Competition as a Coordination Device

Experimental Evidence
from a Minimum Effort Coordination Game

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Abstract

The problem of coordination failure, particularly in 'team production' situations, is central to a large number of mircroeconomic as well as macroeconomic models. As this type of inefficient coordination poses a severe economic problem, there is a need for institutions that foster efficient coordination of individual economic plans. In this paper, we introduce such a rather classical economic institution: competition. In a series of laboratory experiments, we reveal that the true reason for coordination failure is strategic uncertainty, which can be reduced almost completely by introducing a appropriately designed mechanism of (inter–group) competition.

key words coordination failure, team production, competition
JEL classifications C72, C92, J33

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1 Introduction

The problem of coordination among economic agents is central to a large number of macroeconomic as well as microeconomic situations. Coordination failure[1] in economics is stripped down to its very core in order statistic games. In this type of games, coordination failure is particularly compelling for two reasons. First, there is a multiplicity of equilibria in which stable coordination of individual plans in action profiles that are not Pareto efficient is very well possible. Second, apart from the Pareto efficient equilibrium, there exists at least one other equilibrium, which is attractive for risk averse individuals, i.e. a risk dominant equilibrium, an equilibrium in (Maximin–) security strategies, or an equilibrium with maximum stochastic potential. Order statistic games as mentioned above reflect the tension between Pareto efficiency and risk dominance central to important work by, for example, Straub (1995), Kandori et al. (1993), Foster and Young (1990), and Young (1993).

The same type of models is an essential building block of Post Walrasian Macroeconomics.[2] In this branch of literature, some authors argue that coordination problems in certain economic environments are due to strategic complementarities. The existence of strategic complementarities, then, can be seen as one of the main reasons for the 'macroeconomic problem' of actual output being lower than potential aggregate output (Cooper and John, 1988; Cooper, 1999). Phenomena like involuntary unemployment are consequences of this. An important workhorse of this school of thought, on the the anecdotal as well as on the analytical level, is the 'team production' model (see, for example, Cooper and John 1988; Bryant 1996). A group of several workers is engaged in producing a good by means of a Leontief technology. The output level is essentially determined by the worker exerting the lowest effort in the group. All effort exceeding the group minimum effort is wasted. All the team members get wages positively correlated to the output level. As working effort causes disutility, team members exerting at exactly the minimum effort level are best of. This model, which can be interpreted as a form of an order statistic game, was introduced in general terms by Bryant (1983) and extensively analyzed in a more specific version in two seminal papers by Van Huyck et al. (1987, 1990). The latter show that coordination in basic experimental settings does not lead to the Pareto efficient equilibrium, but rather towards the equilibrium which is worst from the point of view of social welfare. Obviously, as there is no (Walrasian or other) 'natural force' driving behavior to efficiency, there is a need for mechanisms leading individual behavior in this desired direction. Quoting Bryant (1996, p. 159),

> Coordination matters, and the institutions that provide coordination

[1] Coordination failure does not mean a situation where people do not coordinate, but rather a situation of coordination in the 'wrong' equilibrium.

[2] On Post–Walrasian Macroeconomics in general, see Bowles and Gintis (1993) along with the comments on this paper by Williamson (1993) and Stiglitz (1993).

become a central element in the analysis of the economy.

The set of coordination devices (or 'institutions') proposed throughout the literature and put to the experimental test includes a number of different approaches. One of the earliest pieces of work aims at the reduction of the number of group members (Van Huyck et al., 2001). Other ideas subsume ways of charging an entrance fee for the right to participate in the game: Cachon and Camerer (1996) directly charge a fee, Van Huyck et al. (1993) stage an auction for the right to participate, and Cooper et al. (1992, 1994) extend the coordination game unsing an outside option such that the choice of the inside option, i.e. the play of the coordination game itself, induces opportunity costs to the respective player. Other alternative institutions involve the introduction of costly and costless communication between participants before and during the game (Blume and Ortmann, 2000; Cooper et al., 1992, 1994), or a dramatic increase in the number of playing periods (Berninghaus and Erhart, 1998).

While in line with this strand of literature, this paper argues in favor of another coordination device. The story we are about to tell is a mere extension of the team production story. If there is more than just one team producing the same good, competition between these teams will solve the problem of coordination failure. For this to take place, it does not matter, whether the teams compete within a firm or whether teams essentially *are* firms. In the first case, competition can be used as an intra–firm incentive scheme (see Nalbantian and Schotter 1997). In the latter case, competition will arise quite naturally by the workings of the market. In this paper, we show that inter–group competition eliminates inefficiency almost completely and drives workers' efforts very close to the Pareto efficient level. Thus, if asking for a coordination device, the answer seems to be right before our very eyes: competition.

This paper is based on the following general idea. Coordination failure is a symptom of a problem rather than the problem itself. There must be a reason why people do not choose the Pareto efficient action but some other action. Consequently, in order to eliminate coordination failure, the first step is to identify what causes this problem. Thus, the first question faced within this paper is, what drives coordination towards inefficient equilibria? There are at least two groups of different possible causes of coordination failure. The first is the group of individual behavioral reasons: spiteful behavior and competitive motives. The second group includes strategic uncertainty.

Thus, the first part of our work aims to point out that it is strategic uncertainty rather than individual behavioral forces that causes the problem of coordination failure.

After the main reason for coordination failure is uncovered, the second part of this paper will be dedicated to the task of finding a coordination device, i.e. a means of reducing strategic uncertainty. In fact, we do not actually 'develop' but rather just 'apply' a concept, which — although stemming from the very heart of economics — has not been proposed as a coordination device in this context before:

competition. This concept is put to the experimental test and shown to improve the efficiency of coordination remarkably.

2 Experimental Set–Up

The Basics

Our analysis is based on the game by Van Huyck et al. (1990), which is a minimum effort coordination game. In this game, players are members of a group. The key determinants of each player's payoff are that player's own choice of action and the minimum choice of any of the group members, including the player himself. Among other things, this game has often been interpreted as modeling the team production problem. The effort level of each of the team members is essential and a perfect complement to the effort of the others. (In fact, this set–up constitutes a situation of strategic complementarities.) Thus, the minimum effort level in a team is the key determinant of the team's output. A fraction of the output minus the individual's effort cost gives this individual's payoff (utility). The formalization of this concept used for the purpose of this paper is given by the equation

$$\pi_i = .2 \min_j \{e_j\} - .1\, e_i + a\,, \tag{1}$$

where π_i stands for individual i's payoff, $\min_j \{e_j\}$ gives the group minimum effort level, e_i is individual i's effort level ($.1\, e_i$ give the effort costs), and a gives a flat payoff independent of efforts. (Although, in this paper, we use the metaphor of team production in order to explain the set–up of the experiments, our experiments themselves were neutrally framed, i.e. presented to the participants without reference to team production.)

