# Outsourcing with Identical Suppliers and Shortest-First Policy: A Laboratory Experiment*

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**Abstract**

We study experimentally in the laboratory two 2-player games that mimic a decentralized decision-making situation in which firms repeatedly outsource production orders to multiple identical suppliers. The first game has a unique (inefficient) equilibrium in mixed strategies, while the second game has two (efficient) equilibria in pure strategies and an infinite number of (inefficient) equilibria in mixed strategies. In both games, the optimal social costs can also be obtained via dominated strategies. We find that only in the second game subjects manage to reach an efficient outcome more often when matched in fixed pairs than when randomly rematched each round. Surprisingly, this is because subjects coordinate on dominated strategies (and not an efficient pure strategy equilibrium). We show theoretically that preferences for efficiency cannot explain our experimental results. Inequality aversion, on the other hand, cannot be rejected.

*Keywords:* laboratory experiment, game theory, outsourcing, social costs, shortest-first policy, social preferences

*JEL–Numbers:* C72, D71, D82.

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# 1 Introduction

In the last decade, outsourcing has become increasingly important as advanced products are typically no longer completely built in-house. Hence, apart from managing their own production facilities, companies have an increasing need to tightly control outsourced operations. In this paper, we report on a laboratory experiment that deals with a stylized model of decentralized decision-making situations in which companies outsource production orders or jobs to multiple identical suppliers. We assume that each company can only freely decide to which supplier it outsources each of its jobs. In particular, outsourcing companies cannot decide on the order in which each supplier processes the received jobs. This assumption reflects the fact that most transactions in supply chains are governed by price-only contracts. A drawback of these contracts is that they do not coordinate the supply chain. That is, locally optimal decisions may lead to a joint outcome that can be improved upon (see, e.g., Perakis and Roels, 2007). We consider the well-known shortest-first policy (i.e., Smith's (1956) rule) where each supplier processes jobs optimally by placing them in order of increasing processing time.

We assume that each outsourcing company is selfishly interested in minimizing the sum of completion times of its jobs. This may reflect for instance the fact that different jobs of the same outsourcing company are part of different final products, all of which the company aims to produce and sell as soon as possible. Thus, individual agents interact to make decisions that affect them collectively. The results of Hamers et al. (2015) imply that this strategic interaction needs not lead to socially optimal schedules. In fact, there is no centralized mechanism that implements socially optimal schedules in Nash equilibrium. In a related study, Braat et al. (2015) provided a tight bound for the price of anarchy, i.e., the ratio between the social costs in the worst Nash equilibrium and the optimal social costs. Their theoretical results and simulations suggest that it is hard to coordinate outsourcing decisions in such a way that social costs are relatively small.

**Objective**

Our laboratory experiment aims to complement the above results by determining to which extent and under which conditions coordination failures occur or are less likely to occur. Most of the literature that studies coordination mechanisms for supply chains and competitive scheduling environments considers one-shot games (for a review see e.g. Li and Wang, 2007). In practice, however, firms usually compete repeatedly in market situations facing the same or possibly different competitors. In particular, this raises the question whether and to which extent there is a difference (in terms of costs, individual behavior, etc.) between outsourcing problems in which firms face the same competitors and outsourcing problems in which firms face possibly different competitors in each period.

**Laboratory experiment in a nutshell**

We carry out a laboratory experiment that mimics a stylized outsourcing problem with 2 players and 2 identical suppliers (the latter will be referred to as "machines"). There are 4 jobs denoted by $A, B, C$, and $D$ which only differ in their processing times: $p_A < p_B < p_C < p_D$. Each player owns exactly 2 jobs. We study the two arguably most interesting stage games. In one stage game ("AC") some player owns jobs $A$ and $C$, and in the other stage game ("AD") some player owns jobs $A$ and $D$. In each session, each of the two stage games is repeatedly played during twenty rounds. We use two different matching mechanisms. In the so-called Partner treatment each subject has a fixed opponent during all twenty rounds, while in the so-called Random treatment in each round each subject is randomly matched to some (possibly distinct) opponent.[1]

From a game-theoretical perspective the stage games are such that it is never worthwhile for players to send both jobs to the same machine. This leaves the players with two undominated strategies. Then, it is easy to see that both games have strong coordination effects. For instance, if one player sends her shortest job to one machine, the other player has incentives to send her shortest job to the other machine. The two games differ because in game AC there is a unique Nash equilibrium in mixed strategies, while in game AD there are two pure strategy Nash equilibria that sustain the optimal social costs and a continuum of mixed strategy Nash equilibria with higher social costs. Finally, in both games the optimal social costs can also be implemented via strategy profiles that consist of dominated strategies.

**Main findings**

Our findings are as follows. First, even though our setting is based on possibly the simplest

[1]Obviously, since the outsourcing problem has a very simple structure, our study should be regarded as a first step in a full-fledged analysis. Indeed, the advantage of its simplicity is that future experimental studies can incorporate more complex real-life features and then more easily determine how these additional features affect behavior and outcomes.

non-trivial outsourcing situation, we observe a non-negligible play of dominated strategies in both treatments which slightly diminishes over time. This behavior can partly be justified for game AD in treatment Partner, as some groups manage to reach repeatedly the optimal social costs via these decisions. Second, subjects coordinate more often –that is, the optimal social costs are obtained with a higher frequency– if they are matched in fixed pairs than under a random matching only in game AD. But this is not because subjects play in treatment Partner a socially optimal pure strategy equilibrium and in treatment Random a socially non-optimal mixed strategy equilibrium (as one might guess): surprisingly the aforementioned coordination on a socially optimal dominated strategy profile is the driving factor of this finding. In game AC, on the other hand, the degree of coordination in treatment Partner is the same as in treatment Random. Third, for both games, the two treatments present the same average social costs. Finally, since our results stand in contrast with expected payoff maximization, we study theoretically the effect of "social preferences" in games AC and AD. We show that preferences for efficiency cannot explain our experimental results as these preferences induce the same equilibrium structure in the two games. Inequality aversion, on the other hand, constitutes a possible explanation since (efficient) dominated strategy profiles can be sustained in equilibrium in game AD but not in game AC.

**Related experimental literature**

Apart from the theoretical literature mentioned earlier, there is a large number of related laboratory experiments on coordination games. For example, Cooper et al. (1989) show that in the "Battle of the Sexes Game" (where subjects have opposing preferences over the set of pure strategy equilibria) coordination cannot be established in the long run. However, if one player communicates the strategy she is going to follow in a non-binding way, then the degree of coordination improves significantly. If the game has multiple Pareto-rankable equilibria in pure strategies, i.e., the "Stag-Hunt Game," Cooper et al. (1990,1992) find that subjects end up in the inefficient equilibrium and that the presence of dominated strategies is not inconsequential (as we do). Clark and Sefton (2001) complement these works by showing that playing the game in fixed pairs helps subjects coordinating on the efficient outcome. Also, according to Brandts and Cooper (2006) and Brandts et al. (2007) it is possible to move away from the bad equilibrium if one player sticks to her part of the good equilibrium, hoping that the other player changes beliefs. Along this line, Terracol and Vaksmann (2009), Danz et al. (2012), and Hyndman et al. (2012) identify players who willingly forego immediate payoffs in order to be able to coordinate later on a better equilibrium. More recently, Hyndman et al. (2014) find that in a game with strategic complementarities a fixed matching leads to higher payoff variability. Our study is different in that the pure strategy equilibria in game AD are not Pareto rankable and that game AC has a unique equilibrium in mixed strategies. Therefore, we cannot expect such a *teaching effect*. Finally, experiments on coordination games typically do not involve dominated strategies. Our study thus allows to analyze if and how the presence of dominated strategies and the presence of pure strategy equilibria that sustain the optimal social costs (i.e., a comparison between game AC and game AD) affect play and the degree of coordination.

