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WITHIN-TEAM COMPETITION IN THE MINIMUM EFFORT COORDINATION GAME

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Abstract. We report the results of an experiment on a continuous version of the minimum effort coordination game. The introduction of within-team competition significantly increases effort levels relative to a baseline with no competition and increases coordination relative to a secure treatment where the pay-off-dominant equilibrium strategy weakly dominates all other actions. Nonetheless, within-team competition does not prevent subjects from polarizing both in the efficient and the inefficient equilibria.

1. INTRODUCTION

Economic interaction often requires a good deal of coordination among agents. In some settings, for example the labour or product markets' prices both aggregate information and coordinate agents' actions. In many settings, however, coordination is only implicitly supported by nothing more than the belief that all agents will act in concert. Such belief-based coordination is quite fragile – even the uncertainty about the behaviour of others can trigger coordination failure. Coordination failure can take the form of both non-equilibrium outcome and coordination on an inefficient equilibrium. Examples of outcomes of the latter range from under-provision of public goods to the selection of inefficient technologies or technological stagnation.

Coordination games have been associated with actual problems seen in firms and industries. Knez and Simester (2002) study the Continental Airlines case in the 1990s where interdependent groups of employees jointly determined the firm's outcome in terms of time arrival; the papers stress the relevance of coordination in complex organizations. Ichniowski *et al.* (1997) study steel plants to find that steel production takes place in an assembly line setting with productivity largely determined by unscheduled downtime. A poor performance by a single employee could seriously affect the efficiency of the entire line. Economic recessions, underdevelopment of poor countries and involuntary unemployment are other examples of coordination failures.

Coordination problems are usually modelled as non-cooperative games with multiple Pareto-ranked equilibria. Several theoretical approaches to the study

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of coordination games address the issue of equilibrium selection. The traditional approach includes Harsanyi and Selten's (1988) general theory of equilibrium selection and its concept of pay-off- and risk-dominance. Other approaches involve equilibrium analysis of perturbed games (Anderson *et al.*, 2001), rational learning models (Crawford, 1995; Crawford and Broseta, 1998; and Broseta, 2000), and evolutionary dynamics (Crawford, 1991 and Kim, 1996).

The experimental method provides an alternative approach to equilibrium selection problems. Van Huyck *et al.* (1990, 1991, 1993) designed coordination games with seven symmetric Pareto-ranked equilibria that were played by large groups repeatedly in the laboratory.[1] The pay-offs for subjects were determined by their strategies called 'efforts' and an order statistic of their own and other subjects' efforts. In van Huyck *et al.* (1990) they report on the minimum effort game in which the minimum effort is the order statistic of interest.[2] All subjects' pay-offs increase in the minimum effort and in the difference of their own effort from the minimum effort. Van Huyck *et al.* conclude on the basis of seven independent observations that the selection of the pay-off-dominant equilibrium is extremely unlikely as all their experiments converge quickly to the most inefficient equilibrium. Maintaining the experimental set-up of van Huyck *et al.* (1990), van Huyck *et al.* (1991) study the median effort game in which the median effort is the order statistic that determines subjects' pay-offs. Though obviously less strategic uncertainty arises in the median game than in the minimum game, the pay-off-dominant equilibrium was selected only once. The striking pattern in the data of van Huyck *et al.* (1991) was that all experiments exhibited a path-dependent pattern. In all observations, strategies converged quickly to the equilibrium of the median effort determined in the first period. In van Huyck *et al.* (1993) reported selection of the pay-off-dominant equilibrium in all median-cum auction experiments, in which subjects bid at a pre-selection auction stage for the right to play the median game with the winners of the auction.[3] Several experimental studies on the minimum effort coordination game report on reduced coordination failure due to parameter changes. Reducing the number of players (van Huyck *et al.*, 1990), money back guarantees (van Huyck *et al.*, 1990), entry fees (Cachon and Camerer, 1996), sequential rather than simultaneous play (Camerer *et al.*, 2004), increased number of repetitions (Berninghaus and Erhart, 1998), pre-play communication (Riechmann and Weimann, 2004), and between-group competition (Bornstein

[1] Experiments on coordination games have also considered the Stag Hunt game (Rankin *et al.*, 2000); the Battle of Sexes game (Cooper *et al.*, 1993; Rapoport, 1997); and other settings. A survey over the literature is presented in Ochs (1995).

[2] The minimum effort game goes back to Bryant (1983), Cooper and John (1988) and Bryant (1996). Hirshleifer (1983) developed a similar game with a public goods story (see also Hirshleifer & Harrison, 1989). Both games are akin to the Stag Hunt game which can be traced back to Rousseau (1973 (1755)).

[3] Cachon and Camerer (1996) who replicated van Huyck *et al.* (1990, 1991) reach the pay-off-dominant solution in the median game with an outside option. Broseta *et al.* (2003) extend the setting of van Huyck *et al.* (1993) to public goods games with provision points-cum auction. The experimental results are comparable as to the convergence to the pay-off-dominant equilibrium. However, in van Huyck *et al.* dynamics come to rest there whereas in Broseta *et al.* they do not.

et al., 2002; Riechmann & Weimann, 2004) improves coordination in the direction of the pay-off-dominant equilibrium.[4]

In the present paper, following the design of Croson *et al.* (2005), we report on laboratory experiments with a rather continuous version of the minimum effort game featuring 51 symmetric Pareto-ranked equilibria in all treatments. We examine the effects of a money-back guarantee and the effects of within-team competition. In two recent papers, Fatas and Neugebauer (2004) and Croson *et al.* (2006), we reported on within-team competition in the voluntary contribution mechanism. The voluntary contribution mechanism-cum within-team competition shares the same equilibrium structure with the three treatments considered in the present paper. In these two previous papers, we found convergence to, and coordination on, the Pareto efficient treatment in all but one observation. The analysis of within-team competition incentives shows them to be particularly appealing to the minimum effort game.