Following Van Huyck et al. (1990), we reduced our participants' action spaces to a discrete set of seven effort levels, labeled from '1' to '7'. Using these in the payoff generating equation (1), we created two different payoff tables (for different values of a) for use in different treatments. The respective payoff tables are given in Tab. 1 (for $a = 1.3$) and Tab. 2 (for $a = .5$). The normal form game represented by each of these two tables has seven symmetric pure strategy Nash equilibria, which are the seven uniform action profiles. While the equilibria are Pareto–ranked, two of these profiles are particularly remarkable. The uniform profile with every player using the effort level of '7' is the Pareto efficient one. The profile with every player playing an effort level of '1' is the worst one in terms of welfare but at the same time it is the most secure, i.e. it consists of security actions in the sense of a maximin strategy. This, in a way, carries over the idea of a risk dominant equilibrium to games of the given type, i.e. games with more than two actions per player and more than two players.[3]

[3] A second reason that this equilibrium resembles the idea of a risk dominant equilibrium is that it has the highest stochastic potential and can been shown to be the global attractor to evolutionary dynamics (Crawford, 1991; Goeree and Holt, 1998; Riechmann, 2002).

Each of our experiments[4] involved a group of seven players who did not encounter each other before, during, or after the experiment and stayed perfectly anonymous.[5] Each player had the same set of actions, '1' to '7', available. Payoffs to the players were given in Euro according to Tab. 1 or Tab. 2, depending on the treatment. Note that the payoffs only differ with respect to parameter a, the flat payoff independent of the particular strategy choice.[6]

		smallest choice within group 'group minimum'						
		7	6	5	4	3	2	1
	7	2.00	1.80	1.60	1.40	1.20	1.00	0.80
individual	6	–	1.90	1.70	1.50	1.30	1.10	0.90
choice	5	–	–	1.80	1.60	1.40	1.20	1.00
	4	–	–	–	1.70	1.50	1.30	1.10
	3	–	–	–	–	1.60	1.40	1.20
	2	–	–	–	–	–	1.50	1.30
	1	–	–	–	–	–	–	1.40

Table 1: Payoff Table for the Baseline and Communication Treatments and for the Winner Groups in the Competition Treatments

		smallest choice within group 'group minimum'						
		7	6	5	4	3	2	1
	7	1.20	1.00	0.80	0.60	0.40	0.20	0.00
individual	6	–	1.10	0.90	0.70	0.50	0.30	0.10
choice	5	–	–	1.00	0.80	0.60	0.40	0.20
	4	–	–	–	0.90	0.70	0.50	0.30
	3	–	–	–	–	0.80	0.60	0.40
	2	–	–	–	–	–	0.70	0.50
	1	–	–	–	–	–	–	0.60

Table 2: Payoff Table for the Loser Groups in the Competition Treatments

In every treatment, participants started by playing three rounds of the game against the computer in order to make sure they understood the game and the handling of the computer program. They were informed of the fact that they were playing against a computer and, consequently, could not learn anything about the behavior of the other members of their group in these rounds. After these training rounds,

[4]The experiments were programmed and conducted with the software z-Tree (Fischbacher, 1999).

[5]This is not true for the communication treatment (see below).

[6]Choosing tables that differ only with respect to the flat parameter a means that we can rule out different potentials of the equilibria being the reason for different behavior of our participants (Goeree and Holt, 1998).

participants played ten rounds of the game against the six other members of their group. After each round, every participant was provided with direct feedback about the minimum effort level in his group and his payoff in the period. Participants initially knew that they would be playing for 10 rounds. The final payoff a participant received consisted of the sum of his payoffs from all 10 rounds. We paid no show up fee.

Treatments

We played four different treatments: the 'baseline' treatment, the 'communication' treatment, and two different 'competition' treatments, later called 'Comp1' and 'Comp2'. We had six groups of seven participants play the baseline treatment and six groups of seven participants play the communication treatment. In the competition treatments, two different groups played 'against' each other in each experiment. Consequently, we had 12 groups of seven participants play each of the two competition treatments.

In the baseline treatment, apart from the group size, we conducted exactly the same experiments as Van Huyck et al. (1987, 1990). In particular, group members were mutually anonymous, there was no communication among group members, and there was no device to foster coordination towards efficiency. The communication treatment is identical to the baseline treatment except for one key difference: whereas participants in the baseline set–up were perfectly foreign to each other and were not allowed to communicate, we introduced the possibility of explicit and extensive communication to this treatment. After the usual two rounds of play against the computer, all members were physically brought together and given a chance to communicate and explicitly make plans on how to behave in the next ten rounds of the game. Our goal in doing this was to provide every possible means of reducing strategic uncertainty.

The competition treatments are the core elements of this piece of work. In every experiment within these treatments, we had two groups of seven members play at the same time. In each round, after participants made their choices, we determined which group had the higher minimum choice (the higher 'group minimum'). We labeled this group the winner group and paid the members of this group according to Tab. 1, which is based on a higher flat payoff, i.e. it delivers a higher payoff to every action profile than Tab. 2. The members of the loser group, i.e. the one with the smaller group minimum, were payed according to Tab. 2. In the case of a tie, i.e. both groups having the same minimum choice, we paid both groups according to the table for the winner group, i.e. Tab. 1. The two competition treatments, Comp1 and Comp2 differ only with respect to the information given to the participants after each round of play. In the Comp1 treatment (which is a low information treatment), along with their personal payoffs and the minimum effort in their group, members of each group were told whether their group was the winner or the loser group. In the Comp2 treatment, we added only one more piece of information: in addition to all the information given to the participants in the Comp1 treatment, participants were also informed about the specific value of the minimum choice in the other group.

3 Experimental Evidence

Before going into the details of experimental results, it will prove helpful to clarify a few technical terms. Coordination of individuals' plans can be *complete* or *incomplete*, and *efficient* or *inefficient*. Coordination is complete if all players of the game choose the same action, i.e. if a Nash equilibrium is played. Coordination is *efficient* if it is complete *and* if the equilibrium reached is the Pareto efficient one, i.e. with all players choosing effort level '7'. *Coordination failure* is a situation of complete but inefficient coordination, whereas *discoordination* is a situation of incomplete coordination, i.e. not an equilibrium profile at all.

The Benchmark Case

The benchmark case for all of our further experiments is the 'baseline' treatment. In the baseline treatment, participants behaved similarly to the participants of the original experiments by Van Huyck et al. (1990). Over time, the minimum choices within the groups tended to drop to the effort level of '1'. The equilibrium of a common play of '1' seems to be the dominant attractor in this treatment (see Figures 1(a) and 1(b)). The fact that convergence to this equilibrium is slower than in the experiements by Van Huyck et al. can be ascribed to the fact that our groups, with a size of seven, are much smaller than those in the original experiments by Van Huyck et al., who used group sizes of 14 to 16. (See Van Huyck et al., 2001, on the effect of the group size on the direction and speed of convergence.)