# 2 Experiment

## 2.1 The outsourcing problem

Below we describe the particular outsourcing problem that we experimentally study. We refer to Hamers et al. (2015) for a description of a general class of outsourcing problems and associated games. There is a set of four jobs $\{A, B, C, D\}$ that are to be processed on either of two identical machines $M_1$ and $M_2$. The only difference between the jobs is their processing time, i.e., the time needed to process a given job on any machine. Specifically, the processing times of the jobs are given by $(p_A, p_B, p_C, p_D) = (10, 20, 50, 60)$. If a machine has to process more than one job, it will process jobs sequentially, i.e., one after the other, and without idle time. It is assumed that if a machine is to process a set of jobs it will do so in order of increasing processing time, i.e., each machine employs the so-called shortest-first policy. Smith (1956) showed that the shortest-first policy is optimal for each individual machine in the sense that it minimizes the sum of completion times of the assigned jobs. The completion time of a job is the sum of processing times of its predecessors and its own processing time.

There are two players, player 1 and player 2, each of whom will own exactly two of the four jobs (the precise assignment of the jobs to players varies in the experiment and is discussed later). The players simultaneously choose an allocation of their jobs to the two machines. More precisely, each player chooses one of the four allocations which we denote by $a(1, 1)$, $a(1, 2)$, $a(2, 1)$, and

$a(2,2)$. Here, $a(x,y)$ denotes the allocation in which the job with the shorter processing time is sent to machine $M_x$ and the other job is sent to machine $M_y$. The costs associated with a job are given by its processing time. Each player aims to minimize the sum of the costs of his two jobs. Given a specification of the ownership of the jobs, the above situation straightforwardly induces a non-cooperative game of complete information, which is explained next in more detail.

Possibly the most interesting (and least trivial) scenario is one in which neither of the players has the two shortest jobs.[2] In our stylized setting this means that none of the players owns jobs $A$ and $B$. More precisely, we consider two specifications of the ownership of the jobs. In the first specification, denoted by AC, player 1 owns jobs $A$ and $C$ and player 2 owns the other jobs, i.e., $B$ and $D$. In the second specification, denoted by AD, player 1 owns jobs $A$ and $D$ and player 2 owns the other jobs, i.e., $B$ and $C$. Before we describe the two induced games we define the *social costs* (associated with a profiles of allocations) as the sum of costs of processing the four jobs. It is easy to verify that the minimal sum of costs of processing the four jobs is 170 in both games. These *optimal social costs* are obtained as long as job $A$ is processed only with either job $C$ or job $D$. (Due to symmetry with respect to $M_1$ and $M_2$, there will be four profiles of decisions in which the social costs are minimized.)

**Game AC**

Table 1 gives the costs for each player in each combination of allocation decisions in game AC.

| $1\backslash 2$ | $a(1,1)$ | $a(1,2)$ | $a(2,1)$ | $a(2,2)$ |
|---|---|---|---|---|
| $a(1,1)$ | 90,170 | 90,**90** | 70,140 | 70,100 |
| $a(1,2)$ | **60**,120 | **60**,140 | 80,**90** | 80,150 |
| $a(2,1)$ | 80,150 | 80,**90** | **60**,140 | **60**,120 |
| $a(2,2)$ | 70,100 | 70,140 | 90,**90** | 90,170 |

**Table 1:** Costs in game AC

For instance, if player 1 chooses $a(1,1)$ (for his jobs $A$ and $C$) and player 2 chooses $a(1,2)$ (for his jobs $B$ and $D$), then jobs $A$, $B$ and $C$ are processed on machine $M_1$ (in order $A, B, C$

[2]In case one player owns the two shortest jobs ($A$ and $B$) his only optimal decision is to send his jobs to different machines. And consequently, the other player's optimal decision is also to send his jobs to different machines (in any of the two possible ways).

since $p_A < p_B < p_C$) and job $D$ is processed on machine $M_2$. Therefore, player 1 incurs costs 10 and $10 + 20 + 50 = 80$ for his jobs $A$ and $C$, respectively, which totals 90. Similarly, player 2 incurs costs $10 + 20 = 30$ and 60 for his jobs $B$ and $D$, respectively, which totals 90 as well. The numbers in boldface indicate the best (i.e., minimal costs) responses of a player given the other player's decision. It follows from Table 1 that for either player $a(1,1)$ is dominated by $a(2,1)$, i.e., independently of the other player's decision, playing $a(2,1)$ induces strictly lower costs than $a(1,1)$. Similarly, $a(2,2)$ is dominated by $a(1,2)$. Moreover, Table 1 shows that there is no Nash equilibrium in pure strategies. Using standard arguments from game theory it also follows that there is a unique Nash equilibrium in mixed strategies where each player chooses each of $a(1,2)$ and $a(2,1)$ with probability $\frac{1}{2}$. The associated costs are $\frac{1}{2}(60+80, 90+140) = (70, 115)$. Hence, the social costs in equilibrium (185) are 8.8% higher than the optimal social costs (170).

### Game AD

Table 2 gives the costs for each player in each combination of allocation decisions in game AD.

| 1\2 | $a(1,1)$ | $a(1,2)$ | $a(2,1)$ | $a(2,2)$ |
|---|---|---|---|---|
| $a(1,1)$ | 150,110 | 100,**80** | 130,**80** | 80,90 |
| $a(1,2)$ | **70**,110 | 120,**80** | **90**,**80** | 140,90 |
| $a(2,1)$ | 140,90 | **90**,**80** | 120,**80** | **70**,110 |
| $a(2,2)$ | 80,90 | 130,**80** | 100,**80** | 150,110 |

**Table 2:** Costs in game AD

It follows from Table 2 that for either player $a(1,1)$ is dominated by $a(2,1)$ and $a(2,2)$ is dominated by $a(1,2)$. Table 2 also shows that there are two Nash equilibria that induce optimal social costs, namely the two profiles in which one player chooses $a(1,2)$ and the other player chooses $a(2,1)$. Obviously, these are the best possible Nash equilibria (in terms of social costs). However, there are (many) other Nash equilibria in mixed strategies, namely player 2 chooses each of $a(1,2)$ and $a(2,1)$ with probability $\frac{1}{2}$ and player 1 assigns strictly positive probability to $a(1,2)$ and $a(2,1)$ only. The costs associated with any of these mixed strategy equilibria are $\frac{1}{2}(90+120, 80+80) = (105, 80)$. Hence, the worst social costs in equilibrium (185) are 8.8% higher than the optimal social costs (170). Observe that the social costs of all mixed strategy equilibria in game AD are equal to the social costs of the unique mixed strategy equilibrium in game AC.

