts in both tasks
No product sold	36%	9%	9%	16%
Only product A sold	24%	81%	1%	24%
Only product B sold	24%	1%	81%	24%
Both products sold	16%	9%	9%	36%

Table 3.5: Probabilities of sale in the conflict treatments.

3.10 APPENDIX C: INSTRUCTIONS

Supplementary material

The following instructions and comprehension questions were handed out to the participants in the treatment with one agent and conflict ($\gamma = 0.3$):

Experimental instructions

In this experiment, you can earn money. Your payoff depends on your decisions and on other participants' decisions.

During the whole experiment communication is not allowed. If you have a question, please raise your hand out of the cabin. All decisions are anonymous; i.e., no participant ever learns the identity of a person who has made a particular decision. The payment is conducted anonymously, too; i.e., no participant learns what the payoff of another participant is.

In this experiment, you will either be a merchant or a sales representative with equal probability. Each merchant is matched with exactly one sales representative. As soon as the experiment starts, you will learn whether you have been assigned to the role of a merchant or to the role of a sales representative.

The merchant can sell exactly one unit of a product A and exactly one unit of a product B via his sales representative. Product A and product B are similar. The merchant receives a revenue of 15 Euro for each product sold. He can pay his sales representative a wage depending on the number of products sold.
(Suppose that the costs the merchant had to incur when purchasing the products are not relevant in this experiment. Furthermore, the merchant does not have to bear any stockkeeping costs if product A or product B is not sold.)

The sales representative can promote each product A and B individually. If the sales representative does not promote any product, the probability of sale of each product is 40%. If the sales representative promotes a product, the probability of sale of this product increases by 50 percentage points while the probability of sale of the other product decreases by 30 percentage points. The sales representative can either *promote no product*, or *promote exactly one product*, or *promote both products.* Depending on the number of products promoted, the probabilities of sale read as follows:

- If the sales representative does not promote any product, then each product will be sold with a probability of 40%.
- If the sales representative promotes *only* product A, then product A will be sold with a probability of 40% + 50% = 90%, and product B will be sold with a probability of 40% - 30% = 10%.
- If the sales representative promotes *only* product B, then product B will be sold with a probability of 40% + 50% = 90%, and product A will be sold with a probability of 40% - 30% = 10%.
- If the sales representative promotes both products, then product A and product B will be sold with a probability of 40% + 50% - 30% = 60% each.

As the products are similar, promotion for one product does not only have a positive effect on the probability of sale of the promoted product, but it has also a negative effect on the probability of sale of the other product.

	No promotion for product B	Promotion for product B
No promotion for product A	40%, 40%	10%, 90%
Promotion for product A	90%, 10%	60%, 60%

In each cell, the first number denotes the probability of sale of product A, while the second number denotes the probability of sale of product B.

If the sales representative promotes a product, he has to incur promotion costs of 2 Euro; i.e. promoting both products causes promotion costs *PC* = 2 Euro + 2 Euro = 4 Euro, while promoting one product causes promotion costs *PC* = 2 Euro. If he promotes no product, he has to incur no promotion costs (*PC* = 0).

The merchant cannot observe whether his sales representative decides to promote a product or not. Thus, the merchant cannot condition his wage offer on the sales representative's promotion decision but only on the number of products sold.

In detail, the experiment proceeds as follows:

The experiment consists of only a single period.
This period consists of two stages.

Stage 1 – Merchant decides on wage offers

The merchant offers his sales representative wages depending on the number of products sold. There are four possible cases. For each case, the merchant can specify one wage:

1. Neither product A nor product B are sold → wage w_{00}
2. Only product A but not product B is sold → wage w_{10}
3. Only product B but not product A is sold → wage w_{01}
4. Both products A and B are sold → wage w_{11}

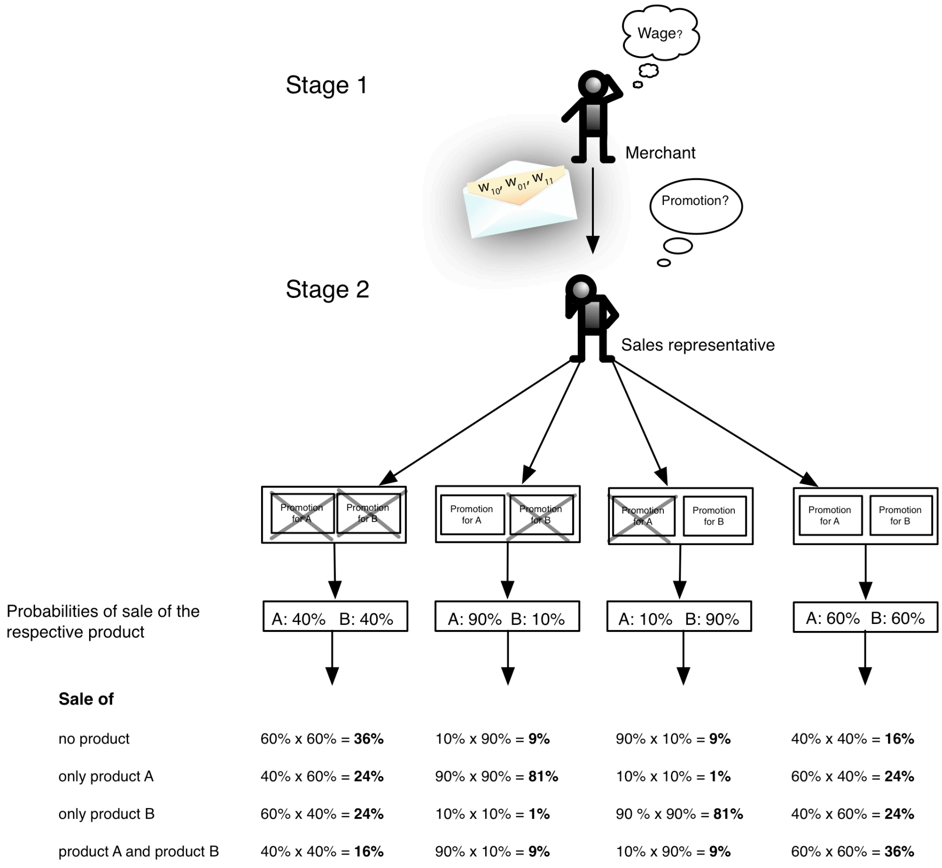
As the merchant obtains no revenue in case 1, the wage w_{00} is fixed at 0 Euro. In the cases 2, 3, and 4, the merchant has to set the wages w_{10}, w_{01}, and w_{11} (see Figure 1 on the last page). (All wages can be specified with up to one decimal place. Please use points instead of commas as decimal separators.)

Stage 2 – Sales representative decides on promotion

The sales representative learns his merchant's wage offers $w_{00} = 0$, w_{10}, w_{01}, and w_{11}. **He can decide whether to promote no product, only product A, only product B, or whether to promote both products A and B** (see Figure 2 on the last page).

Once the sales representative has decided on his promotion effort, the probabilities of sale of the products are determined (as described above). According to these probabilities, the computer decides randomly whether *no*, *exactly one*, or *both products* are sold.

Diagram of the experiment:

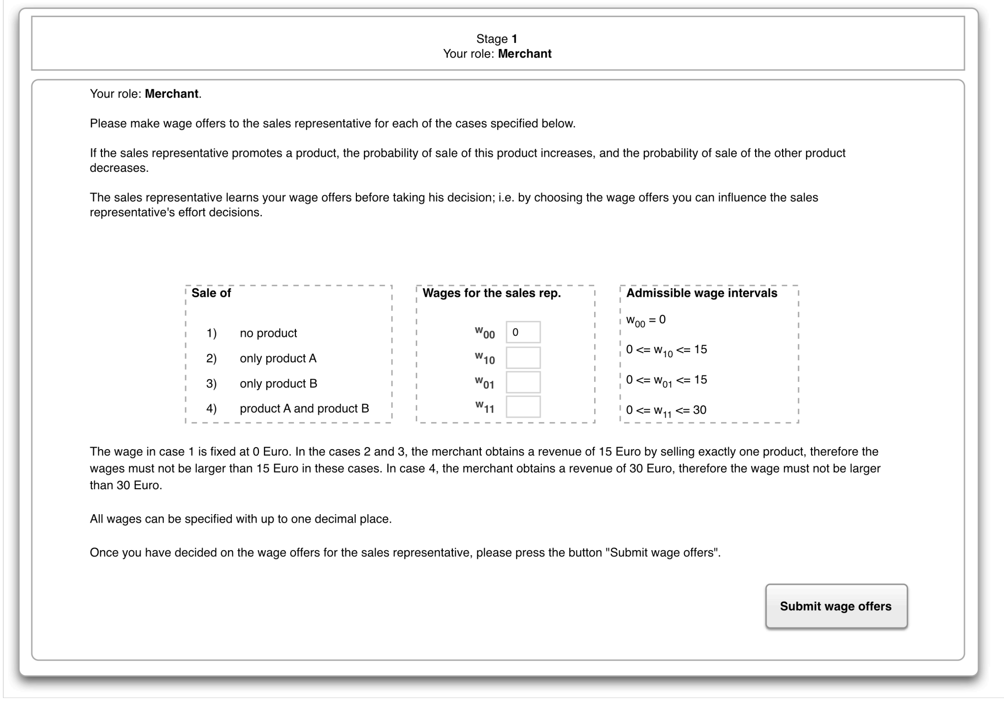


The profits are as follows:

Sale of	**merchant's profit**	**sales rep.'s profit**
no product	$0 - w_{00} = 0$	$w_{00} - PC = 0 - PC$
only product A	$15 - w_{10}$	$w_{10} - PC$
only product B	$15 - w_{01}$	$w_{01} - PC$
product A and product B	$30 - w_{11}$	$w_{11} - PC$

Your payoff:
In addition to the (possibly negative) profit realized in the experiment you get 4 Euro and the resulting amount is paid out to you in cash.

Figure 1: Stage 1 – Merchant decides on wage offers



Stage **1**
Your role: **Merchant**

Your role: **Merchant**.

Please make wage offers to the sales representative for each of the cases specified below.

If the sales representative promotes a product, the probability of sale of this product increases, and the probability of sale of the other product decreases.

The sales representative learns your wage offers before taking his decision; i.e. by choosing the wage offers you can influence the sales representative's effort decisions.

Sale of	Wages for the sales rep.	Admissible wage intervals
1) no product	w_{00} 0	$w_{00} = 0$
2) only product A	w_{10}	$0 <= w_{10} <= 15$
3) only product B	w_{01}	$0 <= w_{01} <= 15$
4) product A and product B	w_{11}	$0 <= w_{11} <= 30$

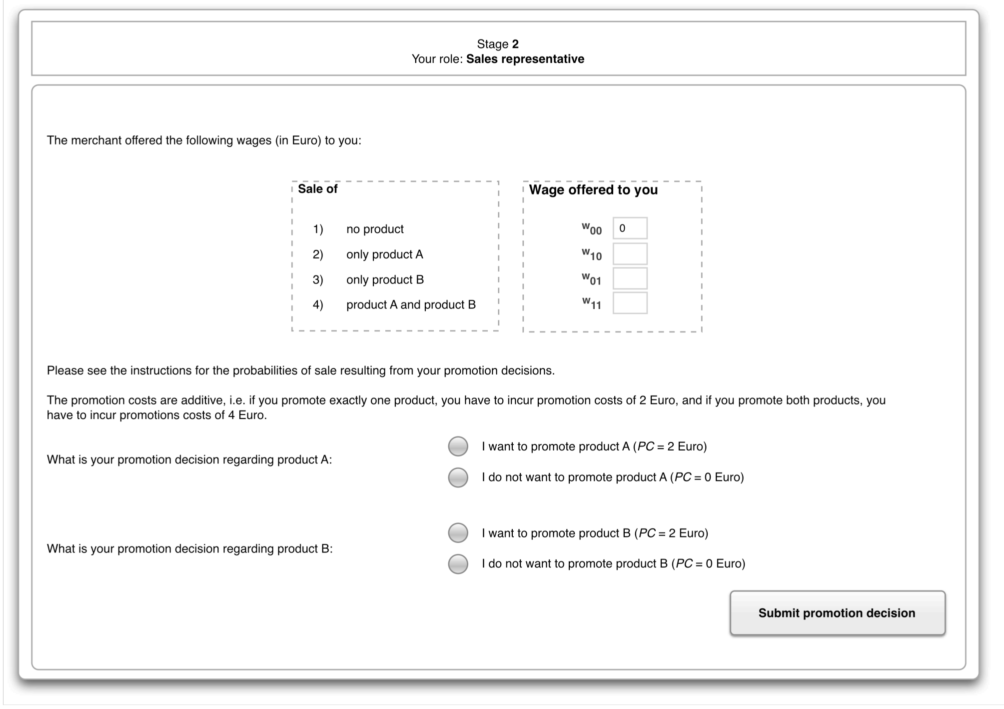
The wage in case 1 is fixed at 0 Euro. In the cases 2 and 3, the merchant obtains a revenue of 15 Euro by selling exactly one product, therefore the wages must not be larger than 15 Euro in these cases. In case 4, the merchant obtains a revenue of 30 Euro, therefore the wage must not be larger than 30 Euro.

All wages can be specified with up to one decimal place.

Once you have decided on the wage offers for the sales representative, please press the button "Submit wage offers".

Submit wage offers

Figure 2: Stage 2 – Sales representative decides on promotion effort



Stage **2**
Your role: **Sales representative**

The merchant offered the following wages (in Euro) to you:

Sale of	Wage offered to you
1) no product	w_{00} 0
2) only product A	w_{10}
3) only product B	w_{01}
4) product A and product B	w_{11}

Please see the instructions for the probabilities of sale resulting from your promotion decisions.

The promotion costs are additive, i.e. if you promote exactly one product, you have to incur promotion costs of 2 Euro, and if you promote both products, you have to incur promotions costs of 4 Euro.

What is your promotion decision regarding product A:
- I want to promote product A (*PC* = 2 Euro)
- I do not want to promote product A (*PC* = 0 Euro)

What is your promotion decision regarding product B:
- I want to promote product B (*PC* = 2 Euro)
- I do not want to promote product B (*PC* = 0 Euro)

Submit promotion decision

Comprehension questions

Question 1:
Which of the following statements is true:

1. Promoting a product increases the probability of sale of this product and decreases the probability of sale of the other product.
2. Promoting a product increases the probability of sale of this product and increases the probability of sale of the other product.
3. Promoting a product decreases the probability of sale of this product and increases the probability of sale of the other product.
4. Promoting a product increases the probability of sale of this product and has no effect on the probability of sale of the other product.

Question 2:
Which of the following statements is true:

1. The merchant offers his sales representative exactly one wage.
2. The merchant can offer his sales representative different wages depending on the number of products sold.
3. The sales representative can demand a wage from the merchant.

Question 3:
Which of the following statements is true:

1. Suppose you are the sales representative. Once you have decided on your promotion effort, you know exactly how many products will be sold.
2. Suppose you are the sales representative. Once you have decided on your promotion effort, the probabilities of sale depend on the magnitude of the wages.
3. Suppose you are the sales representative. Once you have decided on your promotion effort, you know the probabilites of sale of both products.

Question 4:
Which of the following statements is true:

1. The merchant can condition his wages on whether the sales representative has promoted the products.
2. The merchant can offer wages conditional on the number of products sold.
3. The merchant can offer wages conditional on the probabilities of sale of the products.
4. The sales representative sets the wages.

Question 5:
Which of the following statements is true:

1. Wage w_{10} is paid if no product is sold.
2. Wage w_{10} is paid if only product A but not product B is sold.
3. Wage w_{10} is paid if both products are sold.
4. Wage w_{10} is paid if only product B but not product A is sold.

Question 6:
What is the probability that only product B is sold when the sales representative promotes only product A?

Question 7:
What is the probability that wage w_{10} is paid when the sales representative promotes both products?

The following instructions and comprehension questions were handed out to the participants in the treatment with one agent and without conflict ($\gamma = 0$):

Experimental instructions

In this experiment, you can earn money. Your payoff depends on your decisions and on other participants' decisions.

During the whole experiment communication is not allowed. If you have a question, please raise your hand out of the cabin. All decisions are anonymous; i.e., no participant ever learns the identity of a person who has made a particular decision. The payment is conducted anonymously, too; i.e., no participant learns what the payoff of another participant is.

In this experiment, you will either be a merchant or a sales representative with equal probability. Each merchant is matched with exactly one sales representative. As soon as the experiment starts, you will learn whether you have been assigned to the role of a merchant or to the role of a sales representative.

The merchant can sell exactly one unit of a product A and exactly one unit of a product B via his sales representative. The merchant receives a revenue of 15 Euro for each product sold. He can pay his sales representative a wage depending on the number of products sold.
(Suppose that the costs the merchant had to incur when purchasing the products are not relevant in this experiment. Furthermore, the merchant does not have to bear any stockkeeping costs if product A or product B is not sold.)

The sales representative can promote each product A and B individually. If the sales representative does not promote any product, the probability of sale of each product is 40%. If the sales representative promotes a product, the probability of sale of this product increases by 50 percentage points. The sales representative can either *promote no product*, or *promote exactly one product*, or *promote both products.* Depending on the number of products promoted, the probabilities of sale read as follows:

- If the sales representative does not promote any product, then each product will be sold with a probability of 40%.
- If the sales representative promotes *only* product A, then product A will be sold with a probability of 40% + 50% = 90%, while product B still will be sold with a probability of 40%.
- If the sales representative promotes *only* product B, then product B will be sold with a probability of 40% + 50% = 90%, while product A still will be sold with a probability of 40%.
- If the sales representative promotes both products, then product A and product B will be sold with a probability of 40% + 50% = 90% each.

	Probability of sale of the product
No promotion for a product	40%
Promotion for a product	90%

If a sales representative promotes a product, he has to incur promotion costs of 2 Euro, i.e. promoting both products causes promotion costs *PC* = 2 Euro + 2 Euro = 4 Euro, while promoting one product causes promotion costs *PC* = 2 Euro. If he promotes no product, he has to incur no promotion costs (*PC* = 0).

The merchant cannot observe whether his sales representative decides to promote a product or not. Thus, the merchant cannot condition his wage offer on the sales representative's promotion decision but only on the number of products sold.

In detail, the experiment proceeds as follows:

The experiment consists of only a single period.
This period consists of two stages.

Stage 1 – Merchant decides on wage offers

The merchant offers his sales representative wages depending on the number of products sold. There are four possible cases. For each case, the merchant can specify one wage:

1. Neither product A nor product B are sold → wage w_{00}
2. Only product A but not product B is sold → wage w_{10}
3. Only product B but not product A is sold → wage w_{01}
4. Both products A and B are sold → wage w_{11}

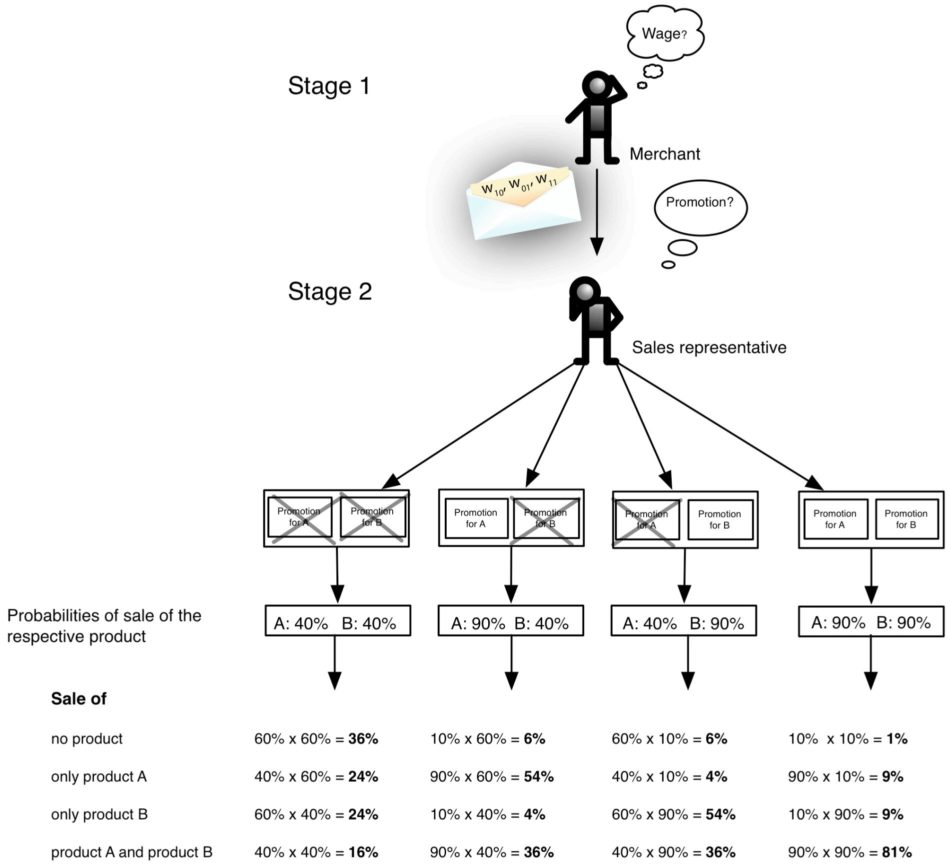
As the merchant obtains no revenue in case 1, the wage w_{00} is fixed at 0 Euro. In the cases 2, 3, and 4, the merchant has to set the wages w_{10}, w_{01}, and w_{11} (see Figure 1 on the last page). (All wages can be specified with up to one decimal place. Please use points instead of commas as decimal separators.)

Stage 2 – Sales representative decides on promotion

The sales representative learns his merchant's wage offers $w_{00} = 0$, w_{10}, w_{01}, and w_{11}. **He can decide whether to promote no product, only product A, only product B, or whether to promote both products A and B** (see Figure 2 on the last page).

Once the sales representative has decided on his promotion effort, the probabilities of sale of the products are determined (as described above). According to these probabilities, the computer decides randomly whether *no*, *exactly one*, or *both products* are sold.