The Causes of Coordination Failure

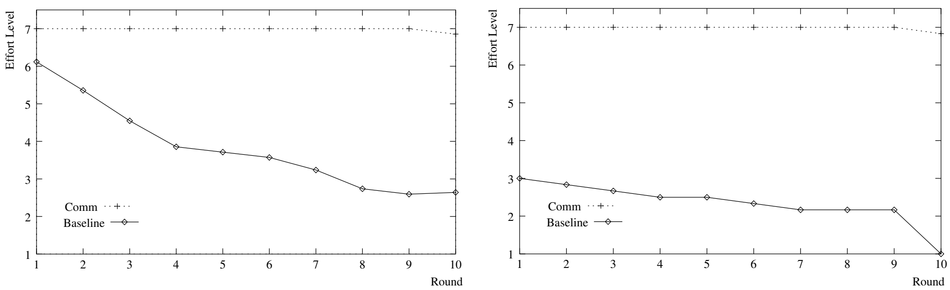
The first step of our analysis consists of exploring if coordination failure (i.e. complete but inefficient coordination) is indeed caused by strategic uncertainty. Although even Van Huyck et al. (1990, p. 247) claim that 'coordination failure results from strategic uncertainty', they do not put this claim to the experimental test. Indeed, on a closer inspection, the reasons for coordination failure are not as clear as they might seem. Apart from strategic uncertainty, there is at least one more group of possible causes of complete but inefficient coordination: modes of behavior due to spiteful or competitive motives.

Spiteful behavior or competitive motives make an individual want to perform better than the other members of his group. The aim of a spiteful or competitive player is the maximization of his *relative payoff*, i.e. the difference between his (absolute) payoff and the (absolute) payoff of the others. This type of behavior will lead an individual to choose the lowest possible effort level, i.e. the effort level of '1'.[7]

[7] For details on spiteful behavior in games, see Riechmann (2002).

Strategic uncertainty, on the other hand, simply means that a player is not sure what the other group members will do. If the player is sufficiently risk averse, he might choose not to play '7', but the 'safest' action instead, which is the effort level of '1'. Thus, in order to distinguish between the effects of competitive behavior, on the one hand, and the effects of strategic uncertainty, on the other, we designed the communication treatment. By giving the participants the chance to communicate, we tried to reduce the degree of strategic uncertainty as much as possible. Note that, while we nearly eliminate strategic uncertainty, individual behavioral motives remain untouched. Thus, an experimental result of coordination to the effort level of '1' should lead to the idea that coordination failure is caused by competitive motives, while a result of efficient coordination is induced by the elimination of strategic uncertainty. Put briefly: efficient coordination in this treatment should be interpreted as strong evidence that strategic uncertainty is the key reason for coordination failure.

In all but the final round of each of the experiments using the communication treatment, every participant chose an effort level of '7'. The only exception to this is one player in the last period of one experiment choosing '1'.[8] This result is extremely different from both the result of the baseline treatment and the result to be expected in the case of spiteful or competitive motives. Experimental results are displayed in Fig. 1(a) for the group mean effort level as well as in Fig. 1(b) for the group minimum effort level. (A summary of all experimental results is given in the appendix.) The differences between play in the baseline treatment and play in the communication treatment are highly significant for every piece of data. In contrast to the baseline treatment, in the communication treatment, i.e. in the absence of strategic uncertainty, coordination towards the Pareto efficient equilibrium seems to be an extremely easy task. This, of course, suggests very strongly that strategic uncertainty indeed is the core reason for coordination failure.



(a) Mean Effort

(b) Group Minimum Effort

Figure 1: Communication vs. Baseline

[8] This clearly suggests an effect of participants knowing the time horizon of the game.

Competition and Partial Coordination

Basic Competition

From the baseline and communication experiments, it becomes obvious that strategic uncertainty is the major reason for coordination failure. Consequently, we develop our core mechanism to reduce strategic uncertainty: group competition.

The basic idea behind this concept is the following. Obviously, the prospect of attaining maximum payoff in the case of common choice of the Pareto efficient action (i.e. '7') is not sufficient to reassure players that every other member of their group will also choose this action. Common knowledge of Pareto efficiency is not enough to sufficiently reduce strategic uncertainty.[9] Consequently, an effective coordination device must provide players with a second reason to believe that all others will take the efficient action, too. This second reason is provided by the mechanism of group competition. In addition to aiming to maximize payoff, players will want to belong to the winner group. (Which, in turn, increases payoffs even more.) The major point of reasoning here is the fact that by using the instrument of competition between groups, we provide a *second* reason to believe in other group members' rationality rather than just enhancing the first reason, i.e. pure payoff maximization.[10]

The results of our experiments show that the instrument of competition does indeed work as a coordination device. Figure 2, for (mean) group minimum effort levels, and Figure 3, for mean effort, display our results. Statistical analysis shows that average performance of all groups involved in the Comp1 treatment (in the figure labeled as Comp. 1 General) as well as performance of winner groups is significantly better than performance of the baseliners. Moreover, there is no significant difference between baseline performance and performance of loser groups, suggesting that even the losers in a situation of competition do not perform worse than players in the baseline situation.

The impression from Fig. 3 is supported by results from regressions (Tab. 3). Depending on the number of the round alone, a regression (model 1) shows that in the core rounds of the experiments, i.e. rounds 3 to 9, the baseline setting generates a significant decline in effort over time (i.e. a coefficient for 'Round' of -.306), while in the Comp1 treatment this decline is much smaller (-.306 + .204 = -.102).

Further regression analysis helps to explore the causes of different behavior between the baseline and the Comp1 treatments. The regression in model 2 (Tab. 3)

[9] See Cooper (1994), who states that in games of the given type, the Pareto dominant equilibrium does not provide a 'natural focal point'.

[10] In order to make sure that there is no stake–effect in our experiments, we conducted another six experiments as a second baseline treatment, using the same rules as in the baseline case, but paying the participants according to Tab. 2 (lower payoffs). In fact, we found no qualitative differences between the results of this and the Baseline treatment, which supports our idea that winner–groups in competition treatments do not perform better, just because their payoffs are taken from a 'higher' payoff table. As we found no qualitative differences, we see no need for further analysis of this treatment in this paper.

