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Coordination with asymmetries in highly volatile and complex environments

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14. ABSTRACT

This final report provides a summary of accomplishments, organized according to the project objectives, and key findings of the two experiments conducted during this award period. Major findings, thus far include:(1) Time pressure in both decision and feedback stages have significant effects on coordination efficiency (2) Intra-firm task heterogeneities can serve as a mechanism for large firms to achieve efficient coordination levels (3) Trust preferences provide an accurate account of subjects' behavior across time, while risk preferences were key in initial conditions. The combined project outcomes provide a systematic analysis of collective trust, its evolution and outcomes, by using both coordination and collective incentive designs when agents have heterogeneities within their group. These are areas of clear and direct relevance to the Air Force and DoD community.

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FINAL REPORT

for

FA9550-18-1-0025
COORDINATION WITH ASYMMETRIES IN HIGHLY VOLATILE AND COMPLEX ENVIRONMENTS
CARLES SOLA BELDA
01 DEC 2017 through 30 NOV 2018

EXECUTIVE SUMMARY

This project developed experimental methods to analyze the effect on certain organizational structures of external and internal characteristics that we define as complexity and volatility. We represent organizations that face a technological production process where the effect of minimal individual performance greatly affects overall performance. This kind of structure may represent situations where organizations face a task highly dependent of every individual to attain its objective with the consequence of collective failure.

To accomplish our objectives, we implemented two experiments. In one of them we address both complexity and volatility by restricting both decision time and deliberation time to our subjects to make decisions. In the second one we restrict the alternatives to some of our subjects in every group and observe overall behavior and specially the behavior of those agents not restricted in their choices.

We used the experimental lab at the Universitat Autonoma de Barcelona and recruited students to pay them for their decisions, as it is the standard in experimental economic methodology. Due to the late implementation of structural reforms in the lab and the seasonality in recruiting university students -exam periods and summer (from May to the beginning of October) are not operartive- we couldn't run all the sessions that were planned. However, we provide preliminary results of our experiments where we show the impact of our design variables.

We expect that as we finish our sessions, our research will result in publications that speak to organizations about how to overcome the effect of complexity and volatility as defined here.

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1 INTRODUCTION

In organizations where individuals' inputs are strong complements, the lowest performing employee often determines group performance. A C-130 cannot take off without the airmen who performs the last maintenance check. C-17s cannot transport injured patients without the medical technician´s patient manifest and medical equipment are approved for flight. These situations are frequently studied in the context of weak-link coordination games. Coordination games certain characteristics (multiplicity of Pareto-ranked equilibria) that make them a good model to observe behavior and propose new theories in economic relevant contexts. They also contain elements of the most widely used trust models in which the trust process includes an evaluation stage, risk assessment, and update of behavior if needed (Mayer, Davis, & Schoorman, 1995).

Our primary objective was to characterize trust and the resulting economic collective outcomes in coordination games characterized by volatility and complexity. The research questions we asked:

1.) How do coordination levels differ with respect to standard coordination games when subjects are faced with heterogeneities in risk and complexity, in addition to strategic uncertainty?
2.) What heuristics do we observe in coordination efforts? Do they bias outcome or serve as a mechanism of judgment to make accurate decisions?
3.) What do our results reveal about trusting behavior and the act of trusting in a collective setting?
4.) Do the independent variables impact the propensity to trust in the beginning stages of the game? Or the final outcome?

The ultimate application of our research can serve as a framework for organizations in various industries. Insights from industrial economists and organizational psychologists have broad applications across industries, yet they are not able to explain systematic behavior in the types of firms that we are interested in. While coordination problems have been widely analyzed, current studies offer very little on the cognitive and behavioral determinants of coordination failure (Devetag & Ortmann, 2007). We have observed that our approach to coordination problems can also help reinterpret the classical collective incentive problem and enrich the analysis of strategic interactions in what we believe are more realistic contexts.

To our knowledge, these considerations are new in the economic literature on strategic interaction. We hope that by studying these interactions, we can shed light on behavior in complex settings, which economists cannot yet explain. The combined project outcomes provide a systematic analysis of collective trust, its evolution and outcomes, by using both coordination and collective incentive designs when agents have heterogeneities within their group. These are areas of clear and direct relevance to the AF and DoD community.

