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RESEARCH ARTICLE

Keeping Up Shared Infrastructure on a Port of Mars: An Experimental Study

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In this study, we discuss Port of Mars, a new experimental design to study collective action problems in extreme environments under conditions of high uncertainty. The game is situated in the first-generation habitat on Mars, providing an engaging narrative for players to navigate collective action problems. This pilot study finds that most groups are able to avoid the collapse of the habitat, and that the existence of thresholds seems to make groups cooperative. The game demonstrates the initial outcomes of a transdisciplinary project that could provide new ways to study commons governance under high uncertainty.

Keywords: behavioral experiments; uncertainty; tipping points; art-science

Introduction

Research showing how communities overcome conflicts related to shared resource problems is substantial (Ostrom, 1990). There is a wealth of knowledge about how small communities successfully manage shared resources in relatively stable environments. This research is vital, but we face an urgent need to broaden our investigations, because in the present age of threats to the well-being of our species, and to the biosphere more broadly, we depend directly and indirectly on the actions of billions of others.

The notion of the "Anthropocene" expresses a recognition that human activities have becoming a dominant driver of Earth's systems (Crutzen, 2006, Steffen et al. 2007). Future well-being and stability of planet-wide ecosystems across several dimensions—climatic, economic, social, biological, and others—require that humans effectively navigate Collective Risk Social Dilemmas (Milinkski et al. 2008). The stakes of avoiding tipping points of Earth's dynamic systems are astronomical, and the costs of failure dire.

It is with these sobering challenges in mind that we crafted the narrative frame for our game, Port of Mars. In this game, players must keep a small group of people alive in the unforgivingly harsh conditions of Mars.

Space exploration metaphors are not at odds with the discourse on sustainable use of shared terrestrial resources. Economist Kenneth E. Boulding (1966) invoked the concept of "Spaceship Earth" to describe the perspective necessary to cope with increasing environmental challenges. He contrasted this perspective with what he called "Cowboy economics," which assumes a world of limitless resources. For the "cowboy economist," when a region's resources are depleted, one simply moves on to a new region. This perspective embraces endless production and consumption, as well as the regular exploration and exploitation of new territories needed to fuel it. Yet this logic has produced negative and dangerous impacts on environments and resources. As a result of this logic, we have likely passed some critical planetary thresholds (Rockström et al. 2009). Our present situation requires a shift to "Spaceperson economics" that accounts for the reality of limited resources, the negative impacts of limitless production—e.g., pollution, CO_2 emissions, biodiversity loss, etc.—and the urgent need for sustainable solutions.

A fictional Martian community provides a useful setting to consider analogous challenges. What is the core commons dilemma for a settlement on Mars and how is it different from communities on planet Earth? The hazardous Martian environment leaves very little room for errors in resource management. When humans arrive on Mars, they will encounter a broad variety of resource, technological, psychological, and social challenges. Since the inhabitants will be entirely reliant on one another, they must work collectively to make decisions and take actions that will keep their community alive and prospering. The Red Planet is not conducive to human life; there are many ways to die on Mars. Habitats must be kept in good repair to provide protection from radiation and the harsh Martian environment. Food must be grown, energy produced, and water harvested from ice deposits. Citizens of Mars will live in complete isolation, with no real-time communication with Earth possible due to the limits of the speed of light.

In spite of these technical challenges, the social aspects of inhabiting Mars might prove to be the greatest challenge of all. Everyone will have to work together constantly to ensure the health and safety of the habitat, with life-or-death consequences. Nearly all resources will be shared, extremely limited, and must therefore be managed with the utmost care. There is no option of moving to a new region if resources become depleted. "Cowboy economics" won't work in space. Establishing a long-term human presence on Mars will require overcoming these social hurdles. As such, the Martian setting provides a fitting analog for investigating challenges of collective action in extreme conditions like those increasingly encountered on Earth due to climate change. The Port of Mars project is an effort to understand how to best approach situations that require human cooperation to navigate hazardous conditions, limited resources, and high uncertainty.

The game is not a typical social science experiment. The results we present are from a small sample size. Nineteen groups are not sufficient to rigorously test precise hypotheses. The goal of the paper is therefore to discuss new game design as a potentially useful platform for research, identify the interesting and novel features of the project, present pilot data, and describe the current efforts to increase sample sizes by producing a digital version of the game.

We acknowledge the game involves a degree of speculation. We cannot fully create a Martian experience for players, only an imaginative one built on narrative and other representations. At its core, Port of Mars is based on the structures of traditional games used in commons dilemmas research. These structures are wrapped in a vivid narrative of an early Martian community. Like other commons dilemma games, if the shared infrastructure and resources are not managed effectively, there is no payoff for the players. In our Martian fiction, this means a catastrophic failure of the community and death to all its members.