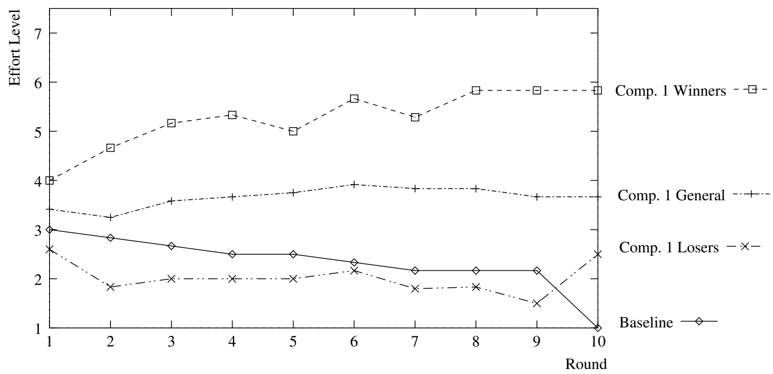


Figure 2: Mean Group Minimum Effort Levels Comp1 vs. Baseline

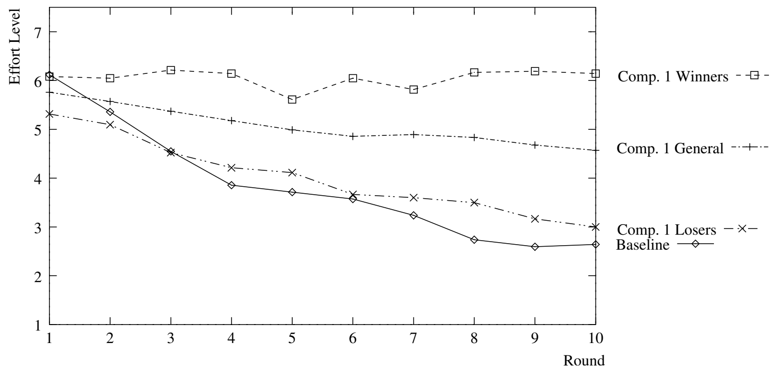


Figure 3: Mean Effort Levels Comp1 vs. Baseline

dep. var: Effort	models	
ind. variable	1	2
Intercept	5.303***	0.351
	(0.37)	(0.344)
Round	-0.306***	-0.038
	(0.058)	(0.041)
Effort(t-1)		0.318***
		(0.052)
Effort(t-2)		0.146***
		(0.049)
GrMin(t-1)		-0.154
		(0.148)
GrMin(t-2)		0.723***
		(0.157)
D_1	0.281	1.414***
	(0.453)	(0.427)
D_1: Round	0.204***	-0.042
	(0.072)	(0.048)
D_1: Effort(t-1)		-0.003
		(0.066)
D_1: Effort(t-2)		-0.038
		(0.063)
D_1: GrMin(t-1)		0.713***
		(0.165)
D_1: GrMin(t-2)		-0.874***
		(0.175)
adjusted R^2	0.141	0.671

standard errors in brackets;
significant at ***= 1 %, **= 5 %, *= 10 %
Basic results for baseline treatment,
D_{C1}: dummy indicating additional effects of Comp1

Table 3: Regressions: Effort Level in Core Rounds, Baseline vs. Comp1

shows that in both treatments, effort levels are positively autocorrelated. The effort levels of the previous round, Effort(t), and the round before the previous round, Effort(t-1), have a significantly positive influence on present effort. The treatments do not significantly differ with respect to autocorrelation of effort.

A significant influence on baseliners' behavior is the group minimum effort in rounds $t-2$, GrMin(t-2). The fact that the group minimum in $t-1$, GrMin(t-1), has no significant influence indicates some level of inertia in baseliners' behavior. Participants in the Comp1 treatment, in contrast, condition the behavior on the group minimum in $t-1$, whereas the total influence of the minimum in $t-2$ is weak and slightly negative. We interpret this negative influence as a kind of correction of the reaction to the minimum in $t-1$.

Thus, the main difference between baseliners and Comp1 participants, which makes the participants in Comp1 much more successful than baseliners, is the ability of Comp1 participants to react to the group minimum effort much more quickly than baseliners apparently do.

Completeness of Coordination

Our results would look even more positive if the loser groups, too, performed better than the baseliners. Thus, the next question to be answered is that of why losers do not perform better than they do. In order to answer this question, it helps to introduce the notion of 'wasted effort'.

An individual i's wasted effort, e_i^w, is his effort e_i exceeding the minimum effort in his group, $e^{\min}$:

$$e_i^w = e_i - e^{\min}$$

Thus, wasted effort is a measure of effort wasted *relative to the group*. We measure mean effort exceeding the *group minimum* effort.[11]

The mean wasted effort in a group of n members, $\overline{e^w}$, is

$$\overline{e^w} = \frac{1}{n} \sum_{j=1}^{n} \left(e_i - e^{\min}\right) = \overline{e} - e^{\min}$$

Mean wasted effort in a group is a measure of the degree of coordination in any of the equilibria in this group, i.e. a measure of completeness of coordination. The lower the group mean wasted effort, the higher the degree of coordination. If group mean wasted effort equals zero, coordination is complete (no deviations) but not necessarily efficient (i.e. on the '7').[12]

Fig. 4 shows mean wasted effort in the baseline treatment and for winners and losers in the Comp1 treatment. The degree of coordination of the winners is very

[11] We *do not* measure the group mean distance to the effort level of '7', which is a more global measure of 'welfare'.

[12] Note that mean wasted effort, though measuring wasted effort relative to the group, still measures wasted effort *in absolute terms*, i.e. neglects the fact that groups with a low group minimum effort level have a much greater potential for wasting effort than groups with a higher minimum effort level. For details on this problem, see the appendix