2 METHODS, ASSUMPTIONS, AND PROCEDURES

Section 2 describes the methods for the two experiments conducted under the project. Results from these studies will be presented in Section 3.

2.1 Participants

Subject recruitment was done through the Online Recruitment System for Economic Experiments, ORSEE (Greiner, 2015). In the first experiment, 308 undergraduate students (168 male, 140 women, M_{age} = 24 years) were recruited from various faculties. A total of 198 undergraduate students (103 male, 95 female, M_{age} = 23 years) participated in the second experiment.

2.2 Experimental Design

Part 1, Weak-Link Game. (See Appendix A for detailed description). The game consists of thirty rounds in which subjects are grouped together as employees of a firm. These groups remain the same throughout the experiment. In this game, players are asked to allocate their private resources (working time) between Activity X and Activity Y. Participants begin with a fixed rate wage and a bonus rate, B, dependent upon the group contribution. The effort level, Ei, is presented in increments of 10. The dependent variables are effort, minimum effort, and wasted effort.

Experiment One analyzes the effect of time constraints on coordination levels when the worst performing agent determines economic output. In our basic 2X2 design one of the factors involved situations in which all subjects faced stringent decision time (seconds to select a strategy) constraints. Another factor varied what we call stringent feedback (seconds to review the outcome of the round) constraints. Treatment designs followed a dual-system framework. This is a concept that individuals have two different sets of processes by which they make decisions. System 1 thinking is automatic, fast, and non-conscious whereas System 2 thinking is controlled, slow, and conscious (Kahneman, 2011).

Selecting the number of seconds assigned to treatments in exogenous time studies is a crucial step in the experimental design. Many studies want to elicit behavior using two different systems in the brain- a matter of seconds could produce different behaviors. Nursimulu and Bossaerts (2014) found different risk behaviors in a matter of 2 seconds: subjects were risk-averse when given 1s, and risk-neutral at the 3s and 5s mark. Researchers in previous studies used various methods to determine exogenous time allotments following a dual-system framework. Subjects under time pressure were typically given 7 to 10 seconds to make their decision (Evans, Dillon, & Rand, 2015; Tinghög et al., 2013). In reflective treatments, subjects were forced to wait 20-30 seconds before making their decisions.

Time constraints in our experimental conditions were defined as mild, 20s, or stringent, 5s. Guided by a dual-system approach, these times were chosen to elicit different system processing. Table 2 provides a summary of all treatments. Our goal was to create a feeling of time pressure in the 5s treatments; section 3 confirms that manipulations were successful.

Table 1: Summary of treatments

Treatment Name	*NoTC*	*TC20X20*	*TC20X5*	*TC5X20*	*TC5X5*
Time Allotment: (seconds) Decision Stage	None	20s	20s	5s	5s
Time Allotment: (seconds) Feedback Stage	None	20s	5s	20s	5s

Experiment Two investigates task structure when subjects were faced with differing action choices in the game. Specifically, we were interested in the dynamics of intra-firm task heterogeneity as a mechanism to achieve more efficient coordination levels. Subjects were exogenously given a role within a firm with two types of employees. Type 1 employees were given the standard five effort choices E$i \in \{0, 10, 20, 30, 40\}$ while type 2 employees were restricted in the effort choices, E$i \in \{30, 40\}$. This illustrates a situation in which an agent has to decide whether his or her payoff will be equal to or higher than others, thus introducing the notion of social preferences (Bolton & Ockenfels, 2000) and (Fehr & Schmidt, 1999).

The control treatment, T1, presents the traditional firm comprised of four type 1 employees. In T2 we increase the group size by adding a type 2 employee. Traditionally we would expect lower coordination levels as we increase group size, but in this case we expect higher levels as the other group members will change their behavior based on this player. Previous studies have demonstrated the important role that group size plays on coordination outcomes (Chaudhuri, Schotter, & Sopher, 2009; Knez & Camerer, 1994, 2000; Van Huyck, Battalio, & Beil, 1991). Subjects in groups of 2 almost always coordinated to the efficient level, but this dropped drastically when group size reached 3. Once group size reached 6 this was not achieved. Next, we increase the group size to 8 employees: T3 is an additional control group of employees with all available effort levels; T4 is comprised of 4 type 1 employees and 4 type 2 employees.