In the next section, we present our experimental design. Then we discuss the implementation and our results. The paper finishes with some conclusions and descriptions of future research.

Experimental Design

Port of Mars was created over the course of two years by a transdisciplinary team of artists, game designers, planetary scientists, sustainability scientists, and education specialists. The project is part of Interplanetary Initiative, a pan-university effort to design and build the future of human space exploration. Set in the near future during the early years of the first human community on Mars, Port of Mars is a resource allocation game examining how people navigate conflicts between individual goals and common interests relative to shared resources. It presents a socially competitive environment in which the survival of the population is constantly in peril. Unexpected events occur regularly. Severely limited resources and deadly conditions hostile to life leave very little margin for error. Players must find ways to balance personal interests with the interest of the community.

The game is built on some well-studied experimental designs in the social sciences. The core dilemma requires players to choose how they will allocate a personal endowment between a public good and private benefits. The experimental design is inspired by recent experiments on the provision of shared infrastructure (e.g. Janssen et al., 2012; Anderies et al. 2013). In those irrigation games participants create shared infrastructure that give them benefits from water provision. In the present experiment, shared infrastructure is a measure of the "system health" of the community and its resistance to external events. Unlike the irrigation games, the Port of Mars game ends when shared infrastructure is destroyed.

We know from public good experiments that informal communication increases cooperation (Brosig et al., 2003; Balliet, 2010). Similar to previous irrigation experiments (Anderies et al. 2013), the Port of Mars experiment allows participants to communicate with one another throughout the game.

Further, participants make decisions under uncertainty; unexpected events occur regularly. Traditional experiments with public good and common pool resources often allow participants to make decisions involving risks, but do not include unknown unknowns. For example, studies on the effect of risk associated with resource size in common-pool resources experiments (Budescu et al., 1990; Walker and Gardner, 1992) and public good experiments (Dickinson, 1998; Wit and Wilke, 1998; Dannenberg et al. 2015; Cardenas et al. 2017) have found that the presence of risk reduces cooperation. In those experiments, participants were informed about the probabilities of events and the possible outcomes. In our experiments, participants do not know what events may occur, nor the probabilities associated with them; they must make decisions in the face of unknown unknowns.

We used thresholds in our experimental design. Threshold public goods refer to public good games where a group needs to invest a minimum amount in order to derive a public good. From prior research on traditional threshold public good experiments, we know that participants invest less if there are no refunds if the threshold is not reached compared to experiments where refund mechanisms exist (Isaac et al. 1989). If there is uncertainty about the threshold level, the contributions are found to be less (McBride, 2010). If the threshold is ambigious, no information about probabilities of threshold levels, the level of contribution is much less (Dannenberg et al. 2015).

A recent body of work on thresholds focuses on the possibility of negative impacts, such as not investing enough in emission reductions to avoid dangerous climate change or passing the tipping point of recovery of a renewable resource (e.g. Milinkski et al., 2008; Barrett and Danneberg, 2012; Schill et al. 2015). The presence of such thresholds of potential losses led to increased cooperation on the part of participants. As we will see below, we will use clear thresholds, but the participants have ambigious information at best what the impact of passing those thresholds will mean for them.

We did not attach monetary rewards to the number of points earned in the game. This is not uncommon in social science. Typically, psychologists do not tie monetary rewards, to performance, arguing that such rewards do not affect participants' decisions (Smith and Walker, 1993). Experimental evidence indicates that payments for participation can have some effect. If participants perceive the rewards as a fair contribution for their effort, experimental results will not be affected by different payment levels tagged to performance (Gneezy and Rustichini, 2000; Amir et al., 2012). However, if the monetary rewards are very low, participants may put in less effort (Gneezy and Rustichini, 2000). Gneezy and Rustichini (2000) found that it can be more effective to appeal to moral incentives (such as contributing to an important activity) rather than providing a monetary reward. The Port of Mars experiment provided monetary rewards and small branded items (magnets) for participation, but no monetary rewards related to the amount of points earned other than a more significant branded item (a stainless-steel water bottle) for the participant who scored the most points. It is unknown how these rewards affected the outcomes.

Port of Mars is distinct from many previous commons dilemma experiments in at least two key ways: 1) the function of narrative, as opposed to monetary remuneration, to motivate subject performance; and 2) the presence of unknown unknowns.

Traditional commons dilemma experiments frequently feature monetary incentives tied directly to the performance of subjects. Despite that in the Port of Mars participants are not paid for the number of points earned, the behavior of the subjects clearly indicated that they did not lack for motivation to perform effectively—either as a group, or individually. We suggest the reason for this was the presence of a compelling narrative.