## 2.2 Procedures

The experiment was programmed within the z-Tree toolbox provided by Fischbacher (2007) and carried out in the computer laboratory at a local university. In total, 120 undergraduates from various disciplines participated in the experiment.

In each of the two sessions (one per treatment), both games AC and AD were played twenty times. In half of the sessions the batch of twenty AC games was played before the batch of twenty AD games. In the other half of the sessions, the order was reversed. More importantly, we introduced two treatments. First, subjects were randomly split into two groups, say $G_1$ and $G_2$, of equal size. More precisely, $|G_1| = |G_2| = 15$. Subjects did not know who belonged to which group. In one treatment (**Partner**), for each batch of games, each subject from group $G_i$ was matched (anonymously and randomly) to a fixed partner in group $G_j$, $j \neq i$. In other words, each subject most likely played against two different subjects (from the other group) over the entire experiment. In the other treatment (**Random**), for each of the forty games, each subject from group $G_i$ was anonymously and randomly matched to a subject from group $G_j$, $j \neq i$.

At the beginning of the experiment the subjects received a detailed description of the outsourcing problem and the game that was played in the first batch of twenty games with several examples (Appendix A). The only difference between the instructions of the two different treatments was the final page. In that final page we explained the partition of the subjects into the two groups (and how these groups were used to match subjects with one another throughout the experiment) and the existence of two batches of twenty games. In particular, subjects knew that after the first batch of games they would play a second different batch of games (without knowing beforehand the precise difference). In other words, the specific details of the second batch of games were explained only after the first batch of games had been played.

Each subject was initially endowed with 5200 ECU. The costs of a subject's two jobs in each game were subtracted from his endowment. Each ECU of the final wealth (i.e., after the fortieth game) was worth 0.008 Euros. After each of the forty games each subject received a summary of his last decision, the decision of the partner in that game, the induced costs (accompanied by an explanatory graph of the induced schedule), and his updated endowment. No further feedback was provided during the entire experiment. Subjects had the opportunity to ask questions regarding the working of the games during the entire experiment.

A typical session lasted about 90 minutes and subjects earned on average 15.06 Euro (including a 3 Euro show-up fee) for their participation.

# 3 Results

We formulate three hypotheses and present our findings. The first hypothesis is based on a rationality assumption. As mentioned in the analysis of the stage games AC and AD, $a(1,1)$ and $a(2,2)$ are dominated strategies. Since the stage games are finitely repeated in our experiment, by backward induction, players should never use dominated strategies. Consequently, we expect a minimally rational agent to choose $a(1,1)$ and $a(2,2)$ less often over time.

**Hypothesis 1:** Dominated allocations are played less often over time.

Table 3 presents aggregate behavior. We see that in treatment Random (two top rows), there

| Treatment - Order | Allocations in AC | | | | | Allocations in AD | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $a(1,1)$ | $a(1,2)$ | $a(2,1)$ | $a(2,2)$ | | $a(1,1)$ | $a(1,2)$ | $a(2,1)$ | $a(2,2)$ |
| Random - AC first | 0.0767 | 0.4583 | 0.4083 | 0.0567 | [0.7303] | 0.0950 | 0.4500 | 0.3983 | 0.0567 |
| | [0.5614] | | | | | | | | [0.4518] |
| Random - AD first | 0.0967 | 0.4600 | 0.3817 | 0.0617 | [0.2324] | 0.0783 | 0.4233 | 0.4367 | 0.0617 |
| Partner - AC first | 0.0800 | 0.4000 | 0.4117 | 0.1083 | [0.9644] | 0.0867 | 0.4033 | 0.4000 | 0.1100 |
| | [0.0306] | | | | | | | | [0.1633] |
| Partner - AD first | 0.1267 | 0.4133 | 0.3717 | 0.0883 | [0.6007] | 0.1250 | 0.3967 | 0.3667 | 0.1117 |

**Table 3:** Frequencies of allocations. In brackets, we present the two-sided $p$-values of the $\chi^2$-tests of homogeneity checking for equal distributions at the subject level. For example, the entry [0.5614] corresponds to the comparison between the distribution in game AC in treatment Random when game AC is played first and the distribution in game AC in treatment Random when game AD is played first. Similarly, the entry [0.6007] corresponds to the comparison between the distribution in game AC in treatment Partner when game AD is played first and the distribution in game AD in treatment Partner when game AD is played first.

is a non-negligible proportion (5.7% to 9.7%) of either of the two irrational allocations –$a(1,1)$ and $a(2,2)$–, independently of the order in which the two games (game AC and game AD) are played. A similar observation holds for treatment Partner (two bottom rows). The $\chi^2$ tests of homogeneity displayed in Table 3 also reveal that the game played –i.e., AC or AD– and the order in which the (two batches of twenty) games are played –i.e., AC first or AD first–, which are the two variables that are subject to within treatments variations, affect behavior only mildly. In fact, only one of the eight comparisons is significant at the five percent level.