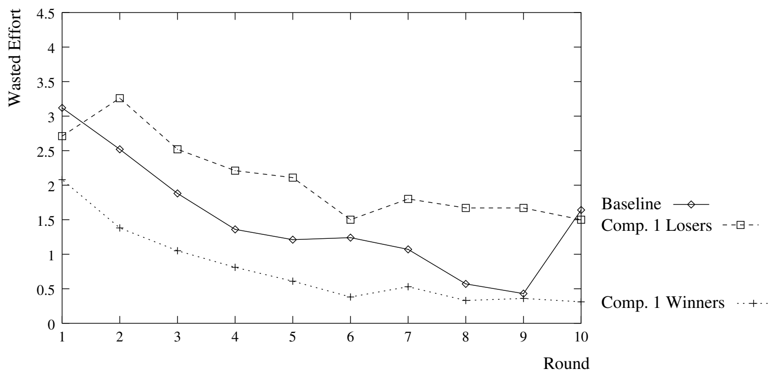


Figure 4: Mean Wasted Effort Competition vs. Baseline

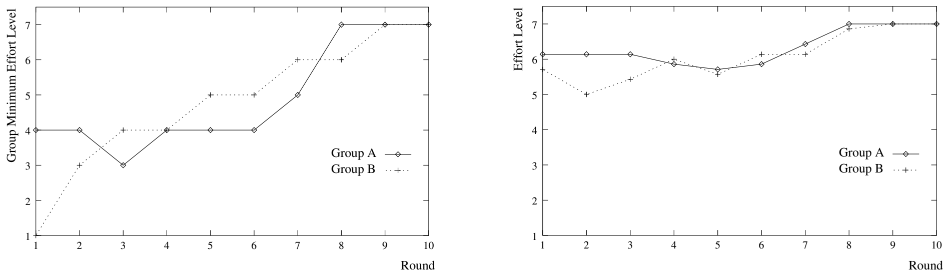
high from the beginning on and becomes even higher. Baseliners seem to learn to coordinate in some equilibrium over time (ignoring the last period). The interesting observation, though, concerns the losers: losers waste considerable effort in more or less every round of the experiment. There is no clear tendency in loser groups to coordinate over time. Thus, our results show that 'losers' perform so badly not because they coordinate to an inefficient equilibrium but because they do not coordinate at all. The losers' problem is not coordination failure but discoordination. Thus, competition in the form we designed in our Comp1 treatment can be seen as a partial coordination device. It fosters efficient coordination of the winners but leaves the losers in a state of discoordination.

Competition as a Coordination Device

The remedy to the problem of loser groups not coordinating lies in the design of the Comp2 treatments. Here, we provide one extra piece of information to the members of both competing groups: the minimum effort level played by their respective opponent group in the preceding period. It turns out that this form of competition is a highly efficient but fragile means of fostering coordination.

The Fragility of Competition

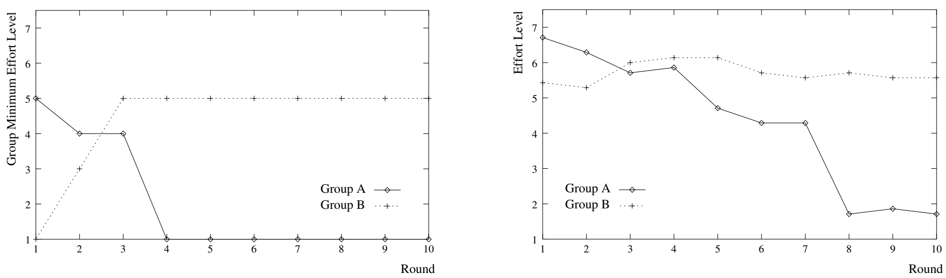
As will be shown in greater detail below, competition in this form, i.e. in the form of our Comp2 treatment, remarkably improves the performance of both loser and winner groups. Still, competition in our experiments turned out to be a slightly fragile process. Altogether, we observed two very different, 'typical' profiles of a Comp2 experiment. The more frequent one (observed in four out of six experiments of the Comp2–treatment) typically looks like that displayed in Fig. 5: Both groups start at somewhat low effort levels and drive each other upwards towards efficiency. We will label Comp2 experiments showing this pattern of behavior Comp2a cases, cases where the mechanism of competition works very well.



(a) Group Minimum Effort (b) Mean Effort

Figure 5: Typical Profile of a Comp2a Experiment

The less frequent profile shows the case of a breakdown of competition. An exemplary profile is displayed in Fig. 6. We mark these experiments as Comp2b experiments. Here, after an initial phase similar to the Comp2a experiments, in one round, one member of one of the groups chooses an effort level of '1'. This action of one single group member triggers a breakdown of the mechanism of mutual competition.[13] In the following rounds, members of the same group lower their effort levels, too. Finally, after some time, the average of effort levels within the group approaches '1'. Even the winner group suffered from this behavior in their opponent group. Winner groups of the Comp2b experiments played less efficiently than winners of the Comp2a experiments.



(a) Group Minimum Effort (b) Mean Effort

Figure 6: Typical Profile of a Comp2b Experiment

Although generally inducing an effective reduction of strategic uncertainty, the process of Comp2 competition is highly sensitive to even just one player playing

[13]We will not speculate on the reasons why people triggered the breakdown. Still, one illustrative remark seems in order. In one experiment, after playing all ten rounds, one participant confessed to not having understood the game completely and thus having 'tried out what happens if I play this and that'. We did not include the results of this experiment into the pool of data evaluated for this paper.

'1'. As long as the process of competition does not break down, players accumulate trust in their group members' rational play. But this trust is very fragile. As soon as one group member violates the others' beliefs in common rationality, it is never restored again.

We did not observe any form of 'intermediate behavior': Either there is a choice of effort level '1' in a non–initial round of the experiment, triggering a breakdown of the coordination process, or the process of mutual driving up to efficiency is observed. As these two patterns of behavior are very clearly distinct, we will analyze Comp2a and Comp2b experiments separately, whenever appropriate, in the further course of this paper.

The Degree of Coordination

One basic problem of the loser groups in the Comp1 experiments has been identified as participants' lacking ability to coordinate. Consequently, the first step in analyzing the Comp2 treatment is to ask whether the degree of coordination improved for the loser groups in this treatment.

Fig. 7 shows a plot of the results concerning the degree of coordination, i.e. it displays the values of group mean wasted effort of the loser groups.[14] In fact, loser groups in the Comp2b–cases (i.e. cases of competition breaking down) coordinate very badly most of the time after the breakdown of competition (which happened in round 4 of both Comp2 cases we observed). Nevertheless, from that point in time on, we observe a remarkable degree of adjustment dynamics. Moreover, as long as competition does not break down (i.e. for the Comp2a cases), group mean wasted effort even of the loser groups falls below the level of the Comp1 losers (see Fig. 7.)[15]

Thus, there is strong evidence that indeed the extra information distinguishing the Comp2 from the Comp1 treatment results in a better degree of coordination.

The Degree of Efficiency

From the results shown so far, it is clear that under the regime of type Comp2 competition, participants manage to achieve a very high degree of coordination. Consequently, the next question to be answered is how *efficient* is coordination? Accordingly, we now turn from the question of coordination or discoordination back to the question of coordination failure. As we have shown before, the winners in the Comp1 treatment manage to achieve a rather high degree of efficiency. The

[14]The degree of coordination in the winner groups is so high that an explicit plot of the results is not necessary in this context. Nevertheless, all the data can be found in the appendix.

[15]The differences between wasted effort levels of the losers in Comp1 and Comp2a are significant at the 5% level for the last three rounds (t-test two–tailed (!) p–values of .003, .015, and .049 for rounds 8, 9, and 10, respectively). The fact that significances are relatively weak can be partly ascribed to the fact that, in the Comp2a, sessions in the later periods there were very few observations of loser groups at all because in the case of a tie in the group minimum efforts both groups are declared winner groups.