The paper is organized as follows: Section 2 discusses the theoretical benchmark and the implications of a minimum incentive system on the game structure and solutions; in Section 3, we report the experimental procedures and results; and Section 4 concludes.

2. THE EXPERIMENT

2.1. *The minimum effort game*

In our experiments we consider a version of Bryant's (1983) minimum coordination game (MEG). Similar issues play an important role in other areas of economics, as team production (van Huyck *et al.*, 1990; Riechman & Weimann, 2004):[5] Four team members simultaneously and privately make their decision on how much effort $e_i \in (0, 50)$, $i = \{1, 2, 3, 4\}$, to contribute to a team product. The team product is produced according to a Leontief production technology. The minimum effort contributed to the team product determines the output of the team, all effort exerted in excess of the minimum effort is lost. The output of the team and the units of effort exerted define a subject's pay-off. Let $e = \min\{e_1, e_2, e_3, e_4\}$ be the smallest order statistic of effort, the formal definition of individual *i*'s pay-off is given in equation (1).

$$\pi_i(e_i, e) = 50 + 2e - e_i \tag{1}$$

The strategic problem of player *i* is thus the trade off between the opportunity costs arising from exerting too little effort and the costs of wasted effort from exerting more than the minimum within the team. Each symmetric strategy

[4] Comparable results were reported from experiments with other coordination games (see Brandts and Holt, 1992, 1993).

[5] Other stories include meeting at the restaurant and start eating not before the last group member has arrived; submitting chapters for a book and publishing the book when the last chapter has been received (Knez & Camerer, 1997); individual construction of a dike on the flat island Antarctica in which all inhabitants own pie slices of land and the flood enters where the dike is lowest (Hirshleifer, 1983).

profile, that is, each allocation in which every subject exerts the same effort, constitutes a Nash equilibrium. The pay-off in a Nash equilibrium is the same to all subjects and increases linearly in the minimum effort, $\pi_i = 50 + e$. Hence, the equilibria are Pareto-ranked, and the pay-off-dominant strategy for all subjects would be to exert maximum effort, that is, $e = e_1 = e_2 = e_3 = e_4 = 50$.

2.2. *Money back guarantee*

One variation of the minimum effort game, considered also in van Huyck *et al.* (1990), is to take away the strategic uncertainty of wasted effort. This treatment decreases strategic uncertainty of subjects to zero, since the best response in all equilibria but the pay-off-dominant one is not unique anymore. The strategic problem thus reduces to exerting at least as much effort as the other team members. The individual pay-off function is formally presented in equation (2).

$$\pi_i(e_i, e) = 50 + 2e - e_i + (e_i - e) = 50 + e \quad (2)$$

This secure game (MBG) compares to money back guarantees common in the literature on public goods with provision points (Isaac *et al.*, 1989; Bagnoli & McKee, 1991; Marks & Croson, 1998; Croson & Marks, 1999; 2000). In the game, the pay-off-dominant equilibrium strategy weakly dominates all other strategies. Hence, coordination on the pay-off-dominant equilibrium should be most frequent. Thus, this treatment is thought of as a benchmark of maximal achievable coordination without communication.

2.3. *Within-team competition*

The within-team competition treatment (WTC) builds on earlier work of Fatas and Neugebauer (2004) and Croson *et al.* (2006) and adds more strategic uncertainty to the minimum game. Subjects' trade-off between contributing either too little or too much has another dimension induced by competition. Subjects who contribute too little are excluded from the team product. The pay-off function is presented formally in equation (3).

$$\pi_i(e_i, e) = \begin{cases} 50 + 2e - e_i, & \text{if } e_i > e \\ 50 + e & \text{if } e_i = e \, \forall i \\ 50 - e & \text{if } e_i = e \text{ and } \exists e_j > e, \; i \neq j \end{cases} \quad (3)$$

The first line in equation (3) corresponds to equation (2). Subjects who exert more than minimum effort receive the same pay-off as in the MEG. In any symmetric strategy profile the same pay-offs apply in all three treatments – this can be read from the second line. The within-team competition feature arises due to the last line in equation (3), according to which no subject receives any pay-off from the team product if effort induces the minimum within the team. Thus, the contribution of the minimum is not always a secure strategy as it is in the MEG.

In this context, it might be worth alluding to the between-team competition settings of Bornstein *et al.* (2002), Riechmann and Weimann (2004). In both studies two teams played the minimum game simultaneously and the team with the greater team product won the competition. In Bornstein *et al.* the winning team received the same pay-off it would have received without competition and the loser team received nothing. In Riechman and Weimann, both teams received the non-competition pay-off and the winner received a fixed bonus payment. Both studies report greater coordination due to competition. However, Riechmann and Weimann (2004) report even more exerted effort in a pre-play communication treatment.

2.4. *General theory of equilibrium selection*

We discuss briefly the theoretical implications of the general theory of equilibrium selection by Harsanyi and Selten (1988) with respect to the experimental treatments. All equilibria of the considered games are pure strategy, symmetric equilibria and can be Pareto-ranked from zero effort to full effort. Therefore, Harsanyi and Selten's theory would suggest the selection of the unique pay-off-dominant equilibrium, in which full effort is exerted. Nevertheless, as already reported by van Huyck *et al.* (1990), the pay-off-dominant equilibrium is rarely observed in laboratory studies of the minimum effort coordination game. Harsanyi and Selten pose risk-dominance as an alternative equilibrium selection concept. We compute in the appendix the risk-dominant equilibria for all games. We find that there is no risk-dominant equilibrium in MEG;[6] in MBG there is a unique risk-dominant equilibrium which coincides with the pay-off-dominant one. Finally, in WTC we find that the pay-off-dominant equilibrium strategy risk dominates all positive effort levels. However, the zero effort level is not risk-dominated by any equilibrium. In other words, in the WTC it is secure to exert no effort at all, but as soon as one contributes any positive amount to the team product it is more secure to contribute a greater amount.