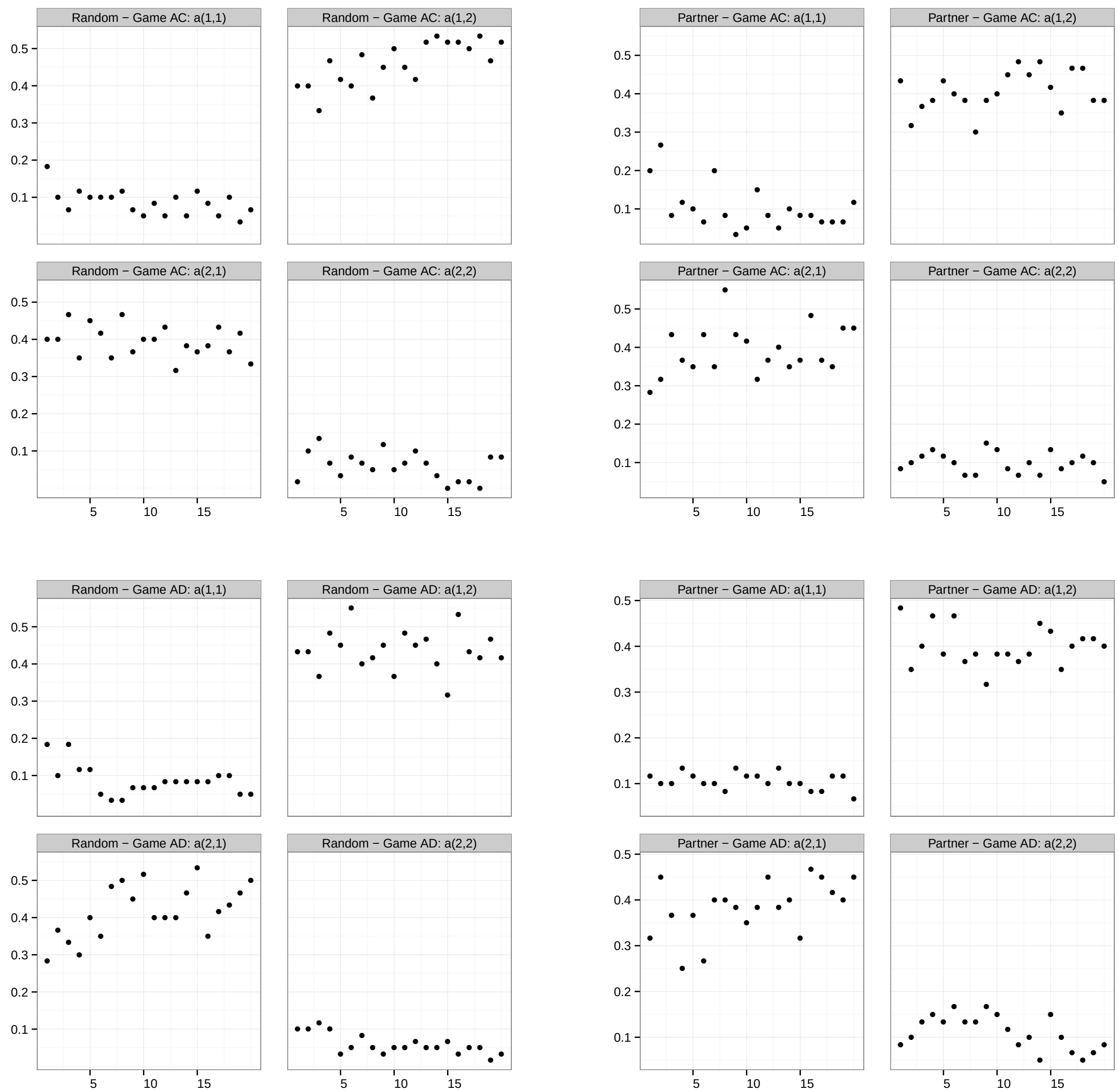


**Figure 1:** Frequencies of allocations

In order to explore whether subjects need time to understand the precise working of the games, we present in Figure 1 the frequencies of allocations in both treatments and games without taking into account the order in which games are played. Typically, $a(1,2)$ and $a(2,1)$ are played more often over time. More importantly though, for a given game (AC or AD), there do not seem to exist important treatment differences.

Table 4 presents the results of our multinomial logit regression. In this analysis, the variable *Round* takes values from 1 to 20 and assesses how repetition affects behavior, *Game AC* is a dummy variable that equals 1 if subjects play game AC and 0 if they face game AD, and *Random* is a dummy variable with value 1 in treatment Random and 0 in treatment Partner. We can see that relative to allocation $a(1,2)$, the dominated allocation $a(2,2)$ is used significantly less often over time (see $\beta_1$). Also, allocation $a(2,2)$ is played significantly less often in treatment Random than in treatment Partner in both game AD (see $\beta_3$) and game AC ($\beta_3+\beta_4$ is significantly smaller than zero; two-sided $p = 0.0001$, $\chi^2$ test). Surprisingly, similar results do not hold for allocation $a(1,1)$. Finally, as intuition suggests, there are no significant effects for allocation $a(2,1)$ relative to allocation $a(1,2)$.

| Allocation | $a(1,1)$ | $a(2,1)$ | $a(2,2)$ |
|---|---|---|---|
| Constant ($\beta_0$) | $-1.2663^{***}$ | 0.0785 | $-0.5422^{***}$ |
| | (0.1502) | (0.0984) | (0.1639) |
| Round ($\beta_1$) | $-0.0058$ | $-0.0022$ | $-0.0143^{**}$ |
| | (0.0042) | (0.0028) | (0.0053) |
| Game AC ($\beta_2$) | $-0.0360$ | 0.0045 | $-0.1402$ |
| | (0.0043) | (0.0028) | (0.0053) |
| Random ($\beta_3$) | 0.0411 | $-0.0050$ | $-1.6022^{***}$ |
| | (0.1371) | (0.0904) | (0.2131) |
| Game AC × Random ($\beta_4$) | $-0.1014$ | $-0.1102$ | 0.4520 |
| | (0.1958) | (0.1276) | (0.2855) |
| Mc Fadden $R^2$ | 0.0190 | | |
| Observations | 4800 | | |

**Table 4:** Panel multinomial logit regression at the subject level. The allocation $a(1,2)$ is used as reference level. We control for the type of the player and the order in which games are played. $^{***}$ indicates significance at $p = 0.001$, $^{**}$ at $p = 0.01$, and $^{*}$ at $p = 0.05$ (all two-sided).

Next, we analyze individual behavior to shed more light on Hypothesis 1 that subjects play dominated allocations less often over time. With respect to game AC we find that out of the 60 subjects who participated in each treatment, 21 subjects in treatment Random and 10 subjects in treatment Partner never choose an allocation that is dominated in the stage game. Out of the 38 subjects in treatment Random and the 43 subjects in treatment Partner who use a dominated allocation at least once in the first ten rounds, 39.5% (15 out of 38 subjects) in treatment Random and 32.6% (14 out of 43 subjects) in treatment Partner avoid dominated allocation in the last ten rounds. Moreover, 1 subject in treatment Random and 7 subjects in treatment Partner never play a dominated allocation in the first ten rounds but do experiment with them at least once in the last ten rounds. On the basis of this data we then obtain by means of Wilcoxon signed-rank tests that fewer subjects play dominated allocations in the last ten rounds than in the first ten rounds in treatment Random (two-sided $p = 0.0051$) but not in treatment Partner (two-sided $p = 0.1316$).

If we look at the whole batch of twenty rounds in game AD, 6 subjects in treatment Random and 10 subjects in treatment Partner never choose dominated allocations. The breakdown in two phases of ten rounds in game AD for treatment Random is given by 11 in the first ten rounds and 30 in the last ten rounds, while the breakdown for treatment Partner is is 14 in the first ten rounds and 29 in the last ten rounds. Since the differences between the two phases are significant in both treatments (two-sided $p$=0.0004 in Random and two-sided $p$=0.0019 in Partner), we conclude that more subjects avoid the play of dominated allocations in game AD over time.

**Result 1:** *A non-negligible proportion of decisions involve players choosing dominated allocations. This irrational behavior slightly fades away over time.*

Our second hypothesis regards the degree of coordination. Formally, we say that *coordination* is achieved if the sum of social costs is minimized. It can be seen from Tables 1 and 2 that in both games social costs are minimized for the four allocation profiles that are on the bottom-left/top-right diagonal of the cost matrices. For this reason we refer from now on to the allocation profiles $(a(1,1), a(2,2))$ and $(a(2,2), a(1,1))$ as *exterior profiles* and to the allocation profiles $(a(1,2), a(2,1))$ and $(a(2,1), a(1,2))$ as *interior profiles.* We next discuss our predictions for each game separately.