Diagram of the experiment:

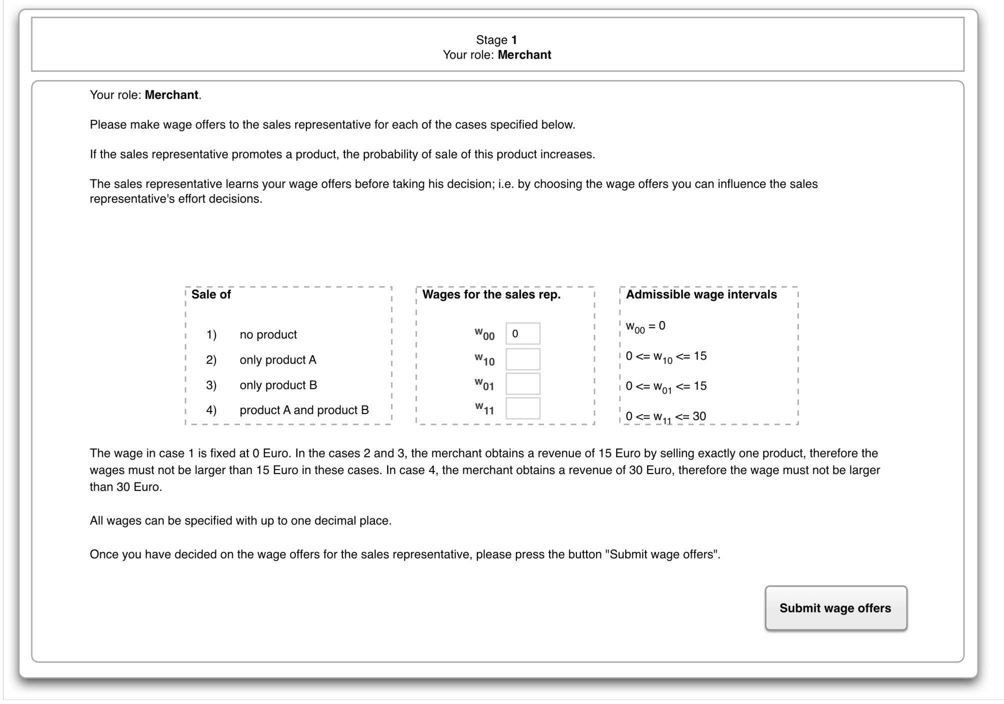


The profits are specified as follows:

Sale of	**merchant's profit**	**sales rep.'s profit**
no product	$0 - w_{00} = 0$	$w_{00} - PC = 0 - PC$
only product A	$15 - w_{10}$	$w_{10} - PC$
only product B	$15 - w_{01}$	$w_{01} - PC$
product A and product B	$30 - w_{11}$	$w_{11} - PC$

Your payoff:
In addition to the (possibly negative) profit realized in the experiment you get 4 Euro and the resulting amount is paid out to you in cash.

Figure 1: Stage 1 – Merchant decides on wage offers



Stage **1**
Your role: **Merchant**

Your role: **Merchant**.

Please make wage offers to the sales representative for each of the cases specified below.

If the sales representative promotes a product, the probability of sale of this product increases.

The sales representative learns your wage offers before taking his decision; i.e. by choosing the wage offers you can influence the sales representative's effort decisions.

Sale of		Wages for the sales rep.		Admissible wage intervals
1)	no product	w_{00}	0	$w_{00} = 0$
2)	only product A	w_{10}		$0 <= w_{10} <= 15$
3)	only product B	w_{01}		$0 <= w_{01} <= 15$
4)	product A and product B	w_{11}		$0 <= w_{11} <= 30$

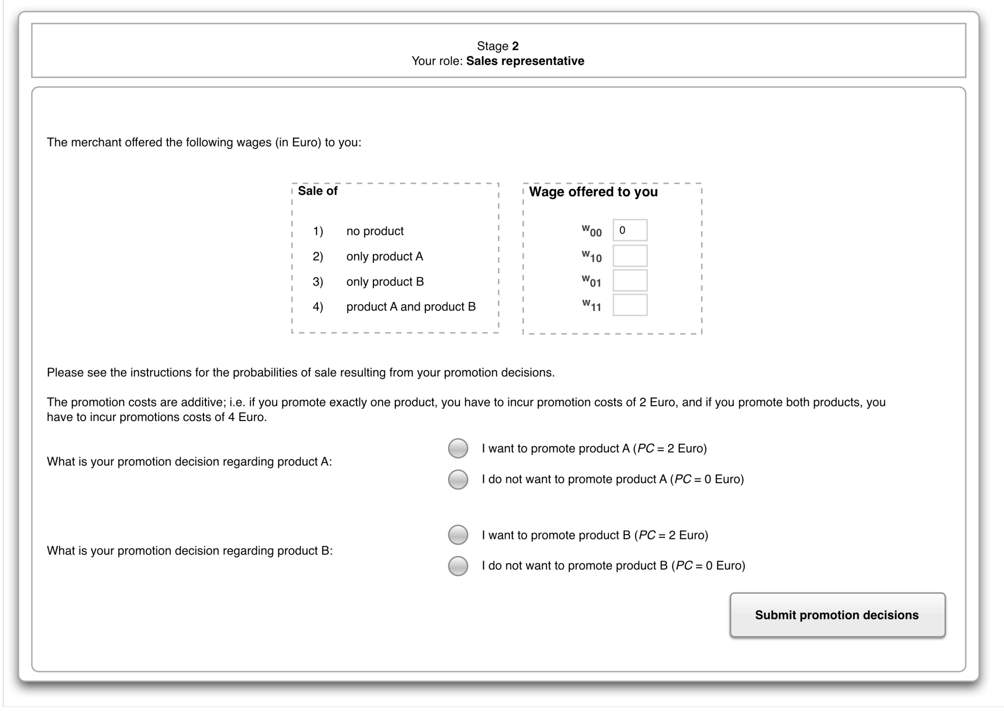
The wage in case 1 is fixed at 0 Euro. In the cases 2 and 3, the merchant obtains a revenue of 15 Euro by selling exactly one product, therefore the wages must not be larger than 15 Euro in these cases. In case 4, the merchant obtains a revenue of 30 Euro, therefore the wage must not be larger than 30 Euro.

All wages can be specified with up to one decimal place.

Once you have decided on the wage offers for the sales representative, please press the button "Submit wage offers".

Submit wage offers

Figure 2: Stage 2 – Sales representative decides on promotion



Stage **2**
Your role: **Sales representative**

The merchant offered the following wages (in Euro) to you:

Sale of		Wage offered to you	
1)	no product	w_{00}	0
2)	only product A	w_{10}	
3)	only product B	w_{01}	
4)	product A and product B	w_{11}	

Please see the instructions for the probabilities of sale resulting from your promotion decisions.

The promotion costs are additive; i.e. if you promote exactly one product, you have to incur promotion costs of 2 Euro, and if you promote both products, you have to incur promotions costs of 4 Euro.

What is your promotion decision regarding product A:
- I want to promote product A (*PC* = 2 Euro)
- I do not want to promote product A (*PC* = 0 Euro)

What is your promotion decision regarding product B:
- I want to promote product B (*PC* = 2 Euro)
- I do not want to promote product B (*PC* = 0 Euro)

Submit promotion decisions

Comprehension questions

Question 1:
Which of the following statements is true:

1. Promoting a product increases the probability of sale of this product.
2. Promoting a product decreases the probability of sale of this product.
3. Promoting a product has no effect on the probability of sale of this product.

Question 2:
Which of the following statements is true:

1. The merchant offers his sales representative exactly one wage.
2. The merchant can offer his sales representative different wages depending on the number of products sold.
3. The sales representative can demand a wage from the merchant.

Question 3:
Which of the following statements is true.

1. Suppose you are the sales representative. Once you have decided on your promotion effort, you know exactly how many products will be sold.
2. Suppose you are the sales representative. Once you have decided on your promotion effort, the probabilities of sale depend on the magnitude of the wages.
3. Suppose you are the sales representative. Once you have decided on your promotion effort, you know the probabilities of sale.

Question 4:
Which of the following statements is true:

1. The merchant can condition his wages on whether the sales representative has promoted the products.
2. The merchant can offer wages conditional on the number of products sold.
3. The merchant can offer wages conditional on the probabilities of sale of the products.
4. The sales representative sets the wages.

Question 5:
Which of the following statements is true:

1. Wage w_{10} is paid if no product is sold.
2. Wage w_{10} is paid if only product A but not product B is sold.
3. Wage w_{10} is paid if both products are sold.
4. Wage w_{10} is paid if only product B but not product A is sold.

Question 6:
What is the probability that only product B is sold when the sales representative promotes only product A?

Question 7:
What is the probability that wage w_{10} is paid when the sales representative promotes both products?

The following instructions and comprehension questions were handed out to the participants in the treatment with two agents and conflict ($\gamma = 0.3$):

Experimental instructions

In this experiment, you can earn money. Your payoff depends on your decisions and on other participants' decisions.

During the whole experiment communication is not allowed. If you have a question, please raise your hand out of the cabin. All decisions are anonymous; i.e., no participant ever learns the identity of a person who has made a particular decision. The payment is conducted anonymously, too; i.e., no participant learns what the payoff of another participant is.

In this experiment, you will either be a merchant with a probability of one-third or a sales representative with a probability of two-thirds. Every merchant is matched with two sales representatives (sales representative A and sales representative B). As soon as the experiment starts, you will learn whether you have been assigned to the role of a merchant or to the role of a sales representative.

The merchant can sell exactly one unit of a product A via sales representative A and exactly one unit of a product B via sales representative B. Product A and product B are similar. The merchant receives a revenue of 15 Euro for each product sold. He can pay his sales representatives wages depending on the number of products sold.
(Suppose that the costs the merchant had to incur when purchasing the products are not relevant in this experiment. Furthermore, the merchant does not have to bear any stockkeeping costs if product A or product B is not sold.)

Each sales representative (sales representative A and sales representative B, respectively) can decide whether he wants to promote his product (product A and product B, respectively). If no sales representative promotes his product, the probability of sale of each product is 40%. If a sales representative promotes his product, the probability of sale of his product increases by 50 percentage points while the probability of sale of the other sales representative's product decreases by 30 percentage points. Each sales representative can decide whether to promote his product or not. The resulting probabilities of sale depend on whether *no sales representative*, *one sales representative*, or *both sales representatives* promote their respective product:

- If no sales representative promotes his product, then each product will be sold with a probability of 40%.
- If sales representative A promotes his product and sales representative B does not promote his product, then product A will be sold with a probability of 40% + 50% = 90%, and product B will be sold with a probability of 40% - 30% = 10%.
- If sales representative B promotes his product and sales representative A does not promote his product, then product B will be sold with a probability of 40% + 50% = 90%, and product A will be sold with a probability of 40% - 30% = 10%.
- If both sales representatives promote their respective product, then product A and product B will be sold with a probability of 40% + 50% - 30% = 60% each.

As the products are similar, promotion effort for one product does not only have a positive effect on the probability of sale of the promoted product, but it has also a negative effect on the probability of sale of the other product.

		Sales representative B: does not promote product B	Sales representative B: promotes product B
Sales representative A	does not promote product A	40%, 40%	10%, 90%
	promotes product A	90%, 10%	60%, 60%

In each cell, the first number denotes the probability of sale of product A, while the second number denotes the probability of sale of product B.

If a sales representative promotes his product, he has to incur promotion costs *PC* = 2 Euro. If a sales representative does not promote his product, he does not have to incur promotion costs (*PC* = 0 Euro).

The merchant cannot observe whether his sales representatives decide to promote their products or not. Thus, the merchant cannot condition his wage offers on the sales representatives' promotion decisions but only on the number of products sold. A sales representative also cannot observe the promotion decision of the other sales representative.

In detail, the experiment proceeds as follows:

The experiment consists of only a single period.
This period consists of two stages.

Stage 1 – Merchant decides on wage offers

The merchant offers his sales representatives wages depending on the number of products sold. There are four possible cases. For each case, the merchant can specify one wage:

1. neither product A nor product B are sold
   → wage w_{00}^{A} for sales representative A and w_{00}^{B} for sales representative B
2. only product A but not product B is sold
   → wage w_{10}^{A} for sales representative A and w_{10}^{B} for sales representative B
3. only product B but not product A is sold
   → wage w_{01}^{A} for sales representative A and w_{01}^{B} for sales representative B
4. both products A and B are sold
   → wage w_{11}^{A} for sales representative A and w_{11}^{B} for sales representative B

As the merchant obtains no revenue in case 1, the wages w_{00}^{A} and w_{00}^{B} are fixed at 0 Euro. In the cases 2, 3, and 4, the merchant has to set the wages w_{10}^{A} and w_{10}^{B}, w_{01}^{A} and w_{01}^{B}, w_{11}^{A} and w_{11}^{B} for his sales representatives A and B (see Figure 1 on the last page).
(All wages can be specified with up to one decimal place. Please use points instead of commas as decimal separators.)

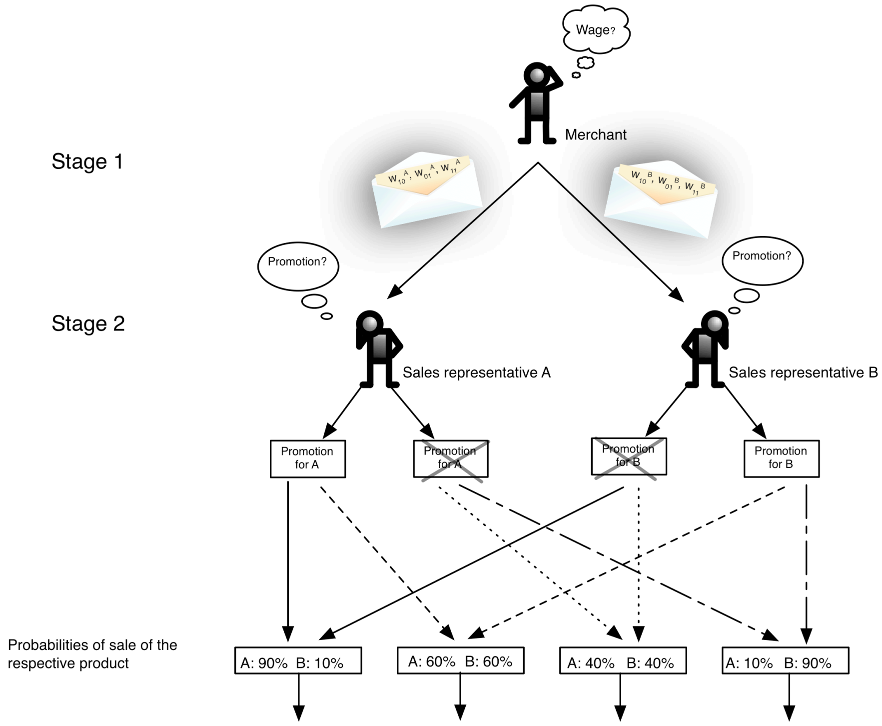
Stage 2 – Sales representatives A and B decide on promotion

The sales representatives A and B learn every wage offer the merchant has made in stage 1. Thus, a sales representative knows the wages he may receive as well as the wages that the merchant may pay to the other sales representative.

Each sales representative then can decide whether to promote his product or not (see Figure 2 on the last page).

Once the sales representatives have decided on their promotion effort, the probabilities of sale of the products are determined (as described above). According to these probabilities, the computer decides randomly whether *no*, *exactly one*, or *both products* are sold.

Diagram of the experiment:



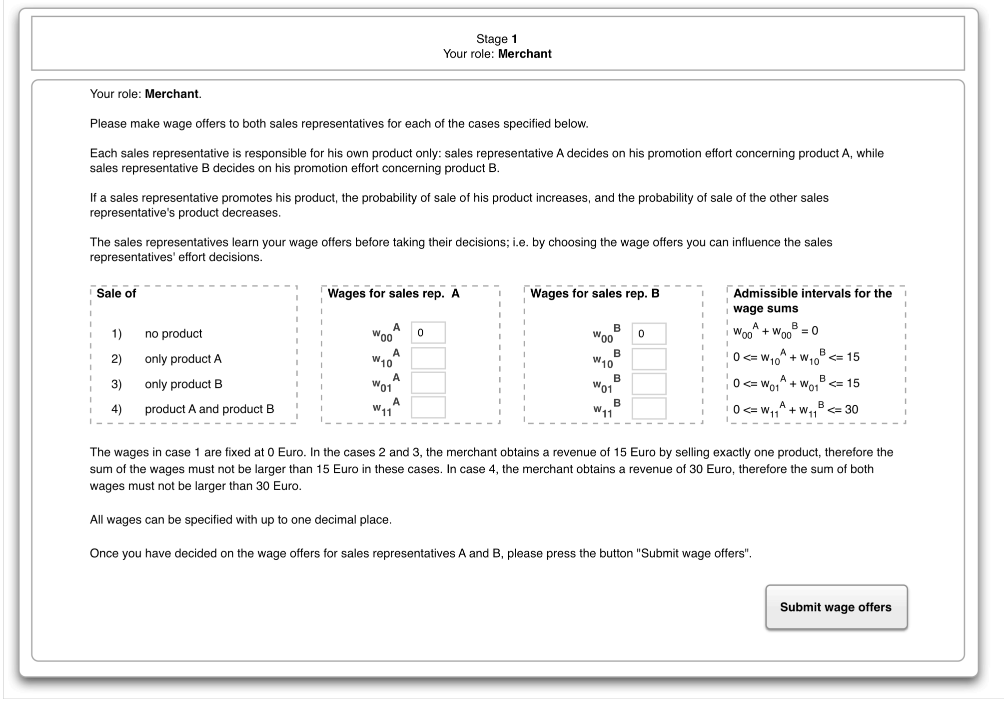
Sale of				
no product	10% x 90% = **9%**	40% x 40% = **16%**	60% x 60% = **36%**	90% x 10% = **9%**
only product A	90% x 90% = **81%**	60% x 40% = **24%**	40% x 60% = **24%**	10% x 10% = **1%**
only product B	10% x 10% = **1%**	40% x 60% = **24%**	60% x 40% = **24%**	90% x 90% = **81%**
product A and product B	90% x 10% = **9%**	60% x 60% = **36%**	40% x 40% = **16%**	10% x 90% = **9%**

The profits are as follows:

Sale of	**merchant's profit**	**sales rep. A's profit**	**sales rep. B's profit**
no product	$0 - w_{00}^A - w_{00}^B = 0$	$w_{00}^A - PC = 0 - PC$	$w_{00}^B - PC = 0 - PC$
only product A	$15 - w_{10}^A - w_{10}^B$	$w_{10}^A - PC$	$w_{10}^B - PC$
only product B	$15 - w_{01}^A - w_{01}^B$	$w_{01}^A - PC$	$w_{01}^B - PC$
product A and product B	$30 - w_{11}^A - w_{11}^B$	$w_{11}^A - PC$	$w_{11}^B - PC$

Your payoff:
In addition to the (possibly negative) profit realized in the experiment you get 4 Euro and the resulting amount is paid out to you in cash.

Figure 1: Stage 1 – Merchant decides on wage offers



Stage **1**
Your role: **Merchant**

Your role: **Merchant**.

Please make wage offers to both sales representatives for each of the cases specified below.

Each sales representative is responsible for his own product only: sales representative A decides on his promotion effort concerning product A, while sales representative B decides on his promotion effort concerning product B.

If a sales representative promotes his product, the probability of sale of his product increases, and the probability of sale of the other sales representative's product decreases.

The sales representatives learn your wage offers before taking their decisions; i.e. by choosing the wage offers you can influence the sales representatives' effort decisions.

Sale of	Wages for sales rep. A	Wages for sales rep. B	Admissible intervals for the wage sums
1) no product	w_{00}^A 0	w_{00}^B 0	$w_{00}^A + w_{00}^B = 0$
2) only product A	w_{10}^A	w_{10}^B	$0 <= w_{10}^A + w_{10}^B <= 15$
3) only product B	w_{01}^A	w_{01}^B	$0 <= w_{01}^A + w_{01}^B <= 15$
4) product A and product B	w_{11}^A	w_{11}^B	$0 <= w_{11}^A + w_{11}^B <= 30$

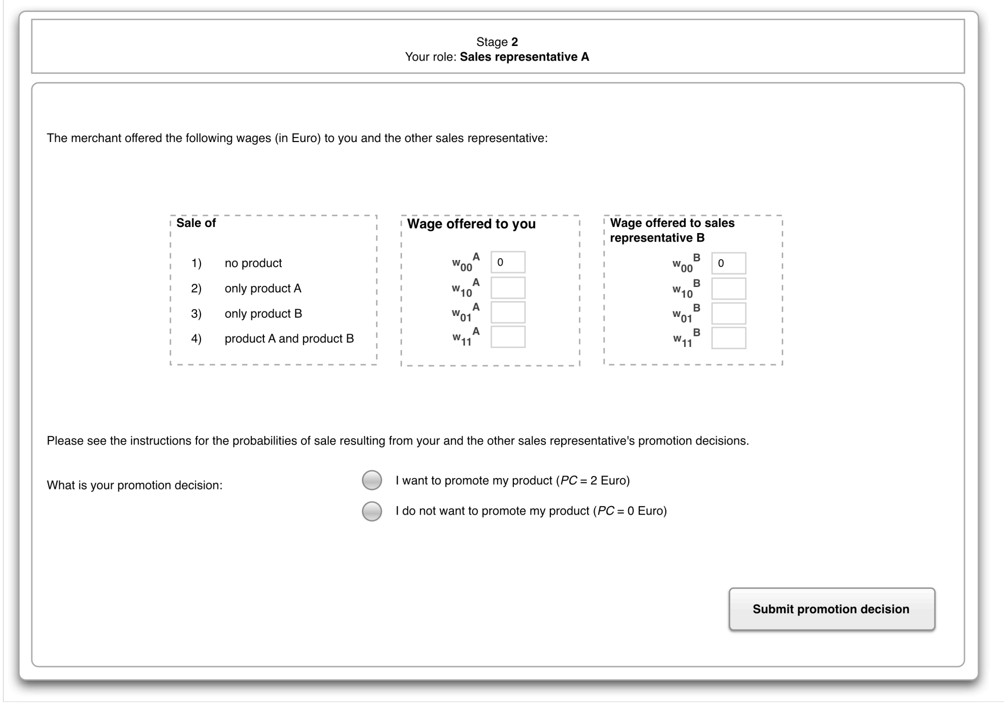
The wages in case 1 are fixed at 0 Euro. In the cases 2 and 3, the merchant obtains a revenue of 15 Euro by selling exactly one product, therefore the sum of the wages must not be larger than 15 Euro in these cases. In case 4, the merchant obtains a revenue of 30 Euro, therefore the sum of both wages must not be larger than 30 Euro.

All wages can be specified with up to one decimal place.

Once you have decided on the wage offers for sales representatives A and B, please press the button "Submit wage offers".

Submit wage offers

Figure 2: Stage 2 – Sales representatives A and B decide on promotion



Stage **2**
Your role: **Sales representative A**

The merchant offered the following wages (in Euro) to you and the other sales representative:

Sale of	Wage offered to you	Wage offered to sales representative B
1) no product	w_{00}^A 0	w_{00}^B 0
2) only product A	w_{10}^A	w_{10}^B
3) only product B	w_{01}^A	w_{01}^B
4) product A and product B	w_{11}^A	w_{11}^B

Please see the instructions for the probabilities of sale resulting from your and the other sales representative's promotion decisions.