2.5. *Experimental procedures*

In this paper we report the results of six computerized experimental sessions conducted at the experimental laboratory of the University of Valencia (LINEEX). The experiment, in which a total of 72 economics undergraduates participated, applied between-subject variation. Subjects were inexperienced, that is, they had not participated in a similar experiment before.

Each experimental treatment involved 24 economics undergraduates, organized into groups of four from a room of 12 following a partners random matching procedure. A subject's average earnings were €16. Experiments took less than an hour to run.

Before the experiment, written instructions were read, subjects filled out a questionnaire to check that all were able to calculate the pay-off. Instructions

[6] However, the recent literature on equilibrium selection with applications to the minimum effort game shows that the most inefficient equilibrium has the highest stochastic potential and represents an attractor to evolutionary dynamics (Crawford, 1991).

and questionnaire were repeated until all subjects had answered the questionnaire correctly. After the experiment, we ran a survey in which we asked subjects to phrase their strategies and personal characteristics. Questionnaire and instruction sheets are available upon request.

The experimental sessions entailed 10 periods (original game) with another ten-period surprise restart game. The restart technique has been applied to public goods experimental settings (Andreoni, 1988; Croson, 1996; Croson *et al.*, 2006). Subjects received in each period an initial endowment of 50 cents, which they had to allocate between a 'public' account and a 'private' one. Subjects were randomly chosen to form groups of four in the first period and remained together throughout both the original and the restart game. Subjects were informed about the individual contributions of their group in increasing order of contribution after each repetition; individual contributions were not identified with their contributor. Additionally, subjects were informed about their own earnings both in total and subdivided by private and public accounts.

3. EXPERIMENTAL RESULTS

3.1. *Equilibrium selection*

Tables 1–3 display the individual effort exerted in every period of each treatment organized by group from maximum to minimum. All allocations in which subjects played a mutual best response are indicated by an asterisk. As the small number of asterisks reveal most outcomes involve non-equilibrium play. We observe no coordination on any equilibrium in the first periods of any treatment. The first equilibrium could be reached in Period 5 of MBG 5. In WTC, the first equilibrium was reached by Period 6 in Group 3 and in MEG 1 we observe a first occurrence of equilibrium by Period 8. In MEG and in WTC, four groups reached an equilibrium allocation at some period of the experiment and in MBG only two groups manage to coordinate throughout the experiment.

In all treatments the observed equilibrium selection involved only one distinct, non-risk-dominated equilibrium per group. However, the equilibria reached in MEG were all Pareto-dominated: in MEG 1 and MEG 4 we observe an equilibrium effort of 10 and in MEG 2 and MEG 3 the equilibrium allocations involve no effort at all. In fact, the equilibrium involving effort level 10 which we observe in two groups of MEG seems to be a focal point of the MEG game. The reached equilibria in MEG seem fragile as we observe no repeated play in two subsequent periods. In sum, all observations document coordination failure throughout in MEG.

Coordination on an inefficient equilibrium, in particular the most inefficient, was also observed in WTC 1 and WTC 6. However, in WTC and in MBG two groups reached the pay-off-dominant equilibrium. In some groups of treatments, WTC and MBG equilibria were repeatedly played over several periods. Although we observe more coordination on the least efficient equilibrium in WTC than in MBG, in which only strictly positive effort levels are chosen, it

Table 1. Effort – MEG

		PERIOD																			
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
MEG 1	Max	35	35	20	20	30	20	18	10	15	25	20	12	20	15	12	15	10	15	12	10
		20	20	15	15	17	15	15	10	10	12	16	10	13	12	8	10	10	10	10	8
		14	20	15	13	16	13	14	10	9	5	15	10	12	10	8	7	8	9	10	7
	Min	10	12	14	12	12	10	10	10*	6	5	10	10	10	6	7	5	7	8	8	6
MEG 2	Max	20	25	15	5	10	10	10	15	8	6	30	20	10	5	5	1	5	5	0	0
		20	10	10	5	10	5	5	5	5	5	10	10	5	5	5	0	2	0	0	0
		10	10	10	5	5	5	5	5	5	5	5	5	2	5	2	0	0	0	0	0
	Min	5	5	5	0	2	0	5	3	5	4	1	0	0	0	0	0	0	0	0*	0*
MEG 3	Max	50	25	10	5	2	2	2	1	1	0	25	13	0	1	1	0	1	1	1	0
		25	20	7	1	1	2	2	1	1	0	25	5	0	0	0	0	0	0	0	0
		25	15	6	1	1	2	2	1	0	0	20	0	0	0	0	0	0	0	0	0
	Min	20	5	1	1	1	1	1	0	0	0*	0	0	0*	0	0	0*	0	0	0	0*
MEG 4	Max	50	33	17	15	12	13	10	15	10	10	30	20	15	15	15	15	13	10	15	13
		25	25	15	15	12	10	5	10	10	10	25	15	15	15	15	13	10	10	13	12
		19	20	10	13	12	10	5	7	7	9	25	10	15	15	13	10	10	10	12	10
	Min	15	4	10	10	5	2	5	5	5	6	10	10	10	10	10	10	8	10*	10	8
MEG 5	Max	40	45	30	50	10	10	10	12	25	30	25	20	20	20	20	16	18	18	16	20
		35	30	25	25	5	5	10	10	25	25	20	20	20	16	16	15	18	16	15	15
		15	20	6	5	1	0	5	10	15	20	13	15	15	12	15	15	15	15	15	15
	Min	10	5	5	2	0	0	2	10	15	10	10	12	14	10	7	12	10	10	10	10
MEG 6	Max	15	40	30	20	14	30	15	33	17	20	35	22	20	16	20	20	20	19	19	20
		10	10	29	15	12	16	14	15	15	15	13	15	17	16	20	19	19	19	19	18
		10	8	10	13	10	12	10	10	10	15	10	14	15	16	18	18	19	18	18	16
	Min	4	7	10	1	5	8	6	8	10	13	10	13	14	15	17	18	18	18	17	12
Avg. minimum		11	6	8	4	4	4	5	6	7	6	7	8	8	7	7	8	7	8	8	6
Avg. contribution		21	19	14	11	9	8	8	9	10	10	17	12	11	10	10	9	9	9	9	8