Part 2, Survey. The first part of the survey contains demographic and behavioral questions. The second part of the survey contains attitudinal and self-reported behavioral measures to capture an individual´s risk preferences in an economic context and beliefs about honesty and the trustworthiness of others. (See Appendix B for descriptions of the survey measures).

2.3 Materials and Procedure

All sessions were conducted at the Autonomous University of Barcelona. The game was played by university students interacting anonymously through specialized software z-Tree

(Fischbacher, 2007). The members of the project developed the specific software in z-Tree to implement the experimental designs. At the beginning of each session, subjects were randomly seated and asked to read the consent form. Once all subjects had signed and dated the consent form, the experimenters read the instructions aloud. Subjects were given a pre-quiz to ensure they understood the design of the game. When all subjects passed the pre-quiz, the game began. At the end of the game, subjects were asked to fill out a questionnaire. During this time the experimenter calculated the earnings and prepared envelopes with cash earnings.

Each session lasted approximately 1.5 hours. All payoffs during the experiment were denominated in an artificial currency, experimental currency units (ECU). At the end of the experiment, ECUs were converted at a rate of one euro per 500 ECUs. The average total payoff including the five-euro show-up fee was €18.00.

3 RESULTS AND DISCUSSION

3.1 Experimental Results

In this section, we summarize the impact of the experimental treatments on firm production levels and individual employee performance. We use three metrics to evaluate performance: effort, minimum effort, and waste. The term effort *is used for the value chosen in period t by employee i.* Minimum effort refers to the minimum contribution of all four employees in a firm in *period t*. Waste is defined as the difference between the effort level of the employee and minimum effort of the firm in a round.

Our standard prediction of behavior was that coordination levels would decrease with the variables we introduced. To test our hypotheses we used standard non-parametric analyses to study differences in efficiency levels. Furthermore, detailed analysis of the differential effects of the variables were analyzed with econometric techniques. Here we provide the treatment-level impact and the differential effects.

3.1.1 Experiment One

Minimum effort was significantly lower when decision constraints were high. Table 4 provides descriptive statistics for each treatment. Mann-Whitney tests indicated that compared to NoTC, minimum effort levels were significantly lower in TC5X5, $U = 2.213$, $p = .0269$, $r = 31$ and TC5X20, $U = 2.42$, $p = .0155$, $r = 31$.

Table 2: Descriptive statistics per treatment

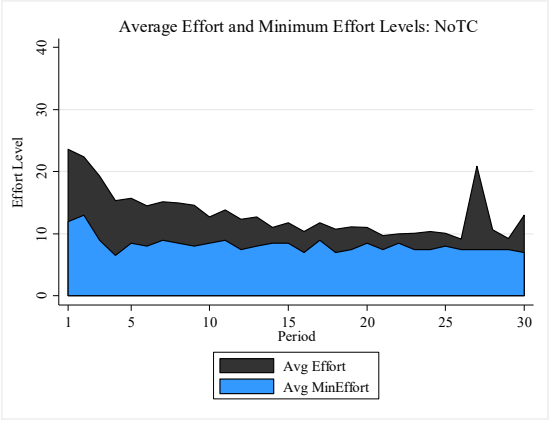
Treatment Name	NoTC	TC20X20	TC20X5	TC5X20	TC5X5
Number of firms	20	12	11	11	11
Number of subjects	80	48	44	44	44
Avg Effort	13.28	12.09	12.52	9.90	12.02
Avg MinEffort	8.25	7.16	6.33	3.45	3.00

Avg Waste	5.03	4.93	6.18	6.45	9.03
Avg Earnings (ECU)	6535	6358	6038	5566	4943

The difference in behavior between the treatments confirmed manipulations were successful. Stringent time constraints in the decision stage reduced subjects´ decision quality. Limiting subjects' ability to learn from each round and update their beliefs accordingly caused more volatile coordination outcomes resulting in coordination failure in which groups were not able to converge at any equilibria. Mann-Whitney test indicated that waste levels were significantly higher in TC5X5 than NoTC, $U = -3.077$, $p = .0021$, $r = 31$.

