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An Experimental Test of Overconfidence as a Cause of Over- and Underinvestment in Conflict

Abstract

Overconfidence has been proposed as a cause of conflicts. However, there is little empirical evidence for this claim. We test overconfidence as a cause of over- and underinvestment in conflicts in a computerised experiment. First, we derive a model where overconfidence explains over- and underinvestment in conflict. We then test the predictions of this model in a laboratory experiment, both on a group level and with individual level regressions. Even though true overconfidence was successfully induced in the experiment, we do not find support for overconfidence as a cause of overinvestment in conflict, but weak support for overconfidence as a cause of underinvestment.

Key Words: Conflict, overconfidence, experiment, imperfect information

JEL Classification: C72; C91; D03; D74; D83

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Know thyself, and know thy enemy,
and you shall never be defeated
in a hundred battles.
- Sun Tzu

1. Introduction

In 1941, having conquered the main part of continental Europe, the German Third Reich launched its invasion of the Soviet Union, known as Operation Barbarossa. When the war ended four years later, the Third Reich had fallen, and the loss of life has been estimated to approximately 60 million people worldwide, in addition to costs of the entire World War of over one trillion dollars not including the immense costs of all capital destroyed in the course of the war[1]. One oft-proposed explanation for the German failure is that Hitler overestimated Germany's military capabilities relative to the Soviet Union, a phenomenon referred to as overconfidence. The German invasion of the Soviet Union can be seen as a case of overinvestment in conflict. However, another possible, but more counterintuitive effect of overconfidence may be underinvestment in conflict. This is perhaps an explanation for the failure of the two late 20th century military superpowers, the Soviet Union and the USA, in conflicts with much inferior opponents, namely Afghanistan and Vietnam. Similarly, there are cases when powerful nations have been overrun by opponents, potentially due to underinvesting in conflicts as a result of overconfidence in their ability. Some examples include the Chinese defeat in the Opium War, or the defeat of the Romans at the hands of the Goths at Adrianopolis. Wars of this kind are costly, but they are not the only instance of conflicts in society. Other kinds of conflicts, such as court cases and strikes, induce costs on society as a whole, and act as distortions in the economy. Hence, from an economical perspective, there is a clear interest in studying conflicts.

To an economist, the concept of conflicts seems puzzling. According to the Coase theorem (Coase 1960), which is one of the founding concepts of neoclassical economic theory, under the assumption that agents will maximise their utility given their constraints in a setting with perfect information and perfect property rights that can be enforced without cost, the agents will attain the socially optimal outcome. However, such a setting is seldom found in the real world. Instead, in many cases property rights are not clearly defined, and are costly to enforce (Dixit 2004). Consequently, it is in such settings that conflict situations most commonly occur (Garfinkel and Skaperdas 2007).

[1] According to the Encyclopedia Britannica.

However, even in a setting with imperfectly defined and enforced property rights, the Coase theorem stipulates that agents would be able to bargain given their relative strengths, and thus reach a peaceful settlement whereby the resource over which they bargained would be divided in such a way that each agent's respective gains are equal or larger than the gains that the parties would have made had a conflict ensued. If this were the case, we would never observe any conflicts. Weaker nations would surrender resources and land to the stronger opponent up to the point where the marginal cost of losing the land equals the marginal cost of defending it, or the marginal benefit of the land to the opponent equals his marginal cost of taking it by force. Of course, this reasoning would apply to court cases too, where litigants would bargain up to the point where the marginal benefits and costs equal the marginal costs of hiring attorneys. Thus, in the framework of the Coase theorem, absence of property rights is a necessary, but not sufficient, condition for conflicts to occur.

A bargaining agreement would, however, only be certain in a world with perfect and symmetric information, and conflicts are situations which are inherently characterised by information imperfections, i.e. von Clausewitz's proverbial "fog of war" (von Clausewitz, 1832). If it were the case that agents were uncertain about, or even misjudged, their relative strengths, they might no longer be able to reach the peaceful bargaining equilibrium proposed by the Coase theorem. If one of the agents overestimates his relative strength, and the counterpart does not equally underestimate his relative strength, an optimal contract cannot be achieved, as the agents will disagree on the division of the resource that would result from a conflict. Thus, the agents' cumulative claims of the resources will sum up to above one hundred per cent. In such a setting, the agents may resort to conflict measures to claim the contested resource.

That agents overestimate their relative strengths, and therefore engage in costly conflict, is an argument which has repeatedly been proposed (Blainey 1973; Tuchaman 1984). This argument has also been put forward by Hirshleifer (2001), who argues that one reason for the occurrence of conflicts could be mistaken judgments of agents' relative capabilities. This claim is conceptually very similar to the phenomenon often referred to as overconfidence, which has repeatedly been studied, within the field of psychology (e.g. Moore and Healy 2008) and within behavioural economics (e.g. Camerer & Lovallo 1999; Van den Steen 2004; Barber and Odean 2000). However, empirical studies of overconfidence in conflicts have been few and far between.

In the existing literature, overconfidence as a reason for the outbreak of conflicts, and overinvestment therein, has been repeatedly proposed. However, as pointed out earlier, there are clear cases when overconfidence may have caused underinvestment in conflicts. Just as the overinvestment case, underinvestment in conflicts could be costly for the individual agent. Therefore, the relationship between overconfidence and over- and underinvestment in conflicts is a subject worthy of further study.

Beyond being proposed as a factor affecting conflict behaviour, overconfidence has been incorporated into conflict models to explain their relationship theoretically (Ando 2004; Hanson 2006; Johnson and Fowler 2011). However, these models are incapable of explaining overconfidence as a cause of underinvestment. Further, there is a lack of empirical studies investigating causal effects of overconfidence in conflicts and empirical evidence is a scientific necessity to justify a claim. Thus, the purpose of this thesis is to test the predictions of a theoretical model against experimental data, to see if overconfidence can cause over- and underinvestment in conflicts.

Our approach is as follows. In Section 2, we present a review of previous literature on the concepts of conflict and overconfidence, and the relation between the two. In Section 3 we formally model overconfidence in a predator-prey conflict model. Based on this model, we formalise hypotheses, which are presented in Section 4. The experimental design is described in Section 5, followed by an explanation of the empirical methodology in Section 6. Our results are presented in Section 7. Finally, Section 8 summarises and discusses our findings.

2. Previous Research

In this section, we define the concepts of conflicts and overconfidence. Moreover, we review the previous literature in economics related to these concepts.

2.1. Conflicts

We shall now go through some of the literature on conflicts within the field of economics, and some of the experimental studies that have been conducted. Before delving deeper into the theoretical modelling, we will need to more clearly define the concept of conflict, and how it relates to similar and sometimes partially overlapping, concepts.

According to Garfinkel and Skaperdas (forthcoming), "a *conflictual* situation is one in which two or more actors engage in the choice of costly inputs that (i) are *adversarially* combined against one another and (ii) generate no positive external effects for third parties". The first condition means, in economic terms, that agents invest resources in income redistribution instead of productive use. The second condition of the definition excludes phenomena such as sports and other competitions where the adverse combination of costly inputs may create benefits for third parties. An additional aspect we add to this definition is that the resource claimed is held by another agent, and not an exogenous pool, which is the case in rent-seeking (see Tullock 1980).

Conflicts differ from the concept of opportunism, defined by Williamson (1979) as "self-interest seeking with guile", in that when discussing opportunism, we are still in the world of perfect property rights. Rather, opportunism mostly deals with, in the framework of Dixit (2004), situations with imperfect contracts. One of the more classic examples of opportunism is the hold-up problem, in which an agent uses (or abuses) the dependency of another agent. For instance, the case of an agent exploiting the fact that another agent has made a relation-specific investment is a common example of the hold-up problem. This is clearly distortive in the economic sense, but there is no adverse combination of resources involved. Hence, it fails to fulfil the first condition in the definition by Garfinkel and Skaperdas (forthcoming).

Another group of theoretical constructs similar to conflicts are Directly Unproductive Profit-seeking (DUP) activities (Bhagwati 1982). Two main differences between conflicts and DUP activities are that conflicts must entail two or more actors, who attempt to redistribute resources from each other, which is not necessarily the case with a DUP, and that DUPs may also create positive externalities, which may increase aggregate outcomes in the economy, and may thus constitute a Pareto improvement. In the framework used by Bhagwati (1982), conflicts can thus be seen as a type of DUP activity, whereby resources that could be used for production are taken out of the regular production function, thus reducing the over-all output "pie", and instead invested in trying to redistribute the existing resources in a way that is more profitable for the individual agent. In essence, this means that all conflicts are DUP activities, but not all DUP activities are conflicts.

Having settled the theoretical boundaries of conflicts to other similar constructs, we now review the literature on how conflicts have been modelled within the field of economics. One of the first scholars to study models with both production and appropriation was Haavelmo (1954). However, his contribution was long overlooked, and it is only relatively recently that the modelling of conflicts as economic phenomena has begun to catch momentum, with contributions from, among others, Hirschleifer (1991), Skaperdas (1992), Wärneryd (1993), and Grossman and Kim (1995). What these kinds of models have in common is the notion of a "conflict technology function" (Hirshleifer 1989), henceforth referred to as conflict function[2], which is not productive, but instead is used to change the allocation of resources within the economy. Thus, one can see this economy as having two separate production functions; one regular production function where inputs generate outputs, and one redistributive conflict function.

Hirschleifer (1991) studies a model of production and appropriation in which the agents engage in joint production of a resource pool. How this pool is divided between the agents is then decided by their investments in a conflict function. This model can be seen as reflecting the power struggle between different interest groups within an organisation, such as a firm or a nation, who together produce a resource "pie", which they then must decide how to split. This, however, always results in investment in the conflict function by both parties. Hence, there is no scope for a peaceful equilibrium in this model.

Unlike Hirshleifer's (1991) model, Grossman and Kim (1995) derive a conflict model with production and appropriation, in which a stable peaceful equilibrium, with no investment in conflict, is possible. In this model, the agents divide initial endowments between appropriation, defence against appropriation, and production. However, the initial endowment is not used up by these activities, but is retained by the agent. It is the agents' initial endowments that are subject to appropriation. The share of the initial endowment that each agent gets to keep is a function of the opponent's investment in attack, the agent's investment in fortification, and a parameter referred to as *decisiveness,* which is defined as the efficiency of attack relative to fortification. Grossman and Kim (1995) use the analogy of the development of artillery and fortifications in the early modern age to explain the decisiveness parameter, where better cannons can be seen as an increase in the decisiveness parameter, while an improvement in the architecture of forts and castles can be seen as a reduction of the decisiveness parameter. In this model, whatever the agents produce may not be appropriated by the opponent. In that sense, unlike in the model by Hirshleifer (1991), the prize is exogenous to the model, as it is not decided within the game. The model assumes that all of the initial endowment is used for either production or conflict, so whatever is not invested in attack or fortification is invested in production. Of particular interest in this model is the fact that the optimal investment for the agents depend on the decisiveness parameter. Thus, it is possible, in situations

[2] The term conflict technology function is slightly misleading, as it does not necessarily have anything to do with technology.

with very low decisiveness, to have situations where neither of the agents invest anything in appropriation, and only arbitrarily small amounts in fortification.

In an extension of this model, Grossman and Kim (1996) derive a predator-prey version of their previous conflict model (Grossman and Kim 1995), in which the agents assume asymmetric roles, constraining their options for investment in conflict. In this model, the agents are denoted Offence and Defence, and are constrained in the sense that Offence may only invest resources in attack, while Defence may only invest in fortification. Thus, it is only Defence's endowment that is subject to appropriation.

As in their previous model, the optimal conflict investment in the extended model (Grossman and Kim 1996) depends on the decisiveness parameter. For arbitrarily small values of the decisiveness parameter, each resource unit invested in appropriation by Offence would create more utility by being used for production, and Offence would therefore refrain from investing in attack. However, as the value of the decisiveness parameter increases, investment in attack becomes more efficient than production for Offence. Meanwhile, Defence will find that investing his resources in defending his endowment will have a higher marginal utility than investing them in production. Eventually, as decisiveness increases, this will lead to an equilibrium with full investment in conflict by both agents. Finally, as the decisiveness parameters take on increasingly higher values, attack will be extremely effective relative to fortification, meaning that Offence will be able to appropriate virtually all of Defence's endowment, regardless of how much had been invested in fortification. Hence, at high values of the decisiveness parameter, Offence will invest an arbitrarily small amount of his endowment in attack, while the rest is retained for production. Meanwhile, for Defence, investment in production will yield a higher marginal utility than investment in attempting to defend his initial endowment and thus, he will invest all of his endowment in production, allowing Offence to appropriate all of his initial endowment. Thus, the optimal investment in the conflict function, as a function of the decisiveness parameter, follows an inverted u-shape. The implications of this model are that depending on the values of the decisiveness parameter, it is possible to have equilibria ranging from peace to full investment in conflict by both agents.

Beyond theoretical modelling, a few experimental studies have been conducted investigating economic behaviour in conflict situations.[3] In a seminal paper, Durham et al. (1998) studied the

[3] See Abbink (forthcoming) for a review of this literature.

Paradox of power (Hirshleifer 1991) and the extent of cooperative and Nash equilibrium strategies played, by allowing subjects with differing initial endowments to play a conflict game with appropriation and production. Their evidence suggests that subjects behave in accordance with Nash predictions. Following the study by Durham et al. (1998), a number of studies have performed experiments on conflicts of varying types, such as Duffy and Kim (2005), who investigate a setting where individuals can choose whether to be predators or producers, and Abbink et al. (2010), who study intergroup conflicts in the presence of intra-group punishment.

In a study by Carter and Anderton (2001), the game theoretic predictions of the model by Grossman and Kim (1996) were tested in an experimental setting. They employed three different treatments, each with a different value of the decisiveness parameter and random matching in multiple rounds. In the study, subjects alternated roles as Offence and Defence, and the game was played sequentially with Defence first choosing a fortification level, and Offence subsequently replying to this by choosing level of attack. The decisiveness parameter was set to 1/6, 2, and 6 in the three treatments respectively, which meant that the subgame perfect equilibrium varied from no predation, to full predation, to partial predation by Offence. All subjects were informed of the decisiveness parameter, and the value of the decisiveness parameter remained the same throughout all periods. Each treatment lasted for eight periods. Defence had an initial endowment of 12, while Offence had an initial endowment of 3, and unlike the original model by Grossman and Kim (1996), investments were discrete variables, and not continuous.

The results in Carter and Anderton (2001) showed that subjects converged on subgame perfect equilibrium strategies as the rounds progressed, with over 70% of subject pairs playing the subgame perfect equilibrium in the last two rounds. Thus, given some opportunity to learn how the game worked, this seemed to support the idea of rational self-interest seeking behaviour. However, one could argue that the design where Offence was informed of Defence's investment in fortification, albeit in line with the specifications of the model (Grossman and Kim 1996), made the choice trivial for Offence. Given that he observed the investment made by Defence, he had a 25% chance of playing the game theoretic prediction, just by randomly choosing a reply.

2.2. Overconfidence

The concept of overconfidence has in the literature been divided into three sub-groups, namely overestimation, overplacement and overprecision (Moore and Healy 2008). These concepts differ in nature and in the settings in which they manifest themselves. Overestimation refers to the tendency of people to unilaterally overestimate their own ability in a specific task or skill (Moore and Healy 2008), and is not related to interaction with other individuals. This may refer to test scores, performance of asset investments, or lap times in athletic sports. In general, it seems as though when uninformed of their actual performance, individuals tend to make overly positive guesses about their actual performance.

Overestimation can be contrasted to the concept of overplacement, which differs in that it is defined in *relative* terms, and not in *absolute* terms, as is the case with overestimation. Overplacement refers to the fact that agents are prone to be overly optimistic about their relative performance, when compared to others (Moore and Healy 2008). This concept, also known as the "Lake Wobegon effect", or the better-than-average effect, has been repeatedly studied. One of the more well-known examples is the seminal paper by Svensson (1981), in which he asked drivers in Sweden and the United States to judge their relative driving skills. He found that in both the Swedish and the American sample, a substantial part of the subjects believed that they were above average in the population as a whole, regarding their safety and skill as drivers.

Lastly, overprecision refers to the propensity of people to be overly optimistic about the precision of their answers to a given question (Moore and Healy 2008). That is, when subjects are asked to state a confidence interval within which they believe that the true answer to a quantifiable question lies, they make this confidence interval too small. One example of such quantifiable questions could be to state a confidence interval for the population size of a nation.

Our focus in this study will be on overplacement, i.e. how people judge their performance relative to other individuals. As we see it, this is the bias that is most likely to manifest itself in conflict situations, where agents have to make decisions about how much to commit to the conflict based on their beliefs about their relative strength in comparison to their prospective opponent. Henceforth, we define overconfidence as overplacement.

Several studies have investigated how overconfidence may manifest itself in economic behaviour, such as Camerer and Lovallo (1999) and Barber and Odean (2000). In the experimental paper by Camerer and Lovallo (1999), subjects played a market entry game, where their success in entering the market was dependent upon how they were ranked relative to the other subjects. Of specific interest is the fact that Camerer and Lovallo (1999) use a method with ranks based on both skill in a quiz or puzzle, and a randomly chosen rank. The idea is that individuals should realise that their rank in the random-based setting should, on average, be at the average. There is no rational explanation for why someone should believe anything else. However, the introduction of a skill-based rank means that the subjects' behaviour should depend upon their beliefs about their relative performance compared to the other subjects. Hence, the effect of overplacement should be captured by the difference in behaviour between the treatment with random-based rank, and the treatment with skill-based rank, and thus, this makes it possible to isolate the effects of overconfidence. In the experiment by Camerer and Lovallo (1999), the subjects' payoffs were decided by their rank and the market capacity, so that profit depended positively on rank and negatively on the number of entrants that the market could take. The experiment was designed in such a way that subjects played the entry game both with the rank decided by the quiz or puzzle and the random rank. The quiz or puzzle which decided the rank based on skill was performed after the entry game, so as not to give the subjects any beliefs about their performance.

It was found that on average, in the treatments with the skill-based rank, more subjects than optimal entered the market and the number of entrants were higher than in the treatment with random-based rank. This, Camerer and Lovallo (1999) argued, implied that the subjects were overconfident in their ability in the tasks relative to the other subjects. This seemed to point towards overconfidence being a cause of excess market entry. The concept of market entry has relatively similar properties to the concept of conflict, in that agents enter in an attempt to claim a share of a fixed "pie". Hence, they compete for resources, but there is no adverse combination of resources, which is required according to the definition of conflicts (Garfinkel and Skaperdas forthcoming), and the "pie" is not held by any agent.

Although overconfidence has been widely employed as an explanation for economic behaviour, most of these studies have taken the existence of overconfidence as given, even in situations in which there is no empirical evidence for its presence (Merkle and Weber 2011). However, not all scholars agree that overconfidence is as prevalent a phenomenon as commonly assumed and that its frequent use in the economic literature may be based on flawed assumptions.

Some of the most recent critique was raised by Benoît and Dubra (2011), who argue that the overconfidence measured in many experimental studies may be what they term *apparent overconfidence*, in the sense that the beliefs held by agents may be the result of perfectly rational Bayesian updating, and not necessarily based on overconfidence. Their argument stems from the fact that most studies use point estimates as measures of overconfidence, which aggregates a potential underlying belief distribution and may hence give misleading results. If individuals are Bayesian updaters, whereby they update their beliefs about their true ability based on what signals they get according to Bayes' rule, it may be the case that more than 50% of agents in a population can rationally believe that they are above average. Benoît and Dubra (2011) use the example of the study by Svensson (1981) and show that only in the American sample in that study can one find evidence for overconfidence which cannot be explained by Bayesian updating. They argue that in order to prove *true overconfidence* in data based on aggregated estimates, one has to find that $2 * x\ \%$ of subjects believe that they are in the top $x\ \%$ (Benoît and Dubra 2011).

This would obviously render a large part of the overplacement literature moot. However, a reply to the arguments made by Benoît and Dubra (2011) has been put forward by Merkle and Weber (2011), who devise a method of separating true overconfidence from apparent overconfidence. They propose that subjects should state their probability distribution for the deciles in which they believe that the true value may be. Due to this method, it is possible to get around the problems pointed out by Benoît and Dubra (2011), by being able to separate apparent overconfidence from true overconfidence, without having to find extremely strong overconfidence. Merkle and Weber (2011) propose a number of tests that may be used to distinguish between the two sources of apparent overconfidence. The tests involve comparing the distribution of mean probability for each decile across individuals to the uniform distribution expected from a population of Bayesian updaters, and also testing if the average probability mass above a certain decile deviates from the probability mass expected from Bayesian updating. All of Merkle and Weber's (2011) tests find support for true overconfidence, which suggests that apparent overconfidence stems from true overconfidence and that the concept of overconfidence thus still is a relevant topic of study.

2.3. Overconfidence in Conflicts

Many scholars have proposed information imperfections as a cause for conflicts and already von Clausewitz (1832) noted the importance of imperfect information, or "fog of war", in conflict situations. Some more recent studies on how information imperfections may influence the occurrence of conflict include the study by Brito and Intriligator (1985), in which the authors study a game theoretic model with asymmetric information, where one of the agents is uninformed of the utility function of his opponent. In this setting, they find that the uninformed agent may, under certain circumstances, play a strategy that could result in a conflict ensuing.

A number of prominent historians and war theorists have also proposed overoptimism regarding relative ability as a main cause for armed conflict (Blainey 1973; Tuchman 1984; Van Evera 1999; Johnson 2004). Hirshleifer (2001) discusses the issue of information imperfection being the cause of conflict and argues that agents may be unaware of the relative costs and benefits associated with conflict and will therefore have to act upon their perceptions thereof, rather than the true costs and benefits. As these perceptions may be erroneous, there is a risk that the agents overestimate their relative probabilities of winning. Hence, it may be the case that overconfident evaluations of one's own strength in relation to potential opponents may be the cause of conflicts. This view is further emphasised by Sanchez-Pages (forthcoming), who analyses bargaining in the shadow of conflict in a setting where agents are uncertain about their relative abilities.

Collier et al. (2004) also discuss Hirshleifer's (2001) concept of conflicts as mistakes and present this as a possible explanation for conflicts. In a study of civil wars, Collier et al. (2004) find evidence that overconfidence increases the conflict duration. This once again seems to point towards overconfidence being a factor that influences conflict behaviour.

Despite being pointed out as an important factor in conflicts, only a few attempts at modelling overconfidence in conflicts have been undertaken by economists. One example is the model by Ando (2004), in which he allows agents in a contest game to be overconfident in their relative ability. This model can account for overconfidence inducing either more aggressive or less aggressive behaviour. However, the model is based on a contest in a principal-agent setting, in which the contest generates positive externalities for the principal. Thus, it fails to fulfil the second condition of the definition by Garfinkel and Skaperdas (forthcoming) and falls outside our definition of conflicts. Hanson (2006) presents a model of confidence in contests. In this model each agent's confidence is decided by what Hanson (2006) calls a "pre-agent". (Hanson (2006) exemplifies pre-agents as parents, or even nature in general, deciding from an evolutionary perspective the confidence of an organism). This pre-agent's utility is a function of the regular agent's utility. Hence, the pre-agent will set the confidence level of the agent so as to maximise his own utility. Therefore, this model falls outside the definition by Garfikel and Skaperdas (forthcoming), since it violates the second condition.

One of the more interesting aspects of overconfidence in conflict is brought up by Johnson and Fowler (2011), who argue that overconfidence may be evolutionary adaptive. This would mean that overconfidence may actually be beneficial for the organisms in which it is prevalent. Thus, through overconfidence in their relative ability, some organisms may have an advantage over unbiased organisms. Johnson and Fowler (2011) use a simulation to test their hypotheses, and find that it seems as though overconfidence can, when the ratio of rewards to costs of conflict is high, lead to better outcomes for the overconfident agent. However, this is dependent on the situation, and Johnson and Fowler (2011) note that in some modern situations, such as war, overconfidence may have negative effects on the outcome as well, as the costs are high relative to the rewards of the conflict. In an extension of the study by Johnson and Fowler (2011), Johnson et al. (2011) discuss a setting where states, defined as either overconfident, underconfident, or unbiased, may engage in war against each other. They find that overconfident states may in fact be better off than underconfident or unbiased states. That overconfidence may indeed improve both relative and absolute performance of an agent was also found in a theoretical paper by Ludwig et al. (2010).

However, there have been few attempts to actually test these theories against real data. The only experimental study of overconfidence in conflict that we are aware of is a study by Johnson et al. (2006), in which subjects play a computerised war game in which subjects may be overconfidence in their relative ability. In this war game multiple subjects interact in a game where they may attack each other. Unlike in the experiment by Camerer and Lovallo (1999), overconfidence was not induced by means of an external task, but instead, subjects were asked about how they believed that they would rank in terms of performance in the war game. In this setting, some evidence of overconfident individuals also being more prone to make unprovoked attacks was found, supporting the claim of overconfidence as a cause of conflict outbreak. However, when separating for gender, this effect was no longer significant. It was further found that male subjects were more overconfident, and also more prone to making unprovoked attacks. That men are more overconfident than women was also found in an experimental study by Niederle and Vesterlund (2007).

However, the game used in the experiment by Johnson et al. (2006) was a rather complex game, in which the subjects could fight for resources, negotiate over resources, invest in production, save resources or trade with other subjects. It was also possible for subjects to be forced to terminate the game before all rounds had been played, due to being destroyed in war by an opponent. Hence, one may question the internal validity of this experiment, as it is not possible to isolate the effects of overconfidence from other aspects of the war game.

2.4 Summary of Previous Research

To summarise, several economic models of conflict have been developed. Some have also been tested in experiments. However, previous models on the relationship between overconfidence and conflicts are insufficient for the purpose of this study, primarily due to modelling other types of conflicts. Hence, in this thesis, we utilise the predator-prey conflict model developed by Grossman and Kim (1996), and extend it to incorporate overconfidence, which we use to derive hypotheses that are tested in a computerised experiment. Carter and Anderton (2001) tested the predator-prey model experimentally, so we build on their methodology while also adopting the methodology of using random- and skill-based ranks pioneered by Camerer and Lovallo (1999) to isolate the effects of overconfidence. The recent critique against the concept of overconfidence put forward by Benoît and Dubra (2011) is also acknowledged. To contribute to this debate, we measure true overconfidence using the method proposed by Merkle and Weber (2011).

3. Model

In this section, we derive a conflict model that incorporates overconfidence. This model allows us to generate hypotheses for the relationship between overconfidence and optimal conflict investment. The conflict model is an extension of Grossman and Kim's (1996) predator-prey model, introducing simultaneous moves and imperfect information regarding the decisiveness parameter. The latter feature is the key component that allows for overconfidence in the model. This model was chosen over the model by Ando (2004), which incorporates similar features, since beside the fact that Ando's (2004) model falls outside our definition of conflicts, the model is difficult to test in an experimental setting. The Grossman and Kim (1996) model, on the other hand, has been tested experimentally by Carter and Anderton (2001), which also gives us priors on behaviour in that type of model.

The conflict model consists of two agents, Offence and Defence. In line with conventional economic assumptions, we assume that the agents are risk-neutral, rational, selfish and materialists. Given these assumptions, the economic problem for Offence and Defence can be formulated as[4]:

[4] Additional parameters in the Grossman and Kim (1996) model which are of minor importance in our setting are the productivity parameter, α, and destructiveness of predation, β. The productivity parameter defines how much a resource unit invested in production yields in utility for the agent, while the destructiveness parameter reduces the gains from conflict. For simplicity, in our model, α is set to one and β is set to zero.

$$\max_{a\geq 0,\, k_o \geq 0} w_o = \begin{cases} 2n_o \quad if\ a = 0\ and\ f = 0 \\ n_o + k_o + \left(1 - \frac{f}{f+\theta a}\right) n_d \quad otherwise \end{cases} \tag{1}$$

$$subject\ to\ n_o = a + k_o$$

$$\max_{f\geq 0,\, k_d \geq 0} w_d = \begin{cases} 2n_d \quad if\ a = 0\ and\ f = 0 \\ k_d + \frac{f}{f+\theta a} n_d \quad otherwise \end{cases} \tag{2}$$

$$subject\ to\ n_d = f + k_d$$

Equation (1) is the optimisation problem for Offence, and equation (2) is the optimisation problem for Defence. The components in the model are the decisiveness parameter, θ, and the initial endowments, n_o for Offence and n_d for Defence. The initial endowment can be allocated to conflict (attack, a, for Offence and fortification, f, for Defence), or production, (k_o for Offence and k_d for Defence). The fraction of the initial endowment, n_d, that Defence gets to keep is a function of the size of fortification relative to attack, weighted for the decisiveness. The rest is appropriated by Offence. The essence of the economic problem is that both agents face a trade-off between investing in production or in conflict. We now present optimal conflict investments in two stages. First, we do this for a model with known decisiveness, then for a model with unknown decisiveness.

Solving the model with known decisiveness, using first-order conditions, yields the following optimal conflict investments[5]:

$$a^* = f^* = \frac{\theta n_d}{(1+\theta)^2} \tag{3}$$

As illustrated by equation (3), the optimal conflict investments are equal for Offence and Defence. The optimal conflict investment increases in Defence's endowment, n_d. Further, the optimal conflict investment increases for low decisiveness levels, from 0 to 1, and decreases as the decisiveness increases above 1 (see figure 1). This gives an inverted u-shape of optimal conflict investment as a function of the decisiveness parameter. As will be shown when incorporating imperfect information about decisiveness, this inverted u-shape allows for overconfidence to cause

[5] See appendix 1 for derivation. A necessary condition for this interior solution to be feasible, is that the following must hold: $4n_a \geq n_d$.

both the more intuitive result of overinvestment in conflict, but also to cause underinvestment in conflict for both Offense and Defence, depending on the decisiveness parameter.