*Denotes mutual best response.

Table 2. Effort – MBG

		PERIOD																			
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
MBG 1	Max	25	30	25	33	35	39	40	42	45	45	35	30	35	39	25	38	39	39	41	49
		20	18	25	28	35	38	40	41	44	45	30	22	27	35	25	30	35	38	40	45
		20	12	15	23	19	33	30	39	40	37	12	15	15	21	25	22	34	37	40	45
	Min	4	10	11	15	19	25	27	35	20	35	5	10	10	18	14	19	30	32	39	41
MBG 2	Max	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
		30	30	49	50	50	50	50	50	50	50	50	46	45	45	50	50	50	50	50	50
		11	12	40	49	48	12	48	46	50	48	46	45	45	45	45	50	49	48	50	50
	Min	1	1	11	11	11	10	40	45	44	45	10	15	40	45	45	46	47	48	49	50*
MBG 3	Max	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
		50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
		10	20	15	12	45	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
	Min	10	5	8	5	10	10	15	17	20	20	10	12	15	17	20	22	25	27	30	32
MBG 4	Max	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
		30	50	50	50	50	40	45	50	50	50	50	50	50	50	50	50	50	50	50	50
		28	40	46	49	50	39	38	40	41	40	45	35	38	50	47	49	45	50	39	40
	Min	22	14	36	39	24	39	20	38	40	35	9	27	26	27	41	32	39	40	39	39
MBG 5	Max	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
		40	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
		25	45	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
	Min	20	40	35	40	50*	50*	45	50*	50*	50*	50*	50*	50*	50*	50*	50*	50*	50*	50*	50*
MBG 6	Max	45	40	39	35	38	43	45	47	45	46	45	40	43	45	43	45	47	50	50	50
		40	37	35	33	30	35	40	45	45	45	45	40	42	43	42	45	46	47	50	50
		35	30	30	29	30	35	37	40	40	43	40	40	40	40	40	42	45	46	48	50
Min		20	30	30	25	29	33	36	35	38	40	28	35	37	35	39	40	43	45	46	46
Avg. minimum		12.8	17	22	23	24	28	31	37	35	38	19	25	30	32	35	35	39	40	42	43
Avg. contribution		28.6	32	35	37	38	39	42	44	44	45	38	38	40	42	42	43	45	46	46	47

*Denotes mutual best response.

Table 3. Effort – WTC

		PERIOD																			
		1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
WTC 1	Max	45	38	15	40	10	26	11	10	12	2	30	25	11	7	3	0	10	7	3	0
		35	20	4	7	7	4	5	3	7	1	25	11	10	1	2	0	3	5	1	0
		33	10	2	3	4	2	1	1	2	0	15	5	1	0	0	0	0	2	0	0
	Min	1	4	1	2	0	0	0	0	0	0	0	0	0	0	0	0*	0	0	0	0*
WTC 2	Max	29	30	30	31	24	8	4	5	6	4	15	17	20	15	17	15	15	15	15	10
		27	30	20	25	5	0	4	4	5	4	15	16	20	15	13	15	12	14	1	2
		25	15	12	15	0	0	1	2	4	0	10	15	17	12	12	8	10	14	0	0
	Min	0	5	11	0	0	0	0	2	0	0	6	8	0	5	0	0	10	0	0	0
WTC 3	Max	35	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
		30	35	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
		20	30	40	40	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
	Min	15	25	35	40	45	50*	50*	50*	50*	50*	50*	50*	50*	50*	50*	50*	50*	50*	50*	20
WTC 4	Max	50	50	50	50	30	40	50	1	5	50	50	50	50	50	50	50	50	50	50	50
		49	50	50	30	30	20	0	0	0	0	40	50	50	50	50	50	50	50	50	50
		40	50	50	15	0	10	0	0	0	0	20	40	50	50	50	50	50	50	50	50
	Min	17	15	10	0	0	0	0	0	0	0	10	25	40	50*	50*	50*	50*	50*	50*	50*
WTC 5	Max	40	45	50	40	30	45	50	12	5	6	50	38	40	46	50	50	50	30	15	16
		36	40	45	35	8	2	15	1	4	2	46	36	38	41	50	50	44	3	0	8
		35	35	40	5	0	0	15	0	0	0	35	10	36	40	47	42	0	0	0	0
	Min	17	0	0	1	0	0	0	0	0	0	1	10	30	40	0	0	0	0	0	0
WTC 6	Max	50	50	50	50	50	50	50	25	10	50	40	0	0	0	0	0	0	0	0	0
		50	50	45	10	40	40	50	0	0	45	0	0	0	0	0	0	0	0	0	0
		40	40	40	0	0	25	30	0	0	0	0	0	0	0	0	0	0	0	0	0
	Min	30	0	40	0	0	0	0	0	0	0	0	0*	0*	0*	0*	0*	0*	0*	0*	0*
Avg. minimum		13	8.2	16	7.2	7.5	8.3	8.3	8.7	8.3	8.3	11	16	20	24	17	17	18	17	17	12
Avg. contribution		31	30	31	22	18	20	20	11	11	15	25	23	26	26	25	24	23	20	18	17

*Denotes mutual best response.

seems remarkable that the pay-off-dominant equilibrium is reached more frequently in WTC than in MBG.