What is your promotion decision:
- I want to promote my product (PC = 2 Euro)
- I do not want to promote my product (PC = 0 Euro)

Submit promotion decision

Comprehension questions

Question 1:
Which of the following statements is true:

1. Promoting a product increases the probability of sale of this product and decreases the probability of sale of the other product.
2. Promoting a product increases the probability of sale of this product and increases the probability of sale of the other product.
3. Promoting a product decreases the probability of sale of this product and increases the probability of sale of the other product.
4. Promoting a product increases the probability of sale of this product and has no effect on the probability of sale of the other product.

Question 2:
Which of the following statements is true:
1. The merchant offers his sales representatives exactly one wage.
2. The merchant can offer his sales representatives different wages depending on the number of products sold.
3. The sales representatives can demand a wage from the merchant.

Question 3:
Which of the following statements is true:

1. Suppose you are a sales representative. Once you have decided on your promotion effort, you know exactly how many products will be sold.
2. Suppose you are a sales representative. Once you have decided on your promotion effort, the probabilities of sale depend on the magnitude of the wages.
3. Suppose you are a sales representative. Once you have decided on your promotion effort, the probabilities of sale depend on the promotion effort decision of the other sales representative.

Question 4:
Which of the following statements is true:

1. The merchant can condition his wages on whether the sales representatives have promoted the products.
2. The merchant can offer wages conditional on the number of products sold.
3. The merchant can offer wages conditional on the probabilities of sale of the products.
4. The sales representatives set the wages.

Question 5:
Which of the following statements is true:

1. Wage w_{10}^{A} is paid if no product is sold.
2. Wage w_{10}^{A} is paid to sales representative A if only product A but not product B is sold.
3. Wage w_{10}^{A} is paid to sales representative B if both products are sold.
4. Wage w_{10}^{A} is paid to sales representative B if only product B but not product A is sold.

Question 6:
What is the probability that only product B is sold when sales representative A promotes product A but sales representative B does not promote product B?

Question 7:
What is the probability that wage w_{10}^{A} is paid if both sales representatives promote their respective product?

The following instructions and comprehension questions were handed out to the participants in the treatment with two agents and without conflict ($\gamma = 0$):

Experimental instructions

In this experiment, you can earn money. Your payoff depends on your decisions and on other participants' decisions.

During the whole experiment communication is not allowed. If you have a question, please raise your hand out of the cabin. All decisions are anonymous; i.e., no participant ever learns the identity of a person who has made a particular decision. The payment is conducted anonymously, too; i.e., no participant learns what the payoff of another participant is.

In this experiment, you will either be a merchant with a probability of one-third or a sales representative with a probability of two-thirds. Every merchant is matched with two sales representatives (sales representative A and sales representative B). As soon as the experiment starts, you will learn whether you have been assigned to the role of a merchant or to the role of a sales representative.

The merchant can sell exactly one unit of a product A via sales representative A and exactly one unit of a product B via sales representative B. The merchant receives a revenue of 15 Euro for each product sold. He can pay his sales representatives wages depending on the number of products sold.
(Suppose that the costs the merchant had to incur when purchasing the products are not relevant in this experiment. Furthermore, the merchant does not have to bear any stockkeeping costs if product A or product B is not sold.)

Each sales representative (sales representative A and sales representative B, respectively) can decide whether he wants to promote his product (product A and product B, respectively). If no sales representative promotes his product, the probability of sale of each product is 40%. If a sales representative promotes his product, the probability of sale of his product increases by 50 percentage points. Each sales representative can decide whether to promote his product or not. The resulting probabilities of sale depend on whether *no sales representative*, *one sales representative*, or *both sales representatives* promote their respective product.

- If no sales representative promotes his product, then each product will be sold with a probability of 40%.
- If sales representative A promotes his product and sales representative B does not promote his product, then product A will be sold with a probability of 40% + 50% = 90%, and product B still will be sold with a probability of 40%.
- If sales representative B promotes his product and sales representative A does not promote his product, then product B will be sold with a probability of 40% + 50% = 90%, and product A still will be sold with a probability of 40%.
- If both sales representatives promote their respective product, then product A and product B will be sold with a probability of 40% + 50% = 90% each.

Sales representative A	Probability of sale of product A
does not promote product A	40%
promotes product A	90%

Sales representative B	Probability of sale of product B
does not promote product B	40%
promotes product B	90%

If a sales representative promotes his product, he has to incur promotion costs *PC* = 2 Euro. If a sales representative does not promote his product, he does not have to incur promotion costs (*PC* = 0 Euro).

The merchant cannot observe whether his sales representatives decide to promote their products or not. Thus, the merchant cannot condition his wage offers on the sales representatives' promotion decisions but only on the number of products sold. A sales representative also cannot observe the promotion decision of the other sales representative.

In detail, the experiment proceeds as follows:

The experiment consists of only a single period.
This period consists of two stages.

Stage 1 – Merchant decides on wage offers

The merchant offers his sales representatives wages depending on the number of products sold. There are four possible cases. For each case, the merchant can specify one wage:

1. neither product A nor product B are sold
   → wage w_{00}^{A} for sales representative A and w_{00}^{B} for sales representative B
2. only product A but not product B is sold
   → wage w_{10}^{A} for sales representative A and w_{10}^{B} for sales representative B
3. only product B but not product A is sold
   → wage w_{01}^{A} for sales representative A and w_{01}^{B} for sales representative B
4. both products A and B are sold
   → wage w_{11}^{A} for sales representative A and w_{11}^{B} for sales representative B

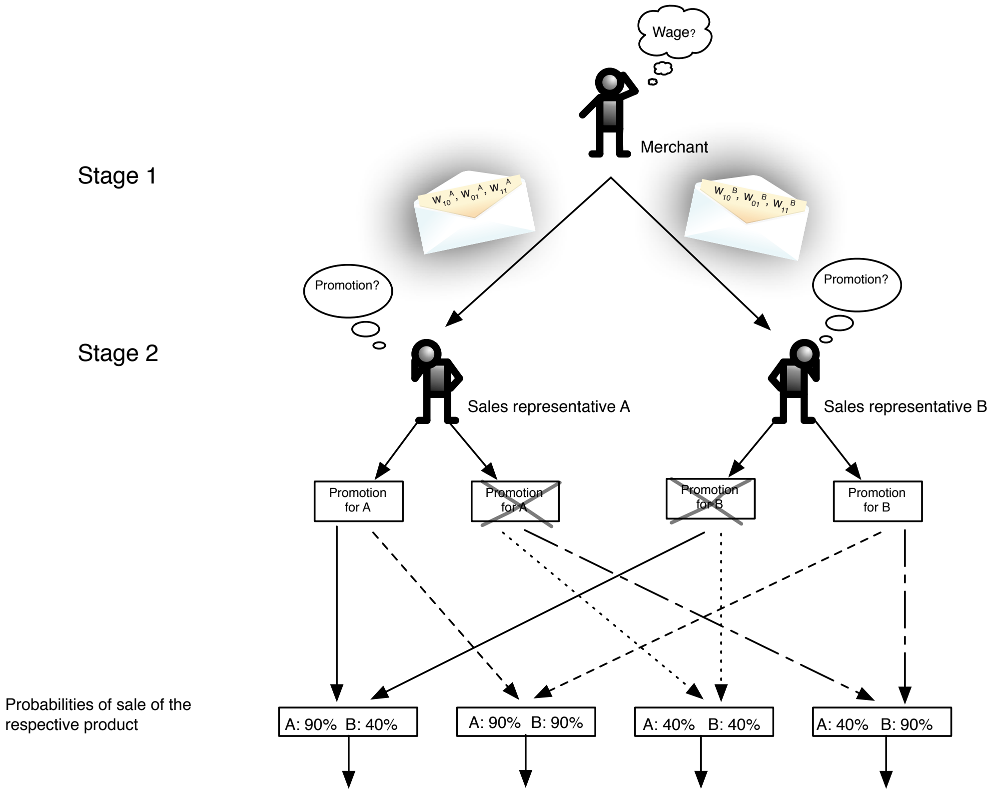
As the merchant obtains no revenue in case 1, the wages w_{00}^{A} and w_{00}^{B} are fixed at 0 Euro. In the cases 2, 3, and 4, the merchant has to set the wages w_{10}^{A} and w_{10}^{B}, w_{01}^{A} and w_{01}^{B}, w_{11}^{A} and w_{11}^{B} for his sales representatives A and B (see Figure 1 on the last page).
(All wages can be specified with up to one decimal place. Please use points instead of commas as decimal separators.)

Stage 2 – Sales representatives A and B decide on promotion

The sales representatives A and B learn every wage offer the merchant has made in stage 1. Thus, a sales representative knows the wages he may receive as well as the wages that the merchant may pay to the other sales representative.
Each sales representative then can decide whether to promote his product or not (see Figure 2 on the last page).

Once the sales representatives have decided on their promotion effort, the probabilities of sale of the products are determined (as described above). According to these probabilities, the computer decides randomly whether *no*, *exactly one*, or *both products* are sold.

Diagram of the experiment:



Sale of				
no product	10% x 60% = **6%**	10% x 10% = **1%**	60% x 60% = **36%**	60% x 10% = **6%**
only product A	90% x 60% = **54%**	90% x 10% = **9%**	40% x 60% = **24%**	40% x 10% = **4%**
only product B	10% x 40% = **4%**	10% x 90% = **9%**	60% x 40% = **24%**	60% x 90% = **54%**
product A and product B	90% x 40% = **36%**	90% x 90% = **81%**	40% x 40% = **16%**	40% x 90% = **36%**

The profits are as follows:

Sale of	**merchant's profit**	**sales rep. A's profit**	**sales rep. B's profit**
no product	$0 - w_{00}^A - w_{00}^B = 0$	$w_{00}^A - PC = 0 - PC$	$w_{00}^B - PC = 0 - PC$
only product A	$15 - w_{10}^A - w_{10}^B$	$w_{10}^A - PC$	$w_{10}^B - PC$
only product B	$15 - w_{01}^A - w_{01}^B$	$w_{01}^A - PC$	$w_{01}^B - PC$
product A and product B	$30 - w_{11}^A - w_{11}^B$	$w_{11}^A - PC$	$w_{11}^B - PC$

Your payoff:
In addition to the (possibly negative) profit realized in the experiment you get 4 Euro and the resulting amount is paid out to you in cash.

Figure 1: Stage 1 – Merchant decides on wage offers

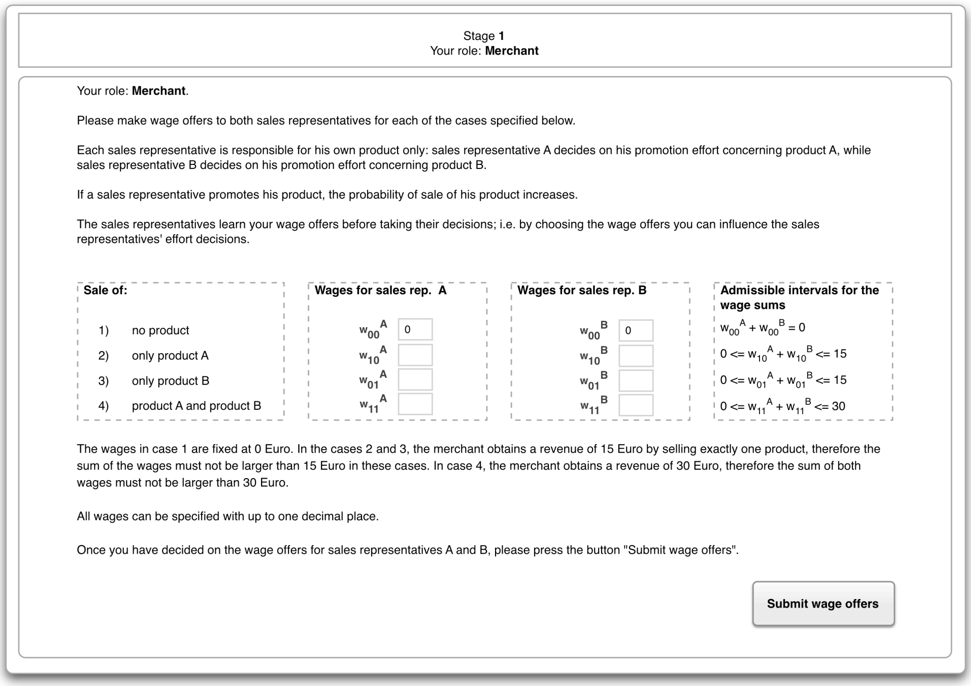
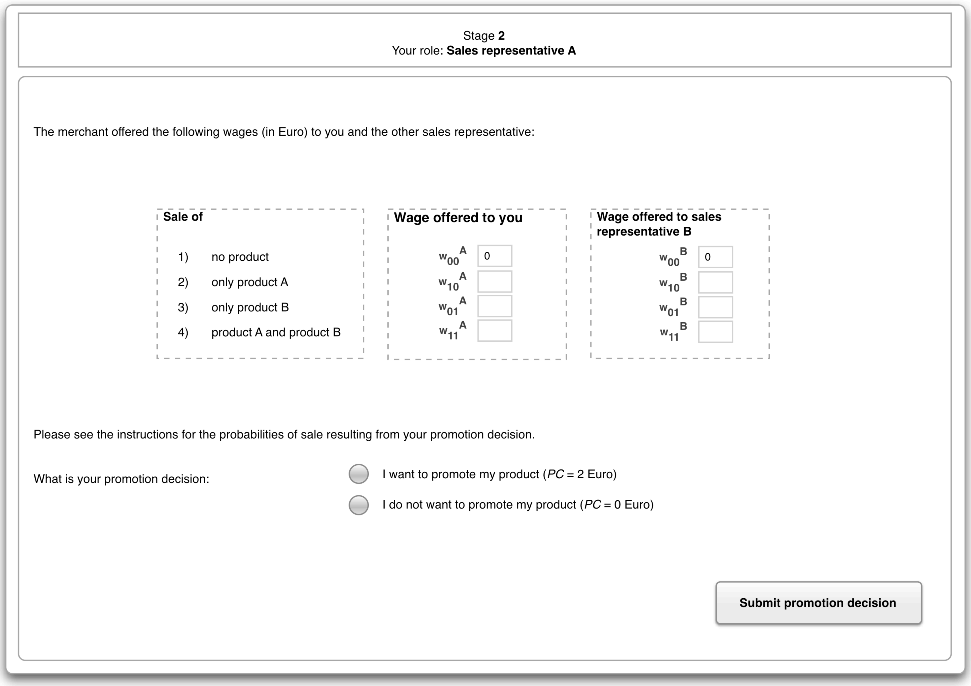


Figure 2: Stage 2 – Sales representatives A and B decide on promotion



Comprehension questions

Question 1:
Which of the following statements is true:
1. Promoting a product increases the probability of sale of this product.
2. Promoting a product decreases the probability of sale of this product.
3. Promoting a product has no effect on the probability of sale of this product.

Question 2:
Which of the following statements is true:

1. The merchant offers his sales representatives exactly one wage.
2. The merchant can offer his sales representatives different wages depending on the number of products sold.
3. The sales representatives can demand a wage from the merchant.

Question 3:
Which of the following statements is true:

1. Suppose you are a sales representative. Once you have decided on your promotion effort, your product will be sold with certainty.
2. Suppose you are a sales representative. Once you have decided on your promotion effort, the probabilities of sale depend on the magnitude of the wages.
3. Suppose you are a sales representative. Once you have decided on your promotion effort, you know the probability of sale of your product.

Question 4:
Which of the following statements is true:

1. The merchant can condition his wages on whether the sales representatives have promoted the products.
2. The merchant can offer wages conditional on the number of products sold.
3. The merchant can offer wages conditional on the probabilities of sale of the products.
4. The sales representatives set the wages.

Question 5:
Which of the following statements is true:

1. Wage w_{10}^{A} is paid if no product is sold.
2. Wage w_{10}^{A} is paid to sales representative A if only product A but not product B is sold.
3. Wage w_{10}^{A} is paid to sales representative B if both products are sold.
4. Wage w_{10}^{A} is paid to sales representative B if only product B but not product A is sold.

Question 6:
What is the probability that only product B is sold when sales representative A promotes product A but sales representative B does not promote product B?

Question 7:
What is the probability that wage w_{10}^{A} is paid if both sales representatives promote their respective product?

Chapter Four

Public-private partnerships versus traditional procurement: An experimental investigation

4.1 INTRODUCTION

Over the last two decades, governments in a growing number of countries initiated public-private partnerships to let the private sector take over the responsibility for building an infrastructure and subsequently operating it to provide public goods or services. In industrialized countries as well as in emerging economies, public-private partnerships have been set up for large-scale projects in various sectors such as public transportation, health care, and education.[1]

A key characteristic of public-private partnerships is that the two tasks of building a facility and subsequently operating it are bundled and delegated to a single private contractor, while under traditional procurement, separate contractors are in charge of these two tasks.[2] An argument often put forward in favor of public-private partnerships is that when the same private contractor is responsible for construction as well as operation of a public facility, then he will be inclined

[1]See Grimsey and Lewis (2004), Yescombe (2007), OECD (2008), and Asian Development Bank (2008). According to Henckel and McKibbin (2010, p. 5), public-private partnerships "have increased sevenfold in developing countries from 1990-92 to 2006-08 and sixfold in Europe during the same period."

[2]See e.g. Grimsey and Lewis (2004, pp. 129, 222). See also Iossa et al. (2007, p. 17), who argue that the "bundling of project phases into a single contract is the main characteristic of PPP contracts."

to invest more during the construction phase in order to reduce the costs incurred in the subsequent operating stage.[3]

Hart (2003) demonstrates that the incomplete contracting approach offers a very useful framework to theoretically investigate the pros and cons of public-private partnerships compared to traditional procurement. In his model, there are two stages. In the first stage, a public infrastructure is built, while in the second stage, the infrastructure is operated to provide a public service. In the first stage, the builder can make investments that reduce the operating costs in the second stage. In line with the above-mentioned argument, Hart (2003) finds that given a public-private partnership, the private contractor has strong incentives to make investments, since they reduce the operating costs that he will have to incur in the operating stage. In contrast, under traditional procurement, the builder has no incentives to invest in cutting the operating costs, since another private party will have to bear these costs.

Whether a public-private partnership or traditional procurement is preferable depends on the effects that the cost-reducing investments have on the service quality. In particular, Hart (2003) assumes that two different kinds of investments can be made. Investment i not only reduces the operating costs, but it also increases the service quality. In contrast, while investment e also reduces the operating costs, it does so at the expense of a reduced service quality. Hence, investment i is socially desirable, while investment e might be socially undesirable if the negative side effect on the service quality is sufficiently strong.

In line with Hart (2003), we consider a situation in which in a first-best world (i.e., if the investments were contractible), a high level of investment i, but a low level of investment e would be chosen. In a second-best world (i.e., if the investments are non-contractible), we are then confronted with the following trade-off. In a public-private partnership, high levels of both kinds of investments are induced. Hence, there is overinvestment with regard to e, while the first-best level of investment i is chosen. In contrast, under traditional procurement, there

[3] See Yescombe (2007, p. 21). Moreover, Grimsey and Lewis (2004, p. 92) argue that a public-private partnership provides the private contractor with incentives "to plan beyond the bounds of the construction phase and incorporate features that will facilitate operations."

are no incentives to make high investments. Thus, there is underinvestment regarding i, while the first-best level of investment e is chosen.

It is an important research question to investigate whether the trade-off identified by Hart (2003) is of empirical relevance. As a first step in that direction, we have conducted a large-scale public procurement experiment in the laboratory.

Specifically, we conducted two main treatments, a public-private partnership (PPP) treatment and a traditional procurement (TP) treatment. We have implemented a parameter constellation where encouraging the desirable investment i is more important than preventing the undesirable investment e, so that according to the theoretical analysis, a public-private partnership is preferable to traditional procurement. The experimental data largely corroborates the theoretical analysis. In the PPP treatment, subjects chose the high levels of both kinds of investments significantly more often than in the TP treatment. As a consequence, also the total surplus generated in the PPP treatment was significantly larger than the total surplus in the TP treatment.

However, modelling the private contractor in a public-private partnership as a single decision maker might be seen as an analytical shortcut. In practice, different skills are needed in the building and operating stages. Thus, it is important to take a closer look at different subcontracting arrangements. For this reason, we have conducted two further treatments. In one treatment (Sub I), the builder is the main contractor and subcontracts with an operator. As has already been pointed out by Hart (2003), in theory this setting induces the same investment behavior as the simple PPP setting (since the main contractor must reimburse the subcontractor for his operating costs, the main contractor internalizes these costs). In another treatment (Sub II), the operator is the main contractor and subcontracts with a builder. In theory, this setting leads to the same investment behavior as traditional procurement (since the subcontractor disregards the operating costs, he has no incentives to invest). Also in the subcontracting treatments, it turns out that the observed behavior in the laboratory is mostly in line with the theoretical predictions.

In recent years, the theoretical literature on public-private partnerships has grown steadily. Building on Hart (2003), several contributions have investigated the implications of bundling the building and operating stages in public procurement projects.[4] Bennett and Iossa (2006a,b) and Chen and Chiu (2010) explore how different ownership structures interact with the choice between a public-private partnership and traditional procurement.[5] Martimort and Pouyet (2008) analyze a model that includes both traditional agency problems and property rights and they find that the most relevant question is not who owns the assets, but instead whether the tasks are bundled or not. Iossa and Martimort (2009, forthcoming) discuss extensions and applications of this framework. Also focusing on the externalities between the tasks of building and operating a public project, Li and Yu (2010) investigate whether these tasks should be auctioned off separately or bundled. Valéro (forthcoming) studies which effect the strength of the institutional framework (i.e., the government's commitment power) may have on the bundling decision. Hoppe and Schmitz (2013) study how the decision to bundle the building and operating stages affects the incentives to gather information about future costs of adapting the service provision to changing circumstances.

While public-private partnerships have received growing attention in the theoretical literature, so far empirical research is scarce.[6] In particular, to the best of our knowledge, our study is the first experimental contribution that compares the performance of public-private partnerships and traditional procurement in the laboratory.[7]

[4]While most papers in this literature consider incomplete contracts, Bentz, Grout, and Halonen (2004) study related questions in a complete contracting framework. On the pros and cons of bundling sequential tasks when complete contracts can be written, see also Schmitz (2005).