Figure 1 shows side-by side treatment comparisons of the average effort and minimum effort levels. Comparing behavior in the two treatments with 5s decision time, we see that the distance between average effort and average minimum effort reduces significantly when additional feedback time is provided. Increased feedback time in TC5X20 seems to improve decision-making in terms of anticipating the behaviors of others and aligning decisions with firm outcomes. This suggests that subjects were able to improve their decisions.

Figure 1: Average effort and minimum effort levels per treatment



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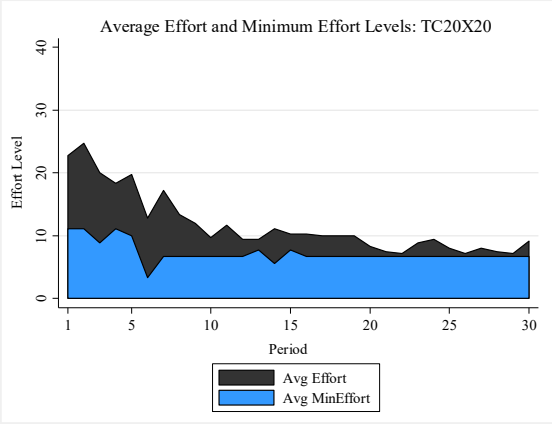

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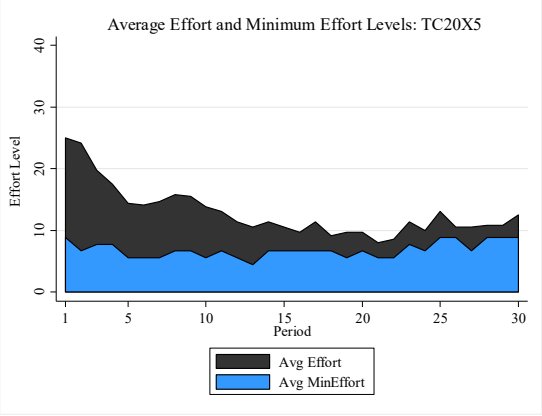

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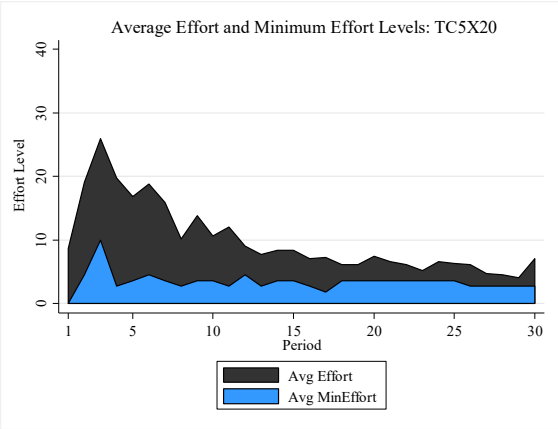

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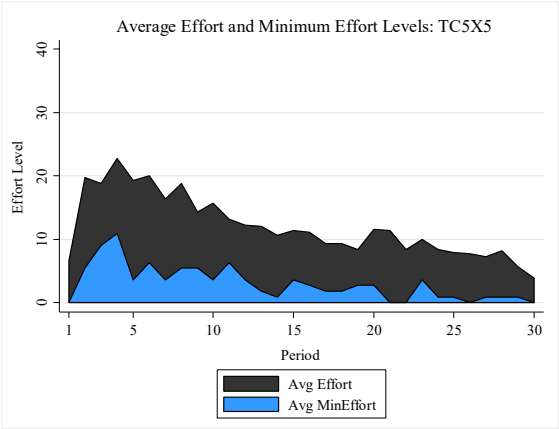


(e)

Dummy treatment variables were created to assess treatment effects. The regressions shown in Table 5 provide formal statistical support to the conclusions in the text.