We count 21 occurrences of the pay-off-dominant equilibrium in WTC and 16 in MBG; in total, we count 32 equilibrium occurrences in WTC and eight in MEG. Nonetheless, it must be taken into account that in the three groups MBG 3, MBG 4 and MBG 6 coordination on the pay-off-dominant equilibrium failed due to only one subject. Nevertheless, it appears striking that coordination failures in MBG are so persistent. After all, an effort of 50 weakly dominates all other effort levels. Below we find out that adaptive dynamics worked against the equilibrium selection process.

3.2. *Minimum effort and average contribution*

In the bottom line of Tables 1–3 we report the average minimum and the average contribution. Additionally, Figures A1–A3 in the appendix plot minimum effort and average contribution by period against each other for every group. According to our team production story, the minimum effort represents the team product (or half of it). The average contribution shows us how much more could have been produced if effort was a substitute and not a complement in the production technology. The difference between the minimum and the average measures the loss of social effort. In other words, the difference between the two numbers, the distance between the two curves respectively, shows how poorly subjects coordinated their actions.

More formally, the ratio between the average contribution (social effort) and the average minimum effort (social product), hereafter social effort–product ratio, reveals how many times the average team product could actually have been produced within a treatment under a linear technology. In the first period of both the original game and the restart game (starting at Period 11) the social effort-product ratio is about two in all treatments. Hence, if subjects were have been matched according to the order of their exerted effort levels, production could have been about double as high. Figure 1 plots the social effort-product ratio over all periods of the original and of the restart game. A

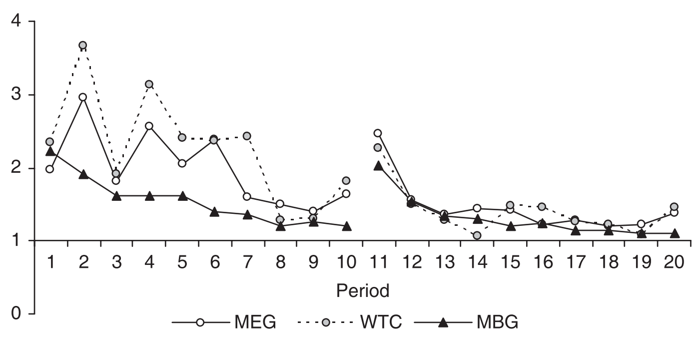

Figure 1. Evolution of the social effort-product ratio

Table 4. Restart effect: individual changes between round 10 and 11

	# increase (relative)	# decrease (relative)	# unchanged (relative)	Average change (relative)	Z† (p-value)
MEG	15	5	4	6.38	–2.627**
	(0.625)	(0.208)	(0.167)	(0.61)	0.009
MBG	2	11	11	–6.84	–2.380*
	(0.083)	(0.458)	(0.458)	(–0.15)	0.017
WTC	13	3	8	10.17	–2.509*
	(0.542)	(0.125)	(0.333)	(0.67)	0.012

†Two-tailed Wilcoxon signed ranks test, $N = 24$. Z-value asympt. Standard norm. distributed.
*Significant at 1%, **significant at 5%.

remarkable feature of these plots is that the ratios of all treatments look very similar during the periods of the restart game and apparently converge to one. A ratio of one represents the allocations in which no loss of social effort occurs.

3.3. *Restart effect*

As suggested already by the trajectories in Figure 1, the data exhibits a restart effect. This effect, reported from several public goods experiments (Andreoni, 1988; Croson, 1996), involves a change of individual behaviour upon restarting the experiment. Table 4 records how many subjects changed their effort levels from the last period of the original game (period 10) to the first period of the restart game (Period 11). The first and second columns of Table 4 record the number of subjects who increased and decreased their effort, respectively, the third column records the number of subjects who did not change and the fourth column records the average change; relative numbers are given in parenthesis. Finally, the last column of Table 4 reports the outcomes of a two-tailed Wilcoxon signed-ranks test which rejects in all treatments the null hypothesis of no restart effect at 5% significance. The restart effect is positive in the treatments MEG and WTC and negative in treatment MBG. Hence, efforts of the first period of the restart game are adjusted to levels between those of the first and the last period of the original game.

3.4. *Adaptive dynamics*

The decrease of the social effort–product ratio indicates that differences between the individual effort and the group minimum declined over the periods in all treatments. In this section, we examine the adjustment dynamics in the experiment. Our analysis is similar to the one presented in Berninghaus and Erhard (1998) who refer to learning direction theory (Selten & Stoecker, 1986; Selten & Buchta, 1999).[7] In fact, there are many learning models that it would

[7] Our results support the findings of Berninghaus and Erhard.

be interesting to apply to our data (see Camerer, 2003 for a survey), including Cason and Friedman (1999) quantitative learning direction theory and the reinforcement learning model of Roth and Erev (1995). Roth (1995) suggests that a modified version of the reinforcement learning model inclusive of 'common learning', that is, subjects adjust as if they had played the most successful strategy in the population, provides a good fit of the data in van Huyck *et al.* (1990). However, in this paper we limit ourselves to surveying our data in light of adjustment dynamics.