[5]Hart, Shleifer, and Vishny (1997) have developed the leading model to study the effects of public and private ownership on investment incentives, building on the property rights approach based on incomplete contracting (Grossman and Hart, 1986; Hart and Moore, 1990; Hart, 1995). See also Hoppe and Schmitz (2010), who extend their framework by considering a richer set of contractual arrangements. Moreover, Besely and Ghatak (2001), Francesconi and Muthoo (2006), and Halonen-Akatwijuka and Pafilis (2009) build on the property rights approach to analyze whether non-governmental organizations should own public goods.

[6]For empirical studies on public-private partnerships, see Chong et al. (2006a,b) on water distribution, de Brux and Desrieux (2010) on the car park sector, and Blanc-Brude and Jensen (2010) on school contracts.

[7]However, there are some laboratory experiments on procurement contracting that focus on quite different aspects. Cox et al. (1996) examine fixed-price and cost-sharing contracts in frameworks with moral hazard and adverse selection. Güth et al. (2006) study the efficiency and profitability of different procurement auctions. Bigoni et al. (2010) investigate the effects of explicit incentives framed as either bonuses or penalties in procurement contracts.

The remainder of the chapter is organized as follows. In Section 4.2, public-private partnerships and traditional procurement are compared, while in Section 4.3, different ways of subcontracting are considered. Each of these two sections consists of subsections in which we describe the theoretical framework, present the experimental design, derive predictions, and report the results. Concluding remarks follow in Section 4.4.

4.2 PUBLIC-PRIVATE PARTNERSHIPS VS. TRADITIONAL PROCUREMENT

4.2.1 THEORETICAL FRAMEWORK

In this section, to motivate our experimental study, we present the theoretical framework based on Hart (2003) as a starting point. We consider a government agency who wants a certain public good or service to be provided. For this purpose, two tasks have to be performed: a suitable infrastructure has to be built and subsequently, it has to be operated. We study two different modes of provision. In case of a *public-private partnership*, the two tasks are bundled; i.e., the government agency contracts with a single party (a consortium) to build the infrastructure and to subsequently operate it. In contrast, under *traditional procurement* the two tasks are separated; i.e., the government agency contracts with one party to build the infrastructure and with another party to operate it.

We assume that only incomplete contracts can be written. In particular, the party in charge of building the infrastructure can make two kinds of observable but non-contractible investments, $i \in \{i_l, i_h\}$ and $e \in \{e_l, e_h\}$, that affect the characteristics of the infrastructure and thus the nature of the service to be provided. The government agency's benefit is given by

$$B(i,e) = B_0 + \beta(i) - b(e),$$

while the operating costs are given by

$$C(i,e) = C_0 - \gamma(i) - c(e).$$

The investments are measured by their costs; i.e., the total investment costs equal $i+e$. The quality-enhancing investment i increases the government agency's benefit from service provision and at the same time it reduces the operating costs. In contrast, while investment e also reduces the operating costs, it does so at the expense of a reduced service quality.

In a first-best world, i.e. if the investments were contractible, the government agency would implement the investment levels that maximize the total surplus

$$\begin{aligned} & B(i,e) - C(i,e) - i - e \\ = \; & B_0 + \beta(i) - b(e) - C_0 + \gamma(i) + c(e) - i - e. \end{aligned}$$

In the first-best benchmark solution, the high investment level would be chosen whenever the additional gains generated outweigh the additional investment costs. In particular, $i^{FB} = i_h$ whenever $\beta(i_h) + \gamma(i_h) - [\beta(i_l) + \gamma(i_l)] \geq i_h - i_l$. Similarly, $e^{FB} = e_h$ whenever $c(e_h) - b(e_h) - [c(e_l) - b(e_l)] \geq e_h - e_l$. In accordance with Hart (2003), we assume that only in case of the quality-improving investment i it is socially desirable to choose the high investment level. Specifically, we make the following assumption.

Assumption 1. (i) $\gamma(i_h) - \gamma(i_l) \geq i_h - i_l$.

(ii) $c(e_h) - c(e_l) - [b(e_h) - b(e_l)] < e_h - e_l < c(e_h) - c(e_l)$.

Assumption 1(i) says that the additional reduction of the operating costs alone already outweighs the additional investment costs when the high investment level i_h instead of the low investment level i_l is chosen. Since moreover this investment increases the benefit, it is clearly first-best to choose $i = i_h$. Assumption 1(ii) says that while the reduction of the operating costs does outweigh the additional investments costs of choosing e_h instead of e_l, the negative side effect on the service quality is so strong that from a social perspective it is optimal to choose $e = e_l$. As a consequence, the total surplus in the first-best solution is $B(i_h, e_l) - C(i_h, e_l) - i_h - e_l$.

We now return to the second-best world in which the investments are non-contractible. Note that since we assume throughout that the investment levels are observable, the party in charge of operating the facility knows its operating costs regardless of the governance structure.

Consider first a *public-private partnership* (bundling). We assume that there is a competitive supply of private consortia that could build the infrastructure and subsequently operate it. They submit offers to the government agency who then decides with whom to contract. The consortium that is awarded the contract will choose the investment levels i and e that maximize its payoff $P_0 - C(i,e) - i - e = P_0 - C_0 + \gamma(i) + c(e) - i - e$, where P_0 is the price that the government agency pays to the consortium. Since by assumption $\gamma(i_h) - \gamma(i_l) \geq i_h - i_l$ and $c(e_h) - c(e_l) \geq e_h - e_l$, the consortium will invest $i^{PPP} = i_h$ and $e^{PPP} = e_h$. Hence, anticipating their investment behavior in case of being awarded the contract, in a competitive market the consortia submit offers equal to their total costs $C(i_h, e_h) + i_h + e_h$. This means, the government agency will make the payment $P_0 = C(i_h, e_h) + i_h + e_h$ to the consortium that is awarded the contract and the government agency's payoff is $B(i_h, e_h) - C(i_h, e_h) - i_h - e_h$.

Now consider *traditional procurement* (unbundling). In this case the government agency initially contracts with one private party to build the infrastructure and subsequently, it contracts with another private party that will operate it. If there is a competitive supply of operators, they will make offers in which they demand to be reimbursed for their operating costs, given the investment levels that were chosen. Hence, the government pays $P_1 = C(i,e)$ to the chosen operator. The builder who is awarded the construction contract chooses the investment levels i and e to maximize his payoff $P_0 - i - e$, where P_0 is the payment from the government agency to the builder. Hence, he will choose $i^{TP} = i_l$ and $e^{TP} = e_l$. Anticipating this, the builders will submit offers equal to $i_l + e_l$. The government agency's payoff is thus $B(i_l, e_l) - C(i_l, e_l) - i_l - e_l$.

The following proposition summarizes the main insights of the theoretical analysis.

Proposition 4.1. *The investment levels given a public-private partnership and given traditional procurement can be ranked as follows.*
$i^{TP} = i_l < i^{PPP} = i^{FB} = i_h$.
$e^{TP} = e^{FB} = e_l < e^{PPP} = e_h$.

Intuitively, the trade-off between the two governance structures is as follows. In case of a public-private partnership, in the building stage the consortium anticipates that it will have to bear the operating costs in the subsequent stage. Hence, the consortium not only chooses the high investment level of i, which is socially

$C(i,e)$	$e=0$	$e=4$
$i=0$	24	12
$i=4$	12	0

$B(i,e)$	$e=0$	$e=4$
$i=0$	48	36
$i=4$	60	48

Table 4.1: The operating costs and the government agency's benefit depending on the investment levels.

desirable, but it also chooses the high investment level of the quality-reducing investment e, which is socially undesirable. This is because the consortium is interested in cutting the operating costs, while it does not internalize the negative impact that the investment e has on the government agency's benefit.

In contrast, under traditional procurement, the builder who is in charge of the investments internalizes neither the operating costs nor the government agency's benefit, as he gets a fixed payment P_0 independent of the investment levels that he chooses. As a consequence, by choosing $i^{TP} = i_l$, he underinvests in the socially desirable investment, while he chooses the first-best level $e^{TP} = e_l$ of the quality-reducing investment.

While the government agency's payoff is always below the first-best level, which one of the two governance structures is optimal depends on the relative impacts of the non-contractible investments.

4.2.2 EXPERIMENTAL DESIGN

In each treatment of our experiment, a government agency wants a public infrastructure to be built and subsequently to be managed. The party in charge of building can decide how much it wants to invest during the construction stage. Specifically, the building party makes the investment decisions $i \in \{i_l, i_h\}$ and $e \in \{e_l, e_h\}$, where $i_l = e_l = 0$ and $i_h = e_h = 4$. The investments influence the operating costs and the government agency's benefit. Depending on the investment decisions, the operating costs are $C(i,e) = C_0 - \gamma(i) - c(e)$ and the government agency's benefit is $B(i,e) = B_0 + \beta(i) - b(e)$, where $C_0 = 24$, $B_0 = 48$, $\beta(i) = \gamma(i) = 3i$, and $b(e) = c(e) = 3e$. Table 4.1 summarizes the operating costs and the government agency's benefit.

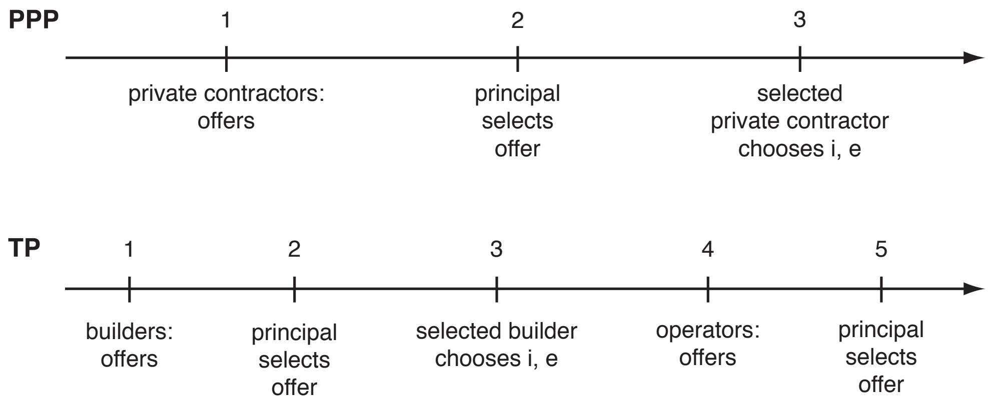


Figure 4.1: The sequences of events in the PPP treatment and the TP treatment.

Hence, taking into account the investment costs $i+e$, the first-best outcome is achieved if $i = i^{FB} = 4$ and $e = e^{FB} = 0$ are chosen, so that the first-best total surplus is 44.

We now describe the two main treatments of our experiment. Figure 4.1 1 summarizes the sequences of events in the two treatments.

Public-private partnership (PPP) treatment. In this treatment, always four subjects interact within a group. One subject is in the role of a principal (representing the government agency) and each of the three other subjects is in the role of a private contractor (each one representing a consortium). There are three stages. In the first stage, each of the private contractors submits an offer at which he is willing to build the infrastructure and to operate it.[8] In the second stage the principal learns the submitted offers and he selects one of the private contractors. The two contractors who are not selected make zero profits. In the third stage, the selected contractor chooses investment levels i and e. Depending on the investment decisions, the principal's payoff is $B(i,e) - P_0$ and the selected contractor's payoff is $P_0 - C(i,e) - i - e$, where P_0 is the price offer made by the selected contractor.

[8]Throughout, offers had to be integers and the upper bounds for the offers were chosen large enough such that for any combination of investment decisions the parties could have shared the net surplus equally. For instance, in the PPP treatment, the private contractors could make offers in the range from 0 to 38.

Traditional procurement (TP) treatment. In this treatment, always seven subjects play within a group. One subject is in the role of a principal (representing the government agency), three subjects are in the role of builders, and the other three subjects are in the role of operators. There are five stages. In the first stage, each builder submits an offer to build the infrastructure. In the second stage the principal learns the submitted offers and he selects one of the builders. The two builders who are not selected make zero profits. In the third stage, the selected builder makes the investments i and e. His payoff is $P_0 - i - e$, where P_0 is the price offer he made in the first stage. In stage 4, the three operators learn the selected builder's investment decisions and thus they know the operating costs. Then each operator submits an offer at which he is willing to operate the infrastructure. In stage 5, the principal learns the selected builder's investment decisions and the operators' submitted offers. He then selects an operator. The other operators make zero profits. The principal's payoff is $B(i,e) - P_0 - P_1$, where P_1 is the selected operator's price offer. The selected operator's payoff is $P_1 - C(i,e)$.

Subjects, payments, and procedures. In total, 176 subjects participated in these two main treatments. Moreover, 224 subjects participated in two additional treatments which will be described in Section 4.3. All 400 subjects were students of the University of Cologne from a wide variety of fields of study. The computerized experiment was programmed and conducted with z-Tree (Fischbacher, 2007), and subjects were recruited using ORSEE (Greiner, 2004).

For the PPP treatment, we conducted two sessions with 32 subjects per session. In each session, there were 8 groups consisting of 4 players (one principal and three contractors). For the TP treatment, we conducted four session with 28 subjects per session. In each session, there were 4 groups consisting of 7 players (one principal, three builders, three operators).[9] In every treatment, the sessions consisted of 20 rounds. Each subject kept its role and stayed in the same group over all rounds, so that we have 16 independent observations per treatment. All

[9] In the two subcontracting treatments described in Section 4.3, we also conducted four sessions with 28 subjects per session. In each session, there were 4 groups consisting of 7 players (one principal, three builders, three operators), so that we also have 16 groups per subcontracting treatment.

interactions were anonymous; i.e., no subject knew the identities of the other group members. At the beginning of each session, written instructions were handed out to the participants. No subject was allowed to participate in more than one session.

We made use of an experimental currency unit (ECU). To prevent the occurrence of losses, each subject was given an initial endowment of 75 ECU.[10] After each round, a subject's payoff was added to his account. The final balance was paid out to them in cash (1 ECU = 0.07 Euro). A session lasted between 70 and 90 minutes. Subjects were paid on average 13.19 Euro.

4.2.3 PREDICTIONS

Under standard contract-theoretic assumptions (in particular, if it is commonly known that all players are rational and have self-interested preferences), the predictions are as follows.

In the PPP treatment, the selected private contractor will minimize his total costs $C(i,e)+i+e$ by choosing the high levels of both investments, $i=4$ and $e=4$, so that his total costs are 8. Since in a subgame-perfect equilibrium, the principal will choose a contractor making the smallest price offer, at least two contractors will make the price offer 8. This implies that the principal obtains the total surplus, which then is 40.[11]

In the TP treatment, since the principal will choose the operator offering the smallest price, at least two operators will make price offers equal to the operating costs $C(i,e)$. The selected builder will maximize his payoff $P_0 - i - e$ by choosing the low investments $i=0$ and $e=0$. Anticipating that the principal will choose a builder making the smallest price offer, at least two builders will offer the price 0. Hence, the principal obtains the total surplus, which now is 24 only.[12]

[10] If in any round a subject's balance became negative, we would have excluded the whole group from our data analysis. Yet, no subject ever had a negative balance.

[11] More precisely, note that since 1 ECU is the smallest monetary unit, the price paid to a contractor may also be 9. If the other two contractors make this offer, the best response is to also offer 9. In this case, the selected contractor's payoff is 1 and the principal's payoff is 39.

[12] Note again that due to the smallest monetary unit, there are further equilibria that differ slightly from the standard equilibrium prediction. E.g., all operators may offer 25 and all builders may offer 1, so that the selected contractors each make a profit of 1 and the principal's payoff is 22.

Since the games we are interested in consist of several stages and involve several players, we wanted the subjects to have a chance to learn how to play the games, so that we implemented a repeated game design. However, a potential drawback of this design could be the well-known fact that in repeated games, subjects often manage to establish cooperation. Hence, we are particularly interested in the final round, which corresponds most closely to the one-shot interaction modelled in the theoretical framework that motivated our study.

Numerous experimental studies have shown that subjects' behavior in the laboratory often violates perfect rationality and pure self-interest.[13] On the other hand, previous work has shown that competitive forces, which are central ingredients of our setting, can be quite strong also in laboratory settings.[14] Thus, our main research question is whether the contract-theoretic reasoning as outlined above can be useful to organize the experimental data. Guided by the theoretical analysis, we make the following qualitative predictions.

Prediction 1. *In the PPP treatment, the high levels of both investments will be chosen more often than in the TP treatment.*

If Prediction 1 is corroborated by the data, then this offers support for the fundamental trade-off identified by Hart's (2003) analysis. More specifically, given the parameters that we have chosen for the experiment, the total surplus is larger if both kinds of investments (i.e., desirable and undesirable) are made than if no investments are made. The theoretical analysis thus suggests that the principal will be better off given a public-private partnership (since due to competition he will be able to extract the total surplus). The following prediction hypothesizes that this finding is also reflected in the data, which is a somewhat more ambitious test of the relevance of the theory.

Prediction 2. *The principals' payoffs will be larger in the PPP treatment than in the TP treatment.*

[13]For surveys, see e.g. Camerer (2003) or Fehr and Schmidt (2006).

[14]Specifically, we decided to model competition using three players, since Dufwenberg and Gneezy (2000) showed that price competition works quite well in experimental markets with three sellers.

	all rounds		final round	
	PPP	TP	PPP	TP
no investments	0.3%	49.1%	0.0%	93.8%
only investment i	4.7%	48.4%	6.3%	6.3%
only investment e	0.9%	1.9%	0.0%	0.0%
both investments	94.1%	0.6%	93.8%	6.3%
investment i	98.8%	49.1%	100.0%	6.3%
investment e	95.0%	2.5%	93.8%	0.0%
principals' payoff	34.86	24.88	37.00	16.63
selected contractors' payoff	5.09		3.25	
selected builders' payoff		6.97		8.13
selected operators' payoff		1.86		0.50
total surplus	39.95	33.71	40.25	25.25

Table 4.2: The first four rows summarize the relative frequencies of the investment decisions in which no investment, only one investment, or both investments were chosen. The following two rows show the relative frequencies of all cases in which investment i and investment e, respectively, were chosen. The final rows show the parties' average payoffs and the average total surplus.

4.2.4 RESULTS

In this section, we describe and analyze the results of our two main treatments. Table 4.2 shows the key findings summarized over all rounds and for the last round.

Let us first consider the investment behavior. Recall that in the PPP treatment, the private contractor builds the infrastructure and subsequently operates it, so that the profit-maximizing decision is to make both investments. In contrast, in the TP treatment the builder who takes the investment decisions is not in charge of operation, so that according to standard theory, he will not invest at all.

In both treatments, the subjects' last-round investment behavior is remarkably close to the standard contract-theoretic predictions. In the PPP treatment, 15 of the 16 selected builders chose the high levels of both kinds of investment (while one selected builder chose the high level of the quality-improving investment only). In contrast, in the TP treatment, 15 of the 16 selected builders chose the

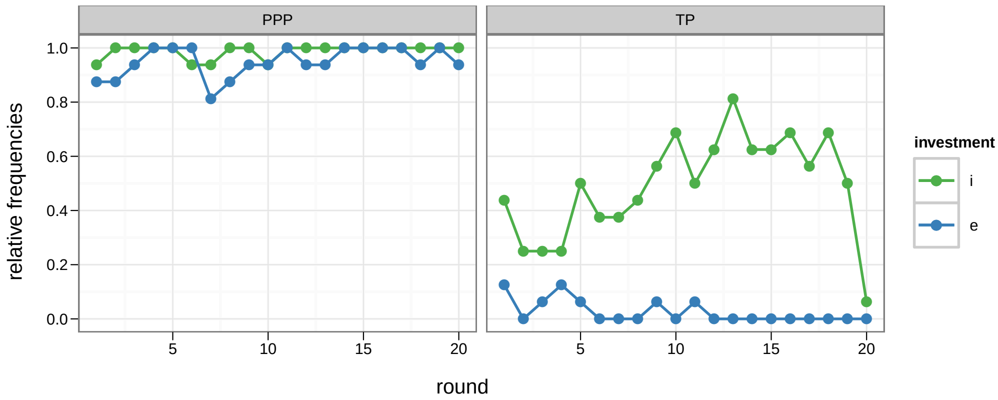


Figure 4.2: The relative frequencies with which the high levels of the investments *i* and *e* were chosen.

low levels of both investments (while one selected builder chose the high level of the quality-improving investment only).

Let us now take all 20 rounds into consideration. For each round, Figure 4.2 illustrates the relative frequencies with which the high levels of the quality-improving investment i and the quality-reducing investment e were chosen. For each investment i and e, we have 320 investment decisions per treatment. In the PPP treatment, the investment behavior was very close to the theoretical prediction over all 20 rounds. Altogether, the high level of the desirable investment i was chosen in 99% of the 320 cases, while the high level of the undesirable investment e was chosen in 95%. In the TP treatment, the high level of the desirable investment i was chosen in 49.1% and the high level of the undesirable investment e was chosen in 2.5% of all cases. The investment behavior regarding e is again very close to the standard prediction. Even though in rounds 1 to 19, the high level of the quality-improving investment i is chosen more often than predicted, we do find strong evidence in support of Prediction 1. Not only in the last round, but also taking averages per group over all 20 rounds, the subjects' behavior with regard to both kinds of investments differs significantly between the treatments.[15]

[15] Between treatments and for each investment, we compare the distributions of average investment levels. An average investment level refers to one single group and describes the relative frequency of high investment levels over all rounds within this group. The p-values of two-sided Mann-Whitney U tests with regard to the investments e and i are both smaller than

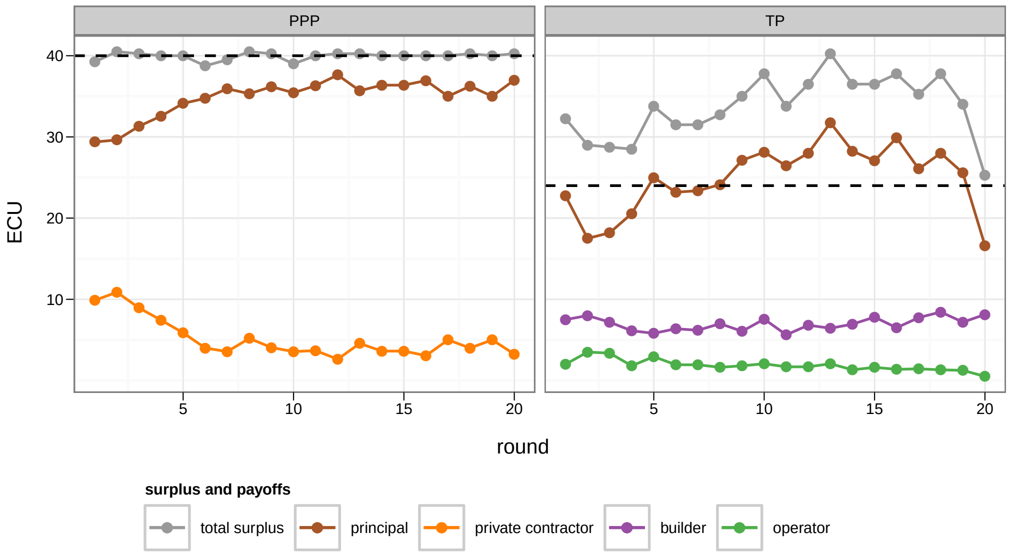


Figure 4.3: The average total surplus and the average payoffs of the principals, the selected private contractors (in PPP), and the selected builders and operators (in TP). The dashed lines represent the theoretically predicted total surplus levels (40 in PPP and 24 in TP).