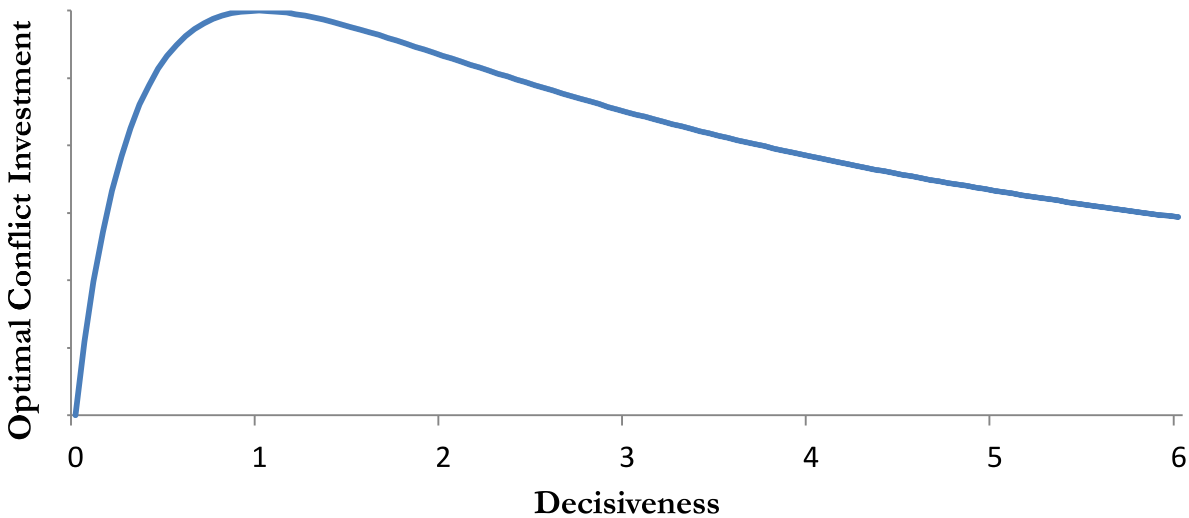

Figure 1: Comparative statics of the predator-prey model with known decisiveness. The figure illustrates optimal conflict investment as a function of decisiveness.

The second alteration of the model is that the decisiveness parameter is unknown. This is the key feature that allows us to incorporate overconfidence in the model. This introduces additional imperfect information, in that Offence and Defence cannot observe the value of the decisiveness parameter. We now present the expected utility functions for the model with unknown decisiveness:[6]

$$E(w_o) = p\left(n_o + k_o + \left(1 - \frac{f}{f+\theta_H a}\right) n_d\right) + (1-p)(n_o + k_o + \left(1 - \frac{f}{f+\theta_L a}\right) n_d) \tag{4}$$

$$E(w_d) = p\left(k_d + \frac{f}{f+\theta_H a} n_d\right) + (1-p)\left(k_d + \frac{f}{f+\theta_L a} n_d\right) \tag{5}$$

$$\theta_L < \theta_H$$

In this model, the decisiveness parameter instead follows a probability distribution and may yield two different values, called low, θ_L, or high, θ_H, where $\theta_L < \theta_H$. For simplicity, we assume a probability distribution where, with probability *p*, the decisiveness is *high*, and with probability 1-*p*,

[6] Note that in these new specifications of the utility functions, just as in (1) and (2), for the case when a = 0 and f = 0, the utilities for both agents are as stated in (1) and (2).

the decisiveness is *low*[7]. We want the optimal conflict investment to be a linear function of p, in order to yield different predictions about conflict investment for over- and underconfidence. This imposes restrictions on the range of the low and high decisiveness. There are two different sets of constraints on p that give this linearity. The first, referred to as *low unknown decisiveness*, is that $\theta_L \geq 0, \theta_H \leq 1$ and the second, referred to as *high unknown decisiveness*, is that $\theta_L \geq 1$. The intuition for these restrictions is captured by the inverted u-shape in figure 1.We now move on to formally model the case when unknown decisiveness is low. To yield maximum sensitivity of overconfidence, we assume that $\theta_L = 0$ and $\theta_H = 1$.

The maximisation problem for each agent is a function of each agent's beliefs about p, and not the actual p. Hence p can differ between agents. Offence's first-order belief about p will be denoted p_o and Defence's first-order belief about p will be denoted p_d. First-order beliefs refer to the agents' beliefs about p. Each agent's decision is also dependent on his beliefs about the opponent's decision, which in turn is a function of the opponent's beliefs. Hence, each agent's decision is also a function of his beliefs about the opponent's beliefs, i.e. higher-order beliefs. For simplicity, we assume that each agent's second- and third-order beliefs are the same, and that both agents hold the same second- and third-order beliefs[8]. Given this assumption about second- and third-order beliefs, we introduce p^* in the model to represent the beliefs about the opponent's beliefs. For this assumption about beliefs, the utility functions stated in expression (4) and (5) yield the following optimal conflict investments using first-order conditions[9]:

$$a^* = n_d\sqrt{p^*}\frac{(2\sqrt{p_o}-\sqrt{p^*})}{4} \tag{6}$$

$$f^* = n_d\sqrt{p^*}\frac{(2\sqrt{p_d}-\sqrt{p^*})}{4} \tag{7}$$

The optimal conflict investment in the model with unknown decisiveness is, as previously, increasing in Defence's initial endowment, n_d. Further, the optimal conflict investment is also a function of the beliefs about the opponent's beliefs, p^*, and each agent's beliefs about p, for Offence, p_o, and for Defence, p_d.

---

[7] The restrictions of p are as follows: $0 \leq p \leq 1$.

[8] The beliefs about the opponent's decision are dependent on the beliefs about the opponent's beliefs about the distribution of p and on the beliefs about the opponent's beliefs about the first agent's beliefs. This spiral of beliefs can go on infinitely. The spiral is broken by these assumptions about second- and third-order beliefs.

[9] See appendix 1 for a step-by step derivation of the general model.

In order to yield predictions for the experiment in Section 5, we restrict this general model to two specified distributions of beliefs. One way of modelling the distribution of the of p_o and p_d, is to make *p* dependent on a rank randomly assigned to each agent. This referred to as unknown *exogenous* decisiveness. In this case it is rational to believe that $p^* = p_o = p_d = 0.5$ for all agents.

Another way to model the distribution of p_o and p_d is to make these dependent on the rank in some ability, where a low rank represents a low ability and a high rank represents a high ability. This is referred to as unknown *endogenous* decisiveness. If an agent has a higher rank than the opponent, the decisiveness will be set to his benefit. This means that p_o linearly increases in the rank for Offence, and p_d linearly decreases in the rank for Defence. However, the endogenous modelling of the unknown decisiveness does not impose any restrictions on the first-order and higher-order beliefs about *p*. We assume that the agents' second-order and third-order beliefs are unbiased, i.e. $p^* = 0.5$. There has also been some empirical support for this assumption regarding second-order beliefs (Ludwig and Nafziger 2007). Further, endowments are set as follows: $n_a = 3$ and $n_d = 12$, which is identical to the levels used by Carter and Anderton (2001). Inserting $p^* = 0.5$, $n_a = 3$ and $n_d = 12$ into the model, we get:

$$a^* = 3\left(\sqrt{2}\sqrt{p_o} - \frac{1}{2}\right) \tag{8}$$

$$f^* = 3\left(\sqrt{2}\sqrt{p_d} - \frac{1}{2}\right) \tag{9}$$

In expression (8) and (9), also illustrated in figure 2, we see that optimal conflict investment increases for both agents in their respective beliefs about *p*, i.e. p_o and p_d. Finally, we arrive at the key mechanism for how overconfidence affects conflict investment. When unknown decisiveness is endogenous, if Offence is overconfident in his ability, p_o increases which results in Offence choosing a higher attack than optimal. Further, if Defence is overconfident in his ability, p_d decreases which results in Defence choosing a lower fortification.

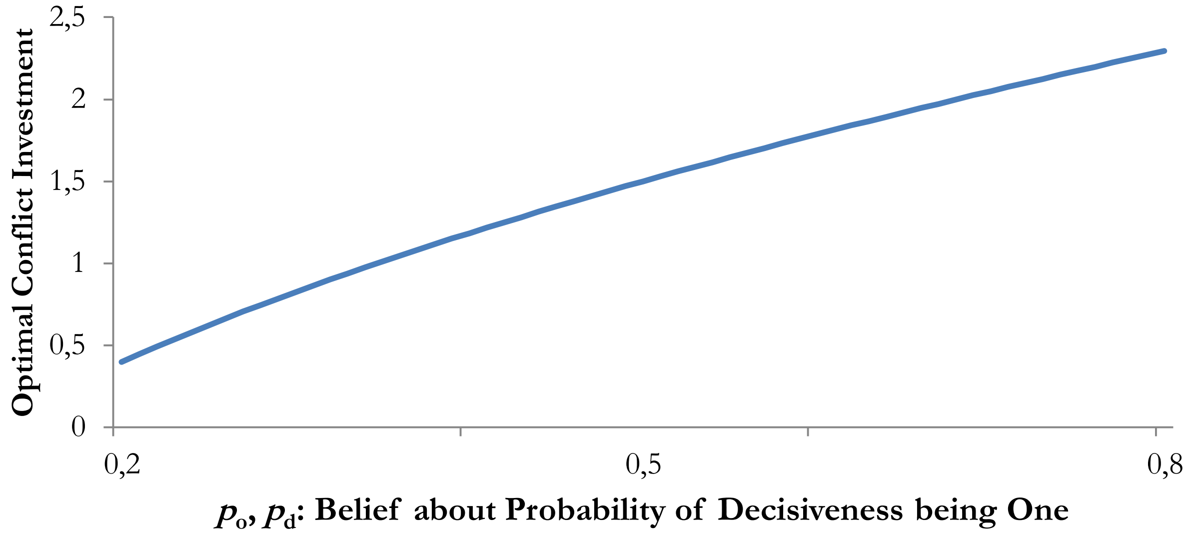

Figure 2: Comparative statics of the equilibrium in the predator-prey model with simultaneous moves and low unknown decisiveness, where low decisiveness is zero and high decisiveness is one, illustrating optimal conflict investment for both Offence and Defence as a function of their beliefs about the probability of decisiveness being one.

In summary, the general model with unknown endogenous decisiveness can explain how overconfidence may cause over- and underinvestment in conflict, which is captured by the parameters p_o and p_d. Overconfidence represents that p_o is larger than the actual p and that p_d is lower than the actual p. If unknown decisiveness is low, i.e. low decisiveness is zero and high decisiveness is one, as illustrated in figure 2, overconfidence will cause Offence to overinvest in conflict and for Defence to underinvest. Even though we do not formally model the case when unknown decisiveness is high, given the u-shape of conflict investment as a function of decisiveness, it seems plausible that overconfidence will have the opposite effect in this case compared to when unknown decisiveness is low. This assumption will be formally verified in the predictions for the games used in the experiment in Section 5.

Hence, the model incorporating overconfidence can help explain phenomena such as the German defeat in the Second World War, through overinvestment as Offence when unknown decisiveness is low, or the Second Italo-Abyssinian war, where it could be argued that the Abyssinians overinvested in conflict as Defence when decisiveness was high. Other historical instances could be the failure of the Soviet Union and the USA in Afghanistan and Vietnam respectively due to underinvestment as Offence when unknown decisiveness is high, and the Chinese defeat in the Opium War due to underinvestment as Defence when unknown decisiveness is low. However, these are just a few examples, and many other such instances may be considered.

4. Hypotheses

Based on the predictions derived from the model with known decisiveness, illustrated in figure 1, and the model with unknown endogenous decisiveness, illustrated in figure 2, we formulate the following four hypotheses regarding the relationship between overconfidence and conflict behaviour:

Overconfidence as a cause of overinvestment in conflict

Hypothesis I: *Due to overconfidence, Offence will invest more in conflict than what is optimal when unknown decisiveness is low.*

Hypothesis II: *Due to overconfidence, Defence will invest more in conflict than what is optimal when unknown decisiveness is high.*

Overconfidence as a cause of underinvestment conflict

Hypothesis III: *Due to overconfidence, Offence will invest less in conflict than what is optimal when unknown decisiveness is high.*

Hypothesis IV: *Due to overconfidence, Defence will invest less in conflict than what is optimal when unknown decisiveness is low.*

5. Experimental Design

In this section, we first explain the three games used in the experiment, then present game theoretic predictions for each game. Thereafter, the experimental procedure is explained.

5.1 Games

The first game corresponds to the first stage of the general model with known decisiveness. Thus, the decisiveness is a set parameter, and its value is common knowledge to all agents.

The second and the third games correspond to the second stage of the general model with unknown decisiveness. The second game has an unknown *exogenous* decisiveness while the third game has an unknown *endogenous* decisiveness. In these games, ten agents are ranked from one to ten, with ten being the highest and one the lowest rank. With unknown exogenous decisiveness, the rank was randomly assigned, while for the unknown endogenous decisiveness the rank is endogenously decided in the experiment.

The endowments of the agents were set to n_a = 3 for Offence and n_d= 12 for Defence, following the experimental design by Carter and Anderton (2001).[10] For simplicity, a restriction was imposed on Defence, limiting his investment at 3. This was done in order to simplify the decision, as a rational agent would never chose any investment above three, and a pilot study revealed that subjects found the game complicated with an extensive number of decisions. On a related note, we aim to compare the decisions as Offence and Defence. Then, having the same range of possible conflict investments will increase comparability between the two roles.

The values of the decisiveness parameter used in the experiment were 0, 1 and 100. The rationale behind these values was to capture that overconfidence may cause both over- and underinvestment. For *low* unknown decisiveness in the range $\theta_L \geq 0, \theta_H \leq 1$, where an overconfident Offence would overinvest and an overconfident Defence would underinvest, we use the lowest and highest values that θ can take, i.e. $\theta_L = 0$ and $\theta_H = 1$. For *high* unknown decisiveness in the range $\theta_L \geq 1$, where an overconfident Offence underinvests and an overconfident Defence overinvests, we set $\theta_L = 1$ and $\theta_H = 100$. Both of these ranges were chosen to make optimal conflict investment more sensitive to changes in beliefs about *p*. Table 1 summarises these decisiveness specifications.

Table 1: Specification of the different values that the decisiveness parameter may take in the second and third game in the experiment when unknown decisiveness is low or high.

Unknown Decisiveness (Range)	Decisiveness (Parameter)	Value
Low	Low	0
	High	1
High	Low	1
	High	100

5.2 Game Theoretic Predictions

In the experiment, the subjects made discrete conflict investment choices, and hence, continuous analysis is not necessary for generating predictions regarding optimal conflict investment in the experiment. In this section, for each game, we present the predictions of the models for the discrete

[10] Note that this fulfills the condition $4n_a \geq n_d$.

choices of conflict investment from zero to three for both Offence and Defence, derived using best-reply analysis of payoff matrices[11].

For the game with known decisiveness, the game theoretic predictions are presented in the left hand column of table 2. These predictions follow a similar pattern as the continuous model, presented in figure 1. However, playing zero in this game can be similar to the signal of contributing to a public good, which has been found to induce conditional cooperation in public good games (Frey and Meier 2004). Hence, when the game theoretic predictions are to play zero, this coincides with the predictions of conditional cooperation.

The predictions for the game with unknown decisiveness are dependent on the beliefs about *p*. In the game with unknown exogenous decisiveness, the rational belief is that both agents assume $p^* = p_o = p_d = 0.5$, and the predictions for this game are presented in the right hand column of table 2. Finally, the predictions for the game with unknown endogenous decisiveness are presented in table 3. To generate these predictions, we assume that $p^* = 0.5$. The predictions are given for each range of p_o and p_d.

Table 2: Game theoretic predictions for the first and the second game

1) Known Decisiveness			2) Unknown Exogenous Decisiveness		
Decisiveness	Role	Prediction	Decisiveness	Role	Prediction
0	Offence	0	0-1	Offence	1
	Defence	0		Defence	1
1	Offence	3			
	Defence	3	1-100	Offence	2
100	Offence	1		Defence	2
	Defence	0			

[11] See appendix 2 for derivations of the predictions for the game with known decisiveness and the game with unknown exogenous decisiveness. The derivation of the predictions for the game with unknown endogenous decisiveness is not reported due to being too extensive to present. The methods used to derive these predictions were similar as for the first two games. For each possible p_o and p_d, assuming that the opponent acts according to $p^* = 0.5$, best-reply analysis was conducted to find the predictions. Note that in the case that best-reply analysis yields multiple Nash equilibria, we use elimination of weakly dominating strategies among these to find an unambiguous equilibrium that can be used to evaluate existence of over- and underinvestment in conflict.

Table 3: Game theoretic predictions for the third game

		3) Unknown Endogenous Decisiveness					
Decisiveness	Role	Prediction					
	p_o, p_d	0-0.16	0.17-0.49	0.5	0.51-0.99	1	
		<----------	UC*		OC*	---------->	
0-1	Offense	0	1	1	2	3	
		<----------	OC*		UC*	---------->	
	Defense	0	1	1	2	3	
	p_o, p_d	0-0.16	0.17-0.49	0.5	0.51-0.52	0.53-0.76	0.77-1
		<----------	UC*		OC*	---------->	
1-100	Offense	3	2	2	2	1	1
		<----------	OC*		UC*	---------->	
	Defense	3	2	2	2	1	0

*OC = overconfidence, UC = underconfidence. The arrows express the direction in which over- and underconfidence respectively affect p_o and p_d.

5.3 Subjects

For the experiment, a sample of 80 students was recruited from universities in Stockholm, primarily from the Stockholm School of Economics. No subject participated more than once. The subjects were told that they would partake in an economic experiment that would entail an economic interaction, and that they could earn at least 100 SEK and up to 265 SEK. They were not told anything else about the nature of the experiment before the start of the session. There were four sessions, and 20 subjects were recruited for each session. Recruitment was conducted by means of e-mails, posters, and face to face recruitment.

Of the subjects in the sample, 24 were female and 56 were male, and the age distribution ranged from 18 to 32, with a mean of 23.08 years of age. The number of Swedish citizens was 62. The subjects on average earned a payoff of 159.5 SEK[12]. Each session lasted a little over an hour, and all subjects finished the experiment.

5.4 Experimental Procedure

The experiment was fully computerised, using Z-tree (Fishbacher 2007) [13]. Upon arriving at the experiment, the subjects were randomised to a computer in one of two rooms[14]. There were ten computers configured for the experiment in each room, so half of the subjects were seated in each

12 At the time of the experiment, the exchange rate USD/SEK was around 6.7.
13 See appendix 6 for the program code used for the experiment.
14 For a schematic representation of the arrangement of the subjects, see appendix 4.

room. Following this, the subjects were told that they had been randomly divided into two groups, but were not told what other subjects were included in this group. They were informed that five of the subjects in their group were located in another room, and that any interactions would take place against these subjects.

Before the experiment commenced, all subjects were provided with written instructions and a payoff table[15]. The subjects were allowed to read through the instructions, and they were also read out loud in each room by the experimenter. After the instructions had been read, subjects were allowed to ask questions. The subjects were forbidden to speak to each other during the experiment, but could call for the experimenter's attention, if there were any questions. They were also informed beforehand about how profits would be calculated and administered.

The experiment was divided into three stages, namely a quiz, the three conflict games, and a questionnaire[16]. In the first stage, the subjects were given a quiz with 20 trivia questions in the fields of geography, cinema knowledge, and sports, and were asked to answer these as correctly as possible. The subjects were given five alternative answers for each question.[17] They were informed that their performance in this quiz would affect their outcomes later in the experiment. The quiz was made relatively simple, so as to maximise the overconfidence effect in the subjects, following the findings of Moore and Healy (2008), that subjects were more prone to be overconfident if the task performed was simple.

Following the design used by Camerer and Lovallo (1999), each subject was assigned two ranks. First, they were assigned randomised rank from one to ten within the group, with ten being the highest rank and one being the lowest rank. This rank was used to decide the unknown exogenous decisiveness, and will henceforth be referred to as the random-based rank. The subjects were also ranked on the same scale within their group, based on the score they got in the preceding quiz. This rank was used to decide the unknown endogenous decisiveness, and will henceforth be referred to as the skill-based rank. The skill-based rank of each subject was based on the performance compared to the other subjects in their group. If two or more subjects got the same score, a tiebreaker question, entailing giving a precise estimate of the population of the United States, decided their

[15] See appendix 2 for payoff tables and appendix 3 for the instructions. Note that the best replies in the payoff table were, of course, not presented in the tables given to the participants. Further, they did not receive the aggregated payoff tables presented in appendix 2.
[16] For a step-by-step walkthrough of the experiment, see appendix 5.
[17] For the questions asked in the quiz and the answer alternatives, see appendix 5, section "Quiz".

rank. This kind of method was also used by Moore and Healy (2008), in order to separate subjects who had the same amount of correct answers in the quiz[18].

After submitting the quiz, the subjects were asked to estimate their absolute score on the quiz (each correct answer being worth one point), as well as their beliefs about the average score of their opponents. The subjects also stated their beliefs about their skill-based rank in their group. Following the response to the critique by Benoît and Dubra (2011) put forward by Merkle and Weber (2011), the subjects were also asked to provide a probability distribution for their rank. For each rank, the subjects provided the probability with which they believed that they had this rank. The subjects were asked to make sure that the cumulative probabilities provided summed up to 100%, but 16 subjects failed to do this. These guesses, as well as all subsequent guesses in the experiment, were incentivised, as will be discussed later.

After all subjects had made all the guesses, the next stage of the experiment commenced. During this stage, the three games explained in Section 4.1 were played. First, all subjects played the first game with known decisiveness. Each subject was assigned a role as either Offence or Defence. The experiment was designed in such a way that within each group, all the subjects who played Offence were located in the same room[19], and all the subjects who played Defence were located in the same room. Every period, the subjects switched roles, so that a subject who played Offence in period one played Defence in period two. The subjects were randomly matched against another subject in their group, but with the other role. The endowments and payoffs in the game were expressed in terms of "resource units". We used an internal rate of exchange where 1 resource unit equals 10 SEK. The subjects were informed of this exchange rate at the start of the experiment.

Before they could start the first game, each subject had to answer four control questions, to make sure that they had understood the game. It was not possible to proceed to the game itself before all four questions had been answered correctly. This feature was introduced in order to have all subjects use the information provided in the instructions and payoff table before they made any real choices, thus helping them learn how the game worked, and getting familiarised with the payoff tables. Once everyone had completed the control questions, the subjects were also asked to estimate how well they would perform in this game, profit-wise. This was done to, following Johnson et al. (2006), estimate if individuals were also directly overconfident in their ability in the game as such, and not

[18], For the tiebreaker question, see appendix 5 in the section "Quiz".
[19] For a schematic representation of the arrangement of the subjects, see appendix 4.

only in the quiz. They were asked to do this by guessing how they would rank in terms of profit in their group, by stating a number between one and ten, ten being the highest and one the lowest.

Once all subjects had made their guess, the conflict game with known decisiveness commenced. The game lasted for six periods, allowing each subject to play both roles (Offence and Defence) three times. The decisiveness level increased every second period, being 0 in the first two periods, 1 in the third and fourth, and 100 in the fifth and sixth. In the game, subjects were presented with a decision of how much of their endowment to allocate to the conflict.

Subjects were asked to state how much they wanted to invest in the conflict as a whole number between zero and three, and confirm this decision. They were also informed on-screen about their role and the decisiveness in that period. After both subjects had made their decisions, a screen appeared displaying information about the preceding period. This information included period number, decisiveness level, role of the subject, both subjects' conflict investments and both subjects' profit in that period. This information was also included in order to facilitate learning, by letting the subjects see the outcomes of their own and their opponent's actions.

After the subjects had played the first game, subjects played the second and third games with unknown endogenous and exogenous decisiveness. The experiment was designed in such a way that all subjects played both the second and third game. In order to avoid possible sequence effects, whereby having played one of the games would affect behaviour in the second game, the two groups played the games in opposite order. Thus, unless one of the configurations affected behaviour in the next more than the other, any such sequence effects would be reduced in the pooled sample. Subjects were reminded of how decisiveness was decided in every period, but were never informed of their rank. Hence, subjects' beliefs about their relative rank would in turn affect their beliefs about the probability that they had a certain decisiveness level.

For the second and third game, the subjects were first asked to answer two control questions. These questions were primarily intended to make sure that the subjects understood how the decisiveness parameter was decided. The subjects were also asked to guess how they would rank relative to the other subjects in their group in terms of profit in each game. The subjects could not proceed with the game until everyone had correctly answered the control questions and made the guess. The guesses were incentivised in the same manner as before.

Once the control questions had been answered, the conflict games commenced. Each game was played for four periods. For the first two turns of each game, $\theta_L = 0$, and $\theta_H = 1$, while in the following two, $\theta_L = 1$ and $\theta_H = 100$. Just as before, subjects played alternating roles, meaning that if they played as Offence in the first period, they played as Defence in the second period, and vice versa. Unlike in the first game, the subjects did not receive any feedback after each period in these games. This was done in order to avoid that the subjects developed beliefs about their rank, which would be possible if they could see their profit in each period, along with their own and their opponent's conflict investment. If they were informed of this, they could from that information infer their rank compared to the opponent, and generalise this to subsequent interactions. This could then affect their decisions in these subsequent stages. Furthermore, including information would also have created sequential effects, and made the decisions statistically dependent upon each other.

After all subjects had played four periods of both the game with exogenous and endogenous decisiveness, profits were calculated. This was done in the following way. From each of the three conflict games, two periods, one where the subject played as Offence and one where the subject played as Defence, were randomly selected, and the average profit of these six periods was calculated. In addition, two of the guesses that the subjects had made during the game, one about the quiz[20] and one about profit rank in the conflict games, were randomly chosen, and compared to the true value of the corresponding variable. If a guess was correct, a further bonus of 20 SEK was added. Further, the eventual bonus for the rank distribution guesses was calculated according to the quadratic scoring rule (Selten 1998). This rule is designed in such a way that it is optimal for agents to answer with their true beliefs, given the assumption that they are risk neutral. For recruitment purposes, a limit was implemented so that the minimum payoff that any subject could earn was 100 SEK. The maximum payoff attainable, given the optimal profit in each of the randomly chosen periods, and bonus for making a correct guess was 265 SEK. The subjects were shown their profit on screen, and the experimenters then took note of all profits, and paid the subjects in person.

In the final stage, the subjects were asked to fill in a short questionnaire. This questionnaire contained mainly questions about age, gender, years of study and school[21]. Subjects were also asked

[20] i.e. the guess about own score in quiz, the guess about average score in the group, and the guess about rank.
[21] The questionnaire also contained a Cognitive Reflection Test (CRT) (Frederick 2005). However, these results were not used in the analysis, and are therefore not further discussed.

to state whether they were Swedish or foreign citizens. After the questionnaire had been answered, and all subjects were paid, the experiment ended, and the subjects were allowed to leave the room where the experiment was conducted.

6. Empirical Methodology

Table 4: Definitions of the relevant variables.

Variable Name	Variable Description
ConflictInvestment	The amount invested in the conflict in a given period.
OptimalConflictInvestment	The optimal conflict investment for the subject in a given period.
Deviation Optimal	Deviation from the optimal conflict investment in a given period, calculated as *ConflictInvestment – OptimalConflictInvestment*.
Skillrank	The rank derived from the relative performance in the quiz.
Overconfidence_absolute	The absolute measure of overconfidence.
Overconfidence_relative	The relative measure of overconfidence.
Overconfidence_distribution	The overconfidence measure derived from the rank distribution.
GuessOwnRank	The subject’s guess about own skill-based rank in the group.
GuessOwnScore	The subject's guess about own score in the quiz.
GuessOtherScore	The subject's guess about average score of other subjects in the quiz.
OwnScore	The subject's true score.
OtherScore	The true average score of other subjects, except the subject himself.
Probability having rank X	Ten variables, from one to ten, each stating the probability with which the subject believed that he had that rank.
Role	Offence = 0, Defence = 1.
Game	Second game = 0, third game = 1.
Gender	Male = 0, female = 1.

6.1 Logic of Testing

The logic behind the testing of the four hypotheses is to first test hypothesis I and IV together, and hypothesis II and III together. The main reason for conducting these tests is to present the results from the hypothesis tests in a concise way. Then we present more thorough tests for each hypothesis separately, which all consist of two group level tests, a matched pairs *t*-test and a Wilcoxon signed rank test, and an individual level multiple regression analysis test.

In order for the hypothesis tests to efficiently test the hypotheses, two conditions must hold. First, for overconfidence to affect conflict investment, subjects have to be overconfident about their performance in the quiz. Secondly, as the main tests build on game theoretic predictions, it is necessary that the subjects behave in accordance with game theoretic predictions in general. Otherwise, the assumptions used to derive the hypotheses and the predictions, do not hold, and the tests of the hypotheses are inefficient. Manipulation checks for these two conditions are presented before the hypothesis tests.

6.2 Statistical Tests

To compute the dependent variable of interest, the deviation from optimal conflict investment, *Deviation Optimal*, optimal conflict investment must first be calculated for each individual in each period in each game. For the first and second game, the optimal conflict investments were based on the predictions in table 2. For the skill-based game, the optimal conflict investments were based on the predictions in table 3. However, to yield predictions for the game with skill-based rank, we need to estimate p_o and p_d for each individual. We use the beliefs stated by the subjects about their rank, from one to ten, in the quiz. This rank is inserted into the following formula, where *n* is the number of subjects in each group:

$$\textit{Implied } p_o = (\textit{GuessOwnRank}\text{-}1)/(n\text{-}1)$$

$$\textit{Implied } p_d = (10 - \textit{GuessOwnRank})/(n\text{-}1)$$

This *implied p* is the belief about the probability of decisiveness being high, rationally derived from the subject's belief about their own rank. The logic behind this variable is that if your rank was six, then five of the nine other subjects in your group would have a lower rank than you. If you are matched against any of these lower-ranked subjects, the decisiveness will be set to your benefit. The *implied p* is calculated for all subjects, and predictions for a given *implied p* can be found in table 3.