In recent years, sustainability scientists and artists have started to collaborate, experimenting with creativity and imaginary futures in ways not often found in traditional science contexts (Scheffer et al. 2015; Galafassi et al. 2018; Janssen et al. 2018). Port of Mars picks up on these new models by situating our experiment in a fictional narrative that makes participation distinctly and emotionally compelling for players.

The use of narratives for experiments in commons dilemmas is hardly novel (see fishery narrative for early experiments: Gifford and Wells, 1991; Mosler, 1993; Moxnes, 1998). But Port of Mars is distinct from other such efforts in that the project team featured artists and commercial game designers skilled in crafting engaging and compelling narratives that motivate players to emotionally invest in the stakes of the game. Though Port of Mars offers a fictional environment and scenario, we found that participants took the game seriously, in part because the (imaginary) survival of their group was at stake. How important the fictional narrative was in the decision-making processes of participants remains, at this stage, an open question that we will explore in future experiments. However, our observations during the pilot study demonstrated that participants were deeply committed to success, and emotionally involved in their in-game decisions.

In many previous commons experiments as discussed above, subjects are aware of the specific character of future events, as well as the probability of their occurrence—e.g., a coin-flip or dice-roll. Yet such an arrangement may not adequately reflect the ways in which individuals and groups confront social dilemmas outside the laboratory.

As of this writing, the world is seized by a global pandemic in the form of COVID-19. The uncertainties accompanying this crisis do not present themselves as clearly identifiable probabilities tagged to a set of well-defined outcomes. Far from it. Yet individuals, organizations, and policy makers must make decisions in the context of this high degree of uncertainty, and many of these decisions will have uncertain, but possibly high-stakes consequences for public health, economic well-being, and even life and death.

Port of Mars differs from many previous experiments in that it features a set of "unknown unknowns." Participants must draw at least one Event card during each round. Each Event will have an undetermined impact on the players. Crucially, the players do not know what sort of impacts these Events will have, much less the probability associated with scale of impact, or the probability that the results will be positive, negative, or neutral.

We believe this is a potentially useful approach to investigating how subjects navigate commons dilemmas and collective action problems in the context of high uncertainty. Further work is necessary to reliably support the utility of such an approach, and our future efforts will involve increased sample sizes, text analysis, and other tools to measure the ways in which subjects respond to unknown unknowns.

The game involves five players, each of whom must decide how much of their time and effort to invest in maintaining public infrastructure and renewing shared resources and how much to expend in pursuit of their individual goals.

In the game, "Upkeep" is a number that represents the physical health of the community—the condition of infrastructure, production of food, water, and breathable air, radiation shielding, energy production, and other necessary resources. This number begins at 100 and goes down by twenty-five points each round, representing resource consumption and wear and tear on infrastructure. If that number reaches zero, the community collapses and everyone dies. No one wins if everyone is dead.

Players take on one of five possible characters: Politician, Pioneer, Entrepreneur, Researcher, and Curator (**Figure 1**). Each player receives ten "Time Blocks" per round. These blocks represent time-based renewable resources that characters may spend contributing to Upkeep or pursuing their own ambitions. Each Time Block spent on Upkeep raises the Upkeep number by one point.

Characters may also spend Time Blocks to purchase Influence cards (**Figure 2**). These cards represent the player's capacity to impact specific domains. There are five kinds of Influence cards: Culture, Legacy, Science, Government, and Finance. Characters can use combinations of Influence cards to purchase Accomplishment

Figure 1: Illustrations of character roles. Illustrations by Titus Lunter.

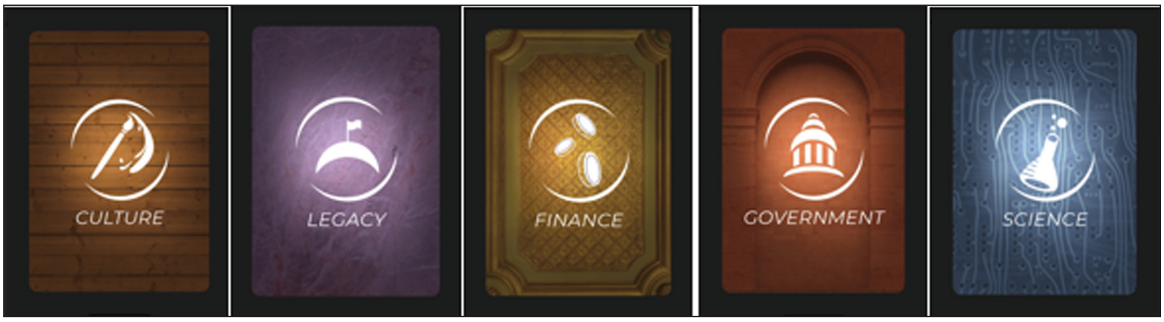

Figure 2: Influence cards. Graphic design by Liz Leo.

cards, representing significant achievements in their domain—e.g., scientific discoveries, cultural productions, political milestones, etc. Each Accomplishment card is worth a set number of points (**Figure 3**). Through purchasing and gathering Influence cards, then using them to purchase Accomplishment cards, players rack up points (Appendix 2). The player with the most points at the end of the game wins.