For each round, Figure 4.3 shows the average total surplus resulting from the described investment behavior. In the PPP treatment, the average surplus is larger than in the TP treatment in every round except round 13 (where the surplus is the same in both treatments).[16] Hence, as predicted, the public-private partnership was the welfare-maximizing governance structure, even though in rounds 1 to 19, the total surplus in the TP treatment was noticeably larger than predicted (due to the fact that in almost half of the cases, the first-best investment decisions were taken). In the final round, the surplus in both treatments is very close to the respective theoretical prediction.

In the PPP treatment, the total surplus is the sum of the principal's and the selected private contractor's payoffs. In the TP treatment, the total surplus is the

0.001. Moreover, we have also compared the individual investment decisions between treatments in each single round. According to χ^2 tests, the p-values regarding investment e are smaller than 0.001 in every round, while with regard to investment i, they are smaller than 0.02 in 18 rounds (in rounds 10 and 13, we still have $p < 0.08$).

[16]Over all rounds, the surplus differs significantly between the two treatments. Comparing the distributions of the average surplus per group over all rounds, the p-value is 0.002 according to a two-sided Mann-Whitney U test.

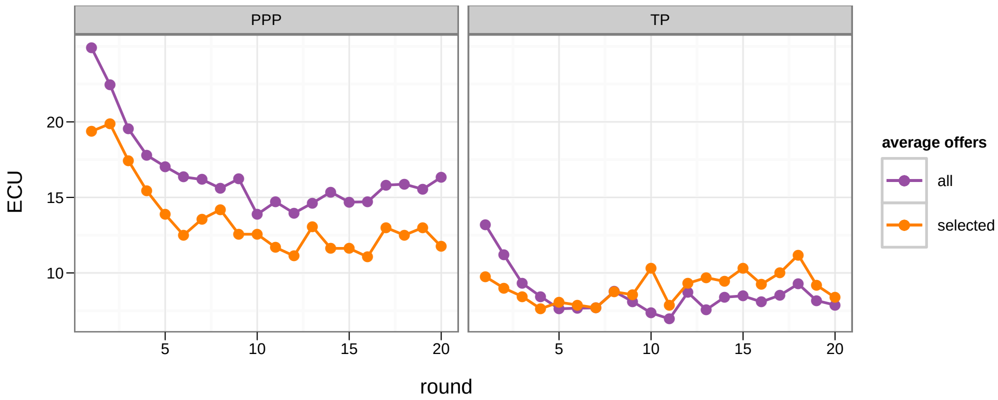


Figure 4.4: The average offers made by all private contractors (in PPP) and by all builders (in TP) as well as the average offers selected by the principals.

sum of the principal's, the selected builder's, and the selected operator's payoffs. In both treatments, the principals obtain by far the largest share of the total surplus. Hence, competition seemed to work quite well. As a consequence, we find strong support for Prediction 2. Over all rounds, the principals' average payoff in the PPP treatment was 34.86, while it was only 24.89 in the TP treatment. Taking averages per group over all 20 rounds, the difference between the distributions of the principals' payoffs is highly significant.[17]

Let us now take a closer look at how the different parties' payoffs developed over time. In the PPP treatment, the private contractors' average profits decreased over the early rounds, while they were small and quite stable in the later rounds. In the TP treatment, the builders' average profits were small and almost constant, while the operators' profits were even smaller.

In the PPP treatment, the principals' payoffs increased over the early rounds, while in the TP treatment the principals' payoffs exhibited an increasing trend from the second to the 13th round. The reasons for these growing payoffs differ between the treatments. In the PPP treatment, increases of principals' payoffs cannot be driven by changing investment behavior (since the average investment levels and thus the total surplus were almost constant over all rounds). Instead,

[17]The p-value of a two-sided Mann-Whitney U test is smaller than 0.001. Comparing the individual profits in each round, the p-values are smaller than 0.04 in 18 of the 20 rounds ($p = 0.213$ in round 1 and $p = 0.125$ in round 13).

the principals' increasing payoffs resulted from the fact that on average, during the first rounds, payments from the principals to the private contractors decreased. This fact is illustrated in the left panel of Figure 4.4, which shows the averages per round of all private contractors' offers and of the selected offers. Note that in every round, the average selected offer is smaller than the average of all offers that were made. In the TP treatment, the principals' growing payoffs are also due to decreasing payments to the builders in the first few rounds (see the right panel of Figure 4.4), while they are mainly driven by increasing investment levels of the quality-enhancing investment i in later rounds (see Figure 4.2).

We will now explore the behavior within the individual groups in greater detail. For each of the 16 groups in the PPP treatment, Figure 4.5 shows all three private contractors' offers, as illustrated by the three colored curves. In each round, the offer actually selected by the principal is indicated by a symbol, whose shape reflects the selected contractor's investment decisions.

Most principals selected the lowest offer right from the beginning,[18] which created competition between the private contractors, so that in most groups we observe decreasing offers over the early rounds (cf. also the left panel of Figure 4.4). As already pointed out, the vast majority of private contractors chose the high levels of both investments, which becomes apparent from inspection of Figure 4.5. Indeed, in most cases making both investments was the only way for the contractors to avoid losses. Recall that the private contractors' total costs were 8 if they made both investments, while their total costs were 16 if they made the first-best investment decisions (by choosing investment i only). 75% of the selected offers were smaller than 16, so that in these cases making the first-best investment decisions would have led to a loss for the contractors. As a matter of fact, competition was so strong that most contractors could make only very small profits even if they chose the high levels of both investments.[19]

For each of the 16 groups in the TP treatment, Figure 4.6 shows all builders' offers, the offers selected by the principal, and the selected builders' investment decisions. Figure 4.6 is particularly helpful to better understand the builders' investment behavior. Recall that in the TP treatment, the average level of the

[18]Over all rounds, the lowest offer was chosen in more than 80% of the cases.

[19]In the last five rounds, 65% of the selected offers were smaller than or equal to 10.

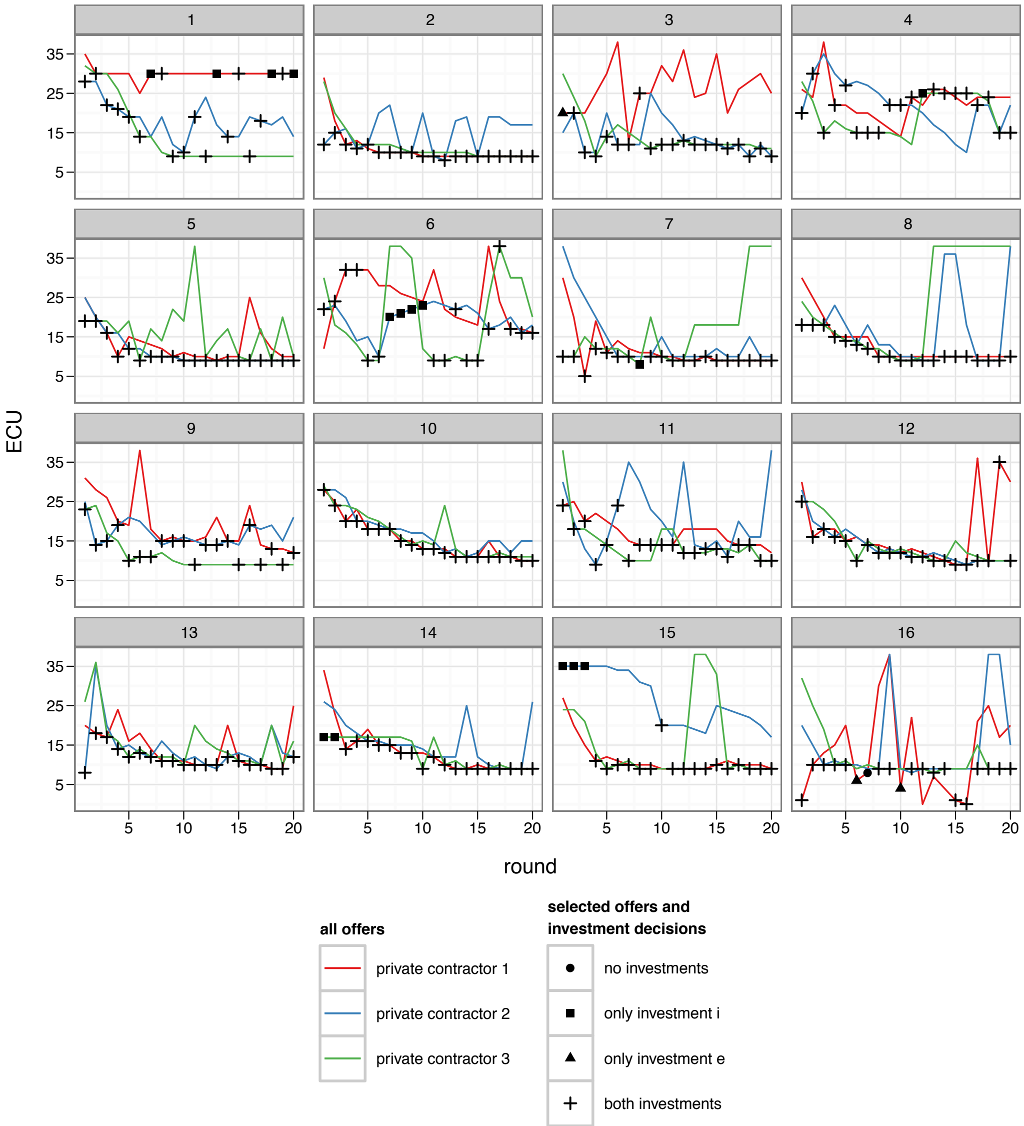


Figure 4.5: The offers made by the three contractors, the principal's choices, and the selected contractors' investment decisions for each of the 16 groups in the PPP treatment.

quality-improving investment i increases during the first rounds, remains relatively high in the following rounds, and then falls steeply close to zero in the last round (see also Figure 4.2). Why do builders in rounds 1 to 19 often choose first-best investment levels, although in a given round, this reduces their monetary payoff? Actually, the strategic situation resembles a gift-exchange game (Akerlof, 1982). In gift-exchange experiments, it is often observed that principals pay relatively generous wages and agents tend to reciprocate principals' behavior by exerting high effort, which they would not do according to standard theory.[20] In our TP treatment, principals could select relatively large offers, thereby paying the builder a generous fixed wage. Builders could then reward principals for doing so by making first-best investment decisions. Indeed, in some groups we observe behavior which is in line with the gift-exchange argument. In these groups, principals persistently preferred not to select the lowest offer. As a matter of fact, in later rounds, average selected offers were larger than the average of all offers (see also the right panel of Figure 4.4). Moreover, selected builders often reciprocated relatively large payments by choosing first-best investments.[21] However, the builders' reciprocal behavior was motivated by strategic considerations, since in the final round all builders but one decided not to invest at all.

Figure 4.7 illustrates all operators' offers and the offers selected by the principals. Note that the operating costs are determined by the builders' previous investment decisions which are again indicated by the different shapes of the symbols. Recall that if no high investment levels were chosen, the operating costs were 24, if only one of the two investment levels was high, the operating costs were 12, while they were 0 otherwise. Most of the operators' offers were only slightly above their respective operating costs and, over all rounds, principals

[20] See e.g. Fehr, Kirchsteiger, and Riedl (1993, 1998) and Fehr and Falk (1999).

[21] Specifically, the first-best investment decisions were taken in 48.4% of all cases, while no investments were made in 49.1%. If the principal did not select the builder making the smallest offer (which happened in 63.4% of the cases), then the first-best decisions were taken in 66% of these instances, while in only 31.5% of these instances no investments were made. Note also that our experimental design was such that on the principals' screens the offers were displayed in a random order, so that they did not know which offer was made by which builder. However, it seems that, by making similar offers over several rounds, in some groups builders managed to establish a reputation for choosing first-best investments when their offers are accepted.

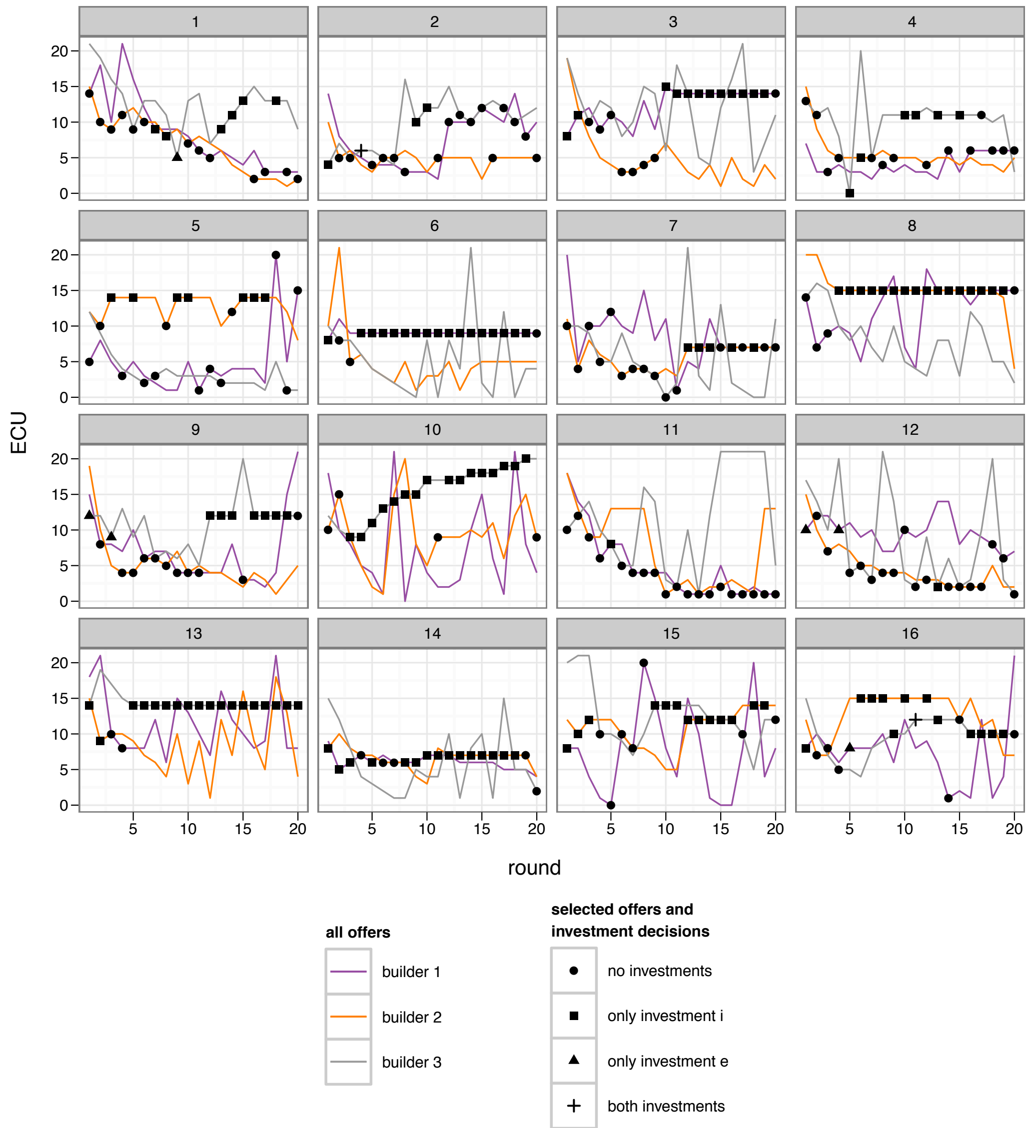


Figure 4.6: The offers made by the three builders, the principal's choices, and the selected builders' investment decisions for each of the 16 groups in the TP treatment.

selected the lowest operating offers in 93.12% of the cases. This indicates that competition for being awarded the operating contract worked very well.

4.3 SUBCONTRACTING

So far, we have assumed that in case of a public-private partnership, the government agency contracts with a single private contractor (representing a consortium), who is then responsible for both, infrastructure construction and operation. However, in practice different skills are required for the two different tasks, so that subcontracting is characteristic for a consortium. Hence, we have conducted two further treatments that capture the two ways of subcontracting that are possible in our public-private partnership setting. Either the government agency selects a builder as main contractor, who then subcontracts with an operator, or it selects an operator as main contractor, who then subcontracts with a builder.

4.3.1 THEORETICAL FRAMEWORK

Keeping the assumptions regarding the available technology unchanged (see Section 4.2.1), we now consider two variants of public-private partnerships in which either the task of building the public facility or the task of operating it is delegated to a subcontractor.

The builder as main contractor and the operator as subcontractor (Sub I). We assume that there is a competitive supply of builders as main contractors who could build the infrastructure and who would then subcontract operation. They submit offers to the government agency who chooses a main contractor. The main contractor who is awarded the contract will build the infrastructure and choose the investment levels i and e. Assuming that there is a competitive supply of operators, they will submit offers in which they demand to be reimbursed for their operating costs, given the investment levels. Thus, the main contractor pays $P_1 = C(i,e)$ to the chosen operator. The main contractor chooses the investment levels i and e that maximize his payoff $P_0 - P_1 - i - e = P_0 - C(i,e) - i - e$, where P_0 is the price that the government agency pays to the main contractor. Given

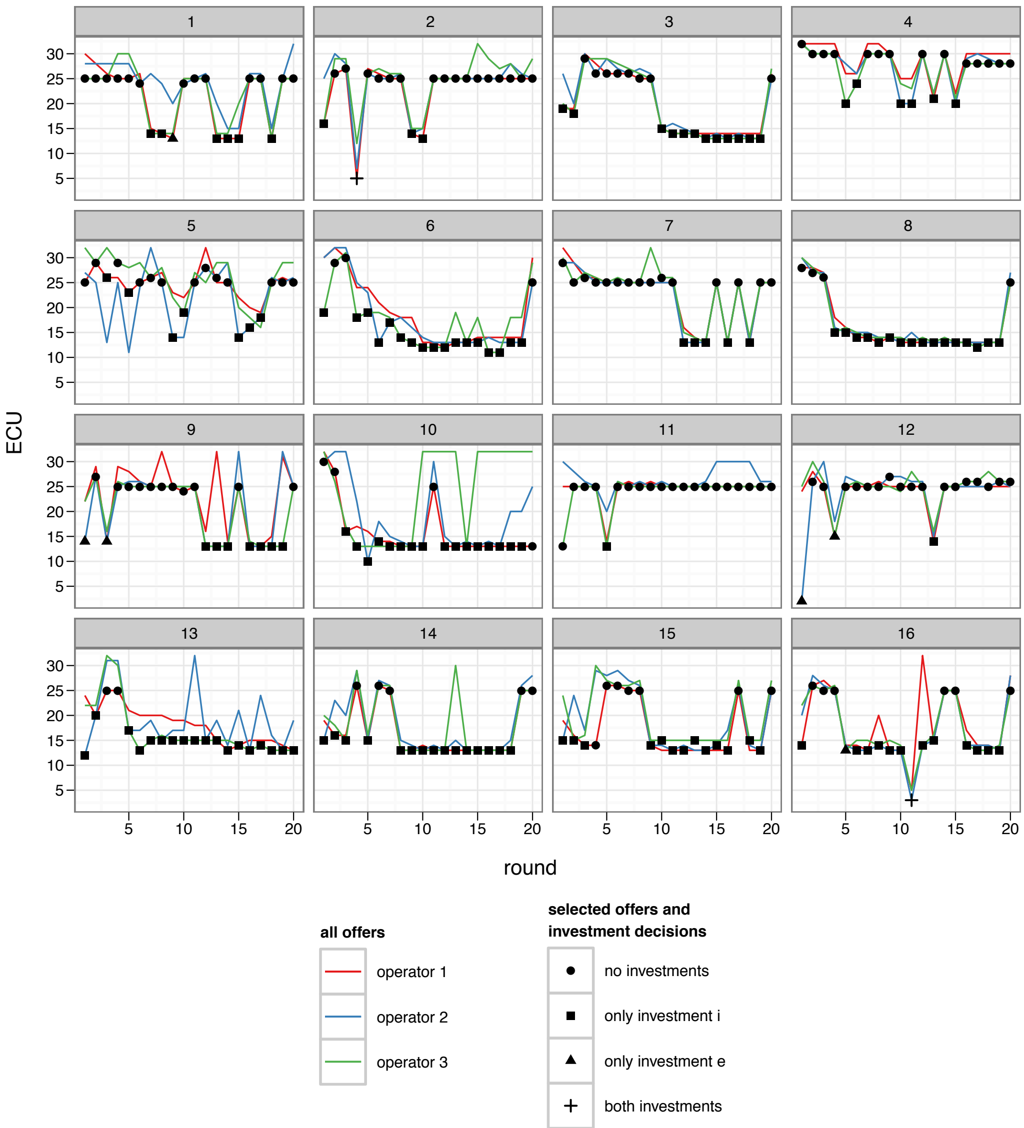


Figure 4.7: The offers made by the three operators and the principal's choices, given the selected builders' investment decisions for each of the 16 groups in the TP treatment.

Assumption 1, the main contractor thus chooses $i^I = i_h$ and $e^I = e_h$. Anticipating their investment behavior in case of being awarded the contract and the price they will have to pay to a subcontractor, the main contractors submit offers equal to their total costs $P_1 + i_h + e_h = C(i_h, e_h) + i_h + e_h$. Therefore, the payment from the government agency to the main contractor is given by $P_0 = C(i_h, e_h) + i_h + e_h$. The government agency's payoff is $B(i_h, e_h) - C(i_h, e_h) - i_h - e_h$.

The operator as main contractor and the builder as subcontractor (Sub II). In this case, the government agency initially contracts with a main contractor who will subcontract the construction of the infrastructure and who will then operate it. The payoff of the builder who will be chosen as the subcontractor is $P_1 - i - e$, where P_1 is the payment from the main contractor to the subcontractor. Hence, the selected builder will choose $i^{II} = i_l$ and $e^{II} = e_l$. Given competition, the builders will submit offers equal to their investment costs $i_l + e_l$. Anticipating that the low investment levels will be chosen, in a competitive market the main contractors will submit offers equal to their total costs $C(i_l, e_l) + P_1 = C(i_l, e_l) + i_l + e_l$. Hence, the government agency pays $P_0 = C(i_l, e_l) + i_l + e_l$ to the operator who is chosen as main contractor. The government agency's payoff is thus $B(i_l, e_l) - C(i_l, e_l) - i_l - e_l$.