We measured overconfidence about performance in the quiz and in the conflict games. The overconfidence in the quiz was measured in three ways. The first, *Overconfidence_absolute*, was derived using the absolute guesses about own score and opponent score, according to the formula suggested by Moore and Healy (2008). The second measure, *Overconfidence_relative*, was simply the variable *GuessOwnRank* minus the variable *skillrank*. The third measure, called *Overconfidence_distribution*, was based on the method suggested by Merkle and Weber (2011), with the addition of subtracting *skillrank* from the derived point estimate of belief about rank:

1) $Overconfidence\_absolute = \left(E[X_i] - E[X_j]\right) - \left(X_i - X_j\right) =$
   $\left(GuessOwnScore - GuessOtherScore\right) - \left(OwnScore - OtherScore\right)$
2) $Overconfidence\_relative = GuessOwnRank - skillrank$

$$3)\ Overconfidence\_distribution = (10 \text{ x } Probability\ having\ rank\_10\ + 9 \text{ x } Probability\ having\ rank\_9 + 8 \text{ x } Probability\ having\ rank\_8 + 7 \text{ x } Probability\ having\ rank\_7 + 6 \text{ x } Probability\ having\ rank\_6 + 5 \text{ x } Probability\ having\ rank\_5 + 4 \text{ x } Probability\ having\ rank\_4 + 3 \text{ x } Probability\ having\ rank\_3 + 2 \text{ x } Probability\ having\ rank\_2 + 1 \text{ x } Probability\ having\ rank\_1) - skillrank$$

The first two are point estimate-based, and may hence only measure apparent overconfidence. However, the third measure is a distribution-based measure which reduces the information aggregation problem, pointed out by Benoît and Dubra (2011). For the conflict games, we only used a point estimate-based measure, i.e. subjects stating their belief about their rank on a scale from one to ten, with one being the lowest and ten the highest rank.

We also test for true overconfidence. To test if the distribution of beliefs follows a distribution predicted by a population of Bayesian updaters, we performed a chi-square goodness-of-fit test of a uniform distribution of beliefs.

In the hypothesis tests, the dependent variable is *Deviation Optimal*, which is a discrete variable with a short range, from zero to three. Hence, the parametric tests of this variable may be questioned, and therefore, we follow up with non-parametric group level tests. The group level parametric tests are repeated measures ANOVAs and matched pairs *t*-tests. Both these tests use the strength of the within-individual design of our experiment to adjust for individual-related error variance, which increases the power of the statistical tests, i.e. the probability of rejecting the zero effect hypothesis given that a certain effect exists in the population. The matched pairs *t*-tests were followed up with Wilcoxon signed rank tests as non-parametric robustness tests. We conducted 2 (*role*: Offence and Defence) x 2 (*game*: Random and Skill) repeated measures ANOVA tests where the dependent variable was *Deviation Optimal*. This statistical test generates a main effect of *role*, and main effect of *game*, and an interaction effect between *role* and *game*. The results from this type of test are illustrated in figures 4 and 5. Figure 4.1 illustrates an absence of all three effects while figure 4.2 illustrates an absence of a main effect of *game* but a significant main effect of *role* and an interaction. The simplest way of explaining the interaction effect is the difference in slopes illustrated in figure 4.2. The interaction between *role* and *game* is the hypothesis tests, as illustrated in the difference between figure 4.1, an absence of interaction for an unbiased population, and figure 4.2, the presence of an interaction in the predictions derived from the overconfidence level in the sample. This interaction effect will test two hypotheses at the same time. When decisiveness is low, hypothesis I and IV are tested, and when decisiveness is high, hypothesis II and III are tested. As illustrated in figure 4.2, for this interaction to efficiently test *both* of the hypotheses, there must be an absence of a main effect of *game*, a main effect of *role* and more importantly, the mean of *Deviation Optimal* in the random game must be zero. Hence, the efficiency of this test is dependent on several conditions being fulfilled and is followed up by other tests that are less constrained by conditions.

In the individual level tests of the hypotheses, we used multiple regression analysis. The dependent variable is *Deviation Optimal* in the skill-based treatment and the independent variable of interest is overconfidence in the quiz. We use both *overconfidence_relative* and *overconfidence_distribution* to check the robustness of our findings. The absolute measure of overconfidence is not explicitly restricted to the other players in each group, and is hence not included. However, since the actual rank in the group is the main determinant of optimal conflict investment in the general model and this rank by construction is highly correlated with overconfidence, we include the variable *skillrank* as a control variable.[22] We use robust standard errors to avoid problems with heteroskedasticity. In the individual level tests, the following regression specification is tested:

$$Deviation\ Optimal_i = \alpha_0 + \alpha_1 overconfidence_i + \alpha_2 skillrank_i + \varepsilon_i$$

Where *i* indicates individual. For each role and unknown decisiveness, the regression is run twice for each hypothesis, using both measures of overconfidence. Hence, in total eight regressions are conducted. All hypothesis tests were two-tailed and had a significance level of 5 %.

7. Results

7.1 Manipulation Checks

In the first manipulation check, we test if overconfidence was successfully induced. First follows tests for overconfidence in the quiz. We start with tests of apparent overconfidence, then move on to tests for true overconfidence. Secondly, we conduct analysis to test for apparent overconfidence in the conflict games. In the second manipulation check, we test if the subjects behaved in accordance with game theoretic predictions.

[22] If an agent has the highest rank, he cannot state any beliefs higher than this rank. Hence, an agent with *skillrank* ten can, by construction only be underconfident or unbiased. Likewise, an agent with *skillrank* one can only be overconfident or unbiased.

Overconfidence

Test for *apparent overconfidence* in the quiz

Regarding apparent overconfidence in the quiz, *t*-tests, where the null hypothesis was that this overconfidence measure was zero, showed a significant overconfidence for all measures. The results of the *t*-tests are presented in table 5. All these measures are supposed to measure the same theoretical construct, i.e. overconfidence defined as overplacement. Hence, there should be a high correlation between these measures which was confirmed by Pearson correlation tests. The correlations are presented in table 6. Spearman's non-parametric correlation test yielded close to identical values for all correlations, and these correlations are therefore not reported. Thus, this analysis confirms that apparent overconfidence was induced in the quiz, although the effect sizes are relatively small.

Table 5: Results from *t*-tests of apparent overconfidence in the quiz.

Overconfidence Measure	*M*	*SD*	*p*-value
Absolute	0.972	3.549	0.017**
Relative	0.600	2.578	0.041**
Distribution	0.711	2.397	0.010***

* $p < .10$ ** $p < .05$ *** $p < .01$

Table 6: Pearson correlation between the three overconfidence measures.

Pearson Correlation	Absolute	Relative	Distribution
Absolute	1.000	0.787	0.807
Relative	0.787	1.000	0.894
Distribution	0.807	0.894	1.000

Test for *true overconfidence* in the quiz

We now test for true overconfidence in the quiz based on the methodology developed by Merkle and Weber (2011). In these tests, only subjects who entered probability distributions that added up to 100 % were included in the analysis, which was 64 subjects, meaning that 16 observations were dropped for this analysis.

The proportion of correct responses in the quiz was 67.4 %, which is similar to the proportions found by Merkle and Weber (2011) for their measures, *Intelligence* and *Knowledge*, 69.5 % and 67.8 % respectively, but lower than *Memory*, 85.9 %. This suggests that the quiz used in our experiment has similar properties to the measures of ability used in their study.

In our first test for true overconfidence, we used *t*-tests to investigate if the total probability mass above some rank was significantly larger than what is expected from a population of Bayesian updaters. In our tests, we find that 64.2% of the total probability mass was rank 6 or above, which is significantly more than the expected 50% ($p < .001$). 48.3% of the total probability mass was rank 7 or above, which is significantly more than the expected 40% ($p < .001$). 30.4% of the total probability mass was rank 8 or above, which is not significantly more than the expected 30% ($p > .050$). 15% of the total probability mass was rank 9 or above, which is significantly less than the expected 20% ($p < .001$). Lastly, 5.8% of the total probability mass was rank 10, which is significantly less than the expected 10% ($p < .001$). Hence, our results add further support to Merkle and Weber's (2011) conclusion that people believe themselves to be *slightly* better than average.

Our second test for true overconfidence was to compare the percentage of the subjects who were ranked above their best expectation (underconfident) which was 3.1%, with the percentage of subjects who were ranked below their worst expectation (overconfident), which was 12.5%. A two-sample *z*-test of proportions showed that this difference in proportions just passed significance ($p = .049$). A final test of true overconfidence is to test whether the average distribution of beliefs assigned to each rank differs from a uniform distribution, which is the prediction for a population of Bayesian updaters. A chi-square goodness-of-fit test rejects the hypothesis that the distribution follows a uniform distribution ($p < .010$). See figure 3 for an illustration of the average belief distribution.

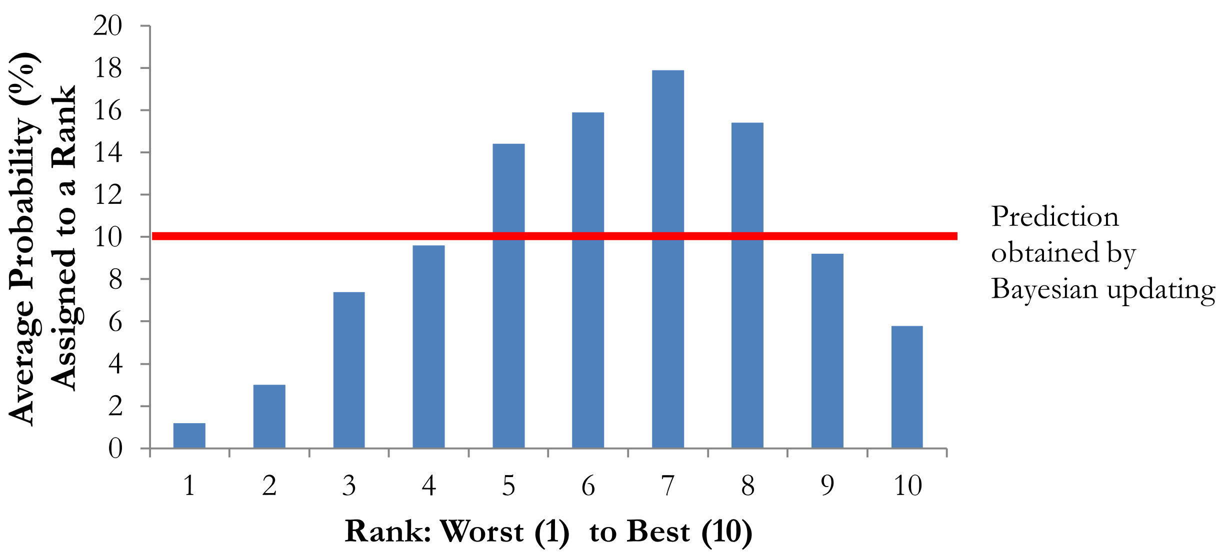

Figure 3: Histogram of average probability assigned to each rank for the sample. The red line is the prediction expected from a population of Bayesian updaters.

To summarise, we do find support for true overconfidence, in line with the results found by Merkle and Weber (2011). Further, the point estimate derived using the belief distributions that were used in the true overconfidence tests, was on a similar level and had a high correlation with the other two point estimates. This strengthens the empirical support for the claim that apparent overconfidence is caused by true overconfidence.

Test for ***apparent overconfidence*** in the conflict games

In addition to the previous measures of overconfidence in the quiz, we also measured if people were directly overconfident in their ability in the conflict games. If individuals were unbiased, the average of this measure should, on the group level, be 5.5. We test this by conducting a *t*-test of the mean against the null hypothesis of 5.5, to see if this holds. The results are presented in table 7. For the first conflict game with known decisiveness, we find that the mean is significantly higher than 5.5 ($p = .028$). Hence, there seems to be some overconfidence in ability, even though the results of the quiz do not affect performance in this game, which rules out spill-over effects from the observed overconfidence in the quiz. Hence, it seems as though individuals are slightly overconfident in their skill at playing this game. Contrary to the results for the first game, in the second game with unknown exogenous decisiveness, we find that people are not overconfident ($p = .768$). In the third game with unknown endogenous decisiveness, overconfidence is borderline significant ($p = .054$). Thus, it seems as though overconfidence about ability in the quiz translated into overconfidence in the game with unknown endogenous decisiveness.

Table 7: Results from *t*-tests of apparent overconfidence in the conflict games. Overconfidence was measured as guesses about rank in terms of profit within the group.

Overconfidence Measure	*M*	*SD*	*p*-value
Game 1: Known Decisiveness	5.950	1.792	0.028**
Game 2: Random-based Rank	5.563	1.888	0.768
Game 3: Skill-based Rank	5.975	2.176	0.054*

* $p < .10$ ** $p < .05$ *** $p < .01$

One should note, however, that in the conflict games with random-based and skill-based ranks, the subjects had a signal about performance from the first conflict game with known decisiveness, in which they received feedback. Hence, subjects may have updated their beliefs based on the feedback, which could affect their overconfidence in the subsequent games. If this was the case, it could mean that the effects of overconfidence would have been stronger, had the subjects not received a signal about their ability in the games.

Gender differences in *apparent overconfidence*

Prior research seems to point towards men being more overconfident than women (Johnson et al 2006; Niederle & Vesterlund 2007). Therefore, we also test if there are gender differences in overconfidence for all apparent overconfidence measures in a regression analysis. See table 8 for a summary of these tests. The sign of the coefficient of *gender* was in the expected direction in all tests but none reached significance ($p > .371$). Hence, we find weak, but not significant, support for the hypothesis that men are more overconfident in their relative ability than women, which was in line with previous findings.

Table 8: Regression results where the dependent variable is (1) overconfidence_absolute, (2) overconfidence_relative, and (3) overconfidence_distribution.

Variable name	**(1)**	**(2)**	**(3)**
gender	-.524	-.339	-.269
	(.421)	(.434)	(.371)
skillrank	-.896***	-.697***	-.739***
	(.001)	(.001)	(.001)
Constant	6.056***	4.534***	4.86***
	(.001)	(.001)	(.001)
Adjusted R^2	.494	.574	.763
N	80	80	80

p-values in parentheses, * $p < .10$ ** $p < .05$ *** $p < .01$

Outcomes compared to game theoretic predictions

Before moving on to the main test of our thesis, we will first analyse to what extent subjects in general play according to game theoretic predictions. For a summary of these results, see table 9. In all games, we have used three different types of solution concepts to derive predictions, namely dominant strategies, Nash equilibrium and iterated elimination of dominated strategies among Nash equilibria. We look at descriptive data for each type of solution[23].

[23] Note that the outcomes in the third game with unknown endogenous decisiveness is not included in this analysis, since they are dependent on the p_o and p_d for each subject. Hence, for a given period and role, different solution concepts may be used to derive game theoretic predictions for different individuals.

Table 9: Summary of experiment results in relation to game theoretic predictions

Game	Known decisiveness						Exogenous unknown decisiveness				Endogenous unknown decisiveness			
Period	1	2	3	4	5	6	1	2	3	4	1	2	3	4
Decisiveness (θ)	0	0	1	1	100	100	0-1	0-1	1-100	1-100	0-1	0-1	1-100	1-100
Equilibrium (percent)	40*	58*	15	18	73	85	28	20	3	10	8	15	15	20
Cooperative eq. (percent)	40*	58*	0	0	5	0	8	0	3	0	8	0	0	0
Optimal attack (percent)	60*	83*	25	33	83	98	73	68	18	23	40	40	55	55
Optimal fortification (percent)	70*	73*	43	40	90*	88*	33	33	20	30	30	48	25	35
Cooperative Offence (percent)	60*	83*	3	0	5	0	13	8	5	0	10	10	3	3
Cooperative Defence (percent)	70*	73*	13	15	90*	88*	40	15	28	20	53	28	40	28

*Game theoretic predictions and cooperative predictions yield the same conflict investment, zero. For a summary of the predictions, see table 2 and 3 in the Section 5.

Dominating strategies: When decisiveness is zero and 100 in the game with known decisiveness, the equilibrium outcomes are dominating strategies for both Offence and Defence. In these cases, which are period 1, 2, 5 and 6 in table 8, we find a high rate of both unilateral optimality in behaviour, i.e. optimal attack and fortification, and equilibrium outcomes, which increases with period, suggesting learning effects. Note that for all cases with an asterisk in table 8, the game theoretic prediction coincides with the conditional cooperative prediction. Hence, these cases are not valid for testing the extent to which subjects behave in accordance with dominating strategies. For Offence, when decisiveness is 100, these two predictions do not coincide, and the optimality in unilateral behaviour is 98 per cent in the last round. These results suggest that people play in accordance to dominant strategies in the conflict games, when such strategies exist.

Nash equilibrium strategies: Moving on to Nash equilibrium strategies, this solution concept is used for both Offence and Defence in the first game when decisiveness is one and in the second game when the exogenous unknown decisiveness is high. In these cases, the percentage of both unilateral optimal behaviour and equilibrium outcomes are substantially lower than for dominating strategies. One sample *z*-tests of proportions against the null hypothesis of 25 per cent, i.e. the probability of playing optimal investment by chance, shows that it is only for Defence in period 3 and 4 in the first game, that unilateral optimal behaviour is higher than the percentage expected by chance ($p < .01$). Hence, we do not find support for people playing Nash equilibrium strategies in conflict games.

These results are contrary to the findings of Durham et al. (1998), who finds support for Nash equilibrium strategies. These results also stand in stark contrasts to the findings by Carter and Anderton (2001), who found strong support for game theoretic predictions in a similar experiment.

Iterated elimination of weakly dominated strategies among Nash equilibria: In the second game with low unknown exogenous decisiveness, iterated elimination of weakly dominated strategies among Nash equilibria was the solution concept used to find an unambiguous game theoretic solution for both Offence and Defence. One sample z-tests of proportions against the null hypothesis of 25 per cent, i.e. the probability of playing optimal investment by chance, shows that it is only for Offence in period 1 and 2 in the second game, that unilateral optimal behaviour is higher than the percentage expected by chance ($p < .010$). Hence, we find the rather puzzling result of stronger support for this solution concept than for Nash equilibrium strategies.

The game theoretic solution concepts used to derive predictions for optimal conflict investment in the second and third game are more often Nash equilibrium strategies and iterated elimination of weakly dominated strategies among Nash equilibria, which we find low support for, than dominant strategies, which we find high support for.

The low concordance between the outcome in the experiment and the game theoretic predictions in general, is alarming for the subsequent main tests. Before continuing with the main tests of the hypotheses, we conclude that mild overconfidence was successfully induced in the quiz and in most conflict games while support for game theoretic predictions was generally low.

7.2 Hypothesis Tests

In this section, we present the hypothesis tests.

Hypothesis I and IV were tested with a 2x2 repeated measures ANOVA for *low* decisiveness where the dependent variable was *Deviation Optimal*. The test showed no main effect of *role*, a significant main effect of *game* ($p < .010$) but no interaction between *role* and *game*. The deviation from optimal conflict investment changed from the game with random-based rank ($M = .188$) to the game with skill-based rank ($M = -.300$). Further, the absence of a significant interaction between *role* and *game* was contrary to our prediction. However, the absence of a main effect of *role* and the presence of a main effect of *game* confounds the interpretation of the interaction between *game* and *role*, which makes this test an inefficient test of hypothesis I and IV. Further, the outcome, illustrated in figure 4.3, shows a great discrepancy to the predictions, especially for Offence.

Figure 4. Graph (1), (2) and (3) all refer to cases with low unknown decisiveness. Graph (1) and (2) illustrates predictions. The predictions in graph (1) are derived for an unbiased population. The predictions in graph (2) are derived from the guesses about rank in the quiz in the sample. These guesses are translated into *implied* p_o and *implied* p_d, which in turn are used to yield individual level predictions for the optimal conflict investment, from which the sample mean prediction is calculated. Graph (3) illustrates the outcomes in the experiment.

Hypothesis II and III were tested with a 2x2 repeated measures ANOVA for high unknown decisiveness where the dependent variable was *Deviation Optimal*. The test showed no significant main effect of *role*, a significant main effect of *game* ($p < .010$), and no significant interaction between *role* and *game*. The deviation from optimal conflict investment changed from the game with random-based rank ($M = -.769$) to the game with skill-based rank ($M = -.306$). More importantly for our hypotheses, the absence of a significant interaction was contrary to our prediction. However, the absence of a main effect of *role* and the presence of a main effect of *game* confounds the interpretation of the interaction between *game* and *role*, which makes this test an inefficient test of hypothesis II and III. Further, the pattern of the outcome illustrated in figure 5.3, shows a great discrepancy to the predictions.

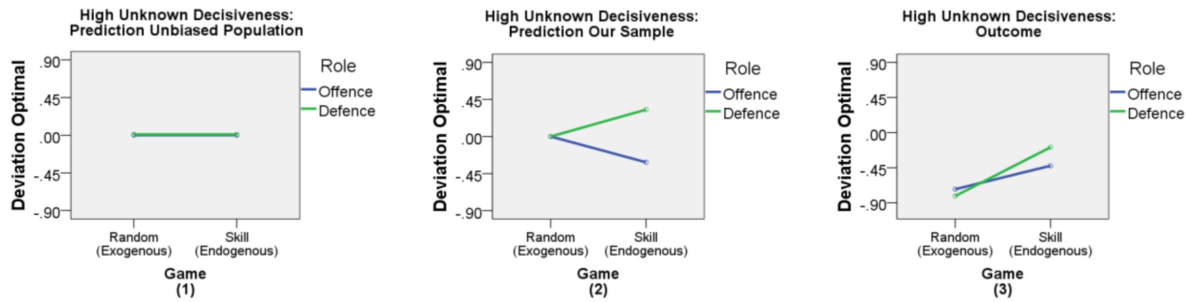

Figure 5. Graph (1), (2) and (3) all refer to cases with high unknown decisiveness. Graph (1) and (2) illustrates predictions. The predictions in graph (1) are derived for a rational unbiased population. The predictions in graph (2) are derived from the guesses about rank in the quiz in the sample. These guesses are translated into *implied* p_o and *implied* p_d, which in turn are used to yield individual level predictions for the optimal conflict investment, from which the sample mean prediction is calculated. Graph (3) illustrates the outcomes in the experiment.

To sum up the ANOVA hypothesis tests, both these concise tests suffer from an absence of main effect of *role* and a presence of a main effect of *game*, making them inefficient tests of the hypotheses. We now test each hypothesis separately, both on a group level, using matched pairs *t*-tests and Wilcoxon signed rank test, and on the individual level, using multiple regression analysis. For a summary of the matched pairs *t*-tests, see table 10, for the Wilcoxon signed rank tests, see table 11, and for the regression analyses, see table 12.

Table 10: Matched pairs *t*-test comparing the difference in *Deviation Optimal* between the games with skill-based and random-based rank.

			Mean Deviation Optimal				
	Unknown		Random	Skill	Expected	Matched pairs *t*-test	
Hypothesis	Decisiveness	Role	(Exogenous)	(Endogenous)	Difference	Difference	p-value
I	Low	Offence	0.138	-0.113	+	-0.250	0.070*
II	High	Defence	-0.813	-0.188	+	0.625	0.001***
III	High	Offence	-0.725	-0.425	-	0.300	0.021**
IV	Low	Defence	0.238	-0.488	-	-0.725	0.001***

* $p < .10$ ** $p < .05$ *** $p < .01$

Overconfidence as a cause of overinvestment conflict

Hypothesis I: *Due to overconfidence, Offence will invest more in conflict than what is optimal when unknown decisiveness is low.*

A matched pairs *t*-test comparing *Deviation Optimal* in the game with random-based rank and the game with skill-based rank for Offence when unknown decisiveness was low, almost reached significance (p = .070). This result is illustrated by Offence's blue line in figure 4.3. The change in *Deviation Optimal* was from a slight overinvestment in the game with random-based rank to a slight underinvestment in the game with skill-based rank. The direction of this change was opposite to the prediction. Hence, this result does not confirm hypothesis I. A corresponding Wilcoxon signed rank test for the same setting showed similar result for the change in *Deviation Optimal* (p = .099). The sum of negative ranked differences between the game with skill-based rank and the game with random-based rank in *Deviation Optimal* was higher than the sum of positive ranked differences, which was in line with the change in the parametric test. Thus, the group level tests do not support hypothesis I. On the contrary, the regression analysis for the game with unknown endogenous decisiveness shows an expected positive effect of overconfidence on *Deviation Optimal*, controlling for *skillrank*, for both measures of overconfidence. The relative measure of overconfidence was borderline significant (p = .066) while the distribution measure was significant (p = .004). However, the slightly negative mean of *Deviation Optimal* in the sample, although not significantly different from zero, calls for cautious interpretation of the overconfidence coefficient, since a slight increase in overconfidence for an average individual in the experiment reduces the deviation from the optimal conflict investment. Hence the regression results give some support for hypothesis I. Overall, results are ambiguous regarding hypothesis I.

Hypothesis II: *Due to overconfidence, Defence will invest more in conflict than what is optimal when unknown decisiveness is high.*

A matched pairs *t*-test comparing *Deviation Optimal* in the game with random-based rank and the game with skill-based rank for Defence when unknown decisiveness was high, was significant (p = .001). This result is illustrated by Defence's green line in figure 5.3. The change in *Deviation Optimal* from the game with random-based rank to the game with skill-based rank was from a substantial underinvestment (M = -.813) to a slight underinvestment (M = -.188). This change was in line with the predicted direction of change. However, due to the substantial underinvestment in the game with random-based rank, the change actually resulted in a lower deviation from the optimal conflict investment. Hence, in sum, this test does not confirm hypothesis II. A corresponding Wilcoxon signed rank test for the same setting showed similar result for the change in *Deviation Optimal* (p = .001). The sum of negative ranked differences between the game with skill-based rank and the game with random-based rank in *Deviation Optimal* was lower than the sum of positive ranked differences, which was in line with the change in the parametric test. Thus, the group level tests do not support hypothesis II. On the contrary, the regression analysis of the game with unknown endogenous decisiveness showed an expected positive effect of overconfidence on *Deviation Optimal*, controlling for *skillrank*, for both measures. However, neither the relative (p = .106) nor the distribution measure of overconfidence (p = .129) was significant. Hence, we do not find support for hypothesis II.

Table 11: Wilcoxon signed rank tests comparing the difference in *Deviation Optimal* between the games with skill-based and random-based rank. *N* is the number of non-zero differences.

Hypothesis	Unknown Decisiveness	Role	*N*	Sum of Negative Ranks	Expected Difference	Sum of Positive Ranks	*Z*	*p*-value
I	Low	Offence	54	925.5	<	559.5	-1.649	0.099*
II	High	Defence	61	498.5	<	1392.5	-3.699	0.001***
III	High	Offence	56	541.5	>	1054.5	-2.220	0.026**
IV	Low	Defence	67	1716.5	>	561.5	-3.295	0.001***

* $p < .10$ ** $p < .05$ *** $p < .01$

Overconfidence as a cause of underinvestment conflict

Hypothesis III: *Due to overconfidence, Offence will invest less in conflict than what is optimal when unknown decisiveness is high.*

A matched pairs *t*-test comparing *Deviation Optimal* in the game with random-based rank and the game with skill-based rank for Offence when unknown decisiveness was high, was significant (p = .021). This result is illustrated by Offence's blue line in figure 5.3. The change in *Deviation Optimal* from the game with random-based rank to the game with skill-based rank was from a substantial underinvestment (M = -.725) to a lower underinvestment (M = -.425). Hence, both the direction of change and the effect on the degree of deviation from optimal investment were contrary to the prediction of hypothesis III. A corresponding Wilcoxon signed rank test for the same setting showed similar result for the change in *Deviation Optimal* (p = .001). The sum of negative ranked differences between the game with skill-based rank and the game with random-based rank in

Deviation Optimal was lower than the sum of positive ranked differences, which was in line with the results in the parametric test. Hence, the group level tests do not support hypothesis III. The regression analysis showed a highly insignificant effect of overconfidence on *Deviation Optimal*, controlling for *skillrank*, for both measures ($p > .862$). Hence, we do not find any support for hypothesis III.

Hypothesis IV: *Due to overconfidence, Defence will invest less in conflict than what is optimal when unknown decisiveness is low.*

A matched pairs *t*-test comparing *Deviation Optimal* in the game with random-based rank and the game with skill-based rank for Defence when unknown decisiveness was low, was significant ($p = .001$). This result is illustrated by Defence's green line in figure 4.3. The change in *Deviation Optimal* from the game with random-based rank to the game with skill-based rank was from a slight overinvestment ($M = .238$) to a larger underinvestment ($M = -.488$). Hence, both the direction of change and the effect on the degree of deviation from optimal investment were in line with the prediction of hypothesis IV. A corresponding Wilcoxon signed rank test for the same setting showed similar result for the change in *Deviation Optimal* ($p = .001$). The sum of negative ranked differences between the game with skill-based rank and the game with random-based rank in *Deviation Optimal* was higher than the sum of positive ranked differences, which was in line with the parametric tests. Hence, the group level tests support hypothesis IV. The regression analysis showed an expected negative effect of overconfidence on *Deviation Optimal*, controlling for *skillrank*, for both measures. The relative overconfidence measure yielded a significant coefficient ($p = .042$) while the coefficient for the distribution measure was insignificant ($p = .522$). There was a significant negative *Deviation Optimal* in the sample ($p < .001$). This makes the effect of overconfidence unambiguously increasing the degree of underinvestment in conflict. Even though the distribution measure in the regression analysis was insignificant, overall, all tests had the expected direction of effect and all other tests were significant. Hence, we interpret these tests as a support for hypothesis IV.