Table 3: Random effects regressions on treatment effects

VARIABLES	(1) Minimum Effort	(2) Effort	(3) Waste
Unit of observation:	Firm	Employee	Employee
TC20X20	-.108	-.118	-.009
	(.1272	(.2782)	(.0902)
TC20X5	-.192	-.075	.116
	(.1308)	(.2860)	(.0927)
TC5X20	-.480***	-.3377	.142
	(.131)	(.2860)	(.0927)
TC5X5	-.525***	-.1256	.399***
	(.1308)	(.2860)	(.0927)
Constant	1.82	2.32	.503
	(.0779)	(.1703)	(.0552)
Observations	9240	2310	2310
Number of Groups	260	65	65

Notes: The control, NoTC, serves as the baseline treatment for comparison. Since basic treatment tests rely on individual observations, clustering was done at the subject level for minimum effort, and group level for effort and waste. Standard errors are corrected for clustering at the level of observation. Three (***), two (**), and one (*) stars indicate statistical significance at the 1%, 5%, and 10% respectively.

Summary key findings: Stringent constraints in both decision and feedback stages have significant effects on coordination efficiency. Overall, we found that stringent decision times lead to lower minimum effort contributions; however, providing higher feedback time improves firm minimum effort levels. Holding decision constraints constant, we found that convergence to

equilibrium is faster with more feedback time. However, this effect was dependent upon the level of decision time; therefore, feedback time impacts coordination outcomes more when decisions are made under time pressure.

3.1.2 Experiment Two

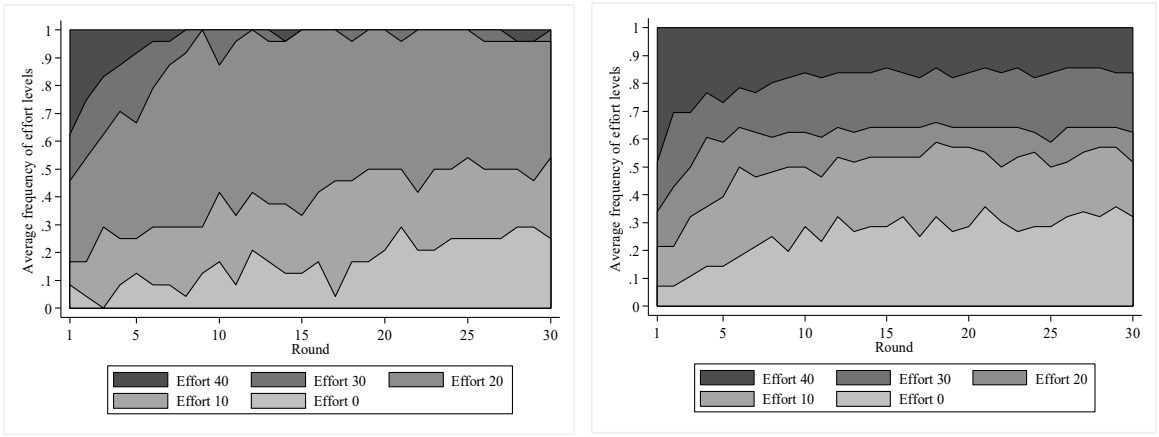
In this section, we present findings. First, we provide firm-level outcomes. Next, we turn our focus to individual workers. We are primarily concerned with the individual behavior of type-1 workers. The largest experimental firm, T4, reports the highest average minimum effort levels, 16.33 hours. T3 has the same amount of subjects per group with the lowest contribution levels, 1.33 hours. Table 6 provides minimum effort frequencies in the final period. Two firms were able to achieve efficient coordination in T2.

Table 4: Distribution of firm minimum effort levels in the final period (R30)

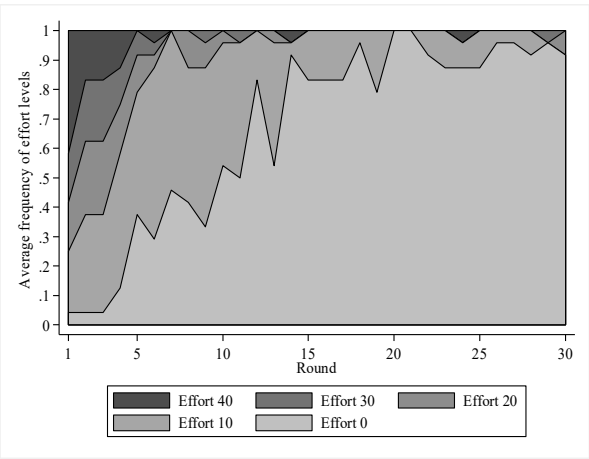
Treatment	Firm Size	Employee Composition		Distribution of (e_{min})				
		Type1	Type2	0	10	20	30	40
T1	n=4	4	0	3	1	2	0	0
T2	n=5	4	1	5	3	1	3	2
T3	n=8	8	0	3	0	0	0	0
T4	n=8	4	4	3	1	4	2	0