Proposition 4.2. *The investment levels given subcontracting can be ranked as follows.*

$i^{II} = i_l < i^I = i^{FB} = i_h.$

$e^{II} = e^{FB} = e_l < e^I = e_h.$

Propositions 4.1 and 4.2 reveal that when operation is subcontracted, then the investment incentives are the same as in a public-private partnership without subcontracting, $i^I = i^{PPP}$, $e^I = e^{PPP}$. In contrast, when the facility construction is subcontracted, then the investment incentives are as in the case of traditional procurement, $i^{II} = i^{TP}$, $e^{II} = e^{TP}$. This is because when the builder is the main contractor, then he anticipates in the building stage that he will have to reimburse the subcontractor for his operating costs in the subsequent stage. Hence, just as in the case of a public-private partnership without subcontracting, the builder is interested in cutting the operating costs, while he does not internalize the

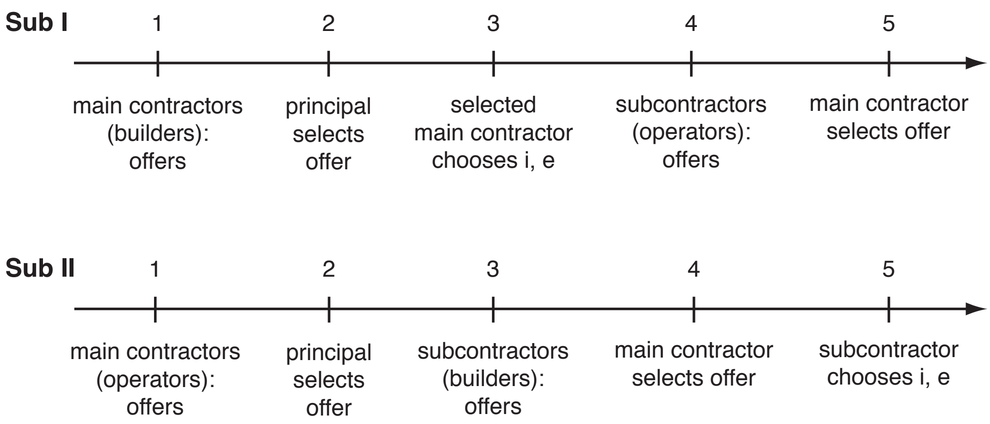


Figure 4.8: The sequences of events in the Sub I treatment and the Sub II treatment.

investments' impact on the government agency's benefit, so that he chooses the high investment levels i_h and e_h. In contrast, when the operator is the main contractor, then the builder as subcontractor who is in charge of the investments obtains a fixed payment independent of the investment levels that he chooses. Hence, just as under traditional procurement, he neither internalizes the operating costs nor the government agency's benefit, so that he chooses the low investment levels i_l and e_l.

As a consequence, the government agency is indifferent between a public-private partnership without subcontracting and a public-private partnership in which operation is subcontracted. Similarly, it is indifferent between traditional procurement and a public-private partnership in which facility construction is subcontracted.

4.3.2 EXPERIMENTAL DESIGN

In our two subcontracting treatments, we consider the same parameter constellation as in the two main treatments (see Section 4.2.2). The sequences of events are illustrated in Figure 4.8.

Treatment Sub I (the builder as main contractor and the operator as subcontractor). In this treatment, always seven subjects interact within a group. One subject is in the role of a principal (representing the government agency), three subjects are in the role of main contractors, and the other three subjects are in the role of subcontractors. There are five stages. In the first stage, each main contractor submits an offer to build the infrastructure and subcontract operation. In the second stage, the principal learns the submitted offers and he selects one main contractor. The two main contractors who are not selected make zero profits. In the third stage, the selected main contractor makes the investments i and e. In stage 4, the three subcontractors learn the investment decisions and thus they know the operating costs. Then each subcontractor makes an offer at which he is willing to operate the infrastructure. In stage 5, the main contractor learns the subcontractors' offers and he selects an operator. The other subcontractors make zero profits. The principal's payoff is $B(i,e) - P_0$, where P_0 is the selected main contractor's price offer. The selected main contractor's payoff is $P_0 - P_1 - i - e$, where P_1 is the selected subcontractor's price offer. The selected subcontractor's payoff is $P_1 - C(i,e)$.

Treatment Sub II (the operator as main contractor and the builder as subcontractor). Again, always seven subjects play within a group. One subject is in the role of a principal (representing the government agency), three subjects are in the role of main contractors, and the other three subjects are in the role of subcontractors. There are five stages. In the first stage, each main contractor submits an offer to operate the facility and to subcontract the facility construction. In the second stage, the principal learns the submitted offers and he selects a main contractor. The two main contractors who are not selected make zero profits. In the third stage, each subcontractor submits an offer at which he is willing to build the infrastructure. In stage 4, the main contractor learns the subcontractors' offers and he selects a builder. The other subcontractors make zero profits. In stage 5, the selected subcontractor makes the investment decisions i and e. The principal's payoff is $B(i,e) - P_0$, where P_0 is the selected main contractor's price offer. The selected main contractor's payoff is $P_0 - P_1 - C(i,e)$, where P_1 is the selected subcontractor's price offer. The selected subcontractor's payoff is $P_1 - i - e$.

4.3.3 PREDICTIONS

We now derive predictions for the subcontracting treatments under standard contract-theoretic assumptions. Consider first the Sub I treatment. Since in a subgame-perfect equilibrium the main contractor (builder) will choose a subcontractor (operator) making the smallest price offer, at least two subcontractors will submit offers equal to their operating costs $C(i,e)$. This implies that the selected main contractor will minimize his total costs $C(i,e)+i+e$ by choosing the high levels of both investments, $i=4$ and $e=4$. Anticipating that the principal will select a main contractor making the smallest price offer, at least two main contractors will offer the price 8. Thus, the principal obtains the total surplus, which then is 40.[22]

In the Sub II treatment, the selected subcontractor (builder) will maximize his payoff $P_1 - i - e$ by choosing the low investment levels $i=0$ and $e=0$. Anticipating that the main contractor (operator) will choose a subcontractor making the smallest offer, at least two subcontractors will offer the price 0. Knowing that the principal will choose the lowest offer and that their operating costs will be $C(0,0)=24$, at least two main contractors submit offers equal to 24. The principal obtains the total surplus, which is 24.[23]

In analogy to the main treatments, we make the following qualitative predictions.

Prediction 3. *In the Sub I treatment, the high levels of both investments will be chosen more often than in the Sub II treatment.*

Prediction 4. *The principals' payoffs will be larger in the Sub I treatment than in the Sub II treatment.*

4.3.4 RESULTS

Table 4.3 displays the key results of the subcontracting treatments summarized over all rounds and for the final round.

[22] Note again that taking into account that 1 ECU is the smallest monetary unit, there are further equilibria. Yet, the principal's payoff is always between 38 and 40.

[23] Due to the smallest monetary unit, there are further equilibria; yet, the principal's payoff is always between 22 and 24.

	all rounds		final round	
	Sub I	Sub II	Sub I	Sub II
no investments	3.4%	71.2%	0.0%	100.0%
only investment i	20.9%	14.4%	12.5%	0.0%
only investment e	10.6%	0.3%	12.5%	0.0%
both investments	65.0%	14.1%	75.0%	0.0%
investment i	85.9%	28.4%	87.5%	0.0%
investment e	75.6%	14.4%	87.5%	0.0%
principals' payoff	31.02	22.55	31.06	21.56
selected main contractors' payoff (builder)	4.98		6.06	
selected subcontractors' payoff (operator)	2.17		0.88	
selected main contractors' payoff (operator)		0.94		–2.63
selected subcontractors' payoff (builder)		5.62		5.06
total surplus	38.16	29.11	38.00	24.00

Table 4.3: The first four rows summarize the relative frequencies of the investment decisions in which no investment, only one investment, or both investments were chosen. The following two rows show the relative frequencies of all cases in which investment i and investment e, respectively, were chosen. The final rows show the parties' average payoffs and the average total surplus.

The investment behavior is again of central interest. In the Sub I treatment, the subjects' last-round investment behavior is very close to the theoretical prediction. 12 of the 16 main contractors (builders) made both investments, while 4 main contractors made one of the two investments. Altogether, the high level of each investment was chosen in 14 out of 16 cases. In the Sub II treatment, the last-round investment levels are exactly as predicted; i.e., there were no investments at all.

Looking at the investment behavior over all rounds (which is illustrated in Figure 4.9), we again have 320 investment decisions for each investment i and e per treatment. The high level of the investment i was chosen in 85.9% of the 320 cases in the Sub I treatment, while the investment e was chosen in 75.6%. The respective relative frequencies for these investments in the Sub II treatment were only 28.4% and 14.4%. Similar to our findings for the main treatments, these results indicate that the theoretical analysis also provides empirically relevant

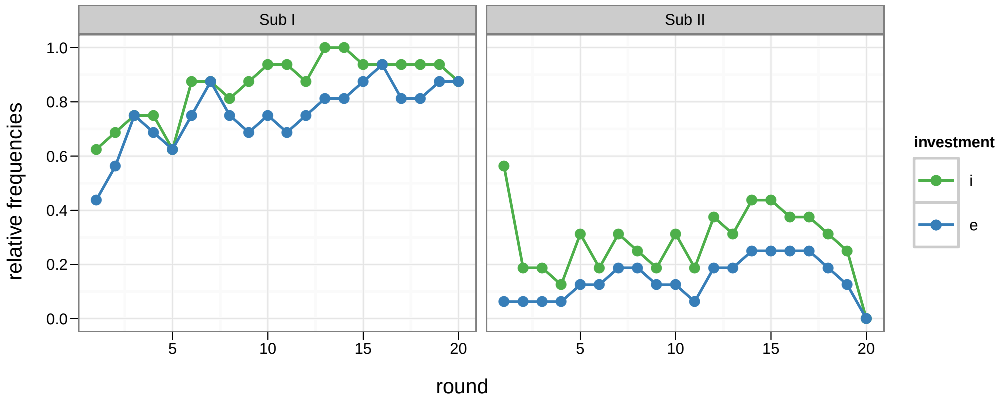


Figure 4.9: The relative frequencies with which the high levels of the investments *i* and *e* were chosen.

insights about the investment incentives in the subcontracting treatments. In particular, Prediction 3 is corroborated by the data. Not only in the final round, but also taking averages per group over all rounds, the subjects' behavior with regard to both investments differs significantly between the two subcontracting treatments.[24]

For each round, Figure 4.10 shows the average total surplus as well as the average payoffs of the principals and the selected contractors. The average total surplus is larger in the Sub I treatment than in the Sub II treatment in every round except round 1.[25] In the final round, the total surplus is again very close to the theoretical prediction. The principals again managed to obtain by far the largest share of the total surplus. The average profits of the principals are larger in the Sub I treatment (31.02) than in the Sub II treatment (22.55). Taking averages per

[24] Between treatments and for each investment, we compare the distributions of within-group average investment frequencies. The p-values of two-sided Mann-Whitney U tests with regard to the investments e and i are both smaller than 0.001. We have also compared the individual investment levels between treatments in each single round. According to χ^2 tests, the p-values regarding investment e are smaller than 0.004 in 19 rounds ($p = 0.014$ in round 1), while with regard to investment i, they are smaller than 0.005 in 18 rounds ($p = 0.719$ in round 1 and $p = 0.077$ in round 5).

[25] Comparing the distributions of the average surplus per group over all rounds between the two treatments, the p-value is smaller than 0.001 according to a two-sided Mann-Whitney U test.

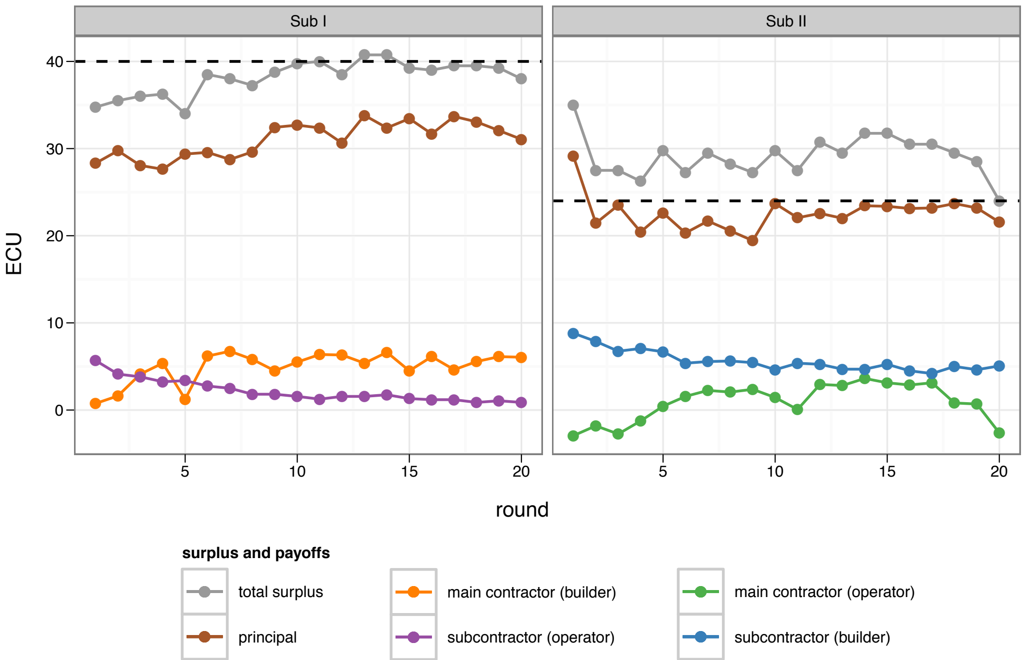


Figure 4.10: The average total surplus and the average payoffs of the principals and the selected (main and sub-)contractors. The dashed lines represent the theoretically predicted total surplus levels (40 in Sub I and 24 in Sub II).

group over all 20 rounds, the difference between the distributions of the principals' payoffs is highly significant.[26] Thus, we find strong support for Prediction 4.

Let us now look at how behavior in the two subcontracting treatments changed over time. In analogy to Figures 4.5 to 4.7, Figures 4.12 to 4.15 show for each group in both treatments the offers that were made, the offers that were selected, and the investment decisions.

Consider the Sub I treatment. As can be seen in Figure 4.13, in the vast majority of cases (98.8%), the main contractors (builders) selected the subcontractor who made the smallest offer. Hence, fierce competition between subcontractors almost completely eroded their profits over time. While the principals sometimes tried to select a main contractor not making the smallest offer, the majority of main contractors did not reply by making the desirable investment i only (see

[26] The p-value of a two-sided Mann-Whitney U test is smaller than 0.001. Comparing the individual payoffs in each round, the p-values are smaller than 0.01 in the last 15 rounds ($p < 0.08$ in rounds 2, 4, and 5, $p = 0.777$ in round 1, and $p = 0.272$ in round 3).

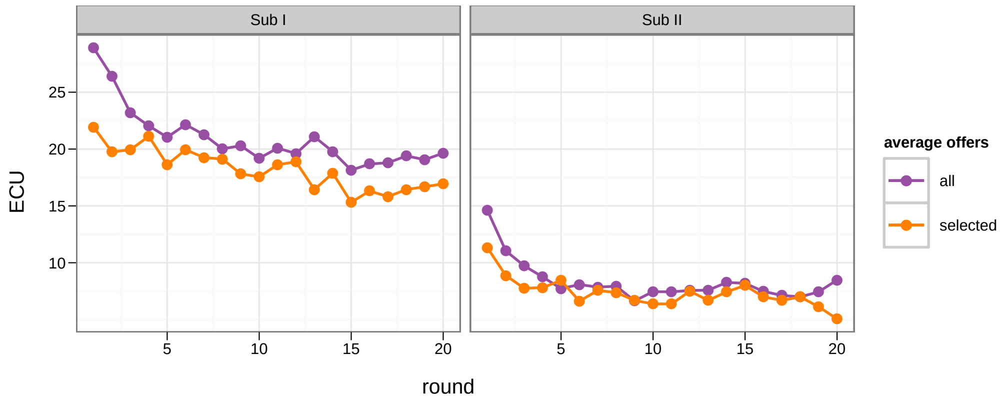


Figure 4.11: The average offers made by the builders (the main contractors in Sub I and the subcontractors in Sub II) and the average offers selected (by the principals in Sub I and by the main contractors in Sub II).

Figure 4.12).[27] The payments from the principals to the main contractors decreased over time (see the left panel of Figure 4.11), so that main contractors decided more and more often to make both investments in order to minimize their total costs. In the Sub II treatment, the principals selected the main contractor (operator) making the smallest bid in 91.9% of the cases, which triggered strong competitive pressures (see Figure 4.14). The main contractors sometimes tried not to select the subcontractor making the smallest offer (see Figure 4.15 and cf. the right panel of Figure 4.11). But if subcontractors reciprocated such offers, they often did so by making both investments (which is good for the main contractor, but not for the total surplus).[28]

[27] Specifically, the first-best investment decisions were taken in 21% of all cases, while both investments were made in 65%. If the principal did not select the main contractor making the smallest offer (which happened in 33.8% of the cases), then the first-best decisions were taken in 37% of these instances, while the majority of main contractors (46.3%) still made both investments.

[28] The subcontractors' investment decisions were no investment in 71.3%, only investment i in 14.4%, only investment e in 0.3%, and both investments in 14.1% of all cases. If the main contractors did not select the subcontractor making the smallest offer (which happened in 63.1% of the cases), then the subcontractors' investment decisions were no investment in 39.8%, only investment i in 23.7%, only investment e in 0.9%, and both investments in 35.6% of these instances.

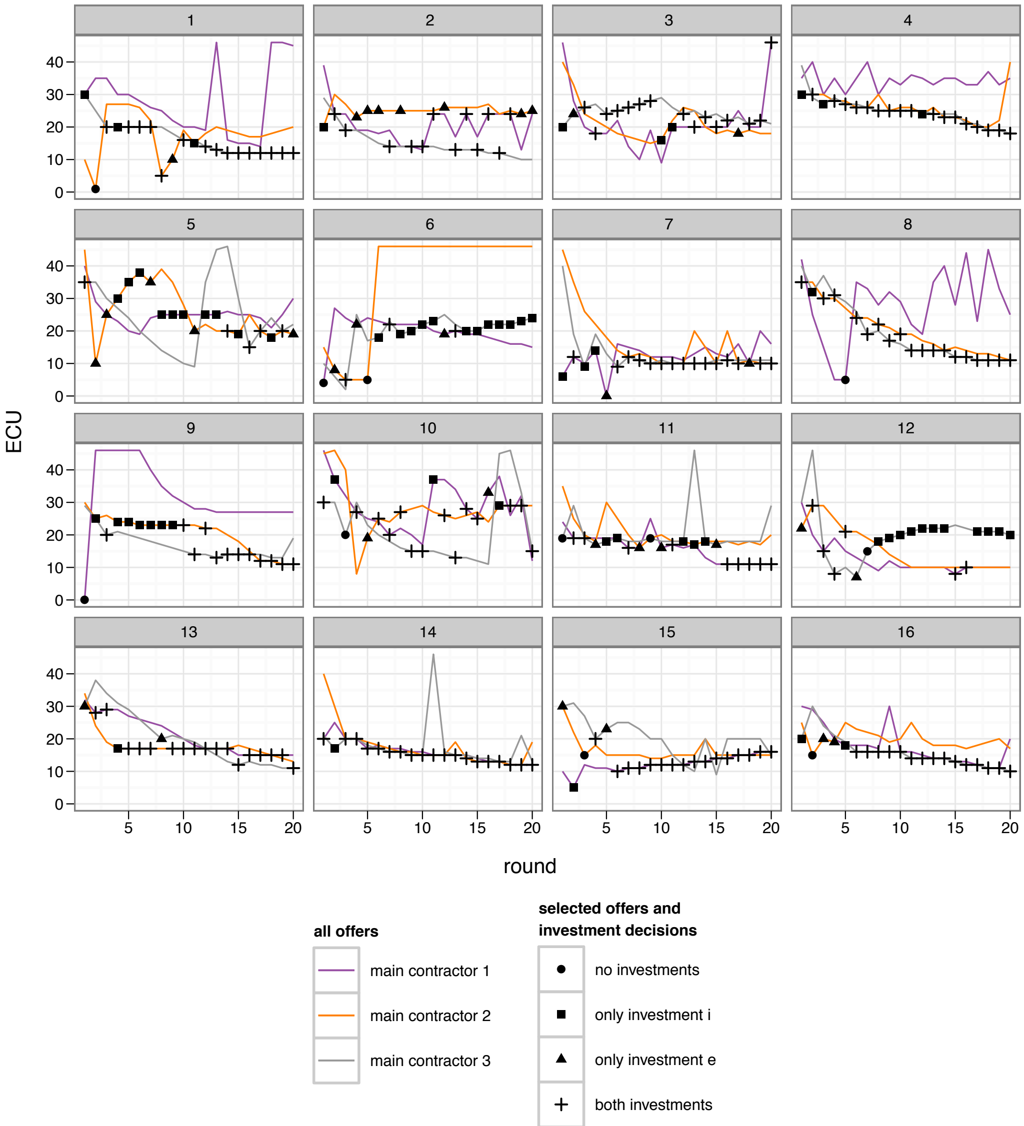


Figure 4.12: The offers made by the three main contractors (builders), the principal's choices, and the selected main contractors' investment decisions for each of the 16 groups in the Sub I treatment.