Table 12: Regression results for individual level hypothesis tests where the dependent variable is *Deviation Optimal* and the independent variable of interest is overconfidence, controlling for *skillrank*. The coefficient presented is the slope coefficient of the overconfidence measure.

Hypothesis	Unknown Decisiveness	Role	Measure of Overconfidence	Expected Sign	Coefficient	*p*-value	Mean Deviation Optimal
I	Low	Offence	Relative	+	0.106	0.066*	-0.113
			Distribution	+	0.209	0.004***	-0.113
II	High	Defence	Relative	+	0.125	0.106	-0.188
			Distribution	+	0.142	0.129	-0.188
III	High	Offence	Relative	-	0.001	0.987	-0.425
			Distribution	-	-0.012	0.862	-0.425
IV	Low	Defence	Relative	-	-0.141	0.042**	-0.488
			Distribution	-	-0.060	0.522	-0.488

* $p < .10$ ** $p < .05$ *** $p < .01$

8. Concluding Discussion

8.1 Summary

The purpose of this thesis is to test the predictions of a theoretical model against experimental data, to see if overconfidence can cause over- and underinvestment in conflicts. To achieve this aim, a predator-prey model with two agents, called Offence and Defence, was extended with simultaneous moves and unknown decisiveness to incorporate overconfidence in a conflict model. Based on the model, we state four hypotheses: I) Due to overconfidence, Offence will invest more in conflict than what is optimal when unknown decisiveness is low, II) Due to overconfidence, Defence will invest more in conflict than what is optimal when unknown decisiveness is high, III) Due to overconfidence, Offence will invest less in conflict than what is optimal when unknown decisiveness is high, and IV) Due to overconfidence, Defence will invest less in conflict than what is optimal when unknown decisiveness is low. We conducted an experiment with three conflict games, where the first game aimed to facilitate learning and the data from the second and third games were used to test the hypotheses. Hypothesis tests were conducted both on a group level and on an individual level. Although mild overconfidence was induced, overall, we only find weak support for the predicted effect of overconfidence on deviations from optimal conflict investment. We find some ambiguous support for hypothesis I, and no support for hypothesis II and III. We do, however, find support for hypothesis IV.

8.2 Discussion

We now discuss possible explanations for why we in general only find weak support for our hypotheses. As stated in Section 6, the efficiency of the hypothesis tests was based on two necessary conditions: existence of overconfidence and behaviour in accordance with game theoretic predictions. A possible explanation for the absence of support for the hypotheses, which has been proposed by some scholars, is that overconfidence as a concept does not exist to extent commonly assumed. However, we find support for the existence of true overconfidence in the quiz. Therefore, we argue that a lack of overconfidence was not the reason for the weak support for the hypotheses. Another related explanation may be that the overconfidence induced was too low. However, the predictions illustrated in figure 4.2 and 5.2 are derived based on the overconfidence in the sample. These figures clearly suggest that the overconfidence in the sample should be strong enough to find effects.

The second necessary condition for the hypothesis tests to be efficient was that subjects behave in accordance with game theoretic predictions. The support for this condition was, in general, weak. We find support for subjects playing dominant strategies, but we do not find support for subjects playing the solution concepts used to derive predictions for the second and third games, which were the games of relevance for the hypothesis tests. These solution concepts were Nash equilibrium strategies and iterated elimination of weakly dominated strategies among Nash equilibria. In the first game, when decisiveness was one, we find low support for subjects playing Nash equilibrium strategies. This points towards Nash equilibrium strategies being played to a low extent in general, which might be one explanation for why the subjects deviate from the optimal conflict investment in the second game, where there was no scope for overconfidence to affect behaviour. Hence, the low extent of behaviour in accordance with game theoretic predictions in the second game may have confounded the hypotheses tests. On another note, the large discrepancy between the predictions for an unbiased population, illustrated in figure 4.1 and 5.1, and the outcome in the experiment, illustrated in figure 4.3 and 5.3, rules out the explanation that subjects act in accordance with game theoretic predictions, but are not overconfident. The low extent of compliance with game theoretic predictions in our sample is contrary to the findings by Carter and Anderton (2001), who tested predictions from a simpler version of the same predator prey model, and Durham et al. (1998).

Another explanation for why subjects do not act in accordance with the game theoretic predictions could be that the subjects had a relatively short time horizon in which to make decisions in the experiment. The solution concepts are cognitively demanding, and may thus be sensitive to time restrictions. Future studies may attempt to simplify the experimental procedure, to allow subjects to take more time for each decision. An additional explanation for the weak support for game theoretic predictions could be that individuals are conditional co-operators, and that signals received in the first game induced beliefs about cooperation. However, only a relatively small part of subjects played the cooperative solutions.

Besides these two necessary conditions for efficient hypothesis testing, there are other methodological issues that may affect the results. One of these is that the order in which decisiveness changed was from low to high in all games and for all subjects. In the first two periods of the first game, investing zero was the game theoretic prediction for both Offence and Defence. This peace equilibrium, in combination with the feedback given in the first game, is potentially problematic since this may induce conditional cooperation early in the game that may affect behaviour in subsequent periods. This is in line with the strictly negative mean of *Deviation Optimal* in the game with skill-based rank, illustrated in table 12, which confounded the interpretation of the individual level tests for hypothesis I and II. Hence, this suggests that the non-balanced order of decisiveness may indeed have been an issue in our experiment.

A further issue with our methodology is the limited range of the variable *ConflictInvestment*. This short range of possible conflict investments was chosen in order to make the games easier for the subjects. However, this creates a limited variation in the dependent variable and gives less scope for nuanced effects of overconfidence on conflict investment. A potential improvement of the design, which may thus get around this problem, would have been to set the initial endowments, and thereby also the possible conflict investments, higher for Offence.

8.3 Concluding Remarks

Methodological issues notwithstanding, our results could have some implications for the understanding of the causes of over- and underinvestment in conflict. The ambiguous support for the first hypothesis implies that overconfidence might help explain such instances as the German invasion of the Soviet Union, but the results are weak. Therefore, the oft-proposed supposition that the German failure in the Second World War was due to overconfidence finds little support in our study. As we reject the second and third hypothesis, our results suggest that overconfidence cannot explain such instances as the Soviet failure in Afghanistan and the failure of the USA in Vietnam, and other explanations for these events may have to be sought. We do, however, find support for the hypothesis that overconfidence may cause underinvestment for Defence when decisiveness is low. This situation is analogous to such historic events as the Roman defeat against the Goths, and the Chinese defeat in the Opium War. In these instances, it may have been the case that these powerful empires were overconfident in their relative military ability, and therefore invested less than what was optimal in the conflict, and suffered defeats as a consequence.

The implications of these results seem to be that as a cause of over- and underinvestment in conflicts, overconfidence is a minor factor. Primarily, it seems to be a factor only in the case of agents underinvesting in protecting themselves against opponents perceived as inferior. That overconfidence could cause powerful agents to underinvest in conflict is a fact which does seem to be corroborated by history. Consequently, this study provides some insight into the explanations for why powerful empires have repeatedly been defeated by other, often inferior, opponents. However, our findings suggest that conflict behaviour is primarily driven by other factors than overconfidence. Factors such as institutions, culture or emotions may drive behaviour in conflicts, and may affect both how common the occurrence of conflicts are, and how much is invested in them. Emotions such as hate may induce individuals to engage more in a conflict than what would have been rational, and moral beliefs may induce agents to refrain from engaging in conflicts.

One final note, worthy of making, is that, as conflicts go, an experiment is a highly stylised setting, bereft of all kind of emotional or contextual effects, in which subjects basically type in numbers on a computer. In a real conflict, such as a war, stakes are infinitely higher, and how people act is a matter of life and death. Hence, the external validity of a laboratory experiment on conflicts can be questioned. Still, if we are to isolate the effects of phenomena such as overconfidence, we are forced to rely on an experimental method, which, although lacking in many of the aspects that are prevalent in conflicts, is still a useful starting point for studying causal relationships. Even though the laboratory environment is stylised, this setting allows researchers to identify and isolate effects, and based on these, we can then extend our findings to more complete theories, with a more readily identifiable external relevance.

9. References

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Appendix 1: Step-by-step Derivations of the General Model

Solving the Predator-prey Model with Simultaneous Moves and Known Decisiveness

The agents' economic problem, for Offence and Defence, can be formulated as follows[24].

$$\max_{a\,\geq 0,\,k_o \geq 0} w_o = \begin{cases} 2n_o & if\ a = 0\ and\ f = 0 \\ n_o + k_o + \left(1 - \dfrac{f}{f + \theta a}\right) n_d & otherwise \end{cases} \qquad subject\ to\ n_o = a + k_o$$

$$\max_{f\,\geq 0,\,k_d \geq 0} w_d = \begin{cases} 2n_d & if\ a = 0\ and\ f = 0 \\ k_d + \dfrac{f}{f + \theta a} n_d & otherwise \end{cases} \qquad subject\ to\ n_d = f + k_d$$

If both players invest zero, i.e. $a = 0$ and $f = 0$, then if $\theta > 0$, Offence can appropriate all of Defence's endowment, n_d, by investing an arbitrarily small amount in attack. Hence, if $\theta > 0$, this set of strategies is not an equilibrium in this model.

Substituting k_o with $n_o - a$, first-order conditions for Offence yield:

$$\frac{dw_o}{da} = -1 + \frac{f\theta n_d}{(f + \theta a)^2}$$

$$\frac{dw_o}{da} = 0 \Rightarrow$$

$$(1) \qquad a^* = \frac{\sqrt{f\theta n_d} - f}{\theta}$$

Substituting k_d with $n_d - f$, first-order conditions for Defence yield:

$$\frac{dw_d}{df} = -1 + \frac{a\theta n_d}{(f + \theta a)^2}$$

$$\frac{dw_d}{df} = 0 \Rightarrow$$

$$(2) \qquad f^* = \sqrt{a\theta n_d} - \theta a$$

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[24] The special case of peace outcomes, i.e. $a = 0$ and $f = 0$ is present in all of the specifications in this appendix. However, to avoid unnecessary repetition, we only explicitly state them for this first specification.

Substituting (2) into (1) yields:

$$a = \frac{\sqrt{\left(\sqrt{a\theta n_d} - \theta a\right)\theta n_d} - \sqrt{a\theta n_d} - \theta a}{\theta} \leftrightarrow \sqrt{a\theta n_d} = \sqrt{\left(\sqrt{a\theta n_d} - \theta a\right)\theta n_d} \leftrightarrow$$

$$a\theta n_d = \left(\sqrt{a\theta n_d} - \theta a\right)\theta n_d \leftrightarrow a = \left(\sqrt{a\theta n_d} - \theta a\right) \leftrightarrow a(1+\theta) = \sqrt{a\theta n_d} \leftrightarrow a^2(1+\theta)^2 = a\theta n_d \leftrightarrow$$

$$(3) \qquad a^* = \frac{\theta n_d}{(1+\theta)^2}$$

Substituting (3) into (2) yields:

$$f^* = \sqrt{\frac{\theta n_d}{(1+\theta)^2}\theta n_d} - \theta\frac{\theta n_d}{(1+\theta)^2} = \frac{\theta n_d}{(1+\theta)} - \frac{\theta^2 n_d}{(1+\theta)^2} = \frac{(1-\theta)\theta n_d}{(1+\theta)^2} - \frac{\theta^2 n_d}{(1+\theta)^2} = \frac{\theta n_d}{(1+\theta)^2} = a^*$$

The following is a necessary condition for this interior solution to be feasible:

$$4n_a \geq n_d$$

Solving the Predator-prey Model with Simultaneous Moves and Unknown Decisiveness

We start off with the same utility functions for the two types of players, Offence and Defence, and insert a probability for decisiveness being high, *p*, or low, 1-*p*.[25] In the most general case, these decisiveness levels can be expressed as decisiveness high, θ_H, and decisiveness low, θ_H, given the following constraint, $\theta_H > \theta_L$. Inserting these new features into the model yields the following expected utility functions:

$$E(w_o) = p\left(n_o + k_o + \left(1 - \frac{f}{f+\theta_H a}\right)n_d\right) + (1-p)(n_o + k_o + \left(1 - \frac{f}{f+\theta_L a}\right)n_d)$$

$$E(w_d) = p\left(k_d + \frac{f}{f+\theta_H a}n_d\right) + (1-p)\left(k_d + \frac{f}{f+\theta_L a}n_d\right)$$

[25] The restrictions of *p* is as follows: $0 \leq p \leq 1$.

$$\theta_H > \theta_L$$

To find optimal conflict investment of this general model, we restrict it to a special case, assuming that $\theta_H = 1$ and $\theta_L = 0$. Further, since there is imperfect information about *p*, each agent's decision is dependent on his belief about *p*, i.e. his first-order beliefs, p^1. However, each agent's decision also depends on his beliefs about the opponents beliefs about *p*, i.e. his second-order beliefs, p^2. This spiral of beliefs continues infinitely. Inserting these assumptions into the maximisation problem yields:

$$\max_{a\,\geq 0,\, k_o \geq 0} E(w_o) = p_o^1\left(n_o + k_o + \left(1 - \frac{f(p_o^2, p_o^3, \dots, p_o^\infty)}{f(p_o^2, p_o^3, \dots, p_o^\infty) + a}\right)n_d\right) + (1 - p_o^1)(n_o + k_o)$$

$$subject\ to\ n_o = a + k_o$$

$$\max_{f\,\geq 0,\, k_d \geq 0} E(w_d) = p_d^1\left(k_d + \frac{f}{f + a(p_d^2, p_d^3, \dots, p_d^\infty)}n_d\right) + (1 - p_d^1)(k_d + n_d)$$

$$subject\ to\ n_d = f + k_d$$

Where the subscript denotes which individual holds the belief and the superscript denotes the order of beliefs. E.g. p_o^2 is Offence's beliefs, subscript *o*, about the opponents beliefs about *p*, superscript two. For simplicity, we assume that second- and third-order beliefs are as follows: $p^* = p_o^2 = p_o^3 = p_d^2 = p_d^3$. In words, this means that both agents hold the same second- and third-order beliefs and that the second-order beliefs are the same as the third-order beliefs. This breaks the infinite spiral of beliefs. We can then rewrite the expressions above as follows:

$$\max_{a\,\geq 0,\, k_o \geq 0} E(w_o) = p_o^1\left(n_o + k_o + \left(1 - \frac{f(p_o^2 = p^*, p_o^3 = p^*)}{f(p_o^2 = p^*, p_o^3 = p^*) + a}\right)n_d\right) + (1 - p_o^1)(n_o + k_o)$$

$$subject\ to\ n_o = a + k_o$$

$$\max_{f\,\geq 0,\, k_d \geq 0} E(w_d) = p_d^1\left(k_d + \frac{f}{f + a(p_d^2 = p^*, p_d^3 = p^*)}n_d\right) + (1 - p_d^1)(k_d + n_d)$$

$$subject\ to\ n_d = f + k_d$$

To solve the maximisation problem, we first have to find the optimal conflict investment that the second- and third-order beliefs yield for the *opponent*. The opponent's optimisation problem can be expressed as follows:

$$\max_{a\,\geq 0,\, k_o \geq 0} E(w_o) = p^*\left(n_o + k_o + \left(1 - \frac{f(p^*)}{f(p^*) + a}\right)n_d\right) + (1 - p^*)(n_o + k_o)$$

$$subject\ to\ n_o = a + k_o$$

$$\max_{f\,\geq 0,\, k_d \geq 0} E(w_d) = p^*\left(k_d + \frac{f}{f + a(p^*)}n_d\right) + (1 - p^*)(k_d + n_d)$$

$$subject\ to\ n_d = f + k_d$$

Substituting k_o with $n_o - a$, first-order conditions for Offence yields:

$$\frac{dE(w_o)}{da} = -p^* + \frac{p^* f(p^*) n_d}{(f(p^*) + a)^2} - 1 + p^*$$

$$\frac{dw_o}{da} = 0 \Rightarrow$$

$$(4) \qquad a^* = \sqrt{p^* f(p^*) n_d} - f(p^*)$$

Substituting k_d with $n_d - f$, first-order conditions for Defence yields:

$$\frac{dE(w_d)}{df} = -p^* + \frac{p^* a(p^*) n_d}{(f + a)^2} - 1 + p^*$$

$$\frac{dw_d}{df} = 0 \Rightarrow$$

$$(5) \qquad f^* = \sqrt{p^* a(p^*) n_d} - a(p^*)$$

Substituting (5) into (4) yields:

$$a = \sqrt{p^*\left(\sqrt{p^* a n_d} - a\right) n_d} - \left(\sqrt{p^* a n_d} - a\right) \leftrightarrow \sqrt{p^* a n_d} = \sqrt{\left(\sqrt{a p^* n_d} - a\right) p^* n_d} \leftrightarrow$$

$$a = \sqrt{p^* a n_d} - a \leftrightarrow 2a = \sqrt{p^* a n_d} \leftrightarrow 4a^2 = p^* a n_d \leftrightarrow$$

$$(6) \qquad a^* = \frac{p^* n_d}{4}$$

Substituting (6) into (5) yields:

$$(7) \qquad f^* = \sqrt{p^* \frac{p^* n_d}{4} n_d} - \frac{p^* n_d}{4} = \frac{p^* n_d}{2} - \frac{p^* n_d}{4} = \frac{p^* n_d}{4} = a^*$$

As before, the following is a necessary condition for this interior solution to be feasible:

$$4n_a \geq n_d$$

So each agent believes that they play against another player who plays according to (6) or (7), where p^* is the belief that the other player hold about the probability of decisiveness being high. For a more intuitive denotation, we redefine the first order beliefs as follows: $p_o^1 = p_o, p_o^1 = p_d$. We can then specify each agent's maximisation problem as follows:

$$\max_{a \geq 0,\, k_o \geq 0} E\big(w_o(p_o, p^*)\big) = p_o\left(n_o + k_o + \left(1 - \frac{f(p^*)}{f(p^*) + a}\right) n_d\right) + (1 - p_o)(n_o + k_o)$$

$$subject\ to\ n_o = a + k_o$$

$$\max_{f \geq 0,\, k_d \geq 0} E\big(w_d(p_d, p^*)\big) = p_d\left(k_d + \frac{f}{f + a(p^*)} n_d\right) + (1 - p_d)(k_d + n_d)$$

$$subject\ to\ n_d = f + k_d$$

Substituting k_o with $n_o - a$, first-order conditions for Offence yields:

$$\frac{dw_o(p_o, p^*)}{da} = -p_o + \frac{p_o f(p^*) n_d}{(f(p^*) + a)^2} - 1 + p_o$$

$$\frac{dw_o(p_o, p^*)}{da} = 0 \Rightarrow$$

$$(8) \qquad a^* = \sqrt{p_o f(p^*) n_d} - f(p^*)$$

Substituting k_d with $n_d - f$, first-order conditions for Defence yields:

$$\frac{dw_d(p_d, p^*)}{df} = -p_d + \frac{p_d a(p^*) n_d}{(f + a(p^*))^2} - 1 + p_d$$

$$\frac{dw_d(p_d, p^*)}{df} = 0 \Rightarrow$$

$$(9) \qquad f^* = \sqrt{p_d a(p^*) n_d} - a(p^*)$$

Now, inserting the predictions about the opponent's conflict investment as a function of p^* into the maximisation problem, i.e. substituting (7) into (8) and (6) into (9):

$$(10) \qquad a^* = \sqrt{\frac{p^* n_d}{4} p_o n_d} - \frac{p^* n_d}{4} = \frac{\sqrt{p_o}\sqrt{p^*} n_d}{2} - \frac{p^* n_d}{4} = n_d \frac{(2\sqrt{p_o}\sqrt{p^*} - p^*)}{4}$$

$$(11) \qquad f^* = \sqrt{\frac{p^* n_d}{4} p_d n_d} - \frac{p^* n_d}{4} = \frac{\sqrt{p_d}\sqrt{p^*} n_d}{2} - \frac{p^* n_d}{4} = n_d \frac{(2\sqrt{p_d}\sqrt{p^*} - p^*)}{4}$$

Once again, the following is a necessary condition for this interior solution to be feasible:

$$4n_a \geq n_d$$

Appendix 2. Best-reply Analysis of Payoff Tables to Derive Predictions

Predator-prey Model with Known Decisiveness

The following payoff tables were analysed to find game theoretic predictions using best-reply analysis. In the tables, the numbers to the left is the payoff earned by Defence and the number to the right is the payoff earned by offense. The underlined numbers mean that the level of conflict investment corresponding to this number is the best-reply for this agent, given that the opponent chooses the level of conflict investment that corresponds to this number. The cells where both numbers are underlined represent Nash equilibria, i.e. that both agents play best-replies. To derive these numbers, n_d is set to 12 and n_a is set to 3.

Best-reply analysis of the payoff table with $\theta = 0$

Defence's fortification	Offence's attack			
	0	1	2	3
0	**<u>24.00</u>, <u>6.00</u>**	<u>24.00</u>, 5.00	<u>24.00</u>, 4.00	<u>24.00</u>, 3.00
1	23.00, <u>6.00</u>	23.00, 5.00	23.00, 4.00	23.00, 3.00
2	22.00, <u>6.00</u>	22.00, 5.00	22.00, 4.00	22.00, 3.00
3	21.00, <u>6.00</u>	21.00, 5.00	21.00, 4.00	21.00, 3.00

Best-reply analysis of the payoff table with $\theta = 1$

Defence's fortification	Offence's attack			
	0	1	2	3
0	<u>24.00</u>, 6.00	12.00, <u>17.00</u>	12.00, 16.00	12.00, 15.00
1	23.00, 6.00	17.00, 11.00	15.00, <u>12.00</u>	14.00, <u>12.00</u>
2	22.00, 6.00	<u>18.00</u>, 9.00	16.00, 10.00	14.80, <u>10.20</u>
3	21.00, 6.00	<u>18.00</u>, 8.00	<u>16.20</u>, 8.80	**<u>15.00</u>, <u>9.00</u>**

Best-reply analysis of the payoff table with $\theta = 100$

Defence's fortification	Offence's attack			
	0	1	2	3
0	<u>24.00</u>, 6.00	**<u>12.00</u>, <u>17.00</u>**	<u>12.00</u>, 16.00	<u>12.00</u>, 15.00
1	23.00, 6.00	11.12, <u>16.88</u>	11.06, 15.94	11.04, 14.96
2	22.00, 6.00	10.24, <u>16.76</u>	10.12, 15.88	10.08, 14.92
3	21.00, 6.00	9.35, <u>16.65</u>	9.18, 15.82	9.12, 14.88

Predator-prey Model with Unknown Decisiveness

In addition to the assumptions made in the model with known decisiveness, in the best-reply analysis for the model with unknown decisiveness, it is assumed that $p^* = p_o = p_d = 0.5$. In the model with unknown exogenous decisiveness, this is the only rational belief that agents can hold. This does not necessarily hold in the model with unknown endogenous decisiveness. However, if we assume that each agent's second- and third-order beliefs are the same and unbiased, and that both agents hold the same second- and third-order beliefs, then $p^* = 0.5$. Hence, the tables below express what a rational agent infers about his/her opponent's behaviour, given these assumptions.

Best-reply analysis of the aggregated payoff table with low unknown decisiveness:
$\theta_L = 0, \theta_H = 1, p^* = p_o = p_d = 0.5$

Defence's fortification	Offence's attack			
	0	1	2	3
0	<u>24.00</u>, 6.00	18.00, <u>11.00</u>	18.00, 10.00	18.00, 9.00
1	23.00, 6.00	**<u>20.00*</u>, <u>8.00*</u>**	**<u>19.00</u>, <u>8.00</u>**	<u>18.50</u>, 7.50
2	22.00, 6.00	**<u>20.00</u>, <u>7.00</u>**	**<u>19.00</u>, <u>7.00</u>**	18.40, 6.60
3	21.00, 6.00	19.50, <u>6.50</u>	18.60, 6.40	18.00, 6.00

* = this is the prediction derived by using elimination of weakly dominating strategies among the derived Nash equilibria. Investing one or two is the Nash equilibria for both Offence and Defence. For all levels of attack, choosing one gives Defence an equal or higher payoff than if Defence chooses two. For all levels of fortification, choosing one gives Offence an equal or higher payoff than if Offence chooses two. Hence, choosing one dominates choosing two for both Offence and Defence.

Best-reply analysis of the payoff table with high unknown decisiveness:
$\theta_L = 1, \theta_H = 100, p^* = p_o = p_d = 0.5$

Defence's fortification	Offence's attack			
	0	1	2	3
0	<u>24.00</u>, 6.00	12.00, <u>17.00</u>	12.00, 16.00	12.00, 15.00
1	23.00, 6.00	14.06, 13.94	13.03, <u>13.97</u>	<u>12.52</u>, 13.48
2	22.00, 6.00	<u>14.12</u>, 12.88	**<u>13.06</u>, <u>12.94</u>**	12.44. 12.56
3	21.00, 6.00	13.67, <u>12.33</u>	12.69, 12.31	12.06, 11.94

Appendix 3. Instructions for the Experiment

Welcome to this experiment!

The experiment will consist of a quiz, a number of two-person decision problems, and a questionnaire. You can earn up to 265 SEK, with a minimum payoff of 100 SEK. The entire experiment will take about one hour. You are not allowed to speak to any other participant during the experiment. All actions will be performed on a computer. Please follow the on-screen instructions at all times. When you are asked to answer questions or make decisions, please make your decisions within the assigned time frame, displayed in the top right corner of the screen.

You have been randomly assigned to one of two groups. You will not know what other individuals are in your group. In the first stage of the experiment, you will be asked to perform a quiz and answer a few questions. There will be 20 questions, each with five alternative answers, numbered one to five. Only one is correct. You should answer each question as correctly as you can, as the results in the quiz will affect your performance in the later stages of the experiment. Once everyone has finished the quiz, you will be ranked relative to the other individuals in your group, based on how many correct answers you had in the quiz. If two or more individuals have the same score, A tiebreaker question will determine their rank. If two or more individuals with the same score give the same answer on the tiebreaker, they will be randomly ranked among each other. The rank based on the score in the quiz will henceforth be referred to as the skill rank. Everyone in each group will also be assigned a random rank, which is completely independent of the skill rank, and which you cannot in any way affect. This rank will henceforth be referred to as the random rank. For both skill rank and random rank, 1 is the lowest rank and 10 is the highest rank.

In the next stage, you will play three versions of a two person decision problem, of six or four periods each. You will be randomly paired with another individual in each period. This individual is seated in another room, and you will not know each other's identity. This will happen in every period, which means that you will not have the same counterpart in every period, but the counterpart will be another individual in your group. The decisions that you and your counterpart make will decide your wealth in each period.

The two person decision problem involves two agents in different roles, for simplicity called Offence and Defence. You will alternate between roles every second period, meaning that if you played Offence in period one, you will play Defence in period two, and vice versa. Thus, in the third period, you will have the same role as in the first period. Both agents will make decisions simultaneously. At the end of the experiment, two periods, one where you played as Offence and one where you played as Defence, from each of the three decision problems, will be randomly chosen, and you will receive the average payoff from these six periods in cash.

The Roles:

Defence: Defence holds 12 resource units (each resource unit earn in the experiment will be converted into 10 SEK), that are indestructible, but may be appropriated by Offence. The resource units may create income for Defence in the following two ways:

1. Defence may invest in production of wealth. Each resource unit invested in production will generate an additional resource unit at the end of the period.
2. As the 12 resource units are indestructible, they themselves constitute wealth. However, this wealth is subject to appropriation by Offence. Defence will get the value of whatever resource units were not appropriated by Offence at the end of the period. How much Offence can appropriate depends on Defence's fortification level relative to how much Offence attacks, and on the decisiveness level, which will be discussed below. Hence, Defence may use up to 3 of the 12 resource units to increase the fortification level.

Offence: Offence holds 3 resource units, which are indestructible. The resource units may create income for Offence in three different ways:

1. Offence may invest in production of wealth. Each resource unit invested in production will generate an additional unit of wealth at the end of the period.
2. As the 3 resource units are indestructible, they themselves constitute wealth. This will be added to Offence's wealth at the end of the period.
3. Offence may use the resource units to appropriate some or all of the 12 resource units originally held by Defence. Offence gets the value of whatever resource units were appropriated at the end of the period. How much Offence can appropriate depends on how much Offence attacks relative to Defence's fortification level, and on the decisiveness level, which will be discussed below. Hence, Offence may use the resource units to increase attack.

Decisiveness Level:

The effectiveness of Offence's attack relative to Defence's fortification depends on the decisiveness level in the given period. The decisiveness level is decided differently in each of the three decision problems.

In the first decision problem, decisiveness is a constant. It will vary over the six periods, but you will be informed of the decisiveness in every period.

In the two following decision problems, decisiveness will depend on the ranks you were assigned in the first stage of the experiment. In one of the versions, decisiveness will depend on the random rank you were assigned. In the other version, decisiveness will depend on the rank derived from your score on the quiz. Everyone will play both versions. One group will play the version with random rank first, and the version with skill rank second, while the other group plays the versions in the opposite order.

When you are matched against an opponent in these versions of the decision problem, decisiveness will be either LOW or HIGH, depending on whether your rank was higher than your opponent's or not. For Offence, if your rank was higher than that of your opponent, decisiveness will be HIGH. A high decisiveness means that you as Offence will be more effective in appropriating resource units from Defence. For Defence, if your rank was higher than that of your opponent, decisiveness will be LOW. A low decisiveness means that Offence will be less effective in appropriating resource units from you as Defence. The values that LOW and HIGH decisiveness take will vary between the periods, but you will be informed of what values it may take in every period. The possible decisiveness levels in this experiment will be 0, 1 and 100. Either, the possible decisiveness levels will be LOW=0 and HIGH=1, or LOW=1 and HIGH=100.