Type 1 employees increase their individual input and improve the output of the firm when type 2 employees were assigned to the firm. Table 7 provides a summary of type 1 employee averages across treatments. Comparing behavior of type 1 employees in T1, T2, and T4, we observe different selection patterns, although the level of strategic uncertainty remains the same. Figure 2 maps the distribution of effort levels chosen throughout the game.

Figure 2: Employee type 1 distribution of effort (T1-T4) (a) T1; (b) T2; (c) T3; (d) T4



(a) (b)



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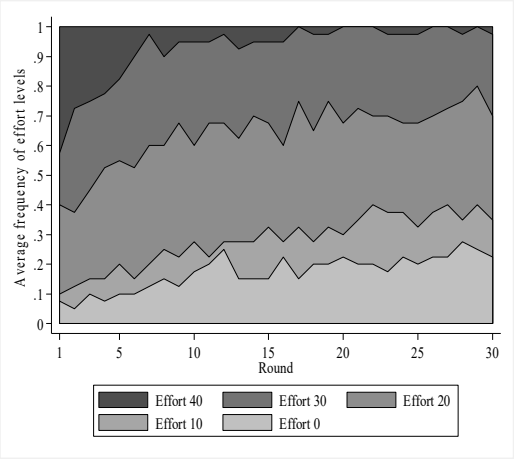

(d)

Dummy treatment variables were created to assess treatment effects. The regressions shown in Table 7 provide formal statistical support to the conclusions in the text.

Table 5: Random effects regressions on treatment effects

VARIABLES	(1) Minimum Effort	(2) Effort	(3) Waste
Unit of observation:	Firm	Employee	Employee
T2	.301	.524	.223
	(.261)	(.422)	(.204)
T3	-1.12***	-1.04*	.083
	(.319)	(.612)	(.295)
T4	.388	.95**	.561***
	(.257)	(.447)	(.215)
Constant	2.24	2.58	.338
	(.2259)	(.3537)	(.170)
Observations	5940	990	990
Number of Groups	198	33	33

Notes: T1 serves as the baseline treatment for comparison. Since basic treatment tests rely on individual observations, clustering was done at the subject level for minimum effort, and group level for effort and waste. Standard errors are corrected for clustering at the level of observation. Three (***), two (**), and one (*) stars indicate statistical significance at the 1%, 5%, and 10% respectively.

3.2 Survey Analysis

In this section, we combine game behavior with self-report answers to examine risk and trust preferences to better understand decision-making throughout the game. The variables to assess individual´s behavior in the game are: first round effort choices and decisions throughout the game. Risk was measured on a 3-point Likert scale that we equated to a risk-level classification

from risk-averse to risk-seeker. Subjects who indicated they were fully prepared to take risks were classified as risk-seekers; subjects who chose not at all were labeled risk-averse. Risk preferences were positively correlated with first round effort levels in both studies: Experiment 1, Spearman $r(305) = 0.1998$, $p < .0004$; Experiment 2, Spearman $r(195) = .1381$, $p < .053$. We used the answers provided in the questionnaire to classify subjects as low/medium/high trustors. Trustor´s propensity was positively correlated with the average effort throughout the game, Spearman $r(306) = .1202$, $p < .0356$; Experiment 2, Spearman $r(196) = -0.1668$, $p < .0198$.

Key finding: Trust preferences provided an accurate account of subjects' behavior across time, while risk preferences were key in initial conditions.