Game AC has a unique equilibrium in mixed strategies with a probability of coordination of 0.5 that stems entirely from interior profiles. But also observe that the costs of player 2 associated with the exterior profiles are equal to 100, which is less than the costs associated with the mixed strategy equilibrium (115). Moreover, player 1 is indifferent between any of the exterior profiles and the mixed strategy equilibrium (costs are 70) and therefore, no player is worse off at the exterior profiles in comparison to the mixed strategy equilibrium. Since it is not clear how players can coordinate on the exterior profiles in treatment Random, our prediction is that the mixed strategy equilibrium prevails in that treatment. In treatment Partner one cannot disregard the possibility that some groups manage to coordinate on the exterior profiles as this joint deviation from the mixed strategy equilibrium does not hurt either player, which should raise the frequency of coordination in comparison to treatment Random.

Game AD has two pure strategy equilibria each of which has a probability of coordination of 1 (on interior profiles), and a continuum of other mixed strategy equilibria each of which has a probability of coordination of 0.5 (also on interior profiles). With respect to the exterior profiles, observe that the lowest costs player 2 can achieve from choosing a dominated allocation are 90, yet costs are 80 for sure when she chooses $a(1,2)$ or $a(2,1)$. Therefore, it is not jointly profitable to move from any equilibrium to the exterior profiles. Hence, there should be no coordination on exterior profiles. In treatment Random, we hypothesize that player 2 follows the prediction of (all) mixed strategy equilibria and plays both $a(1,2)$ and $a(2,1)$ with probability 0.5, so that the frequency of coordination is 0.5 independently of the equilibrium strategy played by player 1. Then, since having a fixed partner should make it possible to coordinate to some extent on either of the two pure strategy equilibria (instead of playing the mixed strategy equilibrium), we expect more coordination on interior profiles in treatment Partner than in treatment Random.

**Hypothesis 2:** The frequency of coordination in treatment Random is 0.5 in both games. Treatment Partner facilitates coordination: In Game AC because of coordination on exterior profiles, in Game AD because of coordination on interior profiles.

Figure 2 presents the frequencies of coordination over time on both interior and exterior profiles. It can be seen that the degree of coordination on interior profiles is increasing over time and roughly the same in all four panels. Aggregated over all rounds, the frequencies for game AC are

0.3667 (Random) and 0.3800 (Partner), while for game AD they amount to 0.3933 (Random) and 0.3950 (Partner). The figure also suggests that coordination on exterior profiles is only feasible in treatment Partner and visibly more so for game AD than for game AC. The aggregated frequencies of coordination on exterior profiles in game AC are equal to 0.0066 (Random) and 0.0233 (Partner). The corresponding numbers for game AD are 0.0083 (Random) and 0.0800 (Partner).

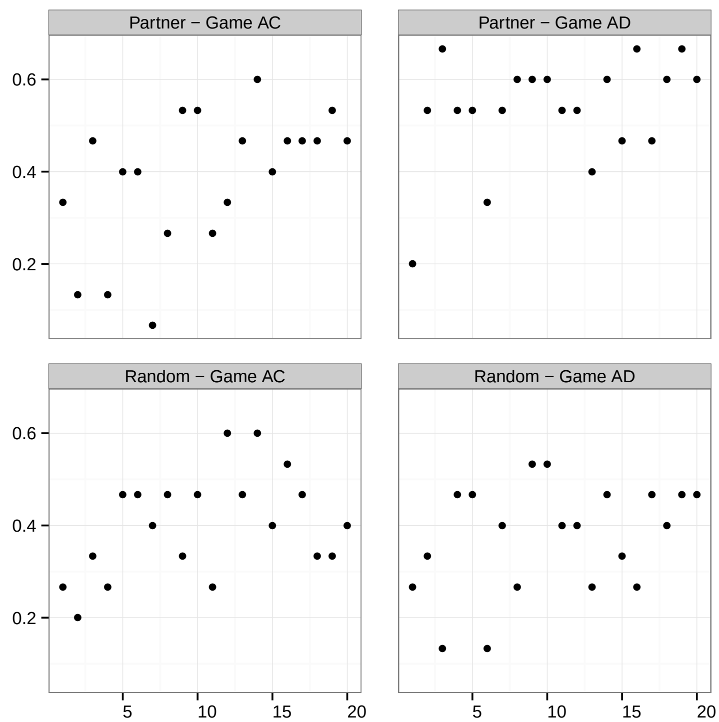


**Figure 2:** Frequencies of coordination on interior (solid line) and exterior profiles (dotted line).

Hypothesis 2 can be statistically tested with the help of a random effects estimation on the different frequencies of coordination. Since the results of this estimation (presented in Table 5) imply that the two-sided $p$-value of the $\chi^2$ test that $\beta_2+\beta_4 = 0$ is equal to 0.1791 in the first, 0.8067 in the second, and 0.1576 in the last column, there are no differences between game AC and game AD in treatment Random. The associated overall frequency of coordination is obviously lower than the point prediction of 0.5 ($\beta_0 + \beta_3 = 0.3724$), because Hypothesis 2 assumes ideally that subjects do not play dominated strategies, which contrasts with Result 1. Still, the play of dominated allocations in treatment Random should be considered pure noise.[3] With respect to the hypothesis

[3]The estimated frequencies of coordination on exterior profiles are 0.0067 in game AC and 0.0084 in game AD.

that treatment Partner facilitates coordination, we find that $\beta_3$ is significantly smaller than zero in the last two columns. Hence, in game AD there is overall more coordination in treatment Partner than in treatment Random (as predicted). This is because there is more coordination on exterior profiles in treatment Partner and because there are no treatment differences with respect to the coordination on interior profiles (contrary to Hypothesis 2). Lastly, the two-sided $p$-values of the $\chi^2$ tests that $\beta_3 + \beta_4 = 0$ are equal to 0.5018 (first), 0.0142 (second), and 0.1345 (last column). Thus, for game AC there are no treatment differences with respect to the coordination on interior profiles and treatment Partner facilitates coordination on exterior profiles (as predicted). Yet, the latter effect is not large enough to find an overall effect (contrary to Hypothesis 2).

| | Interior | Exterior | Overall |
|---|---|---|---|
| Constant ($\beta_0$) | 0.3656*** | 0.0801*** | 0.4456*** |
| | (0.0200) | (0.0069) | (0.0202) |
| Round ($\beta_1$) | 0.0014* | −0.0001 | 0.0012* |
| | (0.0006) | (0.0002) | (0.0006) |
| Game AC ($\beta_2$) | −0.0150 | −0.0567*** | −0.0717*** |
| | (0.0198) | (0.0068) | (0.0200) |
| Random ($\beta_3$) | −0.0017 | −0.0717*** | −0.0733*** |
| | (0.0198) | (0.0068) | (0.0200) |
| Game AC × Random ($\beta_4$) | −0.0117 | 0.0550*** | 0.0433 |
| | (0.0281) | (0.0096) | (0.0284) |
| $R^2$ | 0.0016 | 0.0314 | 0.0067 |
| Observations | 4800 | 4800 | 4800 |

**Table 5:** Random effects estimations on the frequency of coordination on interior and exterior profiles, and the sum of the two (overall) at the subject level. We control for the order in which games are played. *** indicates significance at $p = 0.001$, ** at $p = 0.01$, and * at $p = 0.05$ (all two-sided).