Based on how much Offence allocated to attack, how much Defence allocated to fortification, and the decisiveness level, the share of the 12 resource units originally held by Defence that he/she retains will be calculated according to a pre-defined formula. In essence, for given allocations of resource units to attack and fortification, a higher decisiveness decreases the share that Defence gets to keep. Thus, the resource units not retained by Defence are transferred to Offence.

To simplify the task, you have been provided with tables displaying the payoffs for all possible allocations of resource units to attack and fortification for both Offence and Defence given the three decisiveness levels 0, 1 and 100. However, the payoff functions and short descriptions thereof can be found in the appendix at the end of these instructions, should you wish to see them.

Finally, after all the three versions of the decision problem has been played, you will be asked to answer a few questions on a questionnaire. Please answer all questions as correctly as you can. Once you are finished, please remain seated until the experimenter tells you that the experiment is over. Do not speak to anyone until you have left the room.

Thank you for your participation!

Appendix:

Below follows a short description of the underlying functions of this decision problem. r given allocations of resource units to attack and fortification, a higher decisiveness decreases the share that Defence gets to keep. Thus, the resource units not retained by Defence are transferred to Offence.

$$Resource\ units\ retained\ by\ Defence = \frac{fortification}{fortification + decisiveness\ level * attack}$$

In the case where nothing is invested in fortification, but $decisiveness\ level * attack > 0$, Offence appropriates all of the resource units originally held by Defence for any investment in attack.

The payoffs for Offence and Defence are calculated as follows:

Offence:

$$Payoff = production + (1 - \frac{fortification}{fortification + decisiveness\ level * attack}) * 12 + 3$$

Offence gets whatever was produced by the eventual resource units used for production. In addition to this, he/she gains the share of Defence's 12 resource units that were appropriated, and lastly, retains the original resource units.

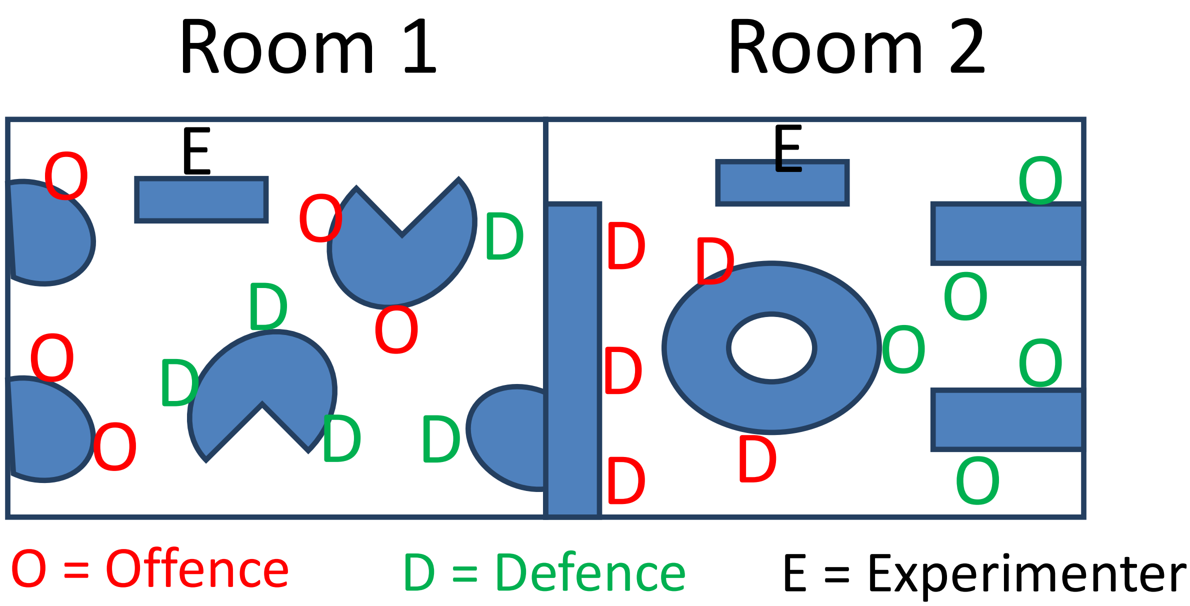
Defence:

$$Payoff = production + \frac{fortification}{fortification + decisiveness\ level * attack} * 12$$

Defence gets whatever was produced by the resource units used for production. In addition to this, he/she retains the share of the 12 resource units that were not appropriated by Offence.

Appendix 4: Illustration of the Arrangement of Subjects in the Experiment

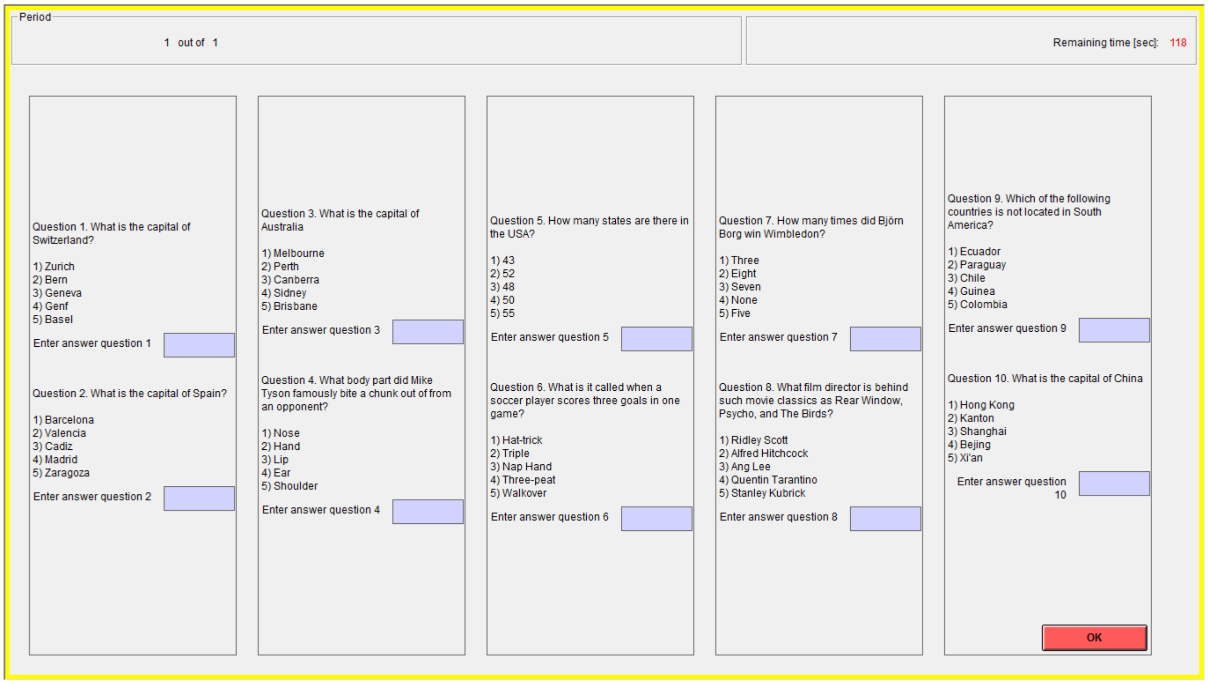
The figure below illustrates the arrangement of subjects in each session of the experiment. The letters denote which role the subjects played in the first period of each game. An O means that this subject started playing as Offence in each game, while a D means that the subject started playing as Defence. The colours of the letters denote which group the subjects belonged to. All green letters belonged to the same group, while all red letters belonged to another group. Within each group, subjects were randomly matched with a player of opposite role in each period. Hence, subjects always played against a person in the other room. Subjects were randomised to groups. There was an experimenter monitoring the subjects in each room.



Appendix 5: Z-tree Experiment Slide-by-slide

Quiz

1



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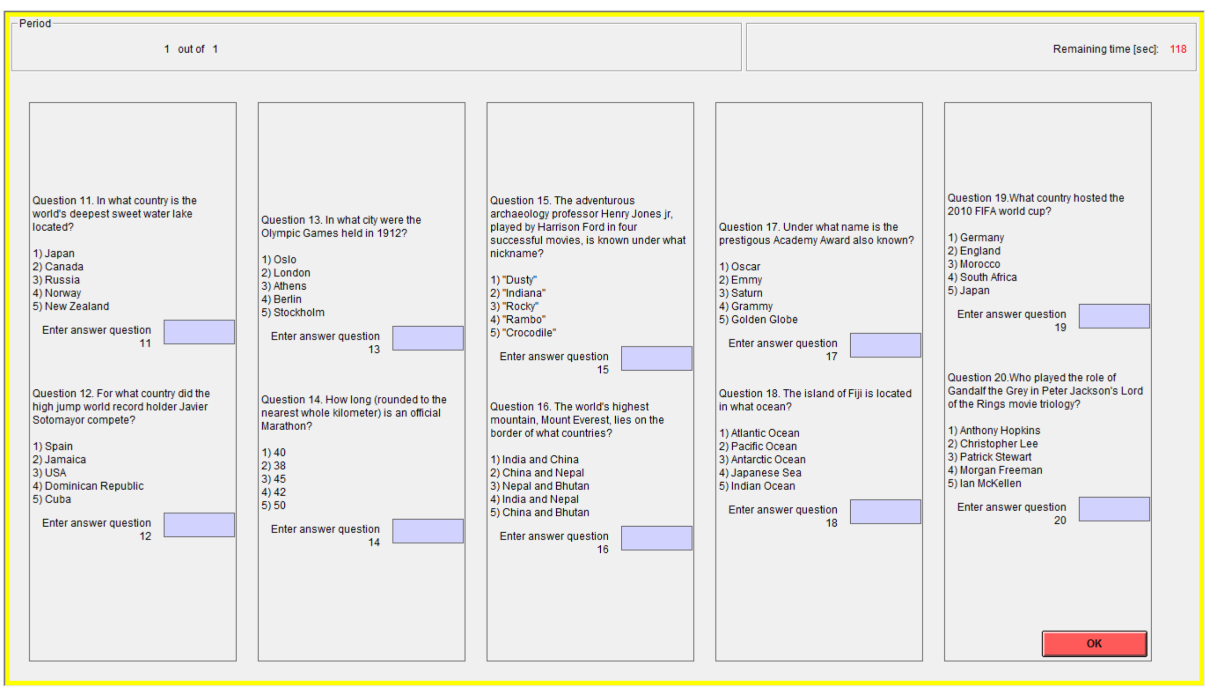
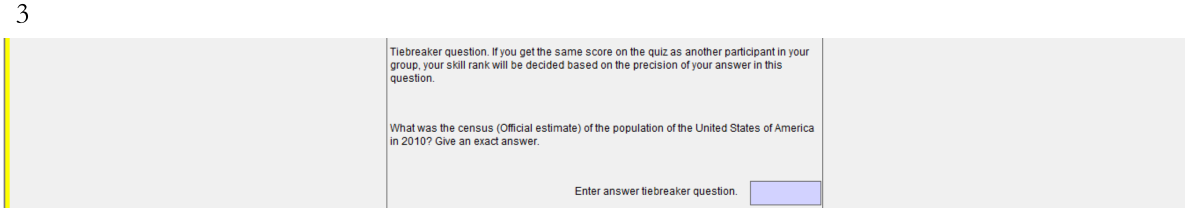


3



4

Period

1 out of 1

Remaining time [sec]: 179

You will now be asked to answer questions about your performance in this quiz. One of these answers will be randomly drawn after the experiment. If question 1, 2 or 3 is drawn and you state the correct answer, you will earn 20 SEK. If question 4 is drawn, your payoff will be based on the following formula: 10*(1+R-W) SEK. R is two times the probability assigned to the actual rank you got in the quiz and W is the sum total of each probability squared. This is a rather complex way of saying that you have the incentive to display your true beliefs, as this will maximize your payoff.

Question 1. What rank in your group do you think you got in the quiz? 1 is lowest rank, 10 is highest rank (There are 10 individuals in your group, including you. As mentioned earlier, you have the same score on th quiz as one or several other individuals in your group, the precision on the tiebreaker question will determine your rank)

Question 2. What do you think that your own score on the quiz was? (There were 20 questions)

Question 3. What do you think that the average score of the other participants was? (one decimal allowed)

Question 4. State for each rank, the probability with which you think you have this rank. A value of 30 in one of the ten choices thus means that you assume to have this rank with a probability of 30 %. A value of 0 states that you definitely do not have this rank, while a value of 100 indicates that you are absolutely sure to have this rank. Rank 1 is the person who had the lowest score in the quiz, while rank 10 is the person who had the highest score.

Please enter the probabilities in the boxes below, corresponding to each rank. The values must add up to 100. Note that you have to type in a number in each box, so enter 0 if you belief that a rank has 0 % probability.

Rank 10, highest

Rank 9

Rank 8

Rank 7

Rank 6

Rank 5

Rank 4

Rank 3

Rank 2

Rank 1, lowest

OK

Control Questions Game 1: Known Decisiveness

1

Period

1 out of 1

Remaining time [sec]: 208

Questionnaire

These questions are designed to test your understanding of the experiment. Please answer them carefully. Raise your hand if you have any doubts.

1.The decisiveness in the period is **0** . You are **defence** . You invest 2 in fortification and your opponent invested 1. What will **your** payoff be?

2. The decisiveness in the period is **1** . You are **defence** . You invest 3 in fortification and your opponent invested 0. What will **your** payoff be?

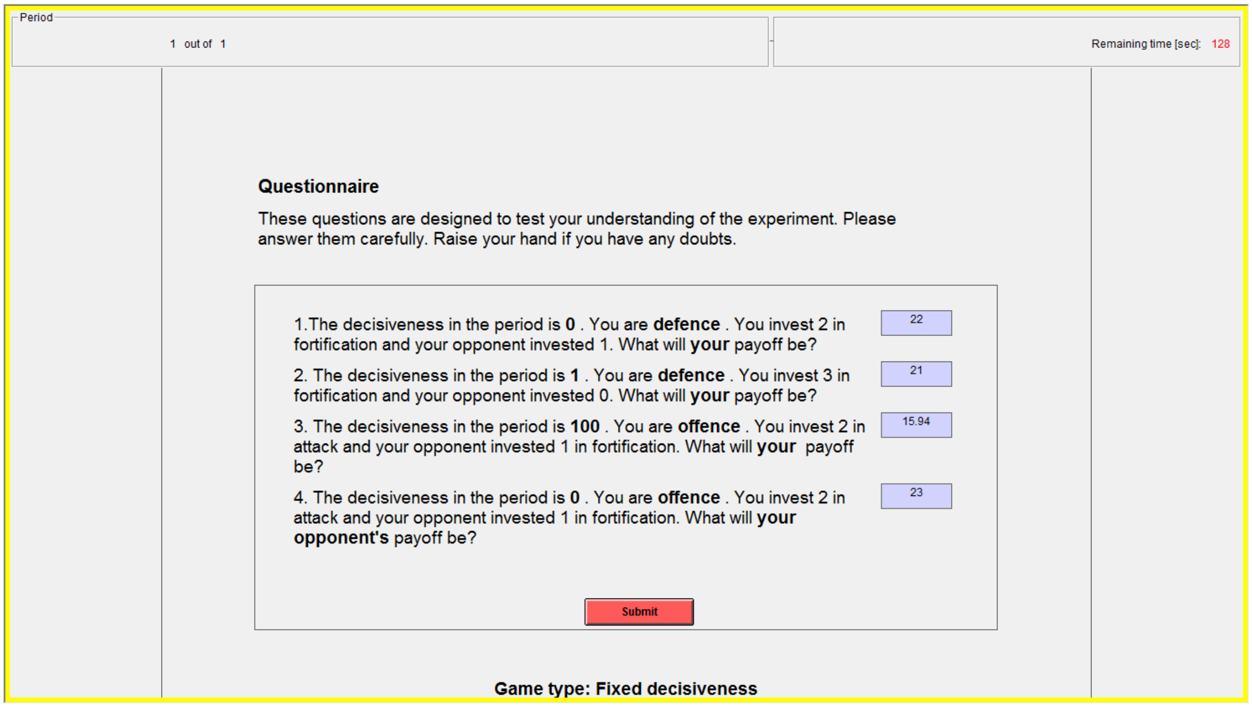
3. The decisiveness in the period is **100** . You are **offence** . You invest 2 in attack and your opponent invested 1 in fortification. What will **your** payoff be?

4. The decisiveness in the period is **0** . You are **offence** . You invest 2 in attack and your opponent invested 1 in fortification. What will **your opponent's** payoff be?

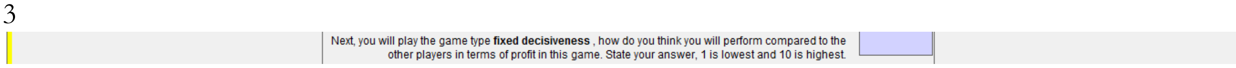
Submit

Game type: Fixed decisiveness

2

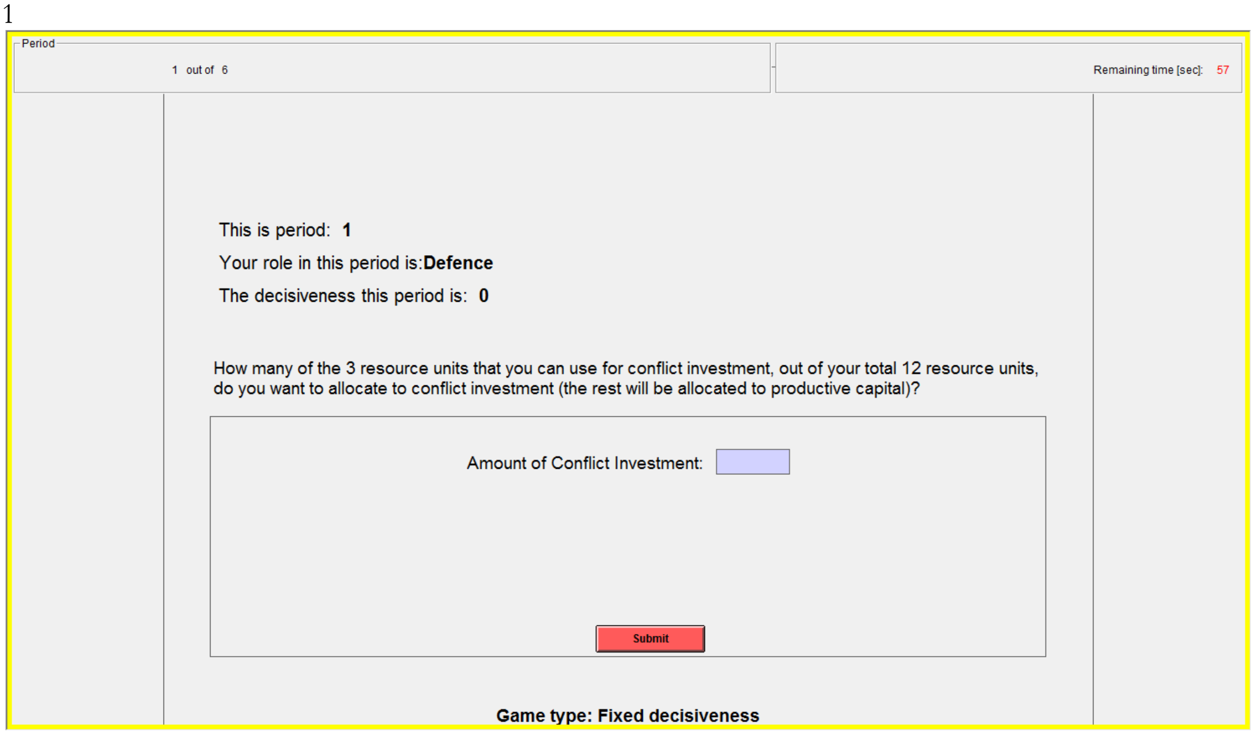


3

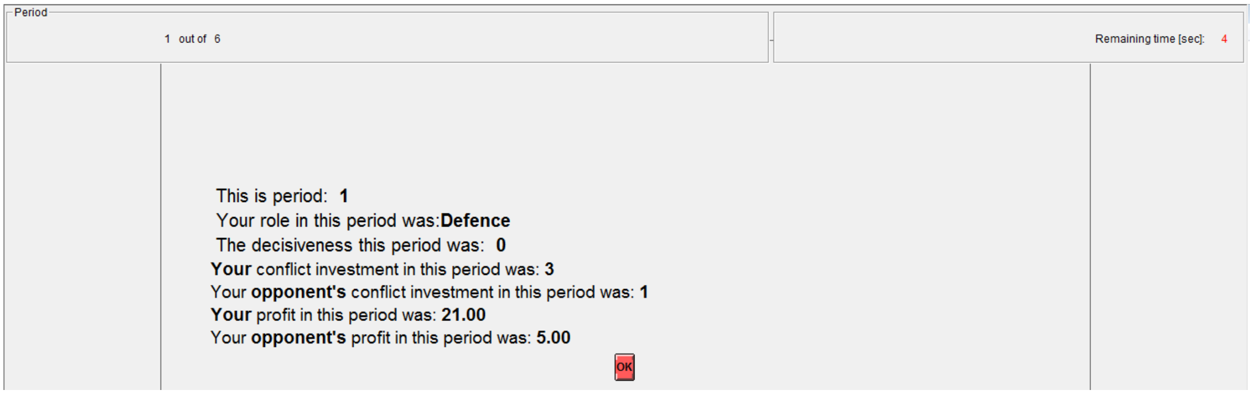


Game 1: Known Decisiveness

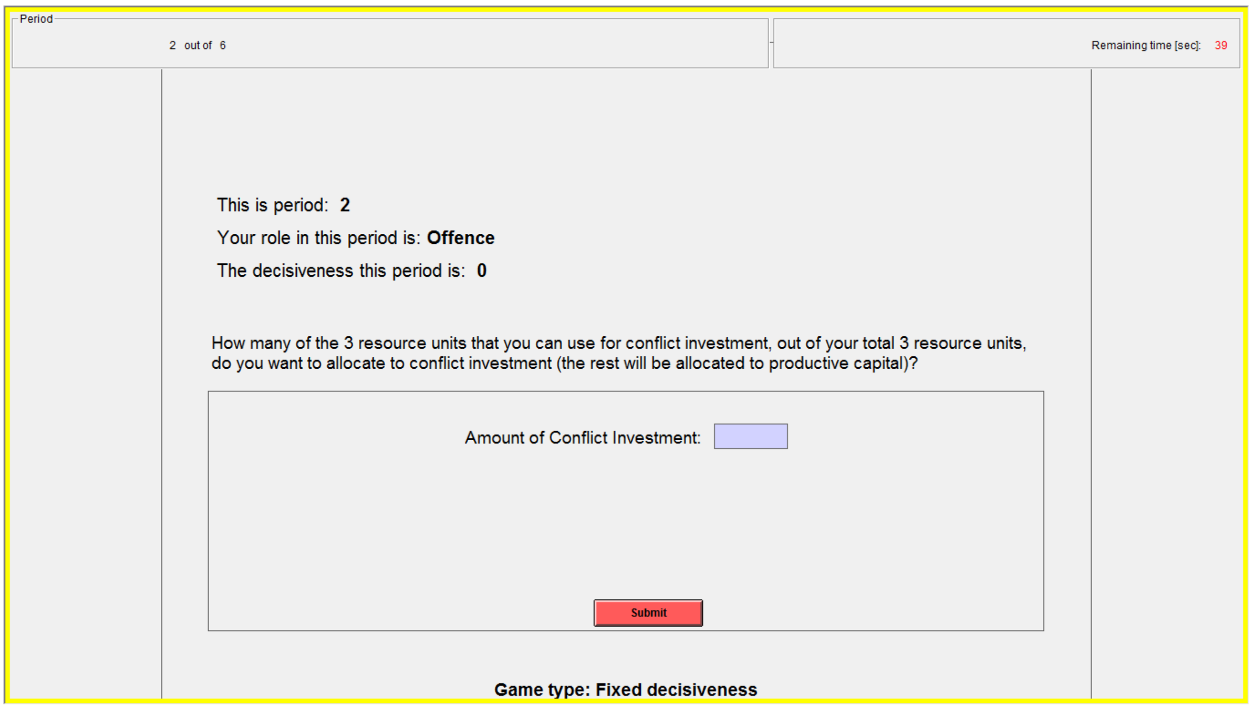
1



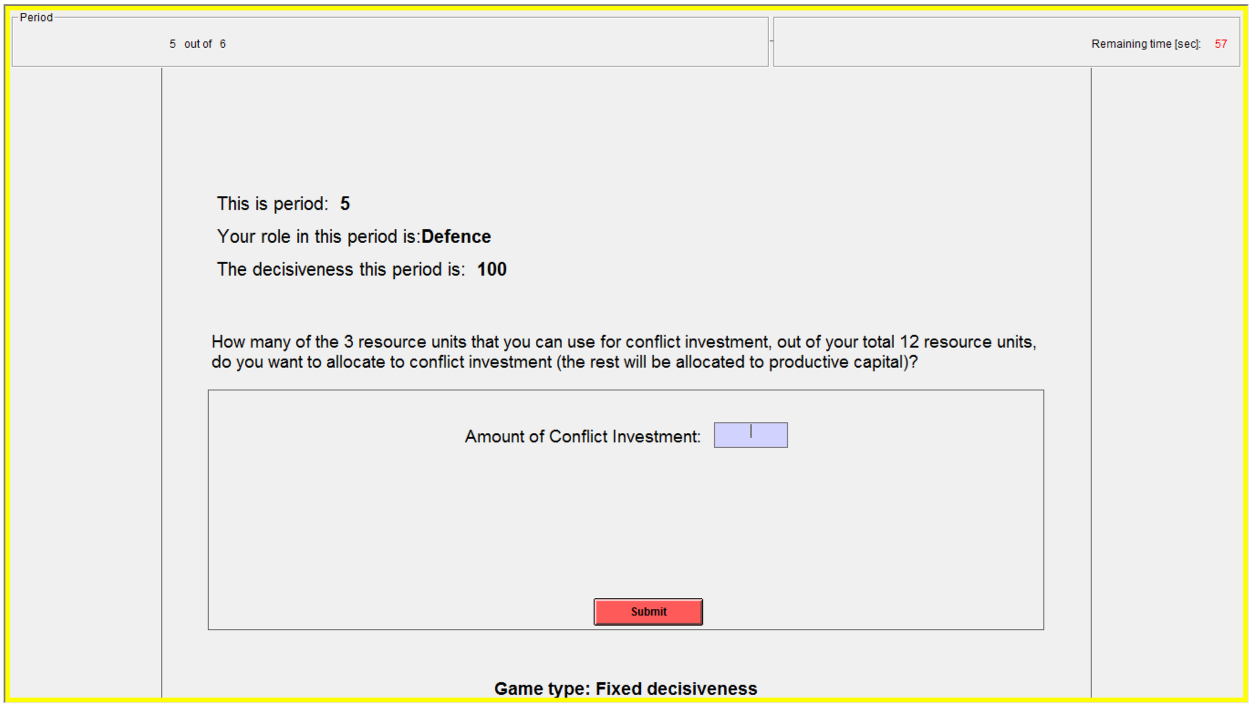
2


Period
1 out of 6
Remaining time [sec]: 4
This is period: **1**
Your role in this period was:**Defence**
The decisiveness this period was: **0**
Your conflict investment in this period was: **3**
Your **opponent's** conflict investment in this period was: **1**
Your profit in this period was: **21.00**
Your **opponent's** profit in this period was: **5.00**
OK

3

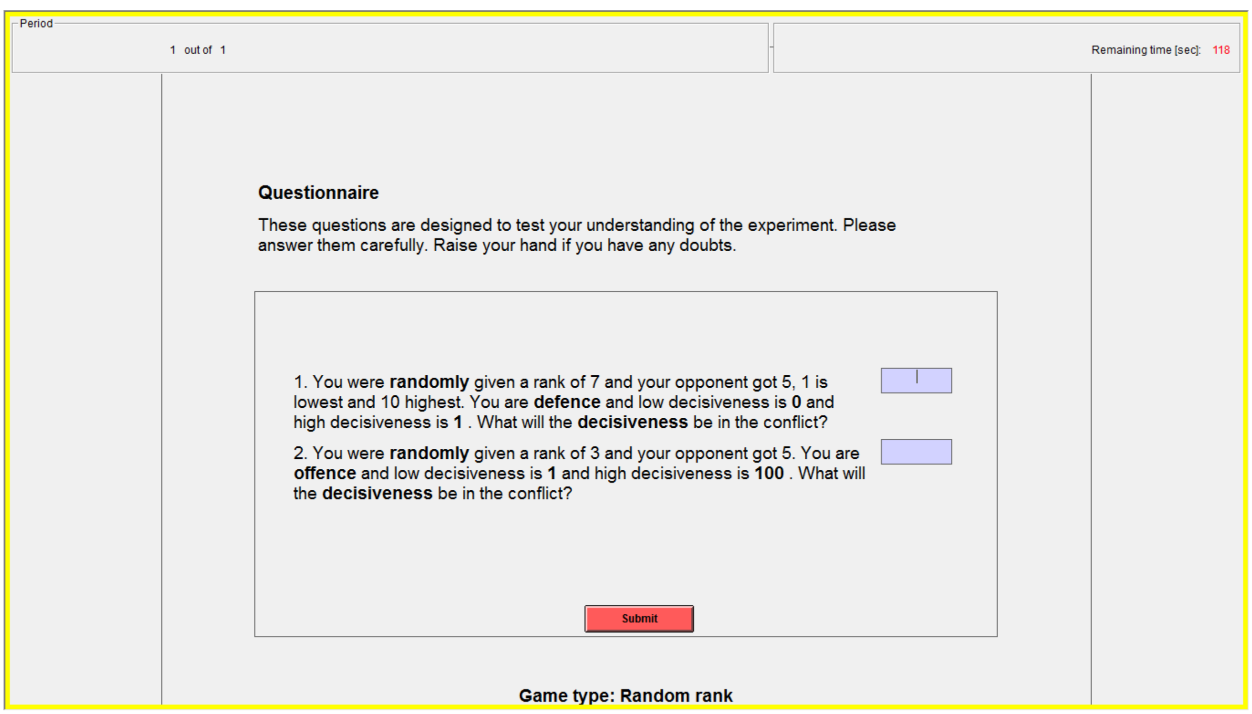

Period
2 out of 6
Remaining time [sec]: 39
This is period: **2**
Your role in this period is: **Offence**
The decisiveness this period is: **0**
How many of the 3 resource units that you can use for conflict investment, out of your total 3 resource units, do you want to allocate to conflict investment (the rest will be allocated to productive capital)?
Amount of Conflict Investment:
Submit
Game type: Fixed decisiveness