Each character specializes in a certain kind of Influence that require less time and effort to produce. For example, the Curator specializes in Culture. It costs him only two Time Blocks to produce one Culture card, whereas it costs him three Time Blocks for a Finance or Legacy card. Each character has two kinds of Influence it cannot produce. The Curator, for example, cannot produce Science of Government. In order for players to acquire types of Influence they cannot produce, they must trade with other players.

Each player has a unique deck of Accomplishment cards for their character. Near the beginning of the game, each player turns over three Accomplishment cards from their deck. These are the Accomplishments available to them to purchase this round. At the end of the round, players may discard any Accomplishment cards they have not purchased, and replace them with new ones drawn from their deck.

Each player's deck consists of fourteen Accomplishment cards, each worth a varying number of points. Twelve of these must be purchased with Influence cards. Two Accomplishment cards—that participants dubbed the "dirty" cards—do not cost any Influence to purchase but instead subtract Upkeep points. Purchasing these cards earns the player points, costs them nothing, but subtracts from the collective resources and infrastructure of the community.

We introduced uncertainty into the game by means of a deck of Event cards (Appendix 1). Players draw one Event card per round (with the exception of round one, in which no Event cards are drawn). Each Event impacts players in a way that is either negative, positive, or neutral (**Figure 4**).

Figure 3: Accomplishment card. Graphic design by Liz Leo.

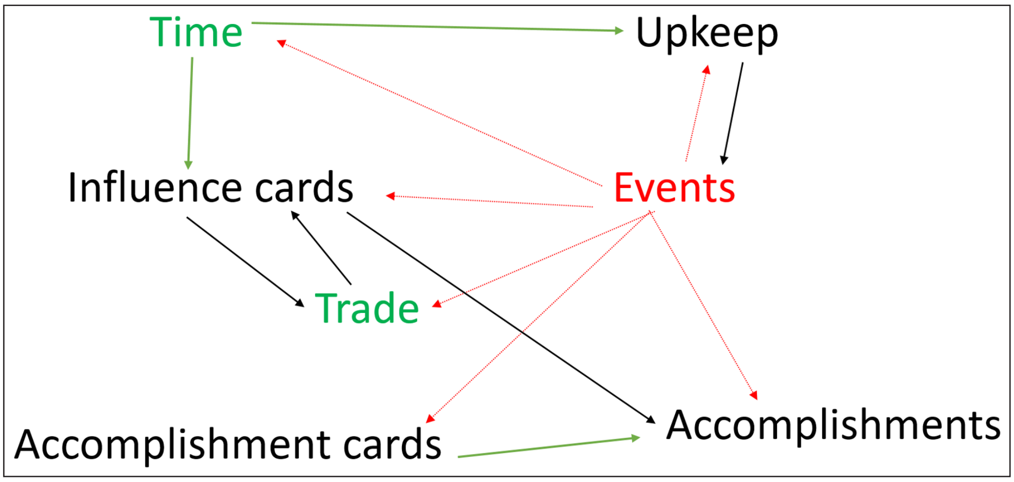

Figure 4: Schematic outline of the game. Green refers to actions of players who decide how to invest Time Blocks between Upkeep and Influence cards, how to Trade, and when to buy Accomplishment cards. The red Event cards refers to the external disturbances which can impact (red arrows) all components of the game. Black refers to the different types of cards and points in the game.

The game features tipping points. If the Upkeep falls below sixty-five, players draw two Event cards per round. If it falls below thirty-five, players draw three Event cards.

When participants arrive, they are asked to read a two-page information sheet with the rules of the game (Appendix 3). A moderator then verbally walks them through the game instructions, highlighting some key elements (Appendix 4). The moderator answers any questions the participants have, and then the first round of play begins. Players often ask questions of the moderator during the first round, as they work to navigate the mechanics and rules. Typically, after the first round, the participants have a solid understanding of the game.

Simulated outcomes

Port of Mars is too complex to calculate specific predictions like Nash equilibria. However, we used a computer simulation to explore the range of possible outcomes given some basic strategies players could use. The resulting model is a highly stylized version of the actual game. Nevertheless, we can demonstrate the significant role Events and the dirty card play in the game. The simulation results allow us to identify effective strategies for group survival, as well as the risk of collapse. We can also compare those strategies with the observed behavior described in the next section.

The model requires us to make some critical assumptions, such as that players are boundedly rational and self-interested. We assume that players only invest in producing their specialty Influences, and trade with other players to acquire other needed Influence cards. We do not simulate trade but assume that players try to buy Accomplishment cards with the highest ratio of points per Time Blocks invested, and are able to buy that card if sufficient Influence cards have been acquired.