Table 5 summarizes how frequently subjects adjusted their contributions from one period to the next. In the table rows, the effort of a subject $0 < e_{it} < 100$ is categorized according to its rank within the group from minimum, third ranked and second ranked to the maximum effort. Additionally, the extreme effort levels of zero and 50 are recorded in separate rows, thus, taking account of the fact that changes from the extremes can only occur into one direction. The columns organize the data according to subjects' qualitative adjustments between periods from decrease of effort, and no change of effort, to increased effort. A decrease of effort means that a subject exerts less effort in a certain period than he did in the preceding period, an increase designates a greater effort in than in the previous period.

In the last column of Table 5, we report the probability values that result from a two-tailed randomization test, in which we compare the importance of individual adjustments in both directions.[8] The test was run on the independent observations we computed for the six groups of a treatment. It should be pointed out that if the most extreme case occurred and all observations had the same sign, the probability value will be no smaller than 3.1% as for instance in case of the minimum in MEG. Therefore, we apply a significance level of 10%. The sign below the *p*-value indicates the tendency of adjustments; a positive sign indicates increases were more important than decreases, and vice versa.

The overall tendency indicates decreasing effort for treatments MEG and WTC and increasing effort for MBG. In WTC the indicated overall direction is insignificant whereas in MEG and in MBG overall directions were significant. In all treatments we find that subjects who exerted the minimum effort within their group in one period increased their effort in the following one. In MEG, subjects who did not exert the minimum effort within their group decreased their effort in the following period. A similar figure is presented by the tendency signs for the WTC, but decreases in the WTC are only significant for subjects who exerted a maximum effort within their group. The downward adjustments by subjects ranked second and third were less pronounced in WTC than in MEG, because subjects in WTC faced the risk of exclusion from the team product payment in case they exerted the minimum effort within the group. Yet, the downward adjustments of subjects whose effort was ranked third in the WTC contrasts with the significant upward adjustments of the 3rd

[8] More accurately, we counted for each group and each condition (i.e., minimum etc.) the observations of upward and downward adjustments and computed the differences between them.

Table 5. Individual adjustments in period t†

Treatment	*Effort in t − 1*	*# decrease (relative)*	*# unchanged (relative)*	*# increase (relative)*	*Column total (relative)*	p-*value‡ Tendency*
MEG	0	–	23 (0.780)	31 (0.220)	54 (0.116)	
	Minimum	13 (0.114)	26 (0.228)	75 (0.658)	114 (0.264)	0.031** +
	Third	55 (0.500)	31 (0.282)	24 (0.218)	110 (0.255)	0.063* –
	Second	48 (0.593)	18 (0.222)	15 (0.185)	81 (0.188)	0.031** –
	Maximum	61 (0.824)	3 (0.041)	10 (0.135)	74 (0.171)	0.031** –
	50	3 (1.00)	0	–	3 (0.007)	
	Row total	180 (0.417)	117 (0.271)	135 (0.313)	432 (1.00)	0.094* –
MBG	0	–	0	0 (0.000)	0	
	Minimum	12 (0.114)	10 (0.095)	83 (0.790)	105 (0.243)	0.031** +
	Third	24 (0.329)	9 (0.123)	40 (0.548)	73 (0.169)	0.500 +
	Second	11 (0.256)	4 (0.093)	28 (0.651)	43 (0.100)	0.125 +
	Maximum	14 (0.538)	1 (0.038)	11 (0.423)	26 (0.006)	1.00 –
	50	9 (0.049)	176 (0.951)	–	185 (0.428)	
	Row total	70 (0.162)	200 (0.463)	162 (0.375)	432 (1.00)	0.031** +
WTC	0	–	81 (0.692)	36 (0.308)	117 (0.271)	
	Minimum	5 (0.139)	1 (0.028)	30 (0.833)	36 (0.083)	0.063* +
	Third	24 (0.490)	6 (0.122)	19 (0.388)	49 (0.113)	0.563 –
	Second	35 (0.538)	10 (0.154)	20 (0.308)	65 (0.150)	0.438 –
	Maximum	38 (0.792)	3 (0.063)	7 (0.146)	48 (0.111)	0.094* –
	50	20 (0.171)	97 (0.829)	–	117 (0.271)	
	Row total	122 (0.282)	198 (0.458)	112 (0.259)	432 (1.00)	0.469 –

†Absolute frequencies of changes from round t–1 to round t, relative numbers in parenthesis, $t = \{2, 3, \ldots, 10, 12, 13, \ldots, 20\}$. ‡Exact probability value of a two-tailed randomization test, N = 6. **Significant at 5%; *significant at 10%.

ranked effort levels in the within-team competition treatment in Fatas and Neugebauer (2004). Fatas and Neugebauer introduced within-team competition in a voluntary contribution mechanism. The result was strikingly different from the one reported in the present study. Dynamics in Fatas and Neugebauer converged quickly to the pay-off-dominant equilibrium. The opposed dynamics of subjects whose effort was 3rd ranked affected most likely the contrary outcome in the present study.

Behavioural adjustments also seem to have influenced the equilibrium selection in MBG. Upwards tendencies were only significant for the minimum, and 70 observations induce decreasing effort between periods, including 23 subjects who exerted maximum effort within their group. Why these adjustments occur is not clear.