4



Control Questions Game 2: Unknown Exogenous Decisiveness (Random)

1



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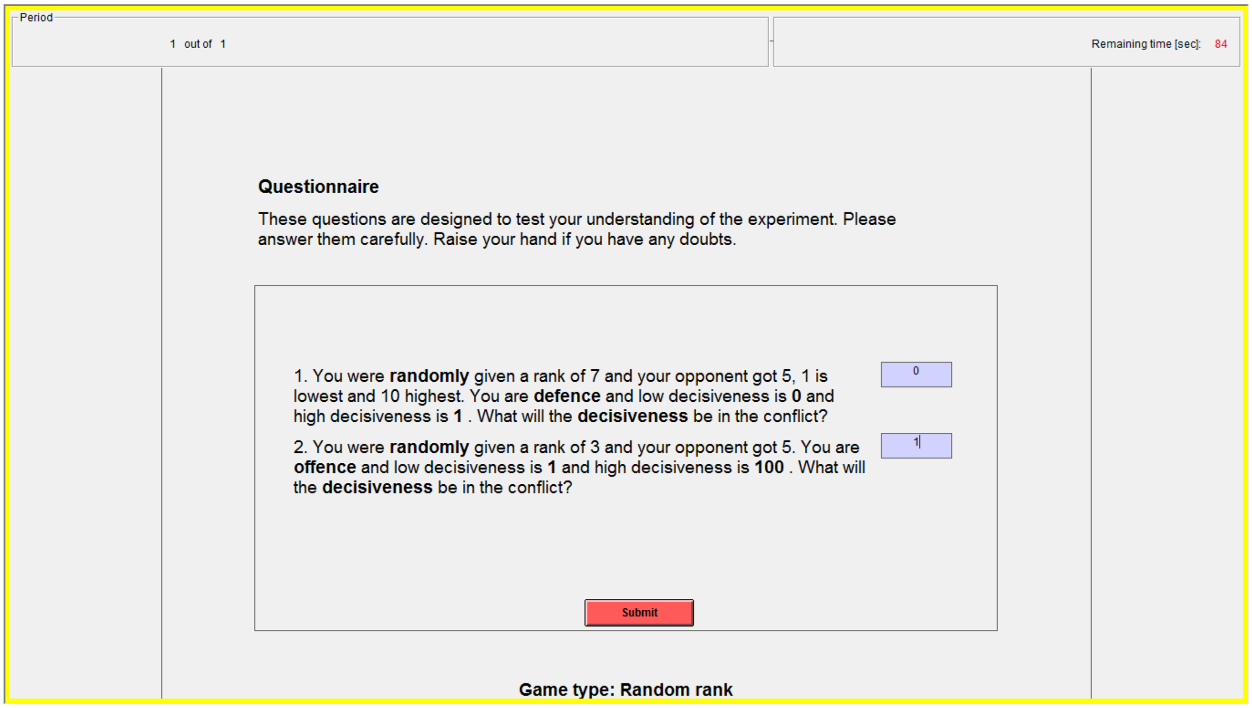
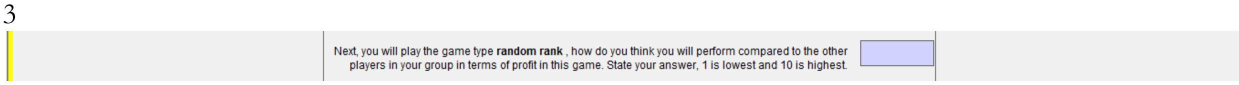
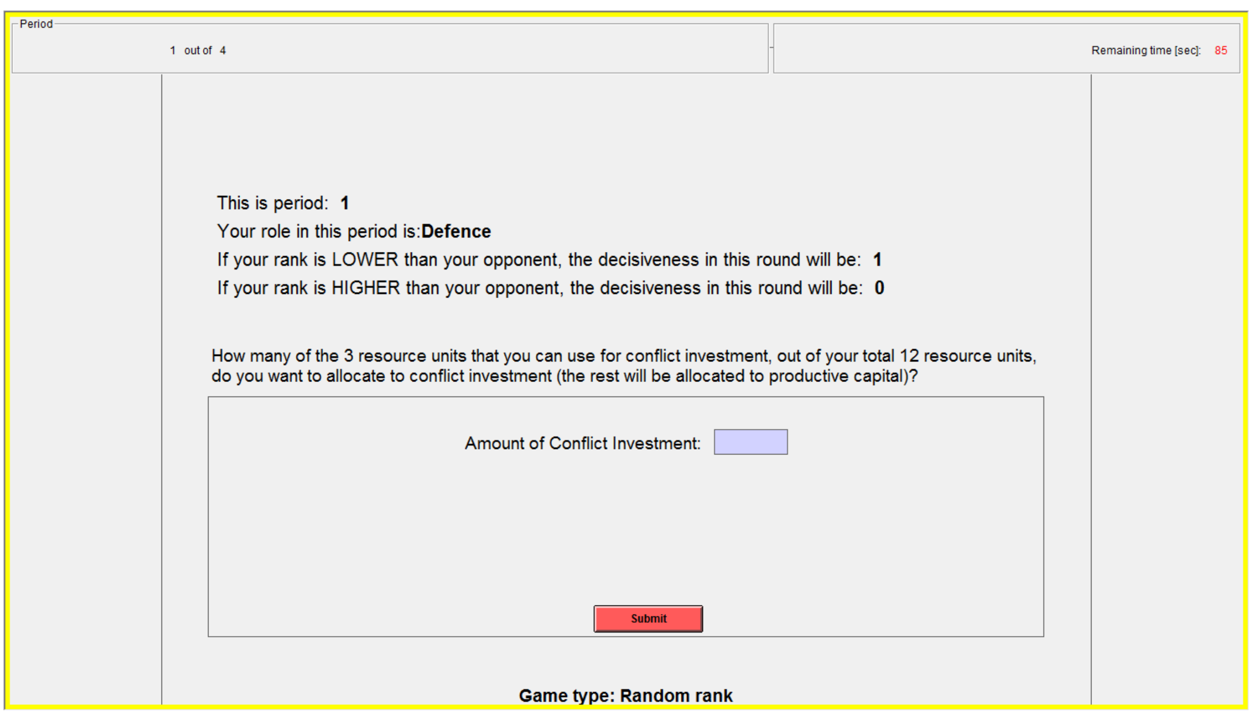


3

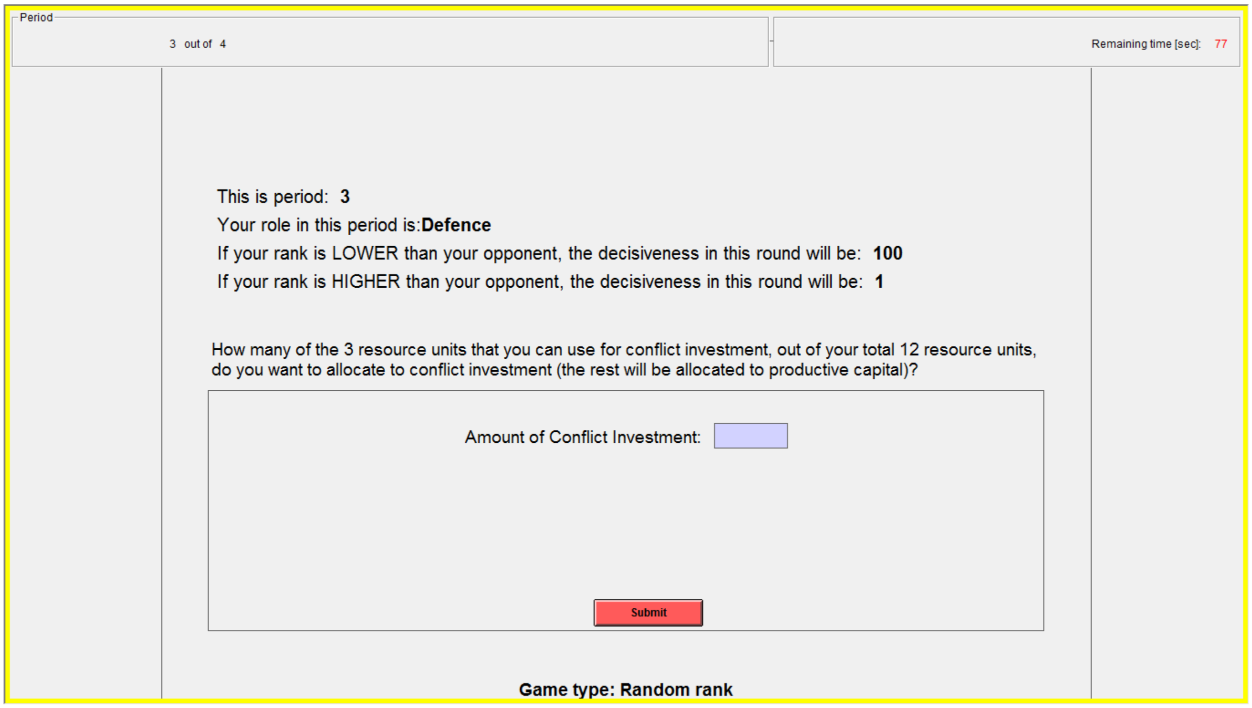


Game 2: Unknown Exogenous Decisiveness

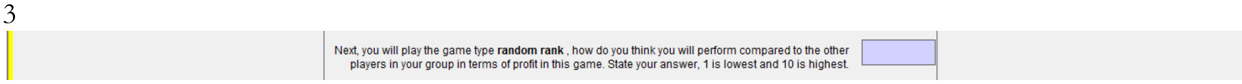
1



2

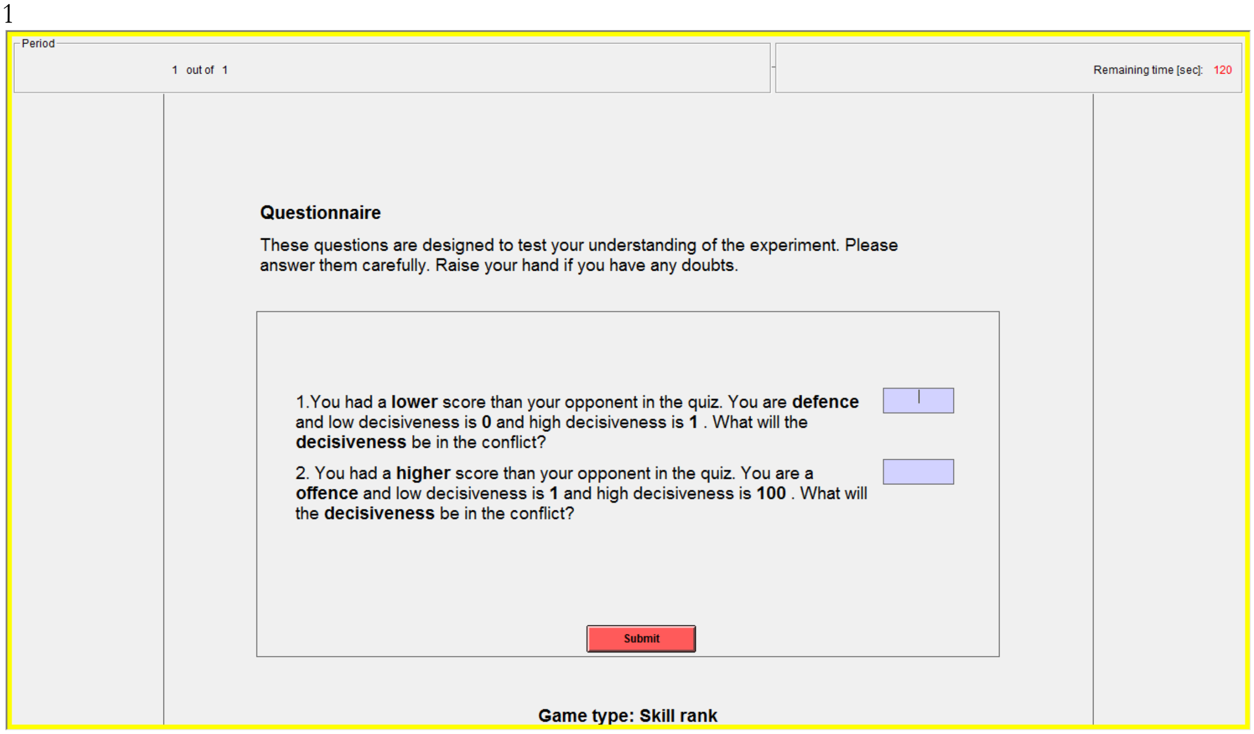


3

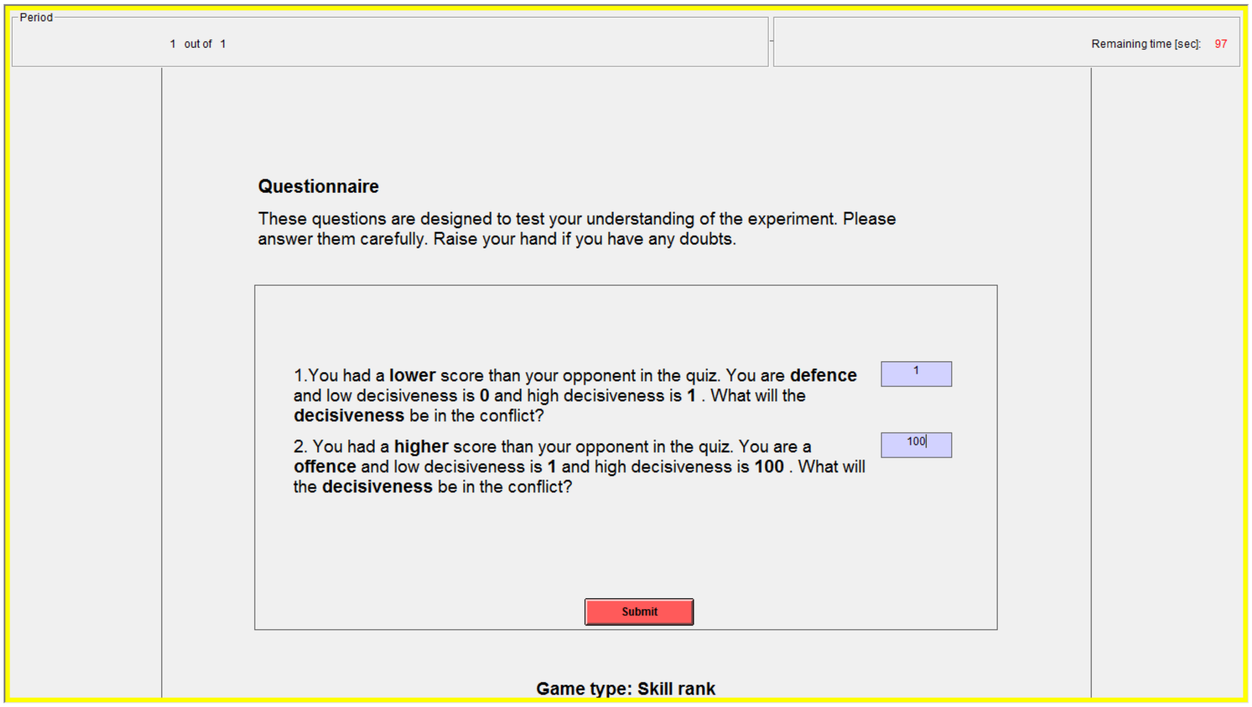


Control Questions Game 3: Unknown Endogenous Decisiveness (Skill)

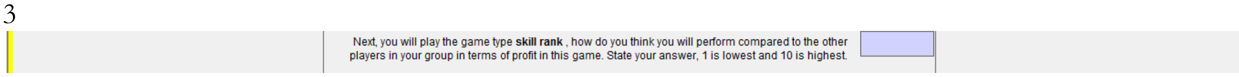
1



2

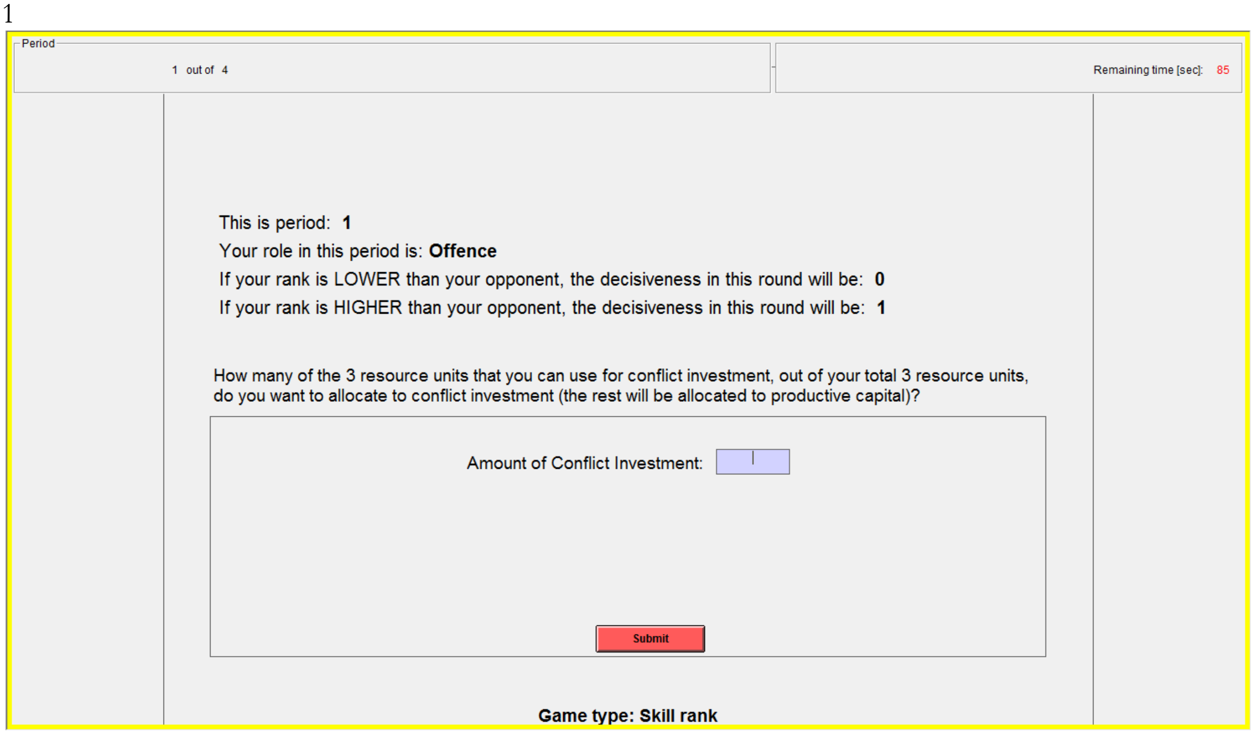


3



Game 3: Unknown Endogenous Decisiveness

1



2

Period

3 out of 4

Remaining time [sec]: 82

This is period: **3**

Your role in this period is: **Offence**

If your rank is LOWER than your opponent, the decisiveness in this round will be: **1**

If your rank is HIGHER than your opponent, the decisiveness in this round will be: **100**

How many of the 3 resource units that you can use for conflict investment, out of your total 3 resource units, do you want to allocate to conflict investment (the rest will be allocated to productive capital)?

Amount of Conflict Investment:

Submit

Game type: Skill rank

Profit

1

Your profit in the experiment was: **141**

OK

Questionnaire

1

Questionnaire

Please state your gender — male / female

Please state your age: [25]

State what year of university studies you are in: [5]

At what school are you a student? [SSE]

What specialization do you study? (If you have not yet chosen a specialization, please type "None"). [Economics]

State if you are a Swedish or Foreign Citizen: — I am a Swedish citizen / I am a foreign citizen

OK

2

Please answer the following questions as correctly as you can. Note that decimals should be denoted with a dot and not a comma. Don't put letters or spaces in your answers.

Question1) A bat and a ball costs $1.10. The bat costs $1.00 more than the ball. How much does the ball cost? [0.05]

Question 2) If it takes 5 machine 5 minutes to make 5 widgets, how long would it take for 100 machines to make 100 widgets? [5]

Question 3) In a lake has 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? [47]

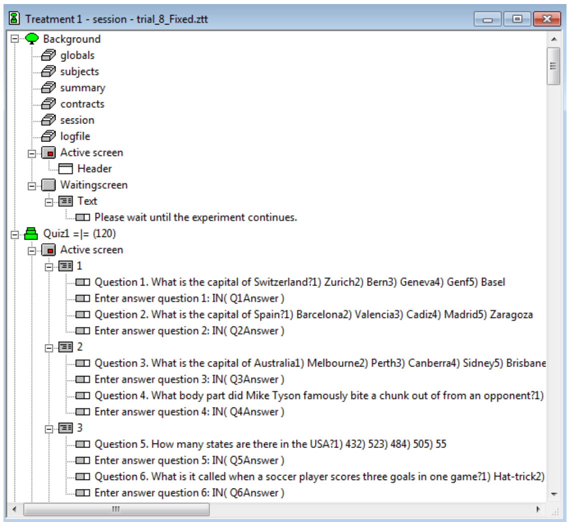
Have you taken this test before? Yes = 1, No = 0. [1]

OK

Appendix 6: Z-tree Code

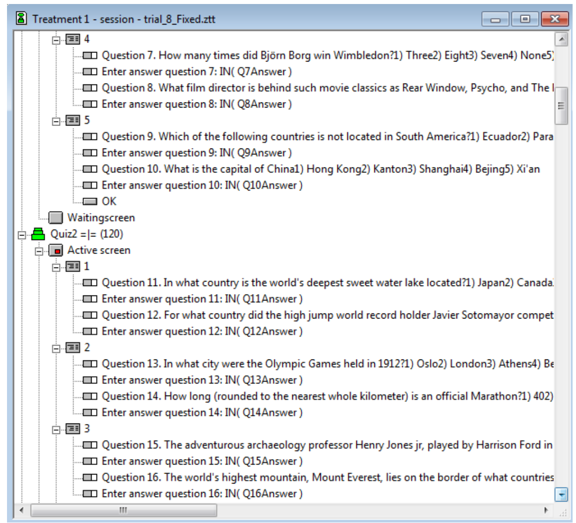
Quiz

1



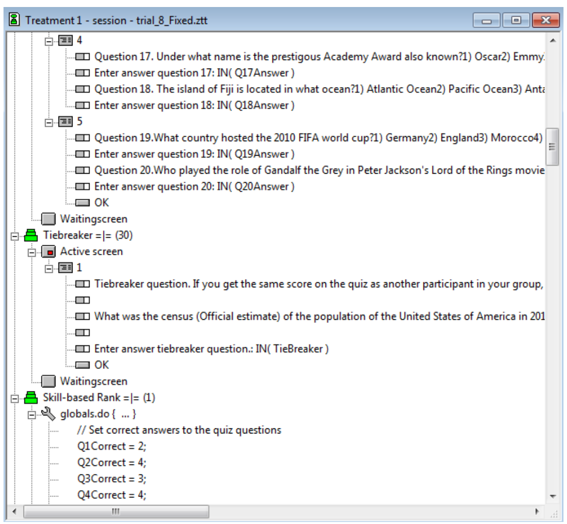
```
Treatment 1 - session - trial_8_Fixed.ztt
Background
  globals
  subjects
  summary
  contracts
  session
  logfile
  Active screen
    Header
  Waitingscreen
    Text
      Please wait until the experiment continues.
Quiz1 =|= (120)
  Active screen
    1
      Question 1. What is the capital of Switzerland?1) Zurich2) Bern3) Geneva4) Genf5) Basel
      Enter answer question 1: IN( Q1Answer )
      Question 2. What is the capital of Spain?1) Barcelona2) Valencia3) Cadiz4) Madrid5) Zaragoza
      Enter answer question 2: IN( Q2Answer )
    2
      Question 3. What is the capital of Australia1) Melbourne2) Perth3) Canberra4) Sidney5) Brisbane
      Enter answer question 3: IN( Q3Answer )
      Question 4. What body part did Mike Tyson famously bite a chunk out of from an opponent?1)
      Enter answer question 4: IN( Q4Answer )
    3
      Question 5. How many states are there in the USA?1) 432) 523) 484) 505) 55
      Enter answer question 5: IN( Q5Answer )
      Question 6. What is it called when a soccer player scores three goals in one game?1) Hat-trick2)
      Enter answer question 6: IN( Q6Answer )
```

2



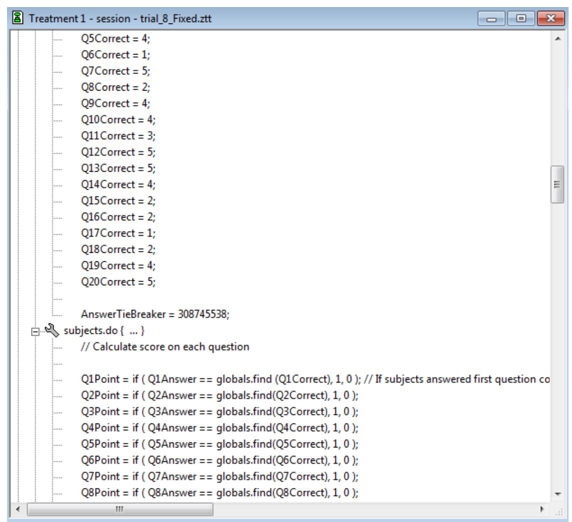
```
Treatment 1 - session - trial_8_Fixed.ztt
    4
      Question 7. How many times did Björn Borg win Wimbledon?1) Three2) Eight3) Seven4) None5)
      Enter answer question 7: IN( Q7Answer )
      Question 8. What film director is behind such movie classics as Rear Window, Psycho, and The
      Enter answer question 8: IN( Q8Answer )
    5
      Question 9. Which of the following countries is not located in South America?1) Ecuador2) Para
      Enter answer question 9: IN( Q9Answer )
      Question 10. What is the capital of China1) Hong Kong2) Kanton3) Shanghai4) Bejing5) Xi'an
      Enter answer question 10: IN( Q10Answer )
      OK
  Waitingscreen
Quiz2 =|= (120)
  Active screen
    1
      Question 11. In what country is the world's deepest sweet water lake located?1) Japan2) Canada
      Enter answer question 11: IN( Q11Answer )
      Question 12. For what country did the high jump world record holder Javier Sotomayor compet
      Enter answer question 12: IN( Q12Answer )
    2
      Question 13. In what city were the Olympic Games held in 1912?1) Oslo2) London3) Athens4) Be
      Enter answer question 13: IN( Q13Answer )
      Question 14. How long (rounded to the nearest whole kilometer) is an official Marathon?1) 402)
      Enter answer question 14: IN( Q14Answer )
    3
      Question 15. The adventurous archaeology professor Henry Jones jr, played by Harrison Ford in
      Enter answer question 15: IN( Q15Answer )
      Question 16. The world's highest mountain, Mount Everest, lies on the border of what countries
      Enter answer question 16: IN( Q16Answer )
```

3



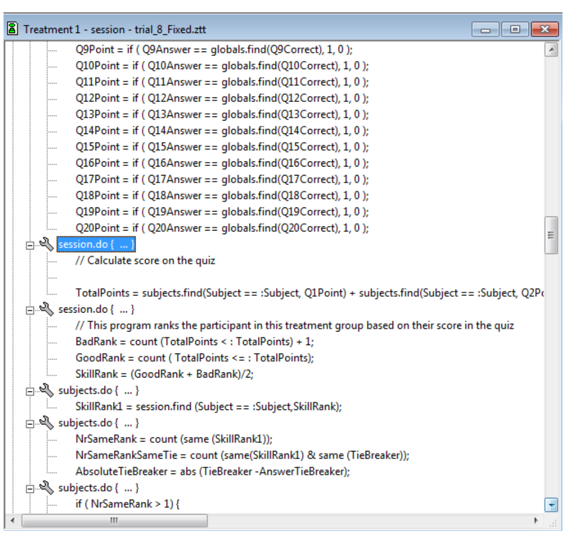
```
Treatment 1 - session - trial_8_Fixed.ztt
    4
      Question 17. Under what name is the prestigous Academy Award also known?1) Oscar2) Emmy
      Enter answer question 17: IN( Q17Answer )
      Question 18. The island of Fiji is located in what ocean?1) Atlantic Ocean2) Pacific Ocean3) Anta
      Enter answer question 18: IN( Q18Answer )
    5
      Question 19.What country hosted the 2010 FIFA world cup?1) Germany2) England3) Morocco4)
      Enter answer question 19: IN( Q19Answer )
      Question 20.Who played the role of Gandalf the Grey in Peter Jackson's Lord of the Rings movie
      Enter answer question 20: IN( Q20Answer )
      OK
  Waitingscreen
Tiebreaker =|= (30)
  Active screen
    1
      Tiebreaker question. If you get the same score on the quiz as another participant in your group,

      What was the census (Official estimate) of the population of the United States of America in 201

      Enter answer tiebreaker question.: IN( TieBreaker )
      OK
  Waitingscreen
Skill-based Rank =|= (1)
  globals.do { ... }
    // Set correct answers to the quiz questions
    Q1Correct = 2;
    Q2Correct = 4;
    Q3Correct = 3;
    Q4Correct = 4;
```