Finally, to shed more light on the capacity to coordinate in treatment Partner, we depict in Figure 3 the costs over time at the group (i.e., pair) level. In particular, we wish to analyze how many of the groups manage to converge to a stable play that leads to the optimal social costs. Of the 30 groups that participated in treatment Partner, groups 1-15 faced game AC first and groups 16-30 faced game AD first. Also note that the costs per subject in a group are 85 if one player chooses $a(1,2)$ and the other player $a(2,1)$, while costs are 100 if both players choose the same allocation $a(1,2)$ or $a(2,1)$. Consequently, one sign for the play of a mixed strategy equilibrium is that we observe alterations of costs per subject of 85 and 100 over time. Also, according to Hypothesis 2, convergence to the optimal social costs through interior profiles should be more difficult in game AC than in game AD, while convergence on exterior profiles should only be possible for game AC.

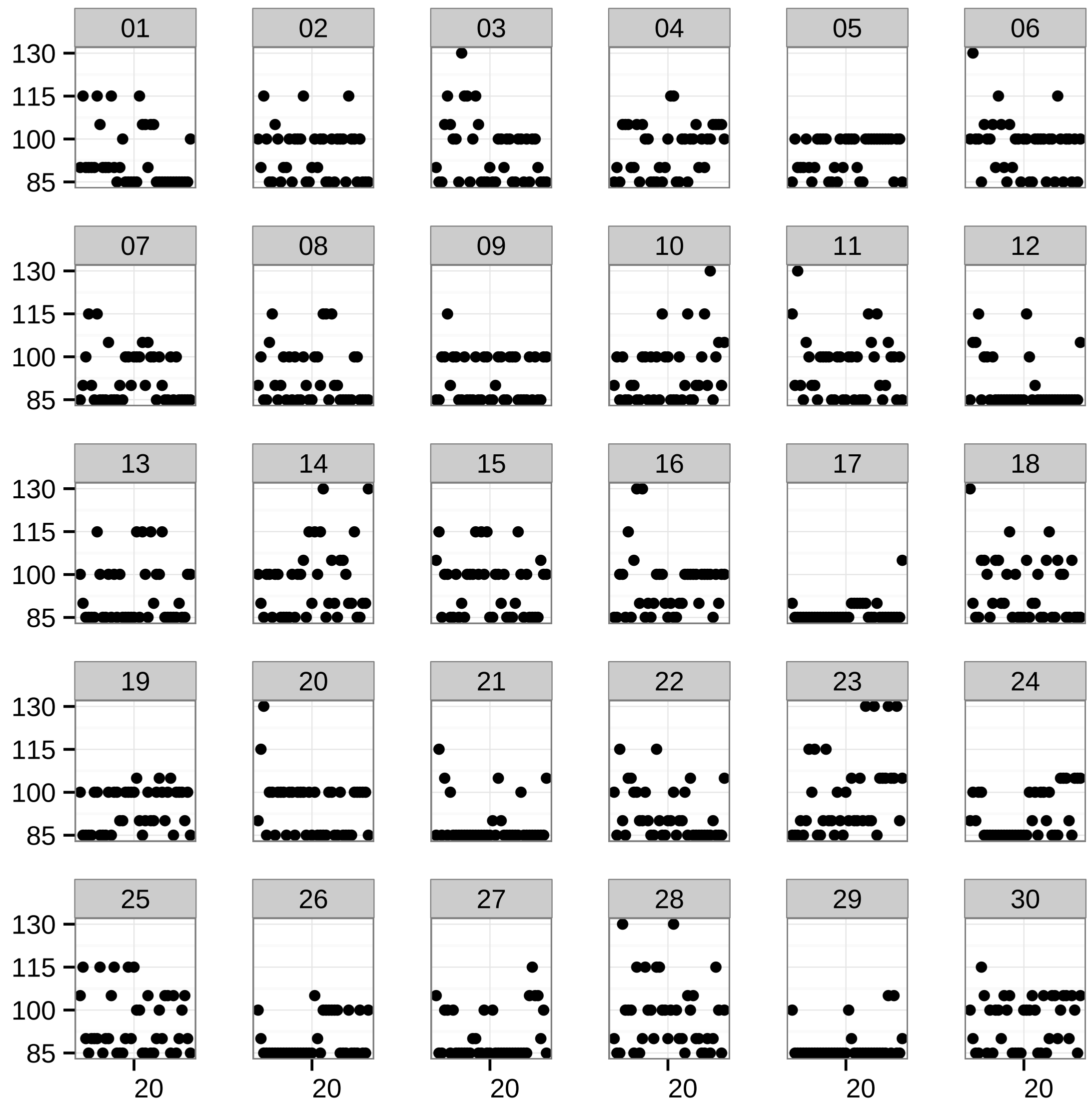


**Figure 3:** Costs per subject over time at the group level in treatment Partner.

Figure 3 reveals that several groups manage to coordinate on the optimal social costs over time in game AD. For example, in the last ten rounds of this game, a total of 9 groups (groups

1, 7, 8, 12, 17, 21, 24, 26, 29) reach at least 8 times the optimal social costs via the same play. Out of these 9 groups, groups 12, 17, and 24 coordinate on exterior profiles, the other 6 groups on interior profiles. We find that only 4 groups (groups 12, 17, 21, and 22) manage to reach the optimal social costs 8 times during the last 10 rounds in game AC via the same play. All these groups coordinate on interior profiles.

**Result 2:** *The frequency of coordination in treatment Random is the same for both games. For both games, (i) there is no difference across treatments with respect to the coordination on interior profiles and (ii) there is more coordination on exterior profiles in treatment Partner than in treatment Random. Overall, treatment Partner facilitates coordination only for game AD.*

Our final hypothesis is related to the social costs. First, social costs should not be different between the two games in treatment Random where subjects are expected to play mixed strategies (Hypothesis 2). Second, due to Result 2, in game AD we expect lower social costs in treatment Partner relative to treatment Random, while the social costs in game AC should not vary across treatments. Finally, since the frequency of coordination increases over time –see $\beta_1$ in the last column of Table 5– repetition should help reducing social costs.

**Hypothesis 3:** (a) In treatment Random, social costs in game AD are equal to those in game AC. (b) Social costs in treatment Partner are lower than those in treatment Random in game AD. There are no treatment differences in game AC. (c) Social costs decrease over time.

Figure 4 plots the pooled data for both treatments and the games AC and AD. The average social costs per player are 94.34 in treatment Random (94.34 in game AC and 94.33 in game AD) and 93.58 in treatment Partner (93.83 in game AC and 93.33 in game AD). Thus, the costs do not seem to depend on the specific game played, which is in line with the aggregate behavior in Table 3.