4. CONCLUSIONS

In the present paper, we have reported an experiment on a continuous version of the minimum effort game. We examined the effects of within-team competition versus a standard minimum effort game and a secure treatment where the pay-off-dominant equilibrium weakly dominates all other actions. We find that within-team competition helps experimental subjects to coordinate in a symmetric equilibrium in the minimum effort coordination game. More strikingly, subjects coordinate even more frequently on the pay-off-dominant equilibrium than in our secure treatment. Nonetheless, within-team competition seems to polarize behaviour to the extreme equilibria of the minimum effort game. This stands in sharp contrast to the behaviour observed in the voluntary contribution mechanism-cum within-team competition by Fatas and Neugebauer (2004). The behavioural differences to the latter seem to be a consequence of the adaptive dynamics.

Our data exhibits a restart effect, as has been reported in several public goods experiments (Andreoni, 1988 and Croson, 1996). In line with Brandts and Cooper (2004), and contrary to the 'bell ringing effect' described in Crawford's (1991) discussion of the work of van Huyck *et al.* (1991), the restart does not always act as a coordinating device, as it is positive in both our baseline and within-team competition treatments, but negative in the secure treatment. Thus it seems that these results don't necessarily extend to this environment.

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APPENDIX A. THEORETICAL PROPOSITIONS

Proposition – Risk-dominance (Minimum Effort Game)

In the MEG no risk-dominant equilibrium exists.

To examine the risk-dominance structure of the MEG, we consider two arbitrary equilibria. The two symmetric equilibria are represented by the effort levels A and B, A > B. We compute the Nash products of losses accruing to the players by deviating unilaterally from the equilibrium strategy. The greater Nash product indicates the risk-dominant equilibrium.

According to the equation (MEG) the following matrix displays the pay-offs at effort levels A and B.

		Player 2, 3, 4 A	B
Player 1	A	2A + 50-A	50 – A + 2B
	B	50 + B	50 + B

$A \in (B, 50);\ B \in (0, A)$

By deviating from the equilibrium strategy A and playing B, player 1 makes the following loss.

$$d(B, A, A, A) = 2A + 50 - A - (50 + B) = A - B$$

By deviating from the equilibrium strategy A and playing B, player 1 makes the following loss.

$$d(A, B, B, B) = 50 + B - (50 - A + 2B) = A - B$$

Since the game is symmetric all Nash deviations are the same. The Nash products are thus equal,

$$d(A, B, B, B)^4 = d(B, A, A, A)^4$$

which implies that no risk-dominant equilibrium exists.

Proposition – Risk-dominance (Money Back Guarantee)

In the MBG, the pay-off-dominant equilibrium is the unique risk-dominant equilibrium.

Player 2, 3, 4

		A	B
Player 1	A	50 + A	50 + B
	B	50 + B	50 + B

$A \in (B, 50]$; $B \in [0, A)$

Deviation from (A, A, A, A): $d(B, A, A, A) = 50 + A - (50 + B) = A - B$
Deviation from (B, B, B, B): $d(A, B, B, B) = 50 + B - (50 - B) = 0$
Comparison of Nash products: $d(A, B, B, B)^4 < d(B, A, A, A)^4$
It follows that (50, 50, 50, 50) is the unique risk-dominant equilibrium.

Proposition – Risk-dominance (Within-team Competition)

In the WTC, the pay-off-dominant equilibrium risk-dominates all equilibria with positive effort levels, but it does not dominate the zero effort equilibrium.

Player 2, 3, 4

		A	B
Player 1	A	2A + 50 − A	50 − A + 2B
	B	50 − B	50 + B

$A \in (B, 50]$; $B \in [0, A)$

Deviation from (A, A, A, A): $d(B, A, A, A) = 50 + A - (50 - B) = A + B$
Deviation from (B, B, B, B): $d(A, B, B, B) = 50 + B - (50 - A + 2B) = A - B$
Comparison of Nash products: $d(A, B, B, B)^4 < d(B, A, A, A)^4$ if $B > 0$

$$d(A, 0, 0, 0)^N = d(0, A, A, A)^N$$

It follows that (50, 50, 50, 50) is risk-dominant and that (0, 0, 0, 0) is not dominated in risk.