4 CONCLUSIONS

This report serves as the final deliverable for Grant FA9550-18-1-0025, ¨Coordination with Asymmetries in Highly Complex and Volatile Environments¨. We are very appreciative of this grant which provided the resources to support a doctoral student´s experimental research. This student was formerly a Captain in the U.S. Air Forc where she served as a Medical Operations Officer. The core output of this project will be her dissertation which we expect will be successfully defended this summer. Upon completion of her Ph.D., she will return to the U.S. where she will continue research projects with other Air Force collaborators. In turn, the grant jointly benefited the scientific base in Spain and the U.S. in matters of national defense.

The work that started from this grant triggered international connections linking the US and Spain which will be sustained by the project team. Additionally, the grant helped build a Behavioral and Economic Sciences laboratory at UAB which is able to sustain operations in the future. This project supported the PI and doctoral student in several professional activities related to the research which helped perfect our design. Our research has gained a lot of interest in the experimental economics community- the abstract of our first paper was presented at the 2018 ESA World Meeting. ESA is the leading association of experimental economists.

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APPENDIX A: WEAK-LINK COORDINATION GAME

The games that we study are based upon the Corporate Turnaround game by Brandts and Cooper (2006). In this game, players are asked to allocate their private resources (working time) between Activity X and Activity Y. Participants begin with a fixed rate wage and a bonus rate, B, dependent upon the group contribution. The effort level, Ei, is presented in increments of 10. Nash equilibrium occurs when all players choose the same number. However, when all players select the highest level, a Pareto-dominant strategy exists. It is in the best interest of each player to select the highest Nash equilibria; however, this strategy involves an element of strategic uncertainty since it is dependent upon the other members to also choose the same strategy.

The game consisted of thirty rounds in which subjects were grouped together as employees of a firm. These groups remained the same throughout the experiment. The volatility of our experiment was generated by small variations in the payoff table. Equation 1 served as the baseline payoff function of the main decision table.

$$\pi_e^i = 200 - 5\mathrm{E_i} + \left(10 \times \min_{\mathrm{j}\in\{1,2,3,4\}} \left(\mathrm{E_j}\right)\right) \qquad (1)$$

These values were selected because past experiments have revealed that coordination failure is common, particularly when the amount of the bonus does not exceed the cost by a great amount. Players incur a cost of 50 to increase their effort at each level. However, if matched, the net gain is also 50. A key feature of the Turnaround Game keeps constant the payoff associated with the secure action in each round. This is the fixed wage that subjects receive for their working week at effort level 0. B=10 appears to be a natural benchmark for average minimum coordination levels, even when B=6 in the last block. (Brandts, Cooper, & Weber, 2015). This induced payoffs found in Table A1.

Table A1: Employee i payoff table

		Minimum Effort by Other Players				
		0	**10**	**20**	**30**	**40**
Effort by player *i*	**0**	200	200	200	200	200
	10	150	250	250	250	250
	20	100	200	300	300	300
	30	50	150	250	350	350
	40	0	100	200	300	400

Using this payoff function as a benchmark, we established a range of values to generate thirty new payoff tables, keeping the cost and potential net gain close to 50. The values of the fixed wage were between 195-205, bonus B ranged from 9.5 to 10.5, and the cost of effort was 4.8, 4.9, or 5.

APPENDIX B: DESCRIPTION OF SURVEY MEASURES

Table B1: Survey measures

Variable name	*Description*
Gender	Participant´s gender, Male=1; Female=0
Age	Age of participant
Faculty	Participant in economics/business department, 1=Yes 0=No
Pressure (subjects in exogenous conditions)	1=Not at all 5=Very much
	I felt under pressure when making my decisions.
Risk measure (SOEP)	1=Avoid 2=Neutral 3=Fully prepared
	How do you see yourself: are you generally a person who is fully prepared to take risks or do you avoid trying to take risks?
Propensity to trust measure (proptrust)	1=Strongly agree 5=Strongly disagree
	Most people can be counted on to do what they say they will do.
	Most adults are competent at their jobs.
	Most people do not cheat.
	People can generally be relied upon to keep their promises.
	Most people are honest in negotiations.
Propensity to trust category (ptcat)	Subjects ranked as low, med, high propensity to trust others: Low trust <= 2; Med trust > 2 <= 3; High trust >3