The model also assigns agents a probability, equal for each card, to discard available Accomplishment cards. The agents decide as a group how much to invest in Upkeep. The group has a target level of Upkeep to maintain during gameplay. This allows us to vary the target and investigate how this impacts outcomes.

The model assumes an agent will either use the "dirty card," or they will not. If an agent uses a dirty card, they use it when it provides the best return on time invested. In actual gameplay, players were more strategic in using the dirty card and often saved it for when they suspected the game was close to ending. In the model, agents do not attempt to mitigate their intentions to use a dirty card by investing extra Time Blocks in Upkeep. Such a pro-active strategy would reduce the difference of consequences between simulations in which the dirty card was used and those in which it was not. We saw this pro-active strategy in some human groups, but not in others.

Figure 5 shows the fraction of groups collapsing in 1000 simulations for each different target levels of Upkeep. While the use of a dirty card by an agent improves their chances of winning the game, it significantly increases the likelihood of community collapse, especially if the target level of Upkeep is below 80. Reducing the target level, while temporarily attractive, also increases the chance of the group of not surviving.

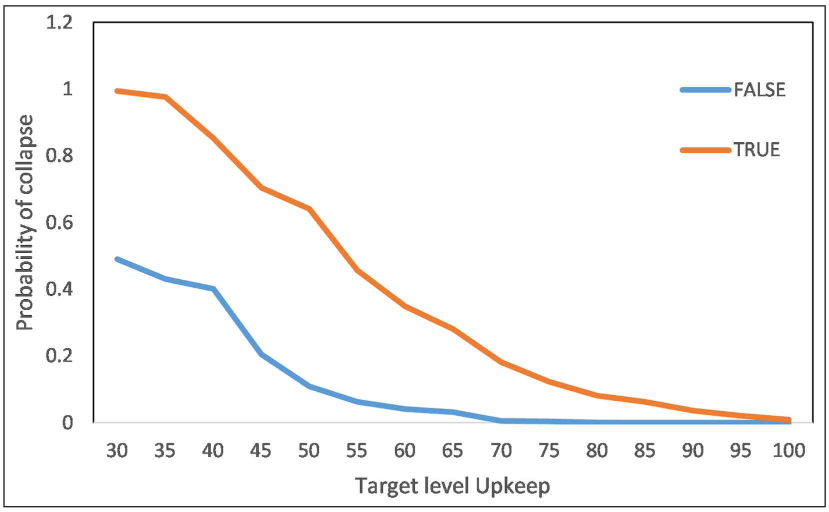

Figure 5: Simulation results. If agents do not use "dirty cards" (FALSE), the probability of extinction for a group remains below 50 if the target level for upkeep is 50 or higher. If agents use "dirty" cards (TRUE) this target level increases to 70. Each point on the lines denotes the mean of 1000 simulations.

We can evaluate the outcomes of simulated games by quantifying the costs of Event cards (see Appendix 1). For example, the Event card called "Crop Failure" costs 20 Upkeep points, and Event card "Difficult Conditions" raises the cost of Upkeep points from one to two Time Block. We can thus estimate the costs of external events in units of Time Blocks. **Figure 6** shows the results for 5000 simulations with a target Upkeep of 100, and no agents using the dirty card. We see that there is a widespread of points groups can derive, but we see also that this spread is strongly related to the kind of Event cards the group drew. The number of points a group derives is not all based on skill, but strongly related to the Events they experience. As the cost of Events increases, the total number of points scored by a group decreases.

Figure 7 shows the mean number of points a group derives over 5000 games for varying target levels of Upkeep both with and without the use of the dirty card. The mean level of points remains quite similar for target levels of 50 and higher. The standard deviation is largely caused by the Event cards groups experience. When the target level for Upkeep drops below 50, the frequency of groups collapsing when they use the dirty card leads to a reduction of the points groups received. These simulation results suggest the decision on the target level should be based on the probability of survival, not the expected number of points the group receives.