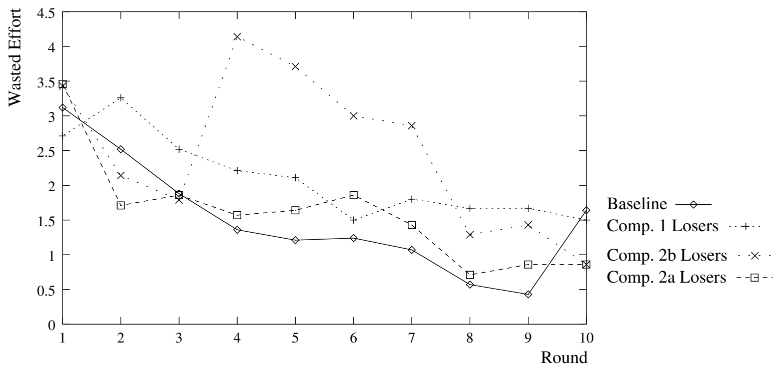


Figure 7: Mean Wasted Effort Comp. Losers and Baseline

problem so far is largely a problem of coordination failure in the loser groups (which we showed is basically a problem of discoordination). Figures 8 and 9 show the effects of introducing the Comp2 treatment on group minimum and group mean effort levels.

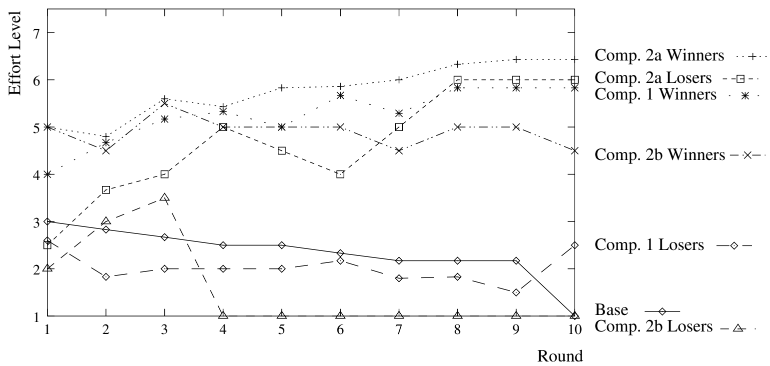


Figure 8: Group Minimum Effort

For group minimum effort (Fig. 8) and, even more obviously, for group mean effort (Fig. 9), two types of profiles of play can be clearly distinguished. The figures show two different 'clusters' of lines. The first cluster, showing an upward moving tendency for group minimum and mean effort levels, consists of the winner groups of the Comp1 treatment, the winner groups of the Comp2b cases, and the winner and, most remarkably, the loser groups of the Comp2a cases. There are no significant differences in mean effort between the groups in the upper cluster from round one on. The lower cluster consists of the baseline groups and the loser groups of the Comp1 treatment. Again, the differences between these two groups are insignificant from the first period on. The differences between the clusters are significant from round three on.[16] The loser groups of the Comp2b cases cannot be subsumed in one of the clusters. Statistical evidence is similar, though a little less clear, for

[16]The highest p–value is the one characterizing the difference in mean effort between Comp2b

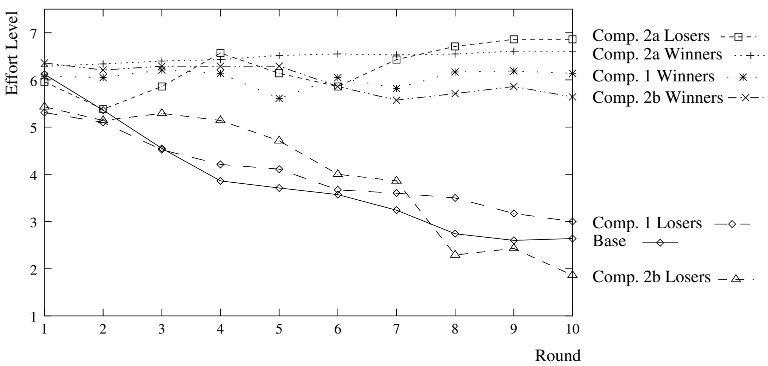


Figure 9: Group Mean Effort

group minimum effort. Here, the upper cluster consists of the same groups as for mean effort, except for the Comp2b winners, who perform significantly worse than members of the upper cluster but significantly better than the groups belonging to the lower cluster, which consists of baseliners and Comp1 losers. Again, Comp2b losers are significantly worse than any other group. The interpretation of these findings is straightforward. Starting with the fact that losers in the Comp1 treatments do not perform better than baseliners, we find that the introduction of the Comp2 setting remarkably improves efficiency, as all groups of the Comp2a cases achieve significantly better results than baseline groups. For both cases of behavior in the Comp2 treatment, i.e. for competition working well and for competition breaking down, winner groups perform much better than baseliners. Even more encouraging is the second finding: if competition does not break down (Comp2a cases), the loser groups perform as well as the respective winners. Statistical analysis shows that there is no significant difference in mean and group minimum effort choice between the Comp2a winner and the Comp2a loser groups.
Summarizing, competition in the form of the Comp2 setting turns out to be a simple and, at the same time, perfectly performing coordination device, fostering efficient coordination of both groups involved, winners and losers.

The Impact of Extra Information

It is obvious that the one piece of extra information that distinguishes the Comp1 from the Comp2 treatment has a remarkable effect on participants' behavior. Thus, it is interesting to explore how this piece of extra information actually works on people's way of acting. For this purpose, we conducted two regressions, the results of which can be found in Tab. 4. The first regression compares the effect of different pieces of information on the behavior of all participants in the winner groups of the Comp1 and Comp2a treatments. The second regression is the

winners and baseliners in round three. The p–values are based on pairwise comparisons using t–tests with a Holm–correction due to the comparison of more than two samples. The results of all statistical computation will be made available on our interne site.

same, but restricted to the individuals who exerted the group minimum effort in the previous respective round. These participants' behavior is particularly important because, in the previous round, they determined the largest part of all the other participants' payoff (and, as the first of the regressions shows, the largest part of all participants' current behavior). The dependent variable in the regressions is the effort in the current round t, `Effort`, where rounds in focus range from $t = 3$ to $t = 9$, thus neglecting initial–round and last–round effects. The regressions explore the effect of the round itself, `Round`, the effect of players' own behavior in the two previous rounds, `Effort(t-1)` and `Effort(t-2)`, of the group minimum in the two previous rounds, `GrMin(t-1)` and `GrMin(t-2)`, and of the other group's minimum effort level in the two previous rounds, `OtherMin(t-1)` and `OtherMin(t-2)`.[17] The regressions are dummy regressions and D_{C2aW} is a dummy indicating the extra effects on the behavior of the winners of the Comp2a cases. As the additional information given to the participants in the Comp2 treatment, i.e. the information about the other group's minimum effort level in the past, is given by the variables `OtherMin(t-1)` and `OtherMin(t-2)`, we expect these variables to have no or very little effect on the behavior of the Comp1 groups but to have a large influence on the behavior of the Comp2 groups.