More formally, we use the results from the random effects estimation in Table 6 to show that the average social costs per player are the same in these four situations. To be more specific, Table 6 shows that both $\beta_2$ and $\beta_3$ are not significantly different from zero, so there is no difference between game AD and game AC in treatment Partner ($\beta_2$) and no difference between between game AD in treatment Partner and treatment Random ($\beta_3$). Also, there is no difference between

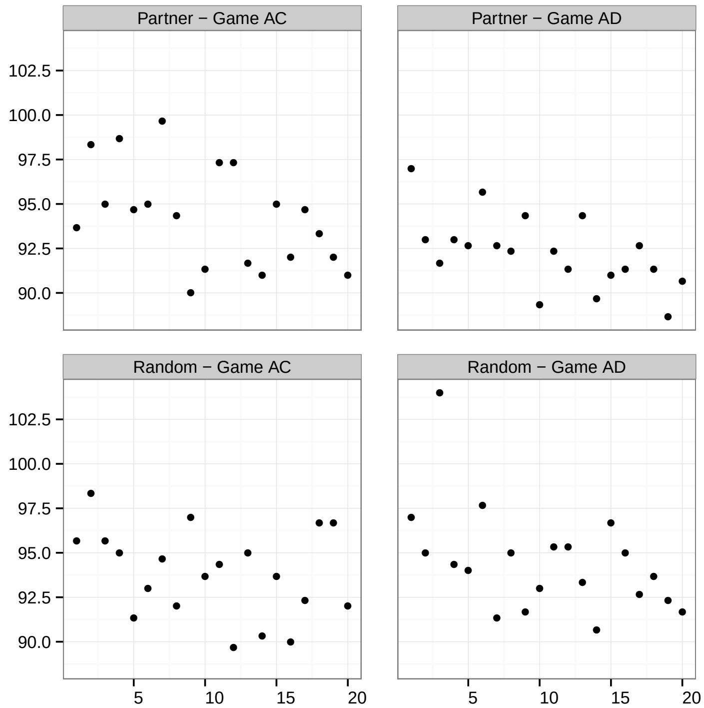


**Figure 4:** Costs per player over rounds.

| | Constant ($\beta_0$) | Round ($\beta_1$) | Game AC ($\beta_2$) | Random ($\beta_3$) | Game AC × Random ($\beta_4$) |
|---|---|---|---|---|---|
| Costs | $90.7919^{***}$ | $-0.1201^{**}$ | 0.5083 | 1.0083 | $-0.5000$ |
| | (3.0010) | (0.0450) | (2.1570) | (2.1570) | (4.3140) |
| $R^2$ | 0.0067 | | | | |
| Observations | 4800 | | | | |

**Table 6:** Random effects estimations on the average social costs per player at the subject level. We control for the type of the player and the order in which games are played. $^{***}$ indicates significance at $p = 0.001$, $^{**}$ indicates significance at $p = 0.01$, and $^{*}$ indicates significance at $p = 0.05$ (all two-sided).

game AD and game AC in treatment Random ($\beta_2 + \beta_4$) and between game AC in treatment Partner and treatment Random ($\beta_3 + \beta_4$), as the two-sided $p$-value of the corresponding $\chi^2$ tests are equal to 0.9978 in the former and 0.8691 in the latter case. Finally, with respect to the third part of Hypothesis 3, Table 6 hints at learning as the social costs decrease significantly over time as the play of dominated allocations reduces (Result 1) and coordination improves to some extent (see $\beta_1$ in the last column of Table 5). This effect is also visible in Figure 4 in all four panels.

**Result 3:** *(a) Social costs in game AC and game AD are not significantly different from each other (for both treatments). (b) Social costs in treatment Random are not significantly different from those in treatment Partner (for both games). (c) Social costs decrease significantly over time.*

# 4 Concluding remarks

In this paper we have studied experimentally in the laboratory two 2-player stylized outsourcing problems. From a strategic point of view the difference between game AC and game AD is that in game AC there is a unique inefficient Nash equilibrium (in mixed strategies), while game AD has an infinite number of mixed strategy Nash equilibria (with the same social costs as the unique Nash equilibrium in game AC) and two efficient Nash equilibria in pure strategies. The optimal social costs can also be obtained in both games via the play of dominated strategies, yet there is another crucial difference between the two games in this respect: in game AC no player is worse off at such profile with respect to the unique Nash equilibrium, while in game AD there is no such joint profitable deviation from any Nash equilibrium. We have then been particularly interested in analyzing whether being matched in fixed pairs (treatment Partner) yields a better coordination (a higher frequency with which the optimal social costs are obtained) than a random matching (treatment Random).

**Experimental insights**

Since it is not clear how subjects could reach a socially optimal outcome in treatment Random, we expected subjects to randomize according to some mixed strategy Nash equilibrium in this treatment. And, in effect, if one disregards the 12%-15% play of dominated strategies –which is substantial but nevertheless pure noise since there are no signs that subjects manage to coordinate on the optimal social costs using these strategies–, this is what we have essentially found. Also, not surprisingly, none of the variables of interest (behavior, frequency of coordination, payoffs) has been significantly different between the two games in treatment Random.

Our main hypothesis has reflected the idea that subjects might be able to escape from the inefficient Nash equilibria when being matched in fixed pairs: in game AC because of coordination on a dominated strategy profile (no player is worse off with respect to the unique Nash equilibrium) and in game AD because of coordination on one of the two efficient pure strategy Nash equilibria (both players are strictly better off with respect to all Nash equilibria in mixed strategies). For game AC we indeed have found that subjects coordinate to some extent on dominated strategies in treatment Partner, but this effect is spurious (i.e., not maintained over time in a given pair) and marginal (i.e., not strong enough to obtain a higher overall frequency of coordination in comparison to treatment Random). Also, it has become clear that the presence of dominated strategies in game AD is not inconsequential (contrary to what we have expected). The overall frequency of coordination in this game has turned out to be higher in treatment Partner than in treatment Random, yet this is because several groups manage to coordinate over a long period of time on dominated strategies and not because they play an efficient Nash equilibrium.

**Social preferences**

Coordination on dominated strategies in game AD stands in contrast with expected payoff maximization. If one looks into the literature on "social preferences" that has suggested richer preference structures in order to explain the behavior of experimental subjects in a wide variety of games, preferences for efficiency and inequality aversion (see, among others, Fehr and Schmidt, 1999, and Bolton and Ockenfels, 2000) come to mind. We next provide an equilibrium analysis of games AC and AD for these preference structures.

Let $S = \{a(1,1), a(1,2), a(2,1), a(2,2)\}$ be the set of all possible strategies (for both players) in the stage games AC and AD. We denote by $s_i \in S$ a generic strategy for player $i = 1,2$. Also, $s = (s_1, s_2) \in S^2$ is said to be a strategy profile. A utility function $u_i : S^2 \to \mathbb{R}$ for player $i = 1,2$ assigns to all strategy profiles $s \in S^2$ a real number $u_i(s) \in \mathbb{R}$. If $c_i(s)$ is the costs player $i$ incurs when profile $s$ is played, then preferences for efficiency can be straightforwardly modeled by means of the utility function $u_i(s) = -c_i(s) - \alpha \cdot [c_1(s) + c_2(s)]$. One observes that $i$'s objective is to minimize simultaneously her private and the social costs (with $\alpha > 0$ denoting the trade-off between the two cost types). Table 7 shows the resulting utilities in game AD.