4



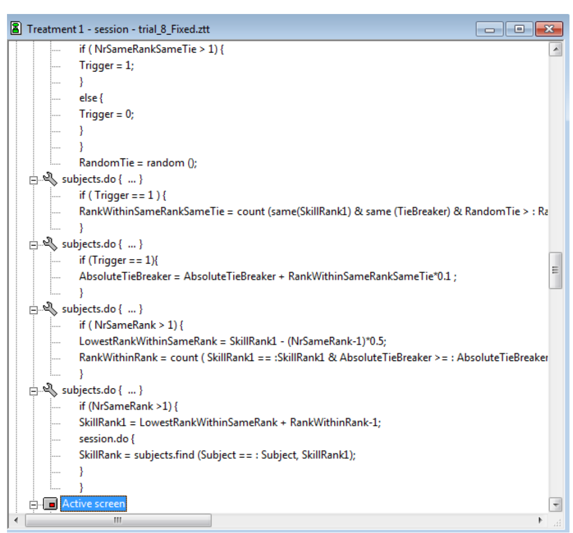
```
Treatment 1 - session - trial_8_Fixed.ztt
    Q5Correct = 4;
    Q6Correct = 1;
    Q7Correct = 5;
    Q8Correct = 2;
    Q9Correct = 4;
    Q10Correct = 4;
    Q11Correct = 3;
    Q12Correct = 5;
    Q13Correct = 5;
    Q14Correct = 4;
    Q15Correct = 2;
    Q16Correct = 2;
    Q17Correct = 1;
    Q18Correct = 2;
    Q19Correct = 4;
    Q20Correct = 5;

    AnswerTieBreaker = 308745538;
  subjects.do { ... }
    // Calculate score on each question

    Q1Point = if ( Q1Answer == globals.find (Q1Correct), 1, 0 ); // If subjects answered first question co
    Q2Point = if ( Q2Answer == globals.find(Q2Correct), 1, 0 );
    Q3Point = if ( Q3Answer == globals.find(Q3Correct), 1, 0 );
    Q4Point = if ( Q4Answer == globals.find(Q4Correct), 1, 0 );
    Q5Point = if ( Q5Answer == globals.find(Q5Correct), 1, 0 );
    Q6Point = if ( Q6Answer == globals.find(Q6Correct), 1, 0 );
    Q7Point = if ( Q7Answer == globals.find(Q7Correct), 1, 0 );
    Q8Point = if ( Q8Answer == globals.find(Q8Correct), 1, 0 );
```

5



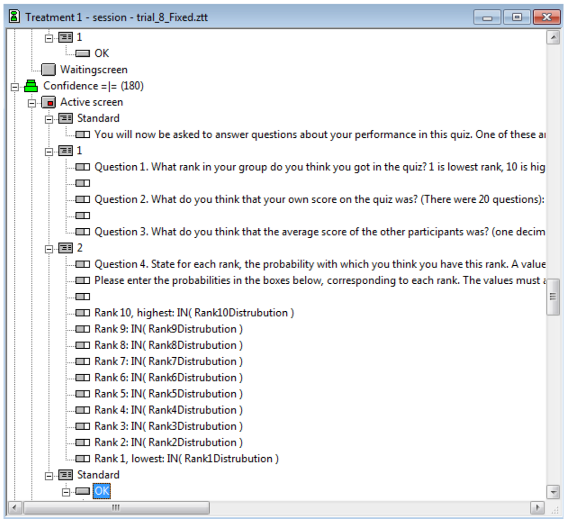
```
Treatment 1 - session - trial_8_Fixed.ztt
    Q9Point = if ( Q9Answer == globals.find(Q9Correct), 1, 0 );
    Q10Point = if ( Q10Answer == globals.find(Q10Correct), 1, 0 );
    Q11Point = if ( Q11Answer == globals.find(Q11Correct), 1, 0 );
    Q12Point = if ( Q12Answer == globals.find(Q12Correct), 1, 0 );
    Q13Point = if ( Q13Answer == globals.find(Q13Correct), 1, 0 );
    Q14Point = if ( Q14Answer == globals.find(Q14Correct), 1, 0 );
    Q15Point = if ( Q15Answer == globals.find(Q15Correct), 1, 0 );
    Q16Point = if ( Q16Answer == globals.find(Q16Correct), 1, 0 );
    Q17Point = if ( Q17Answer == globals.find(Q17Correct), 1, 0 );
    Q18Point = if ( Q18Answer == globals.find(Q18Correct), 1, 0 );
    Q19Point = if ( Q19Answer == globals.find(Q19Correct), 1, 0 );
    Q20Point = if ( Q20Answer == globals.find(Q20Correct), 1, 0 );
  session.do { ... }
    // Calculate score on the quiz

    TotalPoints = subjects.find(Subject == :Subject, Q1Point) + subjects.find(Subject == :Subject, Q2P
  session.do { ... }
    // This program ranks the participant in this treatment group based on their score in the quiz
    BadRank = count (TotalPoints < : TotalPoints) + 1;
    GoodRank = count ( TotalPoints <= : TotalPoints);
    SkillRank = (GoodRank + BadRank)/2;
  subjects.do { ... }
    SkillRank1 = session.find (Subject == :Subject,SkillRank);
  subjects.do { ... }
    NrSameRank = count (same (SkillRank1));
    NrSameRankSameTie = count (same(SkillRank1) & same (TieBreaker));
    AbsoluteTieBreaker = abs (TieBreaker -AnswerTieBreaker);
  subjects.do { ... }
    if ( NrSameRank > 1) {
```

6

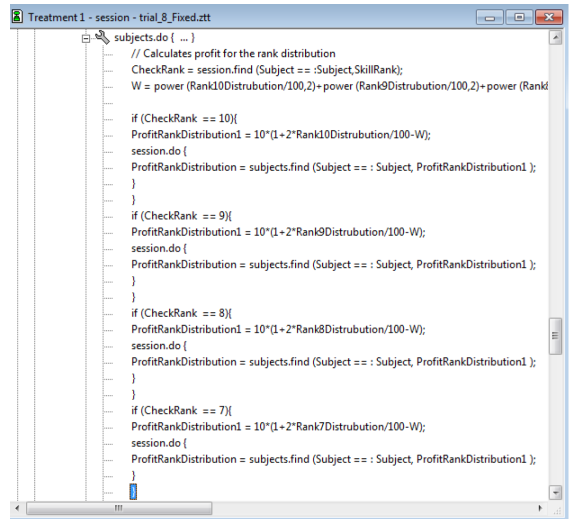


```
Treatment 1 - session - trial_8_Fixed.ztt
    if ( NrSameRankSameTie > 1) {
    Trigger = 1;
    }
    else {
    Trigger = 0;
    }
    }
    RandomTie = random ();
  subjects.do { ... }
    if ( Trigger == 1 ) {
    RankWithinSameRankSameTie = count (same(SkillRank1) & same (TieBreaker) & RandomTie > : Ra
    }
  subjects.do { ... }
    if (Trigger == 1){
    AbsoluteTieBreaker = AbsoluteTieBreaker + RankWithinSameRankSameTie*0.1 ;
    }
  subjects.do { ... }
    if ( NrSameRank > 1) {
    LowestRankWithinSameRank = SkillRank1 - (NrSameRank-1)*0.5;
    RankWithinRank = count ( SkillRank1 == :SkillRank1 & AbsoluteTieBreaker >= : AbsoluteTieBreaker
    }
  subjects.do { ... }
    if (NrSameRank >1) {
    SkillRank1 = LowestRankWithinSameRank + RankWithinRank-1;
    session.do {
    SkillRank = subjects.find (Subject == : Subject, SkillRank1);
    }
    }
  Active screen
```

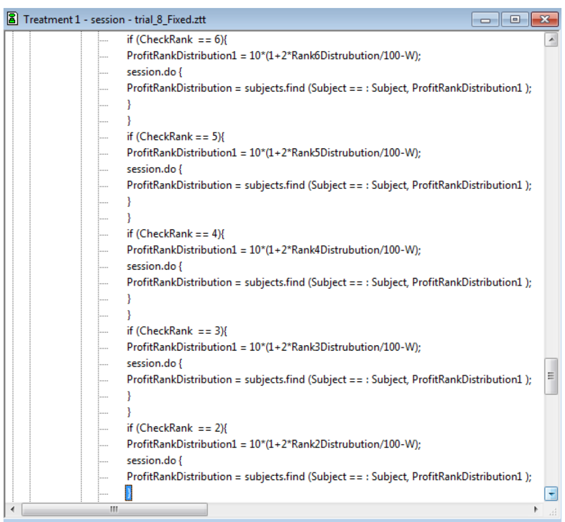
7


Treatment 1 - session - trial_8_Fixed.ztt
1
OK
Waitingscreen
Confidence =|= (180)
Active screen
Standard
You will now be asked to answer questions about your performance in this quiz. One of these a
1
Question 1. What rank in your group do you think you got in the quiz? 1 is lowest rank, 10 is hig
Question 2. What do you think that your own score on the quiz was? (There were 20 questions):
Question 3. What do you think that the average score of the other participants was? (one decim
2
Question 4. State for each rank, the probability with which you think you have this rank. A value
Please enter the probabilities in the boxes below, corresponding to each rank. The values must
Rank 10, highest: IN(Rank10Distrubution)
Rank 9: IN(Rank9Distrubution)
Rank 8: IN(Rank8Distrubution)
Rank 7: IN(Rank7Distrubution)
Rank 6: IN(Rank6Distrubution)
Rank 5: IN(Rank5Distrubution)
Rank 4: IN(Rank4Distrubution)
Rank 3: IN(Rank3Distrubution)
Rank 2: IN(Rank2Distrubution)
Rank 1, lowest: IN(Rank1Distrubution)
Standard
OK

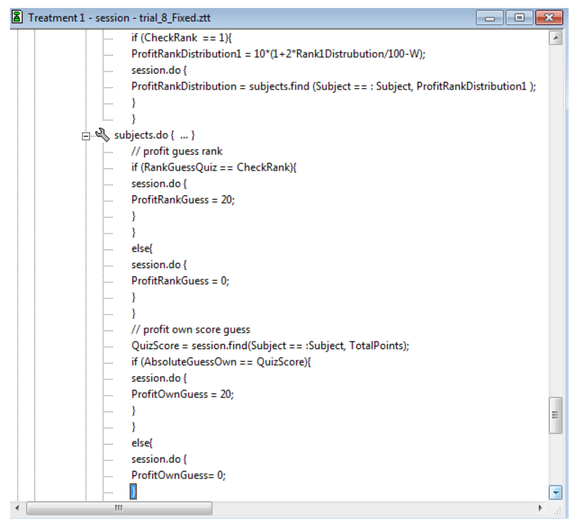
8


Treatment 1 - session - trial_8_Fixed.ztt
subjects.do { ... }
// Calculates profit for the rank distribution
CheckRank = session.find (Subject == :Subject,SkillRank);
W = power (Rank10Distrubution/100,2)+power (Rank9Distrubution/100,2)+power (Rank
if (CheckRank == 10){
ProfitRankDistribution1 = 10*(1+2*Rank10Distrubution/100-W);
session.do {
ProfitRankDistribution = subjects.find (Subject == : Subject, ProfitRankDistribution1);
}
}
if (CheckRank == 9){
ProfitRankDistribution1 = 10*(1+2*Rank9Distrubution/100-W);
session.do {
ProfitRankDistribution = subjects.find (Subject == : Subject, ProfitRankDistribution1);
}
}
if (CheckRank == 8){
ProfitRankDistribution1 = 10*(1+2*Rank8Distrubution/100-W);
session.do {
ProfitRankDistribution = subjects.find (Subject == : Subject, ProfitRankDistribution1);
}
}
if (CheckRank == 7){
ProfitRankDistribution1 = 10*(1+2*Rank7Distrubution/100-W);
session.do {
ProfitRankDistribution = subjects.find (Subject == : Subject, ProfitRankDistribution1);
}

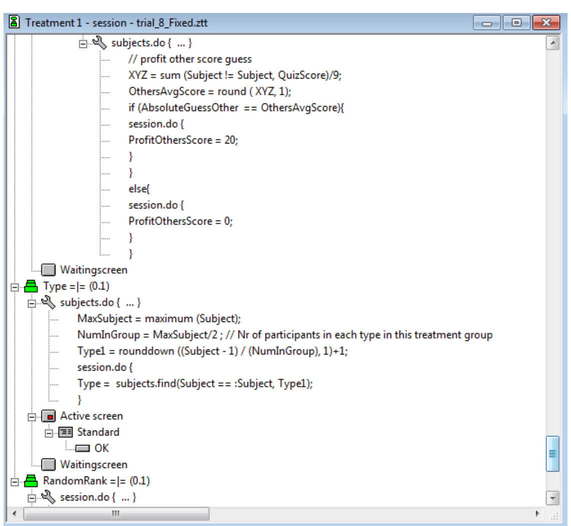
9


Treatment 1 - session - trial_8_Fixed.ztt
if (CheckRank == 6){
ProfitRankDistribution1 = 10*(1+2*Rank6Distrubution/100-W);
session.do {
ProfitRankDistribution = subjects.find (Subject == : Subject, ProfitRankDistribution1);
}
}
if (CheckRank == 5){
ProfitRankDistribution1 = 10*(1+2*Rank5Distrubution/100-W);
session.do {
ProfitRankDistribution = subjects.find (Subject == : Subject, ProfitRankDistribution1);
}
}
if (CheckRank == 4){
ProfitRankDistribution1 = 10*(1+2*Rank4Distrubution/100-W);
session.do {
ProfitRankDistribution = subjects.find (Subject == : Subject, ProfitRankDistribution1);
}
}
if (CheckRank == 3){
ProfitRankDistribution1 = 10*(1+2*Rank3Distrubution/100-W);
session.do {
ProfitRankDistribution = subjects.find (Subject == : Subject, ProfitRankDistribution1);
}
}
if (CheckRank == 2){
ProfitRankDistribution1 = 10*(1+2*Rank2Distrubution/100-W);
session.do {
ProfitRankDistribution = subjects.find (Subject == : Subject, ProfitRankDistribution1);

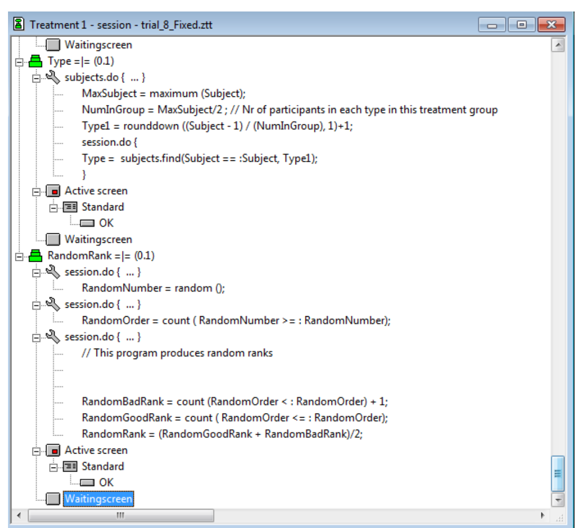
10


Treatment 1 - session - trial_8_Fixed.ztt
if (CheckRank == 1){
ProfitRankDistribution1 = 10*(1+2*Rank1Distrubution/100-W);
session.do {
ProfitRankDistribution = subjects.find (Subject == : Subject, ProfitRankDistribution1);
}
}
subjects.do { ... }
// profit guess rank
if (RankGuessQuiz == CheckRank){
session.do {
ProfitRankGuess = 20;
}
}
else{
session.do {
ProfitRankGuess = 0;
}
}
// profit own score guess
QuizScore = session.find(Subject == :Subject, TotalPoints);
if (AbsoluteGuessOwn == QuizScore){
session.do {
ProfitOwnGuess = 20;
}
}
else{
session.do {
ProfitOwnGuess= 0;

11

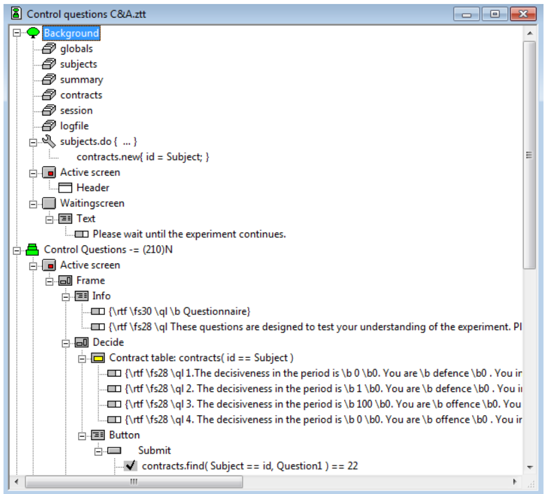

Treatment 1 - session - trial_8_Fixed.ztt
subjects.do { ... }
// profit other score guess
XYZ = sum (Subject != Subject, QuizScore)/9;
OthersAvgScore = round (XYZ, 1);
if (AbsoluteGuessOther == OthersAvgScore){
session.do {
ProfitOthersScore = 20;
}
}
else{
session.do {
ProfitOthersScore = 0;
}
}
Waitingscreen
Type =|= (0.1)
subjects.do { ... }
MaxSubject = maximum (Subject);
NumInGroup = MaxSubject/2 ; // Nr of participants in each type in this treatment group
Type1 = rounddown ((Subject - 1) / (NumInGroup), 1)+1;
session.do {
Type = subjects.find(Subject == :Subject, Type1);
}
Active screen
Standard
OK
Waitingscreen
RandomRank =|= (0.1)
session.do { ... }

12

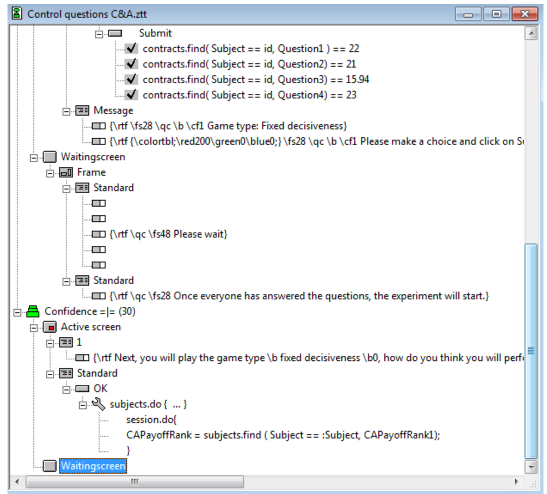

Treatment 1 - session - trial_8_Fixed.ztt
Waitingscreen
Type =|= (0.1)
subjects.do { ... }
MaxSubject = maximum (Subject);
NumInGroup = MaxSubject/2 ; // Nr of participants in each type in this treatment group
Type1 = rounddown ((Subject - 1) / (NumInGroup), 1)+1;
session.do {
Type = subjects.find(Subject == :Subject, Type1);
}
Active screen
Standard
OK
Waitingscreen
RandomRank =|= (0.1)
session.do { ... }
RandomNumber = random ();
session.do { ... }
RandomOrder = count (RandomNumber >= : RandomNumber);
session.do { ... }
// This program produces random ranks
RandomBadRank = count (RandomOrder < : RandomOrder) + 1;
RandomGoodRank = count (RandomOrder <= : RandomOrder);
RandomRank = (RandomGoodRank + RandomBadRank)/2;
Active screen
Standard
OK
Waitingscreen

Control Questions Game 1: Known Decisiveness

1

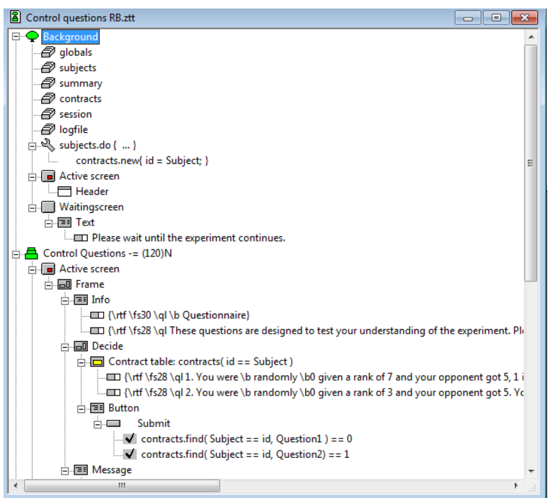


2

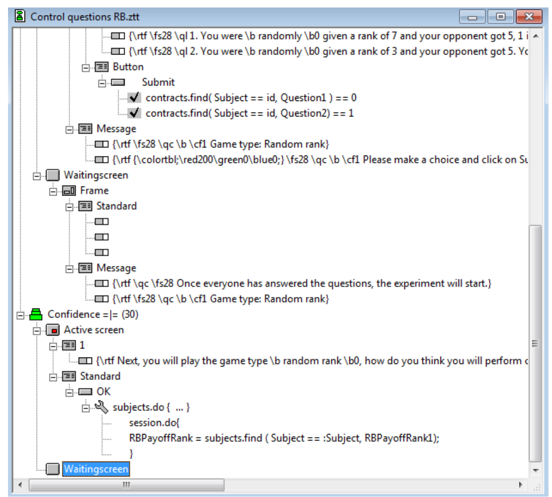


Control Questions Game 2: Unknown Exogenous Decisiveness (Random)

1

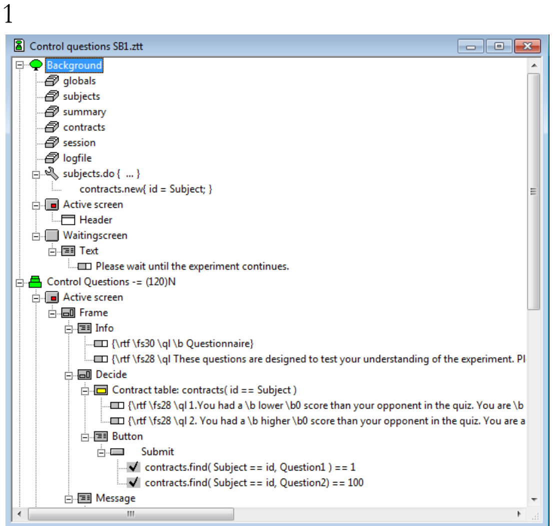


2

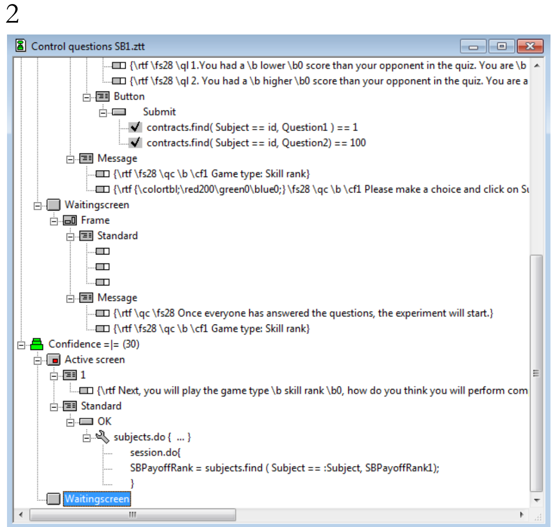


Control Questions Game 3: Unknown Endogenous Decisiveness (Skill)