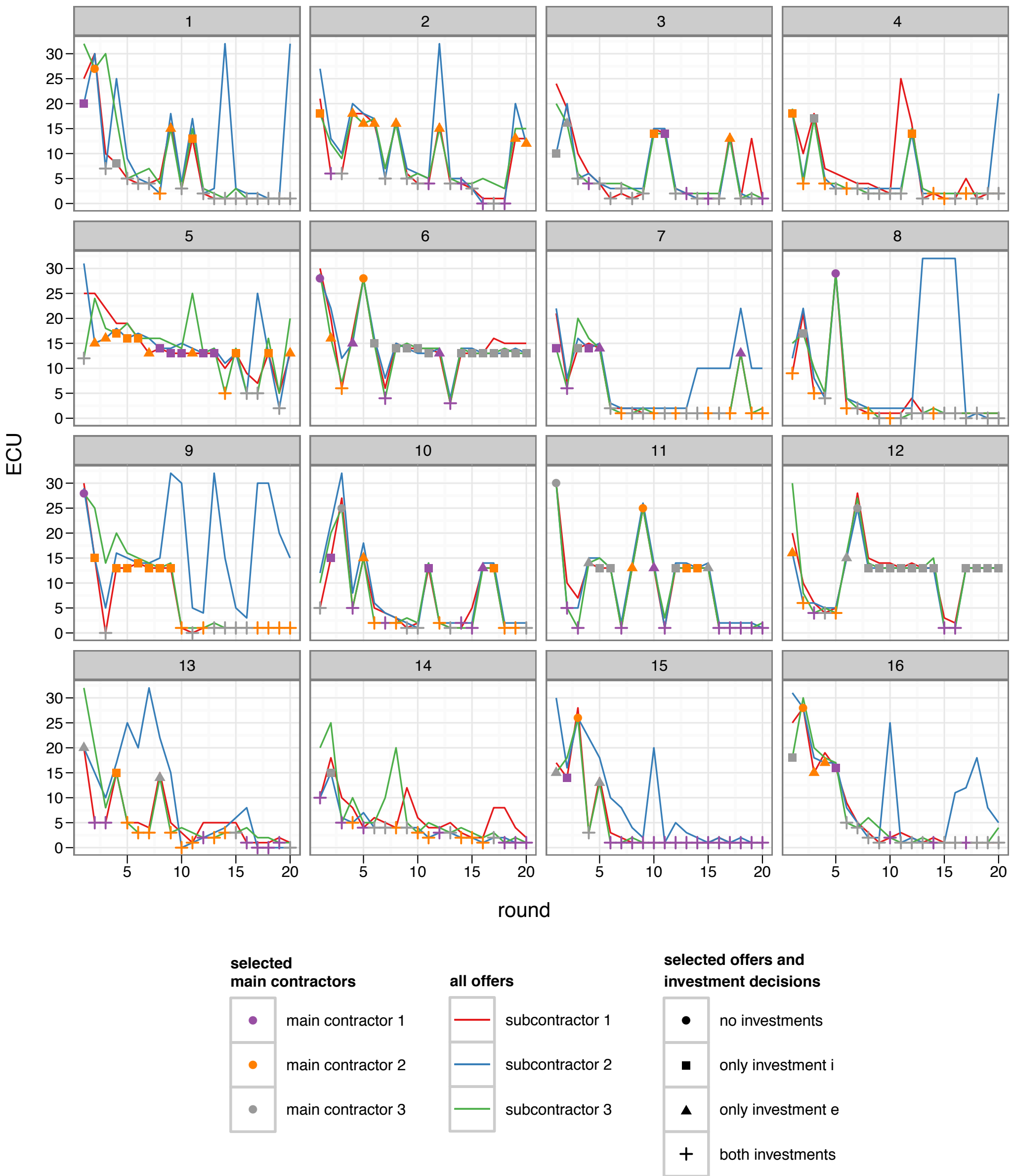


Figure 4.13: The offers made by the three subcontractors (operators) and the main contractors' choices for each of the 16 groups in the Sub I treatment. Note that the operating costs are determined by the investment decisions that were taken by the main contractors. The colors of the symbols identify which main contractor was selected by the principal (cf. Figure 4.12).

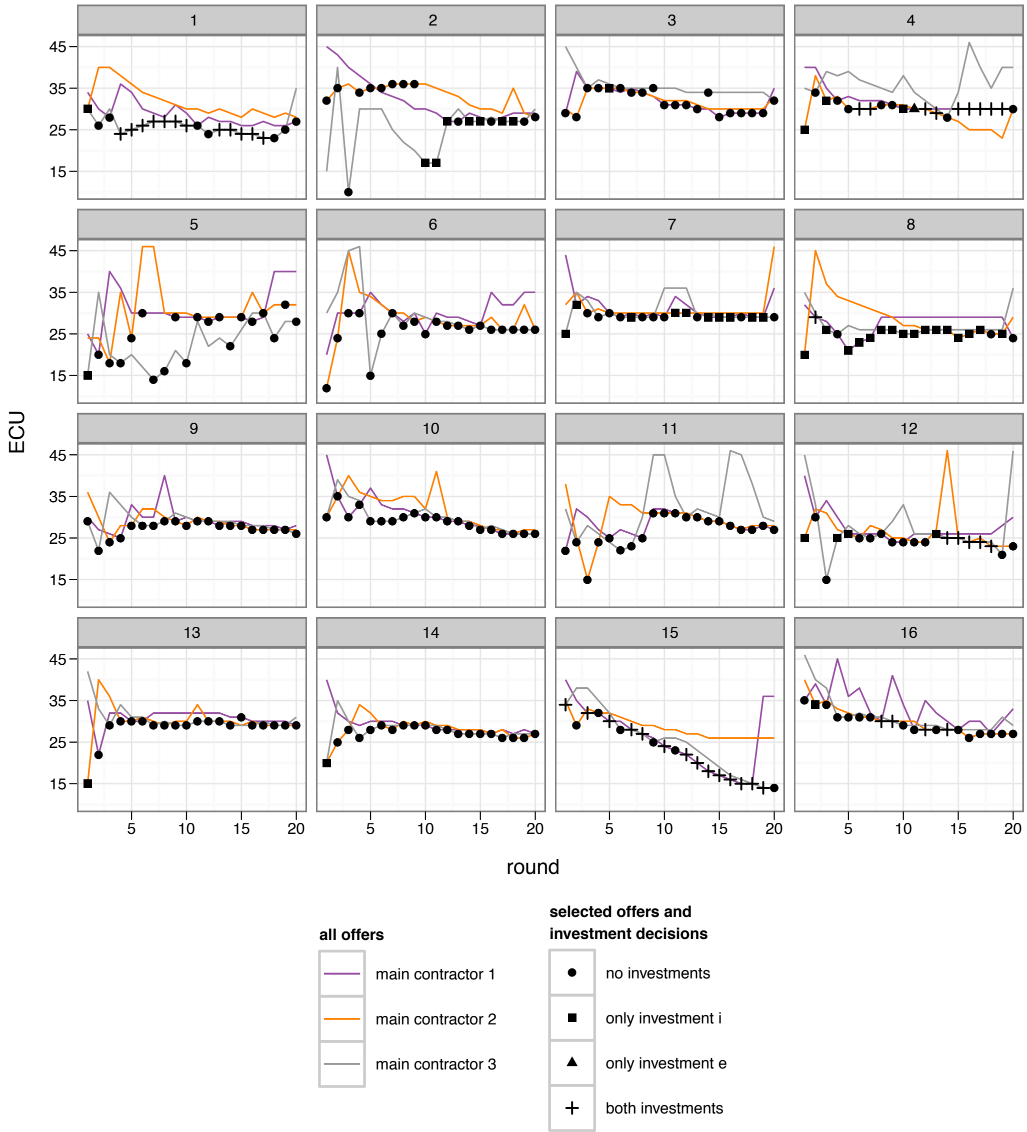


Figure 4.14: The offers made by the three main contractors (operators) and the principal's choices for each of the 16 groups in the Sub II treatment. Note that the shapes of the symbols refer to the investment decisions that will be taken by the selected subcontractors (cf. Figure 4.15).

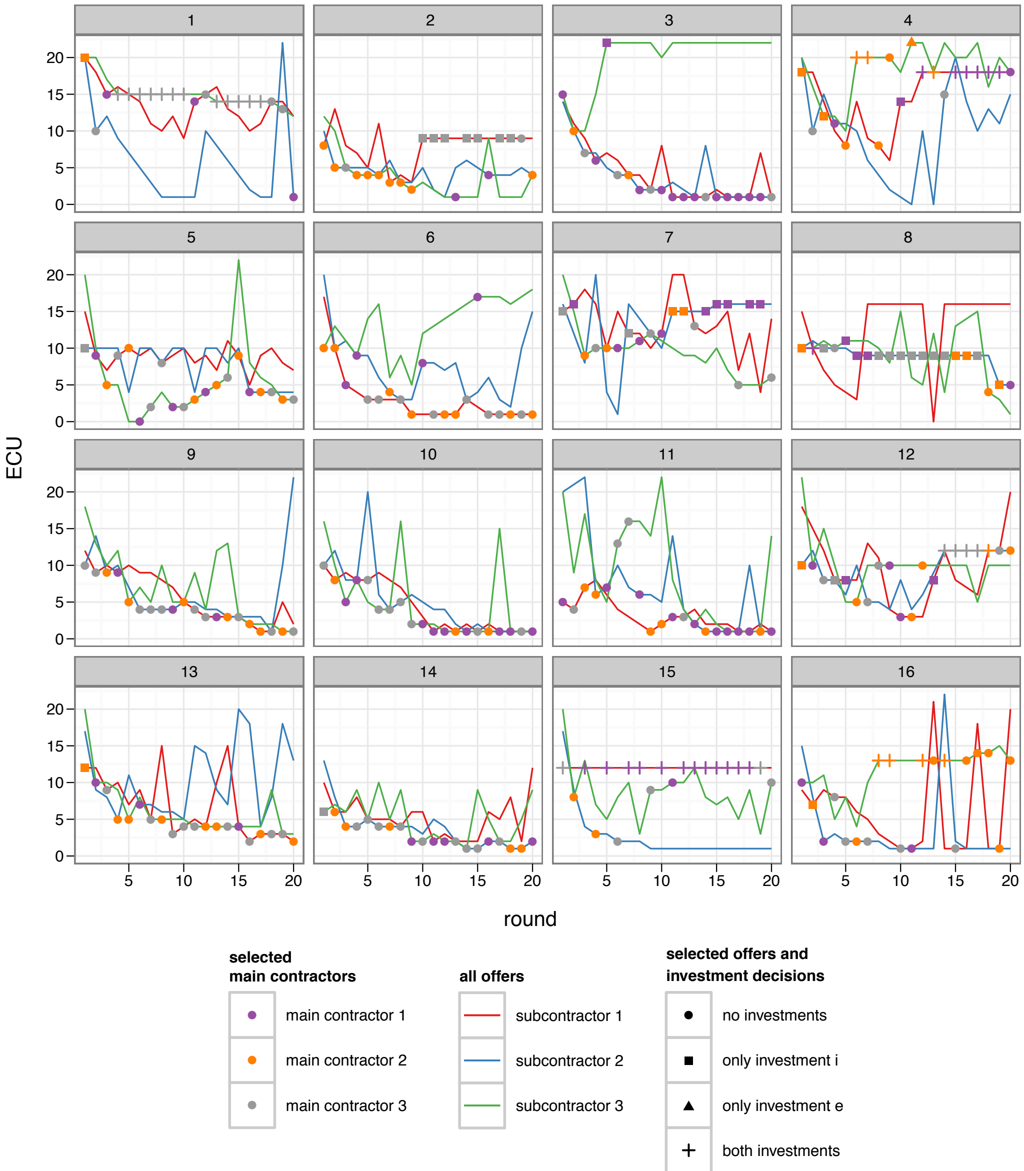


Figure 4.15: The offers made by the three subcontractors (builders) and the main contractors' choices for each of the 16 groups in the Sub II treatment. The colors of the symbols identify which main contractor was selected by the principal (cf. Figure 4.14).

4.4 CONCLUSION

Our two main treatments provide strong evidence for the fundamental trade-off identified by Hart (2003). A public-private partnership induces very strong incentives to invest in cost reductions, which is desirable if the investments are also quality-enhancing, but may well be undesirable if the investments have a negative side-effect on quality. In contrast, under traditional procurement incentives to invest are weak, both with regard to desirable as well as undesirable investments. In the experiment, we considered a parameter constellation where inducing the desirable investment was relatively more important, such that a public-private partnership would be preferable according to the theoretical analysis.

Indeed, in the experiment both kinds of investments were made much more often in the PPP treatment (in line with Prediction 1) and the principal was better off under this governance structure (in line with Prediction 2). While in the last round, almost all investment decisions were as theoretically predicted, the only noticeable deviation from the theoretical analysis was the fact that in the TP treatment, in a relevant number of cases the payments from the principals to the selected builders were relatively large, which was reciprocated by choosing high levels of the desirable investment i.[29]

In addition, we have considered two subcontracting treatments. The investment behavior and the principals' payoffs again differed between these two treatments as suggested by the theoretical analysis (supporting Predictions 3 and 4). According to the theoretical analysis, moreover there should be no differences between the PPP treatment and the Sub I treatment (where the builder is the main contractor), and similarly, there should be no differences between the TP treatment and the Sub II treatment (where the operator is the main contractor).

Figure 4.16 illustrates the average total surplus levels achieved in all four treatments. Note that in the final period, as predicted, neither PPP and Sub I nor TP and Sub II differ much from each other.

[29] It would be interesting to also conduct experiments with parameter constellations in which traditional procurement would be optimal in theory. In the light of our results, we conjecture that given such a parameter constellation, traditional procurement would then turn out to be optimal also in the experiment.

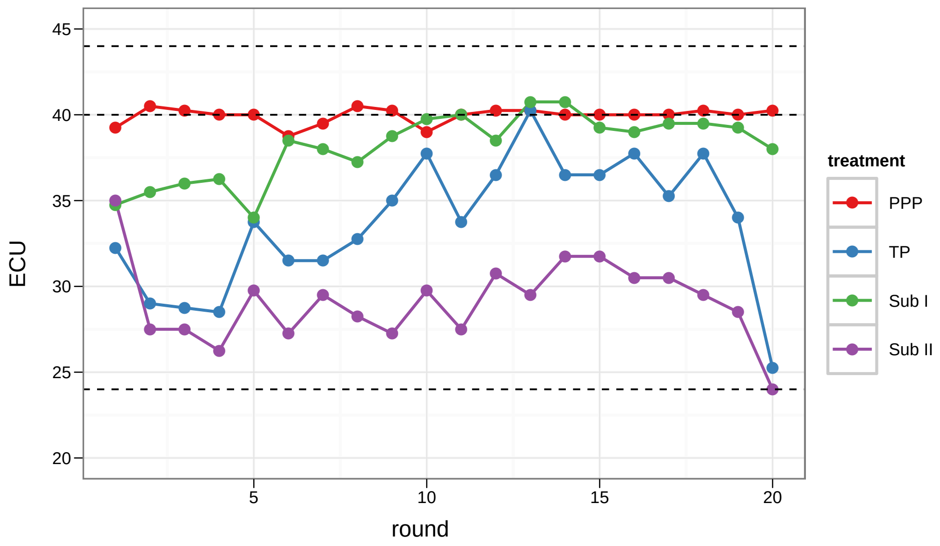


Figure 4.16: The average total surplus in the four treatments. Recall that the first-best surplus is 44. The theoretically predicted surplus is 40 in PPP and Sub I, while it is 24 in TP and Sub II.

In the somewhat more complex Sub I treatment, in the early rounds the average surplus is smaller than in the PPP treatment. Yet, in practice there might be no real choice between PPP and Sub I, since modelling the consortium as a single decision maker might best be seen as an analytical shortcut. Hence, Sub I may be considered to be the relevant alternative if (as in the parameter constellation that we have chosen in our experiment) a high level of the quality-reducing investment e is less harmful than underinvestment in i. Our experiment hence illustrates that frictions within the consortium might make a public-private partnership slightly less attractive than it appears when modelled as a monolithic entity. This result might encourage further theoretical studies of public-private partnerships to open the black box of contracting arrangements within the private consortia.

Moreover, if it is more important to avoid overinvestment in e, our experiment leads to another important insight. If the parties involved are interested in establishing reputations by acting in reciprocal ways, then traditional procurement might be superior compared to a public-private arrangement with the operator as main contractor. The reason is that if the investing party reciprocates generous payments, then it tends to do so by taking the investment decisions that are best for the main contractor in the Sub II treatment, while it takes the first-best decisions in the TP treatment. This finding suggests that paying more attention to reputation and reciprocal behavior might be an interesting avenue for future theoretical research on the organization of public procurement.

4.5 APPENDIX: INSTRUCTIONS

Supplementary material

The following instructions were handed out to the participants in the PPP treatment:

Experimental Instructions

This experiment deals with procurement projects in the public sector.

In this experiment always 4 subjects interact within a group. In each group there is a principal (representing the government) and three private contractors that could build and subsequently operate a public infrastructure (e.g., a school, a prison, or a hospital).

At the beginning of the experiment you are randomly assigned either to the role of a principal or to the role of a private contractor. You will keep your role and stay within the same group throughout the whole experiment.

The currency in the laboratory is called ECU (Experimental Currency Unit).
Your initial endowment is 75 ECU.
Throughout the whole experiment your current balance is displayed on your screen.

The experiment consists of 20 rounds.

In detail, the experiment proceeds as follows.

Each round consists of three stages:

Stage 1:
Each of the three private contractors offers the principal a price P at which he is willing to build and operate the public infrastructure.

Stage 2:
The principal selects one of the three anonymized price offers P.

The two private contractors whose price offers were not selected make zero profits in this round.

Stage 3:
The private contractor selected in stage 2 decides how much he wants to invest in building the public infrastructure. There are two kinds of investments: investment A und investment B, which cost him 4 ECU each.

The investments affect the principal's revenue and the private contractor's operating costs (see the tables on the following page).

Depending on the investment decisions, the total investment costs are:

	no investment B	investment B
no investment A	0 ECU	4 ECU
investment A	4 ECU	8 ECU

Depending on the investment decisions, the operating costs are:

	no investment B	investment B
no investment A	24 ECU	12 ECU
investment A	12 ECU	0 ECU

The selected private contractor's profit in this round equals his price offer P minus his operating and total investment costs:

	no investment B	investment B
no investment A	P – 24 ECU	P – 16 ECU
investment A	P – 16 ECU	P – 8 ECU

The principal's profit in this round equals his revenue minus the payment P to the selected private contractor:

	no investment B	investment B
no investment A	48 ECU – P	36 ECU – P
investment A	60 ECU – P	48 ECU – P

Your payoff:
After the last round your final balance will be paid out to you in cash (1 ECU = 0.07 Euro).
In case that your final balance is negative you will receive no payoff.

Please note:
During the whole experiment communication is not allowed. If you have a question, please raise your hand out of the cabin. All decisions are anonymous; i.e., no participant ever learns the identity of a person who has made a particular decision. The payment is conducted anonymously, too; i.e., no participant learns what the payoff of another participant is.

The following instructions were handed out to the participants in the TP treatment:

Experimental Instructions

This experiment deals with procurement projects in the public sector.

In this experiment always 7 subjects interact within a group. In each group there is a principal (representing the government), three builders that could build a public infrastructure (e.g., a school, a prison, or a hospital), and three operators that could subsequently operate this infrastructure.

At the beginning of the experiment you are randomly assigned either to the role of a principal, to the role of a builder, or to the role of an operator. You will keep your role and stay within the same group throughout the whole experiment.

The currency in the laboratory is called ECU (Experimental Currency Unit).
Your initial endowment is 75 ECU.
Throughout the whole experiment your current balance is displayed on your screen.

The experiment consists of 20 rounds.

In detail, the experiment proceeds as follows.

Each round consists of five stages:

Stage 1:
Each of the three builders offers the principal a price P_0 at which he is willing to build the public infrastructure.

Stage 2:
The principal selects one of the three anonymized price offers P_0.

The two builders whose price offers were not selected make zero profits in this round.

Stage 3:
The builder selected in stage 2 decides how much he wants to invest in building the public infrastructure. There are two kinds of investments: investment A und investment B, which cost him 4 ECU each.

The investments affect the principal's revenue and the operator's operating costs (see the tables in stage 5).

Depending on his investment decisions, the selected builder's profit in this round is:

	no investment B	investment B
no investment A	$P_0 - 0$ ECU	$P_0 - 4$ ECU
investment A	$P_0 - 4$ ECU	$P_0 - 8$ ECU

Stage 4:
The three potential operators learn the builder's investment decisions and thus know the operating costs.

Each of the three operators offers the principal a price P_1, at which he is willing to operate the public infrastructure.

Stage 5:
The principal learns the builder's investment decisions and selects one of the operators' anonymized price offers P_1. Then the selected operator operates the public infrastructure. The two other operators make zero profits in this round.

The selected operator's profit in this round equals his price offer P_1 minus his operating costs:

	no investment B	investment B
no investment A	P_1 – 24 ECU	P_1 – 12 ECU
investment A	P_1 – 12 ECU	P_1 – 0 ECU

The principal's profit in this round equals his revenue minus the payment P_0 to the selected builder and minus the payment P_1 to the selected operator:

	no investment B	investment B
no investment A	48 ECU – P_0 – P_1	36 ECU – P_0 – P_1
investment A	60 ECU – P_0 – P_1	48 ECU – P_0 – P_1

Your payoff:
After the last round your final balance will be paid out to you in cash (1 ECU = 0.07 Euro). In case that your final balance is negative you will receive no payoff.

Please note:
During the whole experiment communication is not allowed. If you have a question, please raise your hand out of the cabin. All decisions are anonymous; i.e., no participant ever learns the identity of a person who has made a particular decision. The payment is conducted anonymously, too; i.e., no participant learns what the payoff of another participant is.

The following instructions were handed out to the participants in the Sub I treatment:

Experimental Instructions

This experiment deals with procurement projects in the public sector.

In this experiment always 7 subjects interact within a group. In each group there is a principal (representing the government), three main contractors that could provide a public infrastructure (e.g., a school, a prison, or a hospital), and three subcontractors that could operate this infrastructure.

At the beginning of the experiment you are randomly assigned either to the role of a principal, to the role of a main contractor, or to the role of a subcontractor. You will keep your role and stay within the same group throughout the whole experiment.

The currency in the laboratory is called ECU (Experimental Currency Unit).
Your initial endowment is 75 ECU.
Throughout the whole experiment your current balance is displayed on your screen.

The experiment consists of 20 rounds.

In detail, the experiment proceeds as follows.

Each round consists of five stages:

Stage 1:
Each of the three main contractors offers the principal a price P_0 at which he is willing to provide the public infrastructure (i.e., to build it and to pay a subcontractor for subsequently operating it).

Stage 2:
The principal selects one of the three anonymized price offers P_0.

The two main contractors whose price offers were not selected make zero profits in this round.

Stage 3:
The main contractor selected in stage 2 decides how much he wants to invest in building the public infrastructure. There are two kinds of investments: investment A und investment B, which cost him 4 ECU each.

The investments affect the principal's revenue and the subcontractor's operating costs.

The principal's profit in this round equals his revenue minus the payment P_0 to the main contractor:

	no investment B	investment B
no investment A	48 ECU – P_0	36 ECU – P_0
investment A	60 ECU – P_0	48 ECU – P_0

The main contractor has to select and pay a subcontractor for operating the infrastructure. Depending on the main contractor's investment decisions, the subcontractor's operating costs are:

	no investment B	investment B
no investment A	24 ECU	12 ECU
investment A	12 ECU	0 ECU

Stage 4:
The potential subcontractors learn the main contractor's investment decisions and thus know the operating costs.