APPENDIX B: FIGURES AND TABLES

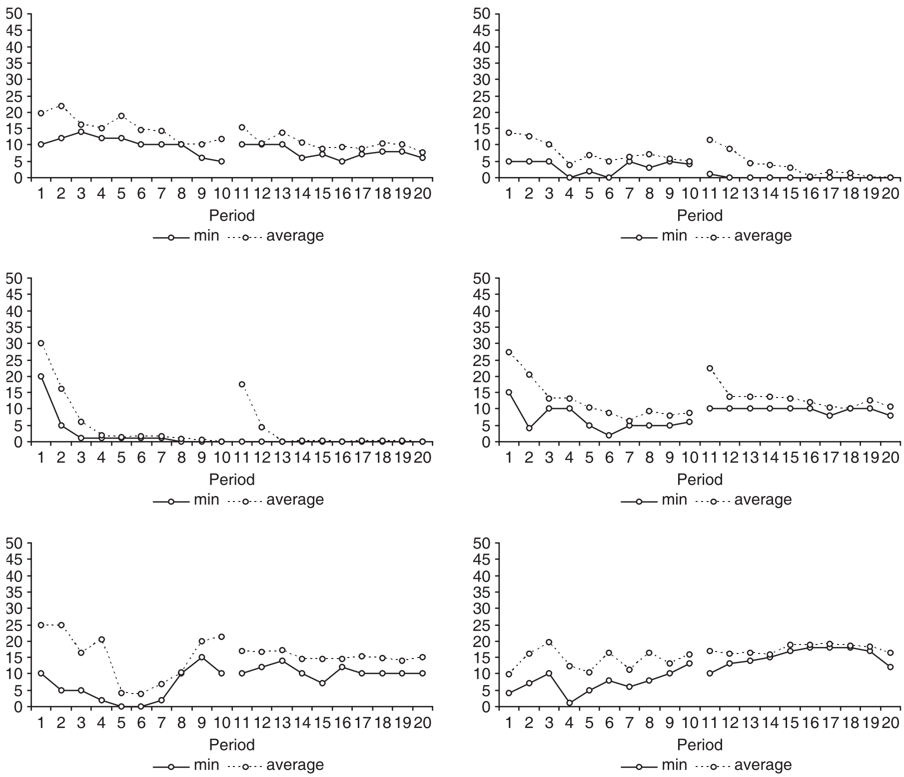

Figure A1. MEG: minimum effort and average contribution by group

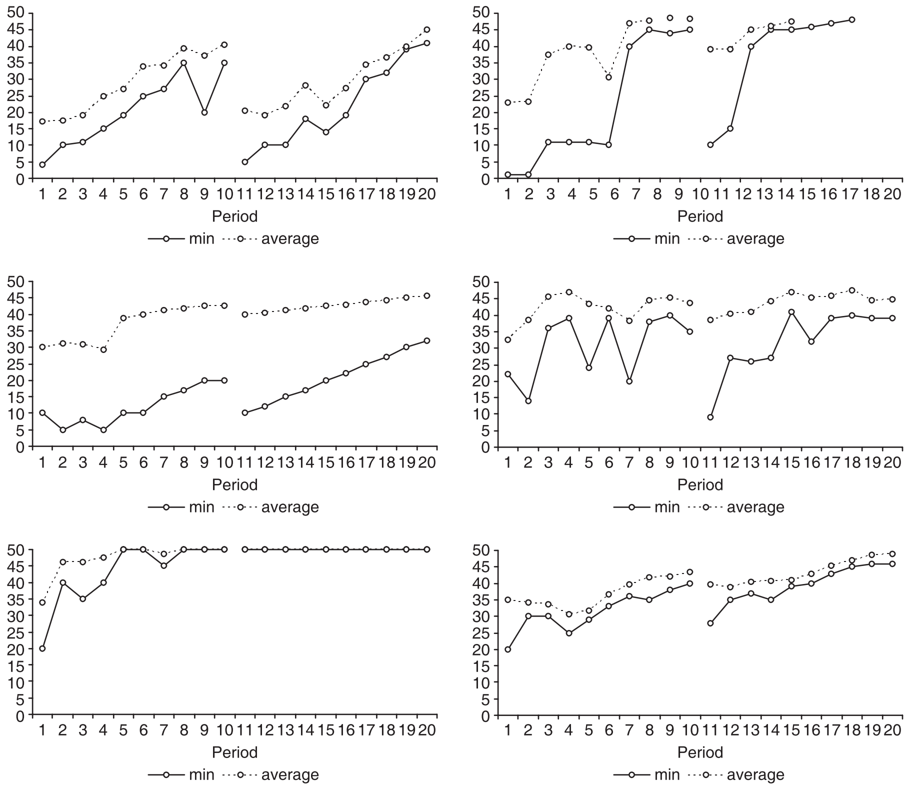

Figure A2. MBG: minimum effort and average contribution by group

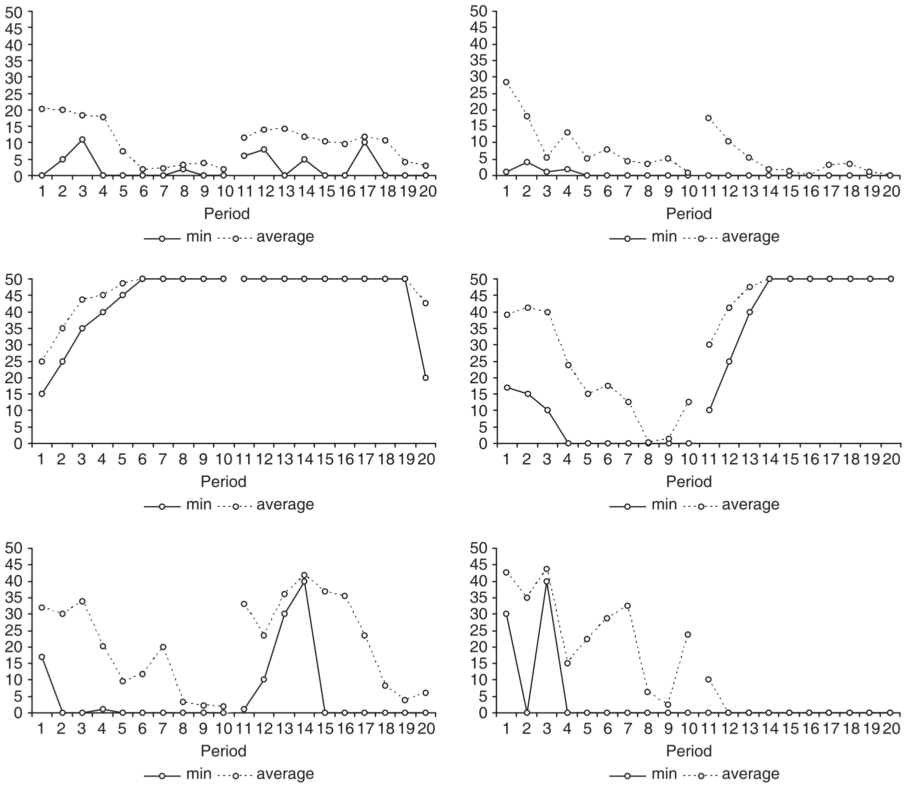

Figure A3. WTC: minimum effort and average contribution by group