1

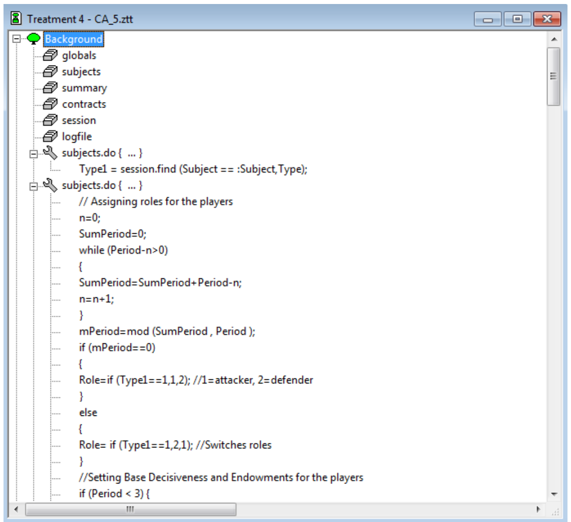


2

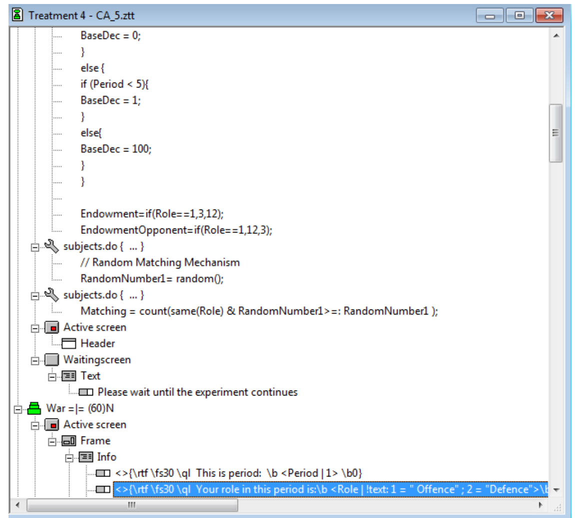


Game 1: Known Decisiveness

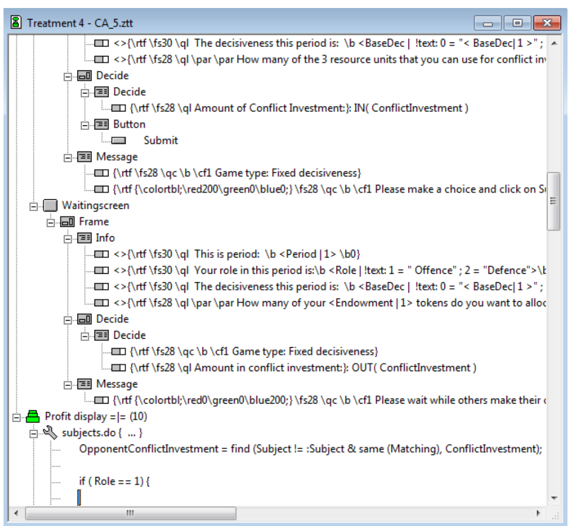
1



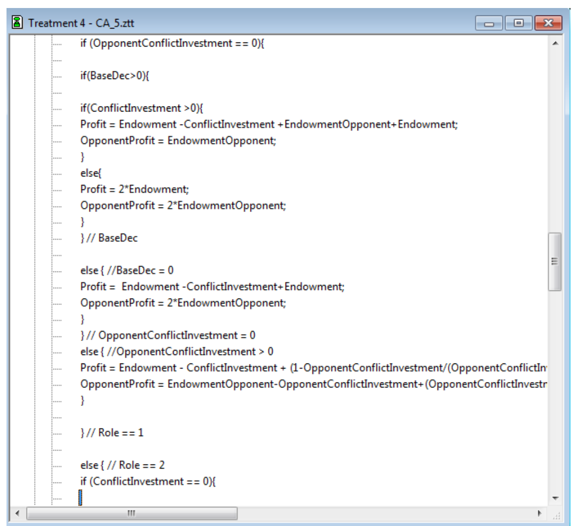
2



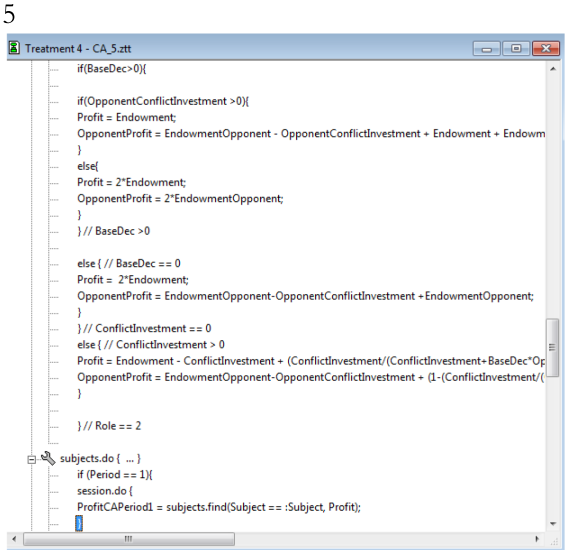
3



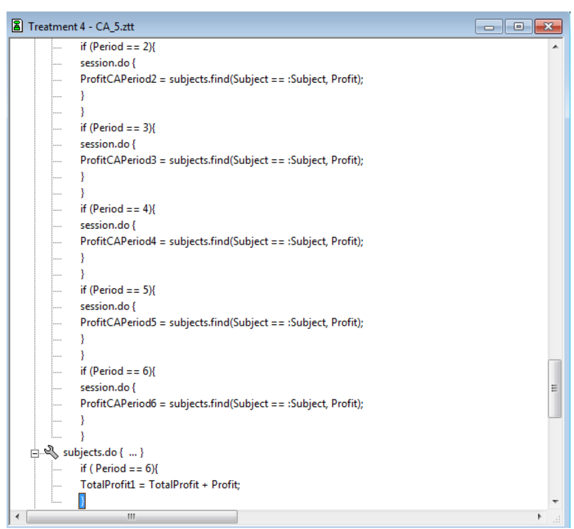
4



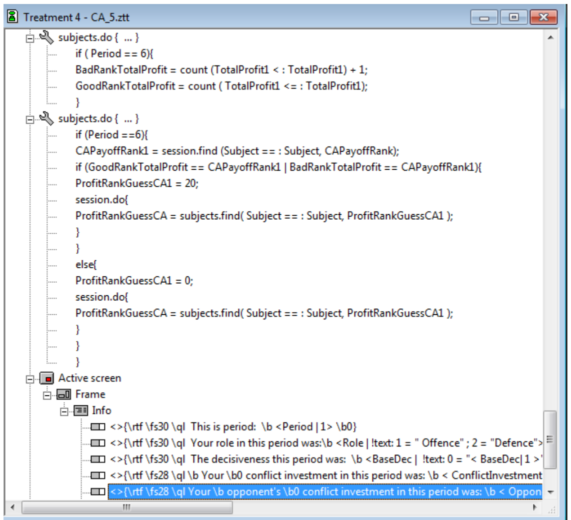
5



6

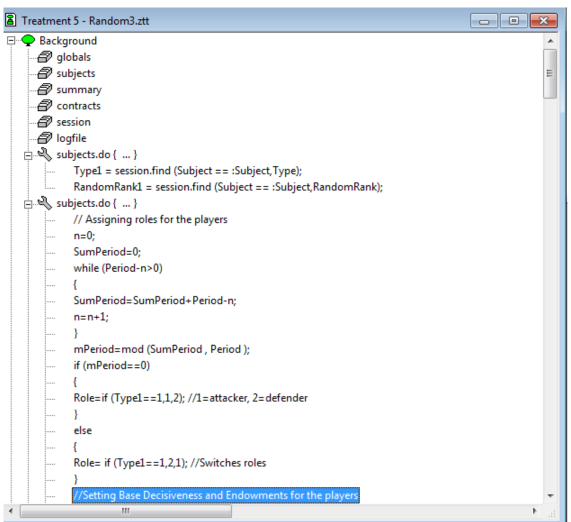


7

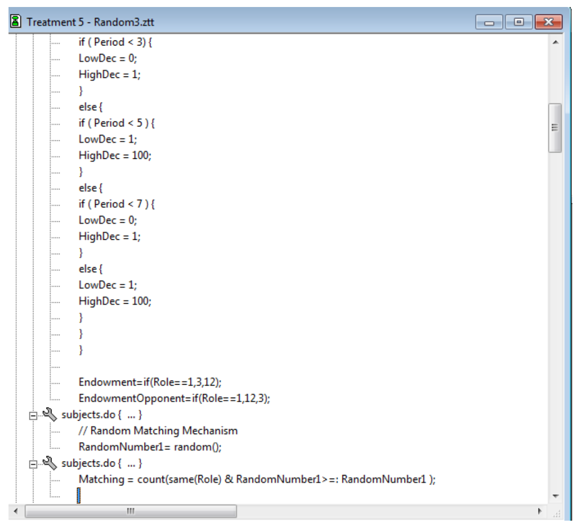


Game 2: Unknown Exogenous Decisiveness

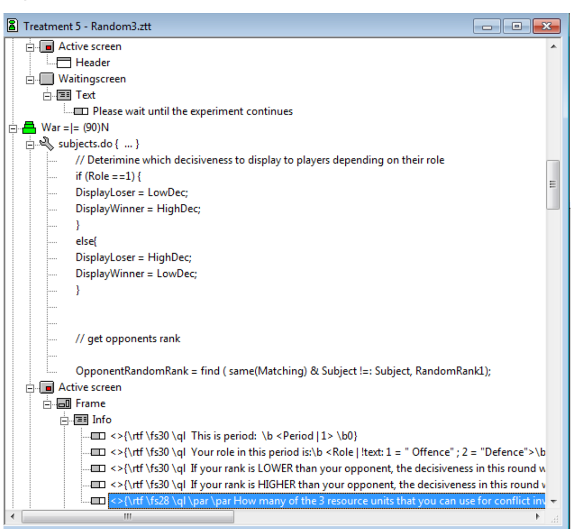
1



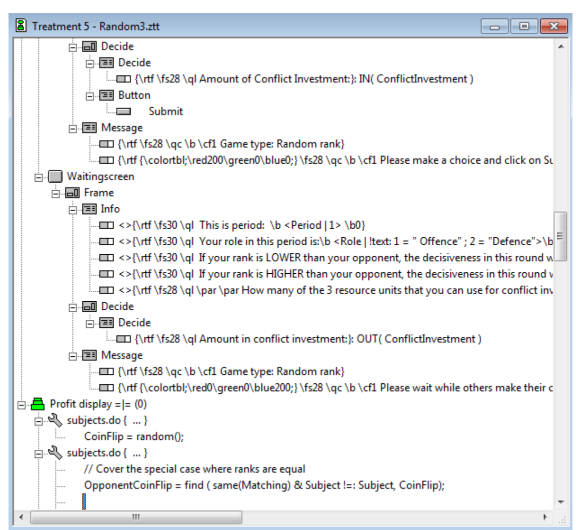
2



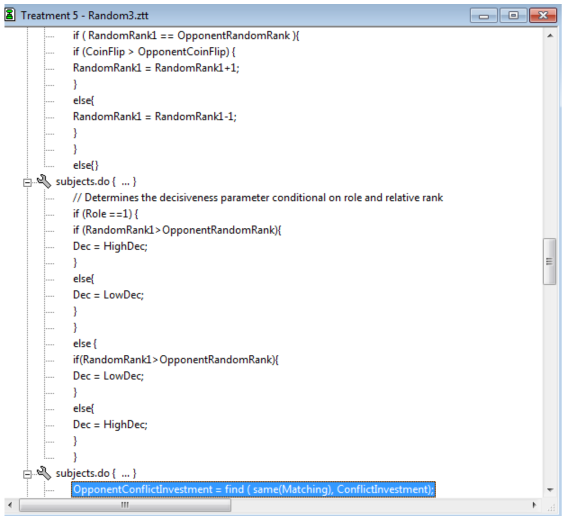
3



4

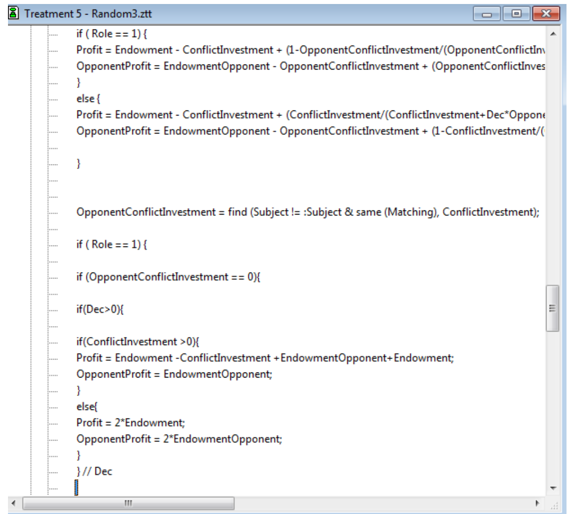


5



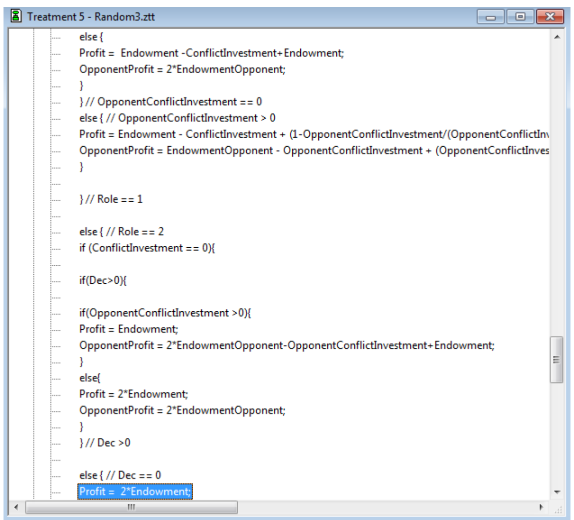
```
Treatment 5 - Random3.ztt
if ( RandomRank1 == OpponentRandomRank ){
if (CoinFlip > OpponentCoinFlip) {
RandomRank1 = RandomRank1+1;
}
else{
RandomRank1 = RandomRank1-1;
}
}
else{}
subjects.do { ... }
// Determines the decisiveness parameter conditional on role and relative rank
if (Role ==1) {
if (RandomRank1>OpponentRandomRank){
Dec = HighDec;
}
else{
Dec = LowDec;
}
}
else {
if(RandomRank1>OpponentRandomRank){
Dec = LowDec;
}
else{
Dec = HighDec;
}
}
subjects.do { ... }
OpponentConflictInvestment = find ( same(Matching), ConflictInvestment);
```

6



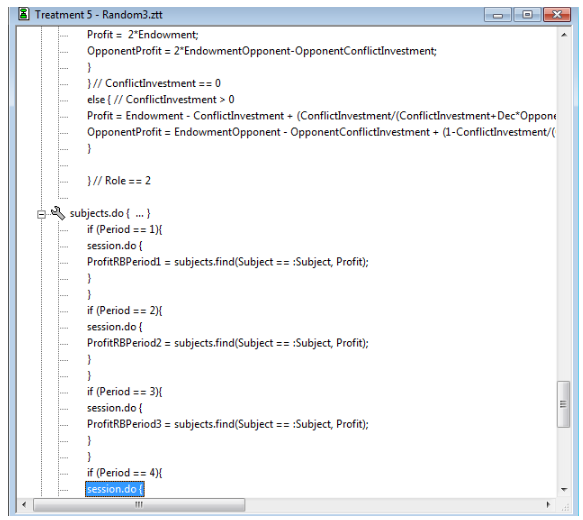
```
Treatment 5 - Random3.ztt
if ( Role == 1) {
Profit = Endowment - ConflictInvestment + (1-OpponentConflictInvestment/(OpponentConflictIn
OpponentProfit = EndowmentOpponent - OpponentConflictInvestment + (OpponentConflictInves
}
else {
Profit = Endowment - ConflictInvestment + (ConflictInvestment/(ConflictInvestment+Dec*Oppone
OpponentProfit = EndowmentOpponent - OpponentConflictInvestment + (1-ConflictInvestment/(

}


OpponentConflictInvestment = find (Subject != :Subject & same (Matching), ConflictInvestment);

if ( Role == 1) {

if (OpponentConflictInvestment == 0){

if(Dec>0){

if(ConflictInvestment >0){
Profit = Endowment -ConflictInvestment +EndowmentOpponent+Endowment;
OpponentProfit = EndowmentOpponent;
}
else{
Profit = 2*Endowment;
OpponentProfit = 2*EndowmentOpponent;
}
}// Dec
```

7



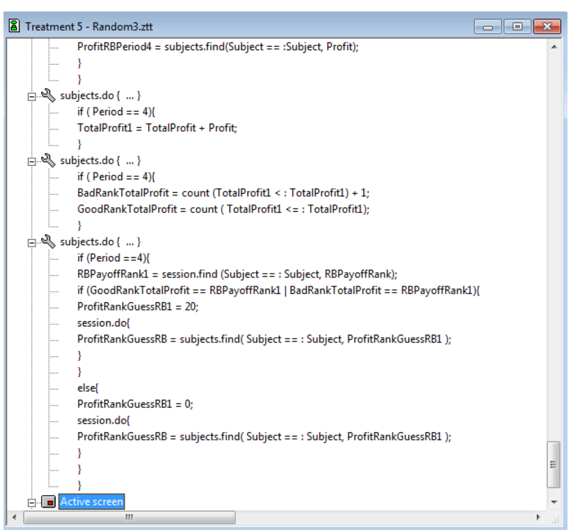
```
Treatment 5 - Random3.ztt
else {
Profit =  Endowment -ConflictInvestment+Endowment;
OpponentProfit = 2*EndowmentOpponent;
}
}// OpponentConflictInvestment == 0
else { // OpponentConflictInvestment > 0
Profit = Endowment - ConflictInvestment + (1-OpponentConflictInvestment/(OpponentConflictIn
OpponentProfit = EndowmentOpponent - OpponentConflictInvestment + (OpponentConflictInves
}

}// Role == 1

else { // Role == 2
if (ConflictInvestment == 0){

if(Dec>0){

if(OpponentConflictInvestment >0){
Profit = Endowment;
OpponentProfit = 2*EndowmentOpponent-OpponentConflictInvestment+Endowment;
}
else{
Profit = 2*Endowment;
OpponentProfit = 2*EndowmentOpponent;
}
}// Dec >0

else { // Dec == 0
Profit =  2*Endowment;
```

8



```
Treatment 5 - Random3.ztt
Profit =  2*Endowment;
OpponentProfit = 2*EndowmentOpponent-OpponentConflictInvestment;
}
}// ConflictInvestment == 0
else { // ConflictInvestment > 0
Profit = Endowment - ConflictInvestment + (ConflictInvestment/(ConflictInvestment+Dec*Oppone
OpponentProfit = EndowmentOpponent - OpponentConflictInvestment + (1-ConflictInvestment/(
}

}// Role == 2

subjects.do { ... }
if (Period == 1){
session.do {
ProfitRBPeriod1 = subjects.find(Subject == :Subject, Profit);
}
}
if (Period == 2){
session.do {
ProfitRBPeriod2 = subjects.find(Subject == :Subject, Profit);
}
}
if (Period == 3){
session.do {
ProfitRBPeriod3 = subjects.find(Subject == :Subject, Profit);
}
}
if (Period == 4){
session.do {
```

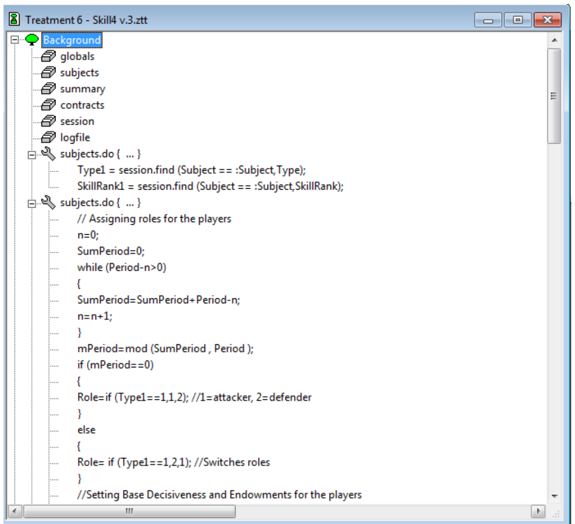
9



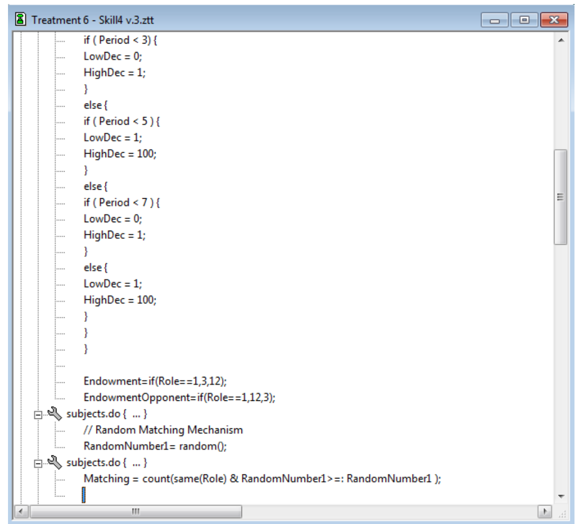
```
Treatment 5 - Random3.ztt
ProfitRBPeriod4 = subjects.find(Subject == :Subject, Profit);
}
}
subjects.do { ... }
if ( Period == 4){
TotalProfit1 = TotalProfit + Profit;
}
subjects.do { ... }
if ( Period == 4){
BadRankTotalProfit = count (TotalProfit1 < : TotalProfit1) + 1;
GoodRankTotalProfit = count ( TotalProfit1 <= : TotalProfit1);
}
subjects.do { ... }
if (Period ==4){
RBPayoffRank1 = session.find (Subject == : Subject, RBPayoffRank);
if (GoodRankTotalProfit == RBPayoffRank1 | BadRankTotalProfit == RBPayoffRank1){
ProfitRankGuessRB1 = 20;
session.do{
ProfitRankGuessRB = subjects.find( Subject == : Subject, ProfitRankGuessRB1 );
}
}
else{
ProfitRankGuessRB1 = 0;
session.do{
ProfitRankGuessRB = subjects.find( Subject == : Subject, ProfitRankGuessRB1 );
}
}
}
Active screen
```

Game 3: Unknown Endogenous Decisiveness

1



2



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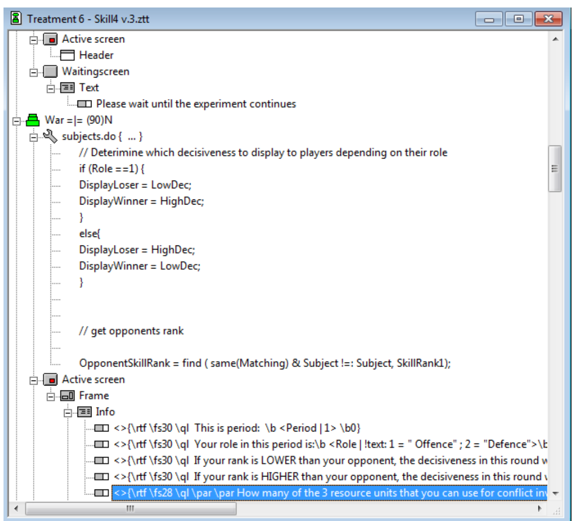

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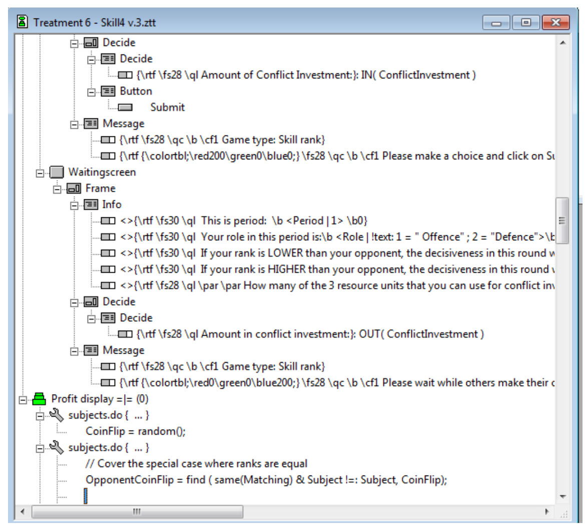

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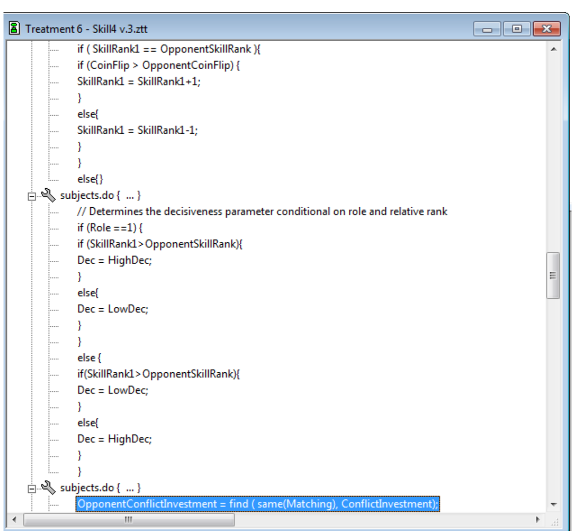

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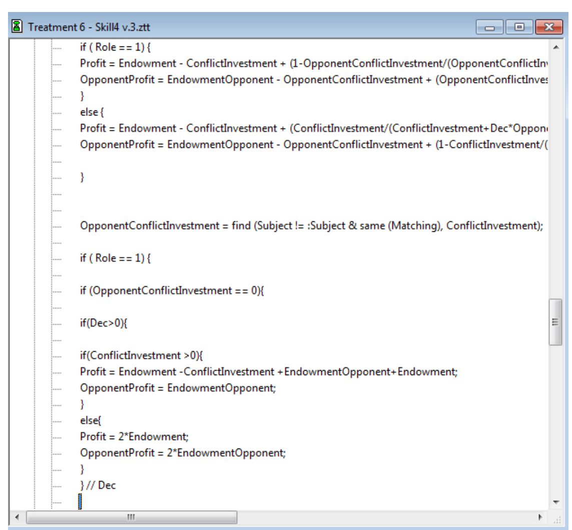

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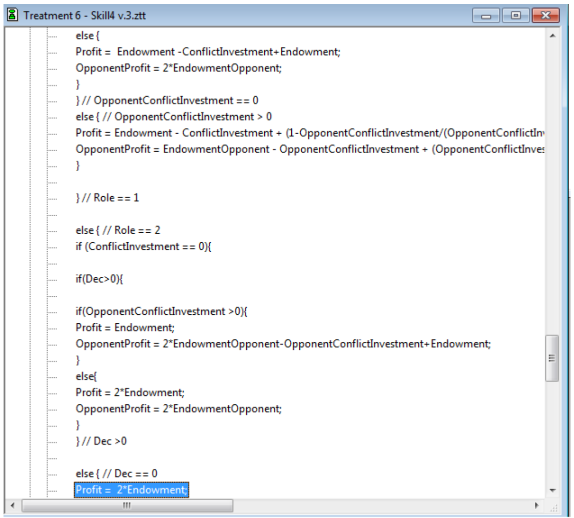
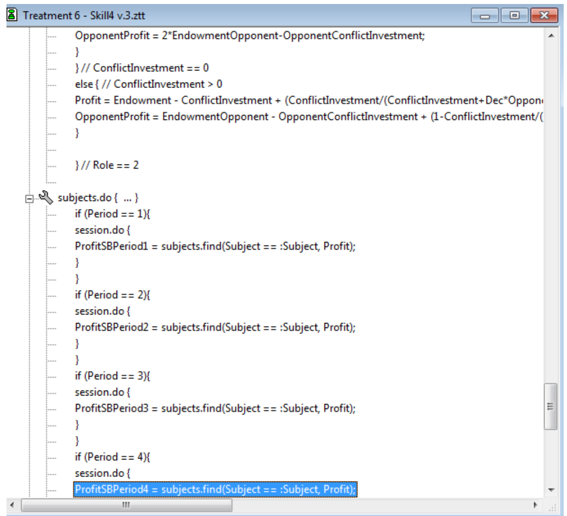
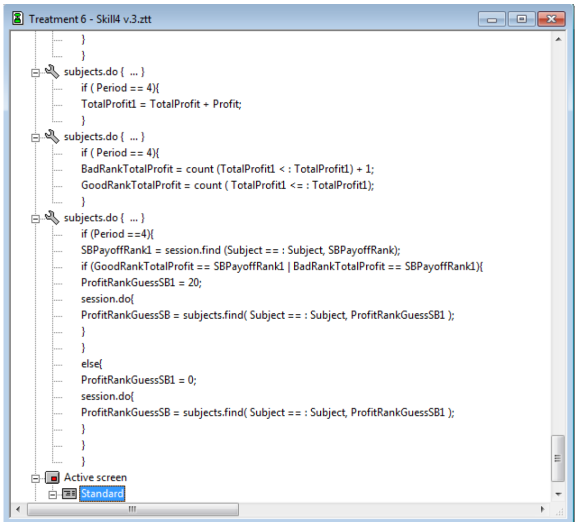

Treatment 6 - Skill4 v.3.ztt
else {
Profit = Endowment -ConflictInvestment+Endowment;
OpponentProfit = 2*EndowmentOpponent;
}
} // OpponentConflictInvestment == 0
else { // OpponentConflictInvestment > 0
Profit = Endowment - ConflictInvestment + (1-OpponentConflictInvestment/(OpponentConflictIn
OpponentProfit = EndowmentOpponent - OpponentConflictInvestment + (OpponentConflictInves
}
} // Role == 1
else { // Role == 2
if (ConflictInvestment == 0){
if(Dec>0){
if(OpponentConflictInvestment >0){
Profit = Endowment;
OpponentProfit = 2*EndowmentOpponent-OpponentConflictInvestment+Endowment;
}
else{
Profit = 2*Endowment;
OpponentProfit = 2*EndowmentOpponent;
}
} // Dec >0
else { // Dec == 0
Profit = 2*Endowment;

8

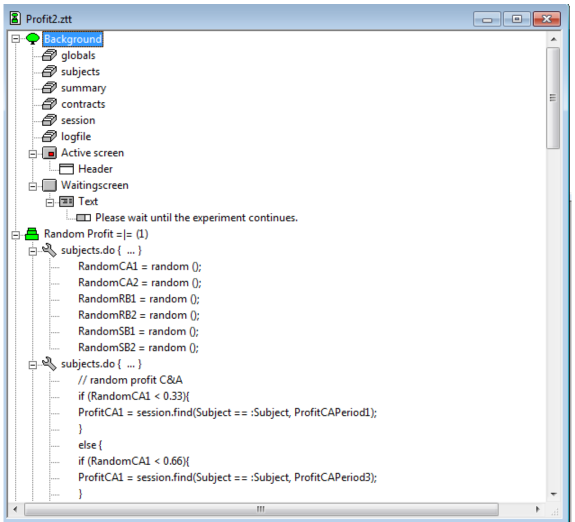

Treatment 6 - Skill4 v.3.ztt
OpponentProfit = 2*EndowmentOpponent-OpponentConflictInvestment;
}
} // ConflictInvestment == 0
else { // ConflictInvestment > 0
Profit = Endowment - ConflictInvestment + (ConflictInvestment/(ConflictInvestment+Dec*Oppon
OpponentProfit = EndowmentOpponent - OpponentConflictInvestment + (1-ConflictInvestment/(
}
} // Role == 2
subjects.do { ... }
if (Period == 1){
session.do {
ProfitSBPeriod1 = subjects.find(Subject == :Subject, Profit);
}
}
if (Period == 2){
session.do {
ProfitSBPeriod2 = subjects.find(Subject == :Subject, Profit);
}
}
if (Period == 3){
session.do {
ProfitSBPeriod3 = subjects.find(Subject == :Subject, Profit);
}
}
if (Period == 4){
session.do {
ProfitSBPeriod4 = subjects.find(Subject == :Subject, Profit);

9

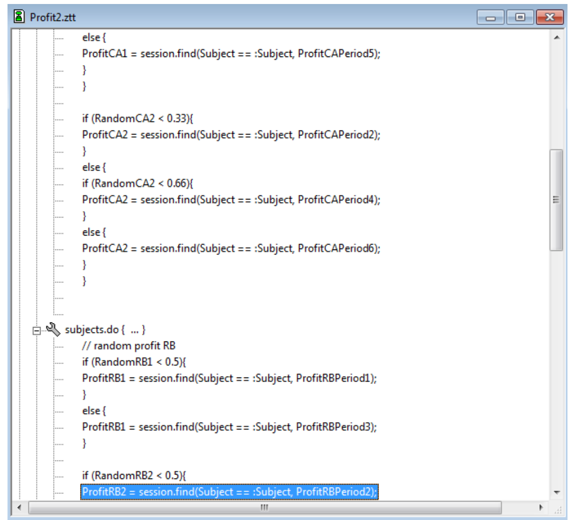

Treatment 6 - Skill4 v.3.ztt
}
}
subjects.do { ... }
if (Period == 4){
TotalProfit1 = TotalProfit + Profit;
}
subjects.do { ... }
if (Period == 4){
BadRankTotalProfit = count (TotalProfit1 < : TotalProfit1) + 1;
GoodRankTotalProfit = count (TotalProfit1 <= : TotalProfit1);
}
subjects.do { ... }
if (Period ==4){
SBPayoffRank1 = session.find (Subject == : Subject, SBPayoffRank);
if (GoodRankTotalProfit == SBPayoffRank1 | BadRankTotalProfit == SBPayoffRank1){
ProfitRankGuessSB1 = 20;
session.do{
ProfitRankGuessSB = subjects.find(Subject == : Subject, ProfitRankGuessSB1);
}
}
else{
ProfitRankGuessSB1 = 0;
session.do{
ProfitRankGuessSB = subjects.find(Subject == : Subject, ProfitRankGuessSB1);
}
}
}
Active screen
Standard

Profit

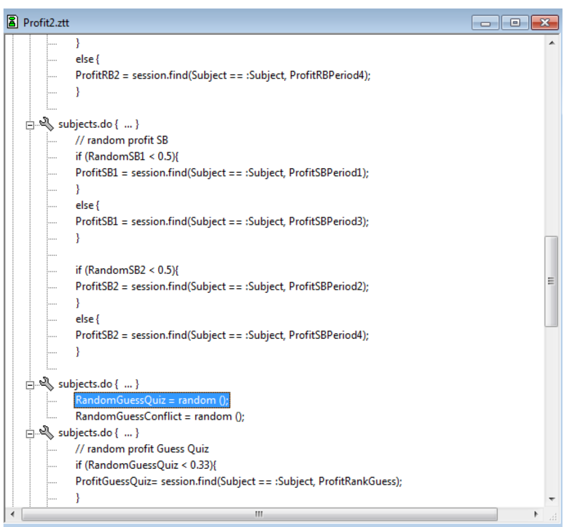
1



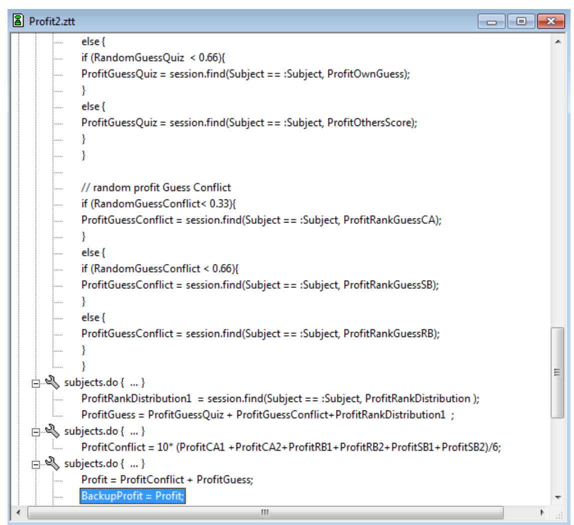
2



3



4



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