In fact, this is what we find in the data. The effect of the other group's minimum effort in the previous round is insignificant for the Comp1 groups in the regression for all players as well as in the regression for minimum players. The opponent group's minimum effort two rounds earlier has a significant influence on all Comp1 players' effort level, but there is no such influence on the most important player in the group, i.e. the minimum player. This is different for the Comp2 groups. For all players, but particularly for the minimum players, the opponent group's minimum play in $t-1$ and in $t-2$ have a highly significant influence. The influence of the other group's minimum effort level in $t-1$ is positive, indicating an increase in one group's effort as a reaction to a high opponent group's effort. The reaction on the opponents' minimum in $t-2$ is negative, thus indicating a kind of correction to the $t-1$ reaction.

Comparing the causes of behavior of the Comp1 and the Comp2a participants, we might conclude that the focus of the participants shifts from their own group's history of play to their opponent group's. In Comp1, participants base their current behavior on their own group's minimum in $t-1$ and in $t-2$, where the first has a positive, and the second a negative, influence on current effort. For members of the Comp2a winner groups, these effects are much weaker. (The effect of `GrMin(t-1)` is reduced to .246, the effect of `GrMin(t-2)` to -.094.) Instead, there is a larger effect of the opponent group's minimum effort level, showing the same directions as the effect of the own group's minimum effort on Comp1 participants: The influence is positive for `OtherMin(t-1)` and negative for

[17] `GrMin(t-1)` does not occur in the regression for the group minimum players because, for this group of players, this is the same as `Effort(t-1)`, the effort level in this round, thus causing a singularity in the regression matrix.

ind. variable	all players	(t-1)–Minimum players
Intercept	1.138***	1.806***
	(0.194)	(0.204)
Round	0.002	-0.067***
	(0.019)	(0.021)
Effort(t-1)	0.491***	0.791***
	(0.051)	(0.092)
Effort(t-2)	0.083*	-0.041
	(0.047)	(0.058)
GrMin(t-1)	0.671***	
	(0.073)	
GrMin(t-2)	-0.447***	0.024
	(0.072)	(0.091)
OtherMin(t-1)	-0.03	0.021
	(0.044)	(0.046)
OtherMin(t-2)	0.104**	0.074
	(0.043)	(0.046)
D_{C2aW}	1.461***	1.228***
	(0.374)	(0.419)
D_{C2aW}: Round	-0.024	0.058*
	(0.028)	(0.033)
D_{C2aW}: Effort(t-1)	-0.07	-0.132
	(0.077)	(0.126)
D_{C2aW}: Effort(t-2)	-0.013	0.038
	(0.067)	(0.083)
D_{C2aW}: GrMin(t-1)	-0.424266***	
	(0.100043)	
D_{C2aW}: GrMin(t-2)	0.353***	-0.109
	(0.087054)	(0.11615)
D_{C2aW}: OtherMin(t-1)	0.169*	0.362***
	(0.087)	(0.123)
D_{C2aW}: OtherMin(t-2)	-0.251***	-0.483***
	(0.075)	(0.103)
adjusted R^2	0.727	0.827

standard errors in brackets; significant at ***= 1 %, **= 5 %, *= 10 %
Dummy D_{C2aW}: indicating additional effects for Comp2a Winners

Table 4: Regressions II: Comp1 Winners vs. Comp2a Winners

`OtherMin(t-2)`. Thus, one might conclude that Cooper (1994) is right in stating that history creates a focal point for people's behavior, but we can make this statement even clearer. It is the history of one's own play that matters in 'simple' (Comp1 type) competition, but if competition is to serve as a truly successful coordination device, it is also the history of the opponent that matters.

4 Summary

Competition, if appropriately designed, is a remarkably successful coordination device. Although the idea of competition as a coordination device goes back to at least Adam Smith's invisible hand, it has not been analyzed in the context of minimum effort coordination games before.

We show that the problem of coordination failure in minimum effort games (e.g. in the famous 'group production' case) can basically be attributed to the prevalence of strategic uncertainty. Strategic uncertainty can be eliminated by using the institution of competition. In a setting of two 'teams' competing against each other, at least the winner team performs nearly Pareto efficiently, while the losers greatly suffer from discoordination. This further problem can be solved by adding a piece of extra information to the process of competition. As soon as both teams learn about the level of last period's minimum effort in their competing team, performance of both teams is significantly better than in the baseline setting (without competition) and nearly efficient.

The only drawback to this result is the finding that the process of competition is extremely sensitive to shocks, such as non–cooperative behavior of group members. Consequently, a question for further research is how to reduce this sensitivity in order to make competition both a successful and robust coordination device.

Appendix A: On Measures of Wasted Effort

The measure of wasted effort used in the main text,

$$e_i^w = e_i - e^{\min},$$

for the individual, and

$$\overline{e^w} = \overline{e} - e^{\min},$$

gives wasted effort relative to the group but not relative to potential maximum wasted effort in the group. The idea is as follows. A group with a minimum effort of $e^{\min} = 1$ has a relatively large potential for wasting effort. The highest possible e_i^w is reached by an individual playing $e_i = 7$: $e_i^w = 7 - 1 = 6$. A group with a high minimum effort level, on the other hand, has a relatively low potential maximum wasted effort, $e_i^w = 7 - 6 = 1$ for $e_i = 7$. Consequently, in the experiments, it might be the case that groups have a higher level of wasted effort, only because their 'potential' level of wasted effort is high.

A better measure of wasted effort, taking this problem into account, might be a measure of wasted effort *relative to* maximum potential wasted effort:

$$w_i = \frac{e_i - e^{\min}}{7 - e^{\min}} \quad \text{for } e^{\min} \neq 7$$

gives individual i's wasted effort $e_i - e^{\min}$ relative to maximum potential effort in his group, $7 - e^{\min}$. This results in a measure of group mean relative wasted effort of

$$\overline{w} = \begin{cases} 0 & \text{for} \quad e^{\min} = 7 \\ \frac{\overline{e} - e^{\min}}{7 - e^{\min}} & \text{else} \end{cases} .$$

This measure has a straightforward interpretation. If group mean relative wasted effort is, say, .43, this means that this group wastes 45 % of the effort it can waste in the worst case. $\overline{w}$ lies between 0 and 1, actually giving a degree of wasted effort. The disadvantage of this measure, though, is the fact that, in our model of discrete effort levels, it is not 'finely grained' enough to sufficiently describe behavior: In a group with a minimum effort level of '6', for example, the only possible positive degree of relative wasted effort an individual can reach is 1 (i.e. 100 %). If the individual chooses '7', nothing is wasted, if he chooses '6' (the only possible other choice), w_i equals 1. This measure is far too coarse to be of any sensible use for our model. Consequently, we do not use it in the main text. The data generated by this measure, however, are given in Appendix B.