Since players do not know the number of rounds in a game, we calculated the frequency of group surviving for different numbers of rounds. The results remain similar as in **Figure 5**. This suggests that keeping the

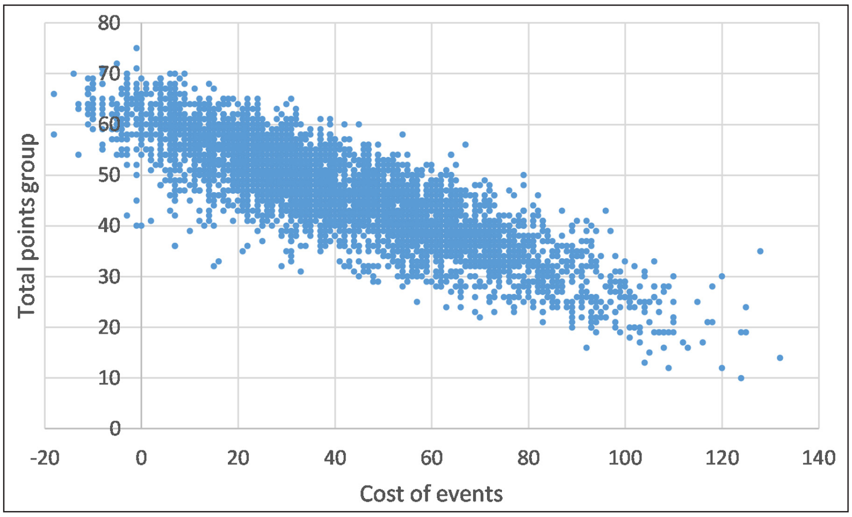

Figure 6: Simulation results. Relation between costs of Events and total points derived by the group after nine rounds with a target Upkeep level of 100 and not using the dirty card. The figure shows the outcome of 5000 simulated games.

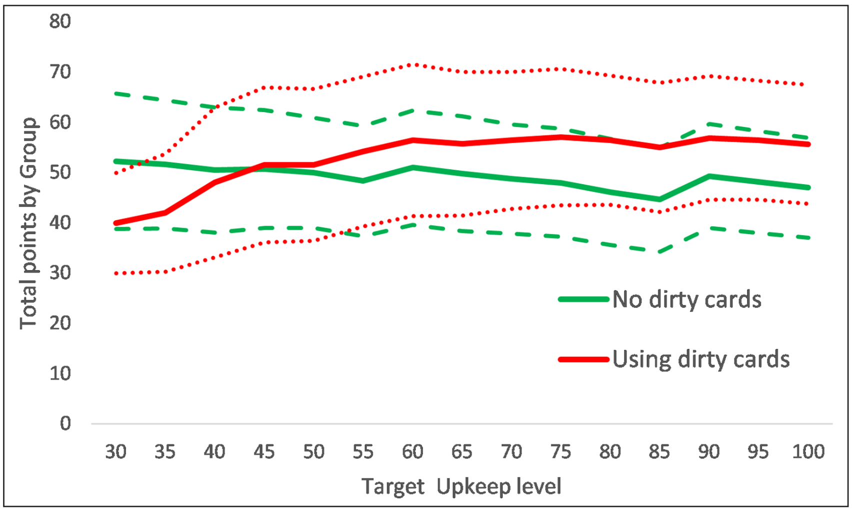

Figure 7: Simulation results. The relation between the target Upkeep level and the average points derived during 5000 simulated games. The dotted lines indicate the mean +/– one standard deviation.

Upkeep at 70 at the start of the round, which lead to an Upkeep level after wear and tear of 45 and thus receiving 2 Event cards, still keeps the probability of group collapse very low provided dirty cards are used wisely.

Experimental Results

We performed a series of experiments with the game in February, and March 2019. Nineteen groups of five undergraduate students from Arizona State University were recruited to play the game. We recruited from a database of students who signed up to participate in experimental social science research. The recruitment email (Appendix 7) refers to a card game related to the social science of space exploration.

Three experimenters were present to moderate the game, document the discussions, and record player decisions during gameplay. Participants received a ten-dollar gift card for participation, and a special Port of Mars magnet when the group survived, and a special Port of Mars water bottle for the player who earned the most Accomplishment points. Participants did not know the number of rounds that would be played, but knew it would not take longer than two hours. Most of the games were finished within ninety minutes for the nine rounds of the experiment.

From the nineteen groups, eighteen kept the Upkeep level positive for the full nine rounds. This is in line with expectations since we know that communication, even when promises cannot be enforced, lead to a high level of cooperation in public good and common-pool resource dilemmas (Isaac and Walker, 1988; Ostrom et al. 1992; Janssen et al. 2010). The participants did not know what the Events would be but assumed they should be avoided, and therefore most groups tried to stay above the sixty-five threshold (**Figure 8**), below which they would need to draw an extra Event card per round. This observation is in line with recent work on tipping points (Schill et al. 2015) and Collective Risk Social Dilemmas (Milinkski et al. 2008) that demonstrate how thresholds lead to a higher level of cooperation.

In 54% of the rounds beyond the second round, the Upkeep level was ninety or higher, which keeps the number of Events equal to one per round. This shows that the groups aim for high levels of the Upkeep. In fact, most groups agreed to keep the Upkeep high enough to avoid it going below sixty-five and increasing the likelihood of negative Events. The participants did not know the nature of possible Events, but they largely assumed that they would be bad. Only one group purposely dropped below sixty-five just to see what would happen.