Table 7 shows in boldface the strategy profiles that are a Nash equilibrium independently of the parameter $\alpha$, i.e., for all $\alpha > 0$. In particular, the interior profiles remain pure strategy Nash equilibria in game AD. This is not true for the exterior profiles: $(a(1,1), a(2,2))$ and $(a(2,2), a(1,1))$

| $1\backslash 2$ | $a(1,1)$ | $a(1,2)$ | $a(2,1)$ | $a(2,2)$ |
|---|---|---|---|---|
| $a(1,1)$ | $-(150,110)-260(\alpha,\alpha)$ | $-(100,80)-180(\alpha,\alpha)$ | $-(130,80)-210(\alpha,\alpha)$ | $-(80,90)-170(\alpha,\alpha)$ |
| $a(1,2)$ | $-(70,110)-180(\alpha,\alpha)$ | $-(120,80)-200(\alpha,\alpha)$ | $\boldsymbol{-(90,80)-170(\alpha,\alpha)}$ | $-(140,90)-230(\alpha,\alpha)$ |
| $a(2,1)$ | $-(140,90)-230(\alpha,\alpha)$ | $\boldsymbol{-(90,80)-170(\alpha,\alpha)}$ | $-(120,80)-200(\alpha,\alpha)$ | $-(70,110)-180(\alpha,\alpha)$ |
| $a(2,2)$ | $-(80,90)-170(\alpha,\alpha)$ | $-(130,80)-210(\alpha,\alpha)$ | $-(100,80)-180(\alpha,\alpha)$ | $-(150,110)-260(\alpha,\alpha)$ |

**Table 7:** Utilities in game AD under preferences for efficiency ($\alpha > 0$).

are equilibria in game AD if and only if

$$\begin{aligned} -80-170\,\alpha &\geq -70-180\,\alpha \quad \text{and} \\ -90-170\,\alpha &\geq -80-180\,\alpha. \end{aligned}$$

Since these conditions are met if and only if $\alpha \geq 1$, preferences for efficiency would at first sight explain coordination on dominated strategies as an equilibrium phenomenon for these values of $\alpha$. However, if $\alpha \geq 1$ then $(a(1,1), a(2,2))$ and $(a(2,2), a(1,1))$ are also pure strategy Nash equilibria in game AC (see e.g. Table 8 for the case $\alpha = 1$). In fact, the equilibrium structure of the two games is now the same, yet our experimental results in treatment Partner have shown that groups coordinate on exterior profiles in game AD but not in game AC.

| $1\backslash 2$ | $a(1,1)$ | $a(1,2)$ | $a(2,1)$ | $a(2,2)$ |
|---|---|---|---|---|
| $a(1,1)$ | -350,-430 | -270,**-270** | -280,-350 | **-240**,**-270** |
| $a(1,2)$ | **-240**,-300 | -260,-340 | **-250**,**-260** | -310,-380 |
| $a(2,1)$ | -310,-380 | **-250**,**-260** | -260,-340 | **-240**,-300 |
| $a(2,2)$ | **-240**,**-270** | -280,-350 | -270,**-270** | -350,-430 |

**Table 8:** Utilities in game AC under preferences for efficiency when $\alpha = 1$.

We will now show that our experimental results are consistent once we suppose that players are inequality averse and have the utility function $u_i(s) = -c_i(s) - \alpha \cdot \max\{0, c_i(s) - c_j(s)\} - \beta \cdot \max\{0, c_j(s) - c_i(s)\}$. Here, $\alpha > 0$ indicates the degree of inequality aversion of player $i$ when player $j \neq i$ gets the lower costs and $\beta > 0$ measures the inequality aversion of player $i$ when player $i$ gets the lower costs. The exterior profiles are equilibria in game AD if and only if (see

Table 9)

$$
\begin{aligned}
-80-10\beta &\geq \max\{-150-40\alpha, -70-40\beta, -140-50\alpha\}, \quad \text{and} \\
-90-10\alpha &\geq \max\{-80-50\beta, -80-20\beta, -110-40\beta\},
\end{aligned}
$$

or equivalently,

$$
\max\{\frac{\alpha+1}{2}, \frac{1}{3}\} \leq \beta \leq \min\{5\alpha+6, 4\alpha+7\},
$$

which has a solution for any $\alpha > 0$. In particular, there exist values of $\alpha > 0$ and $\beta > 0$ for which the exterior profiles are equilibria in game AD.

| $1\backslash 2$ | $a(1,1)$ | $a(1,2)$ | $a(2,1)$ | $a(2,2)$ |
|---|---|---|---|---|
| $a(1,1)$ | $-(150,110)-40(\alpha,\beta)$ | $-(100,80)-20(\alpha,\beta)$ | $-(130,80)-50(\alpha,\beta)$ | $-(80,90)-10(\beta,\alpha)$ |
| $a(1,2)$ | $-(70,110)-40(\beta,\alpha)$ | $-(120,80)-40(\alpha,\beta)$ | $-(\mathbf{90},\mathbf{80})-\mathbf{10}(\alpha,\beta)$ | $-(140,90)-50(\alpha,\beta)$ |
| $a(2,1)$ | $-(140,90)-50(\alpha,\beta)$ | $-(\mathbf{90},\mathbf{80})-\mathbf{10}(\alpha,\beta)$ | $-(120,80)-40(\alpha,\beta)$ | $-(70,110)-40(\beta,\alpha)$ |
| $a(2,2)$ | $-(80,90)-10(\beta,\alpha)$ | $-(130,80)-50(\alpha,\beta)$ | $-(100,80)-20(\alpha,\beta)$ | $-(150,110)-40(\alpha,\beta)$ |

**Table 9:** Utilities in game AD under inquality aversion ($\alpha > 0, \beta > 0$).

We now complete our analysis by showing that the exterior profiles are never equilibria in game AC (see Table 10). The best response of player 2 against player 1's strategy $a(1,1)$ is to play $a(1,2)$, which gives her a utility of $-90$, and not to play $a(2,2)$, which gives her a utility of $-100-30\alpha$. Similarly, the best response of player 2 against player 1's strategy $a(2,2)$ is $a(2,1)$. Consequently, coordination on dominated strategies can be obtained for inequality averse individuals in game AD but not in game AC.

| $1\backslash 2$ | $a(1,1)$ | $a(1,2)$ | $a(2,1)$ | $a(2,2)$ |
|---|---|---|---|---|
| $a(1,1)$ | $-(90,170)-80(\beta,\alpha)$ | $-(90,\mathbf{90})$ | $-(70,140)-70(\beta,\alpha)$ | $-(70,100)-30(\beta,\alpha)$ |
| $a(1,2)$ | $-(60,120)-60(\beta,\alpha)$ | $-(60,140)-80(\beta,\alpha)$ | $-(80,\mathbf{90})-10(\beta,\alpha)$ | $-(80,150)-70(\beta,\alpha)$ |
| $a(2,1)$ | $-(80,150)-70(\beta,\alpha)$ | $-(80,\mathbf{90})-10(\beta,\alpha)$ | $-(60,140)-80(\beta,\alpha)$ | $-(60,120)-60(\beta,\alpha)$ |
| $a(2,2)$ | $-(70,100)-30(\beta,\alpha)$ | $-(70,140)-70(\beta,\alpha)$ | $-(90,\mathbf{90})$ | $-(90,170)-80(\beta,\alpha)$ |

**Table 10:** Utilities in game AC under inquality aversion ($\alpha > 0, \beta > 0$).

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