Appendix B: Data

Tables 6 and 5 give the mean effort levels and the group minimum effort levels of the different treatments. Tables 7 and 8 show data for wasted effort in absolute and relative terms, respectively.

round	base1	comm	comp1			comp2			comp2a			comp2b		
			gen.	win.	los.	gen.	win.	los.	gen.	win.	los.	gen.	win.	los.
1	3.00	7.00	3.42	4.00	2.60	3.67	5	2.33	3.75	5	2.5	3.5	5	2
2	2.83	7.00	3.25	4.67	1.83	4.17	4.71	3.4	4.38	4.8	3.67	3.75	4.5	3
3	2.67	7.00	3.58	5.17	2.00	4.83	5.57	3.8	5	5.6	4	4.5	5.5	3.5
4	2.50	7.00	3.67	5.33	2.00	4.58	5.33	2.33	5.38	5.43	5	3	5	1
5	2.50	7.00	3.75	5.00	2.00	4.67	5.63	2.75	5.5	5.83	4.5	3	5	1
6	2.33	7.00	3.92	5.67	2.17	4.75	5.67	2	5.63	5.86	4	3	5	1
7	2.17	7.00	3.83	5.29	1.80	4.83	5.67	2.33	5.88	6	5	2.75	4.5	1
8	2.17	7.00	3.83	5.83	1.83	5.17	6	3.5	6.25	6.33	6	3	5	1
9	2.17	7.00	3.67	5.83	1.50	5.25	6.11	2.67	6.38	6.43	6	3	5	1
10	1.00	6.83	3.67	5.83	2.50	5.17	6	2.67	6.38	6.43	6	2.75	4.5	1

Table 5: Mean Group Minimum Effort

round	base1	comm	comp1			comp2			comp2a			comp2b		
			gen.	win.	los.	gen.	win.	los.	gen.	win.	los.	gen.	win.	los.
1	6.12	7.00	5.76	6.08	5.31	6.05	6.31	5.79	6.13	6.29	5.96	5.89	6.36	5.43
2	5.36	7.00	5.57	6.05	5.10	5.88	6.31	5.29	5.98	6.34	5.38	5.68	6.21	5.14
3	4.55	7.00	5.37	6.21	4.52	6.06	6.37	5.63	6.2	6.4	5.86	5.79	6.29	5.29
4	3.86	7.00	5.18	6.14	4.21	6.20	6.40	5.62	6.45	6.43	6.57	5.71	6.29	5.14
5	3.71	7.00	4.99	5.61	4.11	6.12	6.46	5.43	6.43	6.52	6.14	5.5	6.29	4.71
6	3.57	7.00	4.86	6.05	3.67	5.95	6.40	4.62	6.46	6.55	5.86	4.93	5.86	4
7	3.24	7.00	4.89	5.82	3.60	5.92	6.32	4.71	6.52	6.53	6.43	4.71	5.57	3.86
8	2.74	7.00	4.83	6.17	3.50	5.73	6.34	4.50	6.59	6.55	6.71	4	5.71	2.29
9	2.60	7.00	4.68	6.19	3.17	5.81	6.44	3.90	6.64	6.61	6.86	4.14	5.86	2.43
10	2.64	6.86	4.57	6.14	3.00	5.68	6.40	3.52	6.64	6.61	6.86	3.75	5.64	1.86

Table 6: Mean Effort

round	base1	comm	comp1			comp2			comp2a			comp2b		
			gen.	win.	los.	gen.	win.	los.	gen.	win.	los.	gen.	win.	los.
1	3.12	0.00	2.35	2.08	2.71	2.38	1.31	3.45	2.38	1.29	3.46	2.39	1.36	3.43
2	2.52	0.00	2.32	1.38	3.26	1.71	1.59	1.89	1.61	1.54	1.71	1.93	1.71	2.14
3	1.88	0.00	1.79	1.05	2.52	1.23	0.80	1.83	1.2	0.8	1.86	1.29	0.79	1.79
4	1.36	0.00	1.51	0.81	2.21	1.62	1.06	3.29	1.07	1	1.57	2.71	1.29	4.14
5	1.21	0.00	1.24	0.61	2.11	1.45	0.84	2.68	0.93	0.69	1.64	2.5	1.29	3.71
6	1.24	0.00	0.94	0.38	1.50	1.20	0.73	2.62	0.84	0.69	1.86	1.93	0.86	3
7	1.07	0.00	1.06	0.53	1.80	1.08	0.65	2.38	0.64	0.53	1.43	1.96	1.07	2.86
8	0.57	0.00	1.00	0.33	1.67	0.56	0.34	1.00	0.34	0.21	0.71	1	0.71	1.29
9	0.43	0.00	1.01	0.36	1.67	0.56	0.33	1.24	0.27	0.18	0.86	1.14	0.86	1.43
10	1.64	0.86	0.90	0.31	1.50	0.51	0.40	0.86	0.27	0.18	0.86	1	1.14	0.86

Table 7: Mean Wasted Effort

round	base1	comm	comp1			comp2			comp2a			comp2b		
			gen.	win.	los.	gen.	win.	los.	gen.	win.	los.	gen.	win.	los.
1	0.80	0.00	0.67	0.71	0.62	0.69	0.64	0.74	0.70	0.63	0.78	0.68	0.68	0.67
2	0.64	0.00	0.64	0.66	0.62	0.60	0.66	0.52	0.61	0.66	0.51	0.60	0.67	0.54
3	0.45	0.00	0.50	0.49	0.51	0.57	0.59	0.55	0.59	0.61	0.56	0.53	0.54	0.52
4	0.33	0.00	0.41	0.36	0.45	0.66	0.63	0.72	0.65	0.63	0.79	0.67	0.64	0.69
5	0.30	0.00	0.30	0.19	0.45	0.64	0.64	0.65	0.65	0.64	0.68	0.63	0.64	0.62
6	0.27	0.00	0.23	0.13	0.33	0.56	0.57	0.54	0.61	0.61	0.62	0.46	0.43	0.50
7	0.23	0.00	0.25	0.16	0.38	0.52	0.50	0.56	0.55	0.53	0.71	0.44	0.40	0.48
8	0.12	0.00	0.22	0.13	0.32	0.32	0.25	0.46	0.34	0.21	0.71	0.29	0.36	0.21
9	0.08	0.00	0.22	0.13	0.31	0.29	0.24	0.44	0.27	0.18	0.86	0.33	0.43	0.24
10	0.27	0.14	0.20	0.12	0.28	0.27	0.24	0.38	0.27	0.18	0.86	0.29	0.43	0.14

Table 8: Mean Relative Wasted Effort

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