Each of the three subcontractors offers the selected main contractor a price P_1 at which he is willing to operate the infrastructure.

Stage 5:
The main contractor selects one of the three anonymized price offers P_1 and the selected subcontractor will then operate the public infrastructure. The two other subcontractors make zero profits in this round.

The selected subcontractor's profit in this round equals his price offer P_1 minus the operating costs (which depend on the selected main contractor's investment decisions in stage 3):

	no investment B	investment B
no investment A	P_1 – 24 ECU	P_1 – 12 ECU
investment A	P_1 – 12 ECU	P_1 – 0 ECU

Depending on his investment decisions, the selected main contractor's profit in this round is:

	no investment B	investment B
no investment A	P_0 – P_1 – 0 ECU	P_0 – P_1 – 4 ECU
investment A	P_0 – P_1 – 4 ECU	P_0 – P_1 – 8 ECU

Your payoff:
After the last round your final balance will be paid out to you in cash (1 ECU = 0.07 Euro). In case that your final balance is negative you will receive no payoff.

Please note:
During the whole experiment communication is not allowed. If you have a question, please raise your hand out of the cabin. All decisions are anonymous; i.e., no participant ever learns the identity of a person who has made a particular decision. The payment is conducted anonymously, too; i.e., no participant learns what the payoff of another participant is.

The following instructions were handed out to the participants in the Sub II treatment:

Experimental Instructions

This experiment deals with procurement projects in the public sector.

In this experiment always 7 subjects interact within a group. In each group there is a principal (representing the government), three main contractors that could provide a public infrastructure (e.g., a school, a prison, or a hospital), and three subcontractors that could build this infrastructure.

At the beginning of the experiment you are randomly assigned either to the role of a principal, to the role of a main contractor, or to the role of a subcontractor. You will keep your role and stay within the same group throughout the whole experiment.

The currency in the laboratory is called ECU (Experimental Currency Unit).
Your initial endowment is 75 ECU.
Throughout the whole experiment your current balance is displayed on your screen.

The experiment consists of 20 rounds.

In detail, the experiment proceeds as follows.

Each round consists of five stages:

Stage 1:
Each of the three main contractors offers the principal a price P_0 at which he is willing to provide the public infrastructure (i.e., to pay a subcontractor for building the infrastructure and to subsequently operate it).

Stage 2:
The principal selects one of the three anonymized price offers P_0.

The two main contractors whose price offers were not selected make zero profits in this round.

Stage 3:
Each of the three subcontractors offers the selected main contractor a price P_1 at which he is willing to build the public infrastructure.

Stage 4:
The main contractor selects one of the three anonymized price offers P_1. The two other subcontractors make zero profits in this round.

Stage 5:
The selected subcontractor decides how much he wants to invest in building the public infrastructure. There are two kinds of investments: investment A und investment B, which cost him 4 ECU each.

Depending on his investment decisions, the selected subcontractor's profit in this round is:

	no investment B	investment B
no investment A	P_1 – 0 ECU	P_1 – 4 ECU
investment A	P_1 – 4 ECU	P_1 – 8 ECU

The investments affect the principal's revenue and the main contractor's operating costs.

The principal's profit in this round equals his revenue minus the payment P_0 to the main contractor:

	no investment B	investment B
no investment A	48 ECU – P_0	36 ECU – P_0
investment A	60 ECU – P_0	48 ECU – P_0

The main contractor's profit in this round equals his price offer P_0 minus the payment P_1 to the subcontractor and minus the operating costs (which depend on the selected subcontractor's investment decisions):

	no investment B	investment B
no investment A	P_0 – P_1 – 24 ECU	P_0 – P_1 – 12 ECU
investment A	P_0 – P_1 – 12 ECU	P_0 – P_1 – 0 ECU

Your payoff:
After the last round your final balance will be paid out to you in cash (1 ECU = 0.07 Euro). In case that your final balance is negative you will receive no payoff.

Please note:
During the whole experiment communication is not allowed. If you have a question, please raise your hand out of the cabin. All decisions are anonymous; i.e., no participant ever learns the identity of a person who has made a particular decision. The payment is conducted anonymously, too; i.e., no participant learns what the payoff of another participant is.

Chapter Five

Behavioral biases and cognitive reflection

5.1 INTRODUCTION

Only recently, researchers have started to investigate the impact of cognitive ability on judgment and decision making. Frederick (2005) introduces the cognitive reflection test (CRT) which is a simple, three-item test to measure a person's mode of reasoning and cognitive ability.[1] Frederick (2005) shows that people with high CRT scores are generally more patient and more willing to gamble in the domain of gains.[2] In a related study, Oechssler et al. (2009) replicate the findings regarding time and risk preferences and in addition they study the relationship between cognitive abilities and the conjunction fallacy, conservatism, and anchoring.[3] One central result is that individuals with low cognitive abilities tend to be significantly more affected by behavioral biases.

In the present study, we investigate whether the incidence of further behavioral biases is related to cognitive abilities. Specifically, we study the base rate fallacy, overconfidence, and the endowment effect. Moreover, we replicate the finding of Oechssler et al. (2009) related to the conservatism bias in order to investigate an interesting question that was brought up in their paper. Are people that exhibit the conservatism bias (i.e., overweight the base rate) less susceptible to the base rate

[1]The CRT has recently also been used to assess the decision making processes of professional groups such as judges and financial planners, see Guthrie et al. (2007) and Nofsinger and Varma (2007).

[2]Using other measures of cognitive ability, Brañas-Garza et al. (2008) and Slonim et al. (2007) also study whether there are relations between cognitive abilities and risk or time preferences.

[3]See also Bergman et al. (2010), who analyze the anchoring effect and find that the amount of anchoring decreases but does not vanish with higher cognitive ability.

fallacy (i.e., to underweight the base rate)? We observe the contrary. In particular, we find that individuals with lower cognitive abilities are significantly more likely to exhibit both, the base rate fallacy and the conservatism fallacy. With regard to overconfidence, we find that subjects with higher CRT scores have a significantly more precise self-assessment. Finally, test scores do not affect the occurrence of the endowment effect which is striking in both, low and high CRT groups.

5.2 EXPERIMENTAL DESIGN

The experiment was conducted in July 2009.[4] Using ORSEE (Greiner, 2004), we recruited the participants from the subject pool of the Cologne Laboratory for Economic Research. In total, 414 students from the University of Cologne participated in the experiment. Following several socio-demographic questions (concerning gender, age, field of study, and length of study), the subjects had to fill in a questionnaire consisting of three questions building the CRT and several questions related to the behavioral biases mentioned in the introduction.[5] Participants were given 15 minutes to fill in the questionnaire and the experimenter stopped the experiment after the time was over.[6]

Subjects were paid 0.40 € for each CRT question they answered correctly. Moreover, for the decision problems related to the base rate fallacy and conservatism, they received 0.40 € if their answer did not deviate more than 15 percentage points from the correct answer. Regarding overconfidence, subjects had to answer five general knowledge questions and they had to assess how many of these they answered correctly. For each correct answer (including the assessment question) they received 0.20 €. Finally, with regard to the endowment effect, subjects could receive additional 0.20 € or, alternatively, take a highlighter home. In total, subjects earned between 0 € and 2.80 €, and the average payoff

[4]It was run subsequent to an unrelated principal-agent experiment (see Hoppe and Kusterer, 2011b and Chapter 3 of this thesis). In this previous experiment, the participants earned 11.03 € on average including a show-up fee of 4 €. The sessions lasted between 30 and 40 minutes.

[5]Subjects found a calculator, a pen, and a piece of paper in their cabin.

[6]Note that only three participants did not complete the questionnaire within the given time limit so that our analysis is based on 411 completed questionnaires.

was 1.24 €. Moreover, 180 subjects left the lab with a brand new highlighter. The experiment was programmed and conducted with z-Tree (Fischbacher, 2007).

5.3 COGNITIVE REFLECTION TEST

To measure cognitive ability, we use the three-item cognitive reflection test (CRT) that was introduced by Frederick (2005). The three questions are designed such that they have an intuitive but wrong answer that comes to mind quickly and a correct answer that is easy to understand when explained. Hence, the test is supposed to measure a person's ability to engage in cognitive reflection and thus to resist reporting the spontaneous but wrong answer. In particular, the three questions read as follows.

1. A bat and a ball together cost 110 cents. The bat costs 100 cents more than the ball. How much does the ball cost? (spontaneous answer: 10 cents; correct answer: 5 cents)

2. If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets? (spontaneous answer: 100 min; correct answer: 5 min)

3. In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake? (spontaneous answer: 24 days; correct answer: 47 days)

In our sample, 13% of the subjects answered none of the questions correctly, 24% knew the correct answer to one question, 27% to two questions, and 36% answered all three questions correctly. On average, the subjects answered 1.84 of the CRT questions correctly.[7]

[7] There is a strong gender difference: male subjects have an average score of 2.12, while female subjects have an average score of 1.61 only. The difference is highly significant ($p < 0.0001$, two-sided Mann-Whitney U test). This gender difference has also been found in other studies using the CRT, e.g. Frederick (2005) and Oechssler et al. (2009).

Question	Correct	Intuitive	Other
Bat and ball	56.7%	39.9%	3.4%
Widgets	58.9%	28.2%	12.9%
Lily pads	68.9%	16.1%	15.1%

Table 5.1: Distribution of answers to the CRT questions.

Table 5.1 shows the distribution of the answers to the CRT questions. For each question, the majority of the subjects gave the correct answer. Among the subjects who did not submit the correct answer, the intuitive answer was given most frequently.

5.4 RESULTS

The central results of our study are summarized in Tables 5.2 and 5.5. Depending on their CRT score, we divide the participants in two groups. The "low" group consists of individuals who answered zero or one of the questions correctly, while the "high" group consists of participants that gave the correct answer to two or three questions.[8] We refer to subjects in the "high" group as the more *analytical* decision takers, while we describe subjects in the "low" group as relatively *intuitive* decision takers.

5.4.1 BASE RATE FALLACY

When people are asked to judge the probability of an event, they often have to take into account information about the base rate probability and at the same time, they have to consider specific evidence about the case at hand (Tversky and Kahneman, 1982). In such a context, they exhibit the base rate fallacy if they follow the representativeness heuristic and neglect the base rate probability.

[8]This categorization was used by Oechssler et al. (2009). We also considered the categorization of Frederick (2005) who assigned subjects with zero correct answers to the "low" group and those with three correct answers to the "high" group. However, with regard to our data this would imply not to analyze more than 53 % of the observations. Note that the latter categorization would not change our results qualitatively.

Category	Item	CRT group low	CRT group high	p-value
Base rate fallacy	Avg. prob. stated (correct: 9%)	77.4%	61.5%	$p \approx 0.0002$
Conservatism	Avg. prob. stated for urn A (correct: 97%)	56.8%	60.1%	$p \approx 0.056$
Overconfidence	% overconfident	60.7%	57.4%	$p \approx 0.056$
	% correct self-assessment	23.2%	32.4%	
	% underconfident	16.1%	10.2%	

The p-values regarding the base rate fallacy and the conservatism bias result from two-sided Mann-Whitney U tests, while the p-value regarding overconfidence is obtained using a two-sided χ^2 test.

Table 5.2: Behavioral biases by CRT group.

In analogy to the mammography problem in Eddy (1982), subjects in our study faced the following problem: "In a city with 100 criminals and 100,000 innocent citizens there is a surveillance camera with an automatic face recognition software. If the camera sees a known criminal, it will trigger the alarm with 99% probability; if the camera sees an innocent citizen, it will trigger the alarm with a probability of 1%. What is the probability that indeed a criminal was filmed when the alarm is triggered?" The correct answer is $\approx$ 9%, but in both CRT groups, a large fraction of the subjects stated a probability larger than 90%. These subjects exhibit the base rate fallacy since they do not or barely consider the low base rate of criminals in the population. However, compared to the low CRT group, subjects in the high CRT group are considerably less susceptible to this bias and state the correct probability more often (see Figure 5.1).[9]

It is also striking that the average CRT score of subjects who correctly take into account the small base rate is considerably larger than the average CRT score of subjects who exhibit the base rate fallacy (see Table 5.3).

[9]In the high CRT group, 19.1 % of the subjects choose 9 or 10 % as their answer, while in the low CRT group, this answer is stated in only 9.7 % of the cases ($p = 0.01$, two-sided χ^2 test). Moreover, the average probability assessed by the subjects in the high CRT group equals 61.5%, which is significantly smaller than 77.4%, the average probability assessed in the low CRT group.

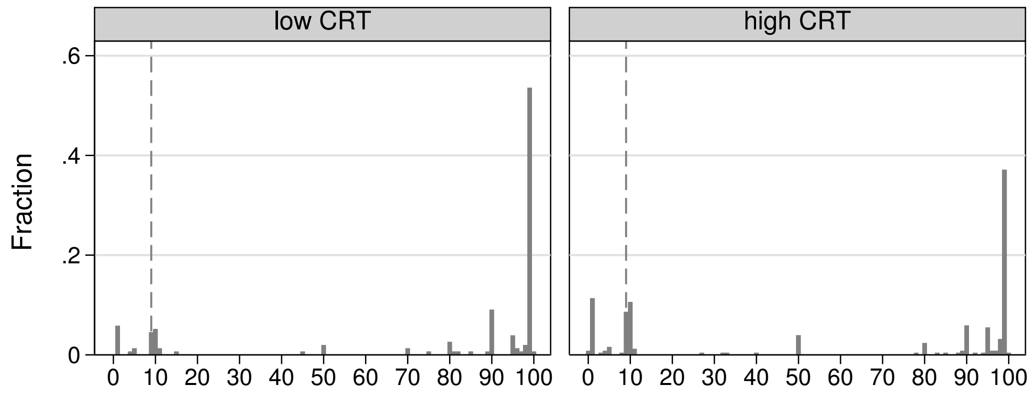


Figure 5.1: Distribution of probabilities stated for the base rate fallacy problem. The dashed line indicates the correct answer.

Prob. stated	Average CRT score	n
0–10 %	2.16	115
11–90 %	1.74	76
91–100 %	1.72	220

Table 5.3: Average CRT scores for categorized answers to the base rate fallacy problem.

5.4.2 CONSERVATISM BIAS

While people that exhibit the base rate fallacy underweight base rates, there are also situations where base rates are overweighted relative to sample evidence. In such situations, subjects are too conservative in adapting prior probabilities to new evidence, and hence this fallacy is called conservatism bias. In order to test whether the tendency to exhibit this fallacy is related to a person's CRT score, we confronted the subjects with the following problem that was first studied by Edwards (1968): "There are two urns; each one contains ten balls. Urn A contains 7 red and 3 blue balls, while urn B contains 3 red and 7 blue balls. One urn is randomly chosen by flipping a fair coin. 12 balls are now drawn from this urn with replacement. The result is the following: 8 red and 4 blue balls were drawn. What is the probability that the randomly drawn urn is urn A when observing this result (8 red and 4 blue balls)?" The correct answer is 97 %, but many subjects (34 % in the low CRT group and 28 % in the high CRT group) simply entered

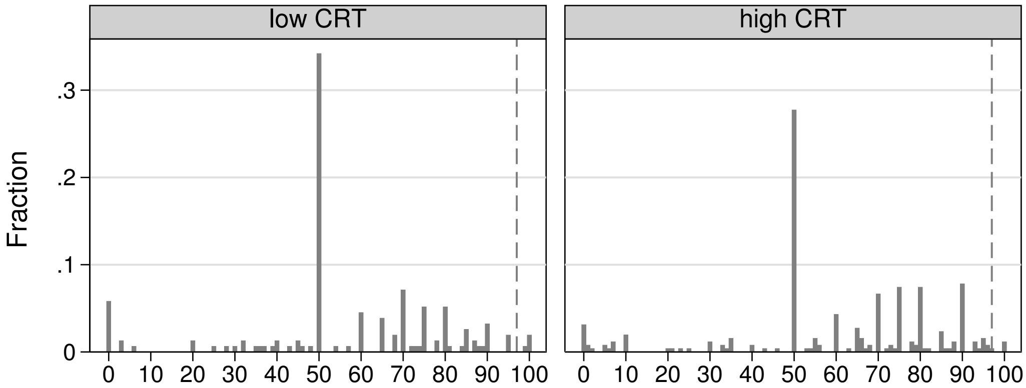


Figure 5.2: Distribution of probabilities stated for the conservatism problem. The dashed line indicates the correct answer.

Prob. stated	Average CRT score	n
0–49 %	1.68	70
50 %	1.73	124
51–89 %	1.90	171
90–100 %	2.20	46

Table 5.4: Average CRT scores for categorized answers to the conservatism problem.

the base rate of 50 % as their answer (see Figure 5.2). The average answer in the low CRT group is 56.8 %, while it is 60.1 % in the high CRT group. The fact that the intuitive decision takers' average answer is closer to the base rate than the analytical decision takers' average answer shows that the former group is more heavily affected by the conservatism fallacy than the latter group.

Again, it is remarkable that subjects whose answer is close to the correct one have a larger CRT score on average (see Table 5.4). This indicates that more reflection and analytical reasoning is helpful to prevent falling for the bias.

5.4.3 OVERWEIGHTING AND UNDERWEIGHTING OF BASE RATES

The results in Sections 5.4.1 and 5.4.2 show that subjects with a low CRT score are on the one hand more inclined to neglect base rates when facing a representativeness problem, but on the other hand they also tend to overemphasize prior information when confronted with conservatism problems. In this context, Oechssler et al. (2009) raise the question whether subjects who exhibit a conservatism bias (i. e., who overweight base rates) are less likely to neglect base rates in representativeness problems. We cannot find evidence for this conjecture. It turns out that subjects who neglect the base rate also tend to overemphasize prior information stronger than subjects who are not susceptible to that bias.[10] It seems to be simply the framing of these problems which leads low CRT subjects to focus more heavily on very salient pieces of information and not to process all available information correctly.

5.4.4 OVERCONFIDENCE

We asked the subjects five questions related to general knowledge. After answering the questions, they were also asked to estimate the number of general knowledge questions they had answered correctly.[11] Within each CRT group, we divided the participants into three subgroups. Subjects were classified as being overconfident (underconfident) when the estimated number of correct answers was larger (smaller) than the actual number, and otherwise they were classified as assessing the number of right answers correctly.

Compared to the low CRT group, relatively more subjects in the high CRT group assessed their number of right answers correctly (see Table 5.2). The difference is statistically significant. While the more intuitive decision takers are

[10]For this specific question, we restricted our analysis to a subset of subjects who, for each bias, either clearly exhibited the bias or stated the correct answer. Concerning the base rate neglect problem, subjects exhibit this fallacy when their answer is $\geqslant 90\,\%$, while they do not if their answer is 9 % or 10 %. Concerning the conservatism problem, subjects overemphasize prior information when their answer equals 50 %, while they do not if their answer is $\geqslant 90\,\%$. There are 100 subjects who neglect the base rate of which 76 also overweight prior information, while of the 30 subjects who do not neglect the base rate, only 18 overweight prior information (two-sided χ^2 test, $p = 0.086$).

[11](1) What is the distance between earth and sun in astronomical units? a) 587; b) 1; c) 4553; d) 14. (2) How many inhabitants does the Saarland (a German federal state) have? a) 2,132,000; b) 1,670,000; c) 1,037,000; d) 890,000. (3) In which year did Albert Einstein die? a) 1955; b) 1947; c) 1961; d) 1938. (4) Who is the author of "Wilhelm Tell"? a) Johann Wolfgang von Goethe; b) Friedrich Schiller; c) Friedrich Hölderlin; d) Theodor Fontane. (5) Which metropolitan area has the largest number of inhabitants? a) Shanghai; b) Istanbul; c) Los Angeles; d) Moscow. (6) What do you think: how many of the preceding questions have you answered correctly?

	CRT group		
	low	high	p-value
Scenario 1	61.0 %	67.0 %	$p \approx 0.38$
Scenario 2	20.6 %	24.2 %	$p \approx 0.55$

The p-values result from a two-sided χ^2 test.

Table 5.5: Endowment effect: Fraction of subjects buying the highlighter per scenario and CRT group.

relatively less successful in assessing the right number of correct answers, there is no clear tendency that they are more overconfident than the analytical decision takers (in the low CRT group, the share of subjects being overconfident and also the share of underconfident subjects is larger than in the high CRT group).

5.4.5 ENDOWMENT EFFECT

In experimental economics, it is often observed that subjects' willingness to pay differs substantially from their willingness to accept (see e.g. Horowitz and McConnell, 2002). This phenomenon is often explained by the endowment effect (Kahneman et al., 1991). In our experiment, half of the subjects found a yellow 'Stabilo Boss' highlighter on the desk in their cabin (scenario 1) while the other half of the subjects was given the opportunity to buy such a highlighter from the experimenter when leaving the laboratory (scenario 2). At the end of the questionnaire, subjects in scenario 1 faced the following decision: "From now on, the yellow highlighter on your desk belongs to you. You can decide between the following alternatives: (1) I take the highlighter home when leaving the laboratory; (2) When the payment is conducted, I sell the highlighter to the experimenter at a price of 0.20 €. In case 2, 0.20 € are added to your profit realized in the experiment." In contrast, subjects in scenario 2 saw a bowl with highlighters when entering the lab and at the end of the questionnaire they were confronted with the following decision: "When the payment is conducted, you can buy a yellow 'Stabilo Boss' highlighter at a price of 0.20 €. (1) I want to buy a yellow highlighter; (2) I do not want to buy a yellow highlighter. In case 1, you will receive 0.20 € less."

Overall, we find very strong evidence for the endowment effect. When the highlighter is in the cabin (scenario 1), 64.6% of the subjects decided to take the highlighter home, while only 22.9% of the subjects decided to buy it when the payment is conducted (scenario 2). This difference is highly significant ($p < 0.0001$, two-sided χ^2 test). However, higher cognitive ability does not reduce the susceptibility to the endowment effect (see Table 5.5).[12]

To conclude, is subjects' performance on the CRT a good predictor for their susceptibility to behavioral biases? While we have found strong evidence that this is indeed the case for the base rate fallacy and the conservatism bias, the susceptibility to the endowment effect does not vary with the CRT score. Hence, our results suggest that the CRT has strong predictive power only for biases that may arise in problems for which there exists a correct solution and where analytical skills are helpful to derive this solution.

[12]Note that the endowment effect is the stronger, the larger is the difference in buying decisions between the two scenarios. In the high CRT group this difference is 42.8%, while it is 40.4% in the low CRT group.

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