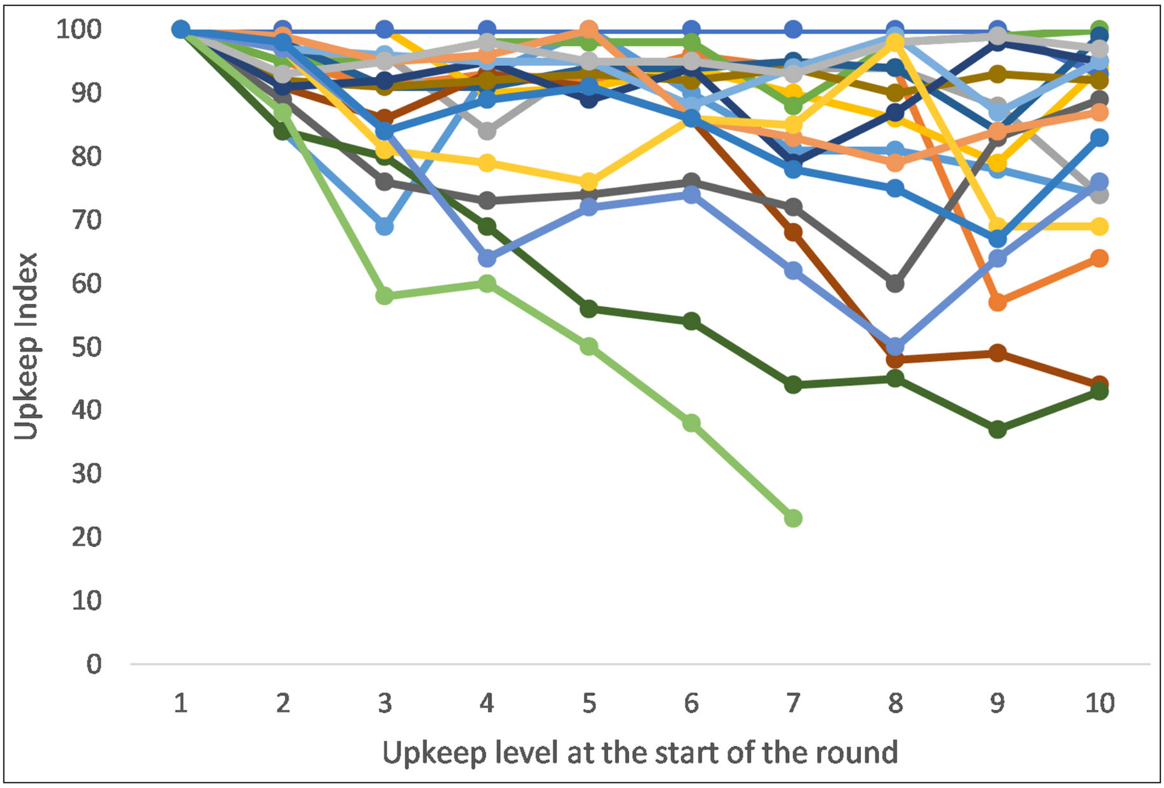

Figure 8: Upkeep level at the start of the round. Round ten could be calculated after decisions made in the final round nine.

When we calculate the cost for event cards for all the groups, we see that there is a strong correlation with the points of the group as a whole collected (**Figure 9**). The low performing groups typically had a bad start due to costly Events in rounds two or three, or not investing fourteen or more in round one, triggering the requirement to draw two Event cards in round two.

A linear regression model shows the group performance measured in points over nine rounds (**Table 1**). We included only the eighteen groups who survived the game. We tested the impact of Event cards, the number of points derived divided by the number of Time Blocks available (efficiency), the number of trades made, and the majority of the group pointing to the same person as the leader (Appendix 5). In exit interviews, we asked subjects which players they identified as the leader of the group (Appendix 5). When the majority of the group pointed to the same person, we identified this person as a "clear leader".

We found that the higher the cost of Event cards drawn by a group, the lower the total number of points they earned, as shown in **Figure 9**. We also found that the more points per Time Block a group derived (after accounting for Event cards), the higher the number of total points a group earned. This means that groups are efficient in obtaining Influence cards. Furthermore, we found that the number of trade events correlated with a better group performance, though this was not significant. Finally, the presence of a clear leader has a non-significant positive effect on the performance of the group.

Table 1: Results of linear regression for the 18 groups who survived the 9 rounds of the game. The number between brackets are the standard deviations of the estimated coefficients. ***refers to $p < 0.01$; **refers to $p < 0.05$ and *refers to $p < 0.01$.

Variable	**Coefficients**	**Coefficients**
constant	36.160 (5.765)***	33.289 (7.858)***
Cost event cards	–0.336 (0.027)***	–0.328 (0.034)***
Efficiency	117.225 (15.626)***	118.617 (16.818)***
Number of trade events		0.032 (0.094)
Clear leader		1.317 (2.058)
n	18	18
R^2	0.957	0.958

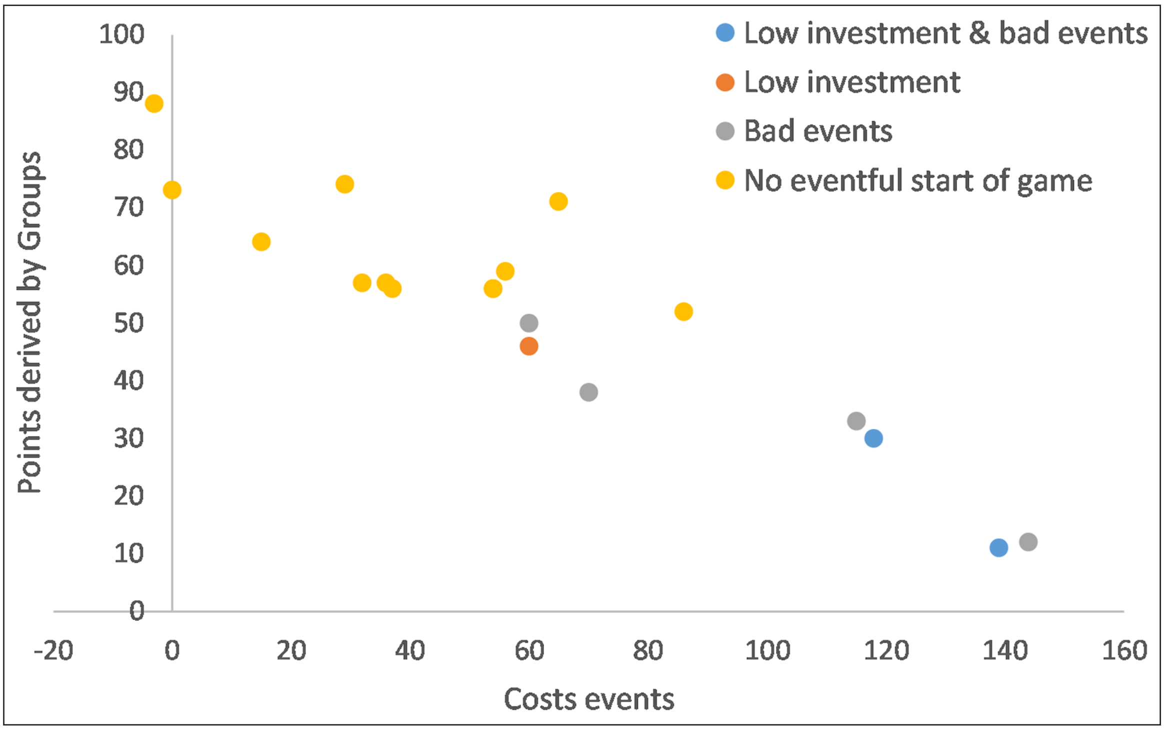

Figure 9: Relation between points groups earned over nine rounds and the costs of the event cards.

Table 2: Results of a mixed-effect ordered logistic regression for the ninety individuals in the eighteen groups who survived the nine rounds of gameplay. ***refers to $p < 0.01$; **refers to $p < 0.05$ and *refers to $p < 0.1$.

Variable	**Estimations**
Dirty card	2.136 (0.425)***
Share leader	1.740 (0.783)**
Relative Upkeep investment	–3.734 (2.172)*
"Out of Commission" Event card	–0.467 (0.463)
Number of trades	0.183 (0.104)*
Trade efficiency	1.925 (1.214)
Number of observations	90
Wald Chi-Square test	37.96 ($p < 0.001$)
$p >= \chi^2$	0.0007

For the individual-level data, we used a mixed-effect ordered logistic equation to estimate which factors impact the probability that an individual will win the game (**Table 2**). Winning the game is achieved when a player received the most points. In some games, two players ended with the same number of points after which the winner was determined by a coin toss. In our statistical analysis, however, both players are identified as winning the game.

We found the use of the 'dirty' card to be the most distinctive predictor of a person winning the game. Interestingly, a high percentage of winners were identified by players as the leader of the group. This could be because leaders had a better understanding of the game and superior strategic insight. A more cynical explanation is that these players used their leadership skills to manipulate others into making decisions that increased their chances of winning.

Players who won the game made comparatively smaller contributions to Upkeep than other group members. Lower investment in Upkeep allowed these players to devote more Time Blocks to gaining Influence, and thus increased their ability to purchase Accomplishment cards to rack up points. Receiving the "Out of Commission" Event card did not impact the chances of a person winning the game, and engaging in more trade events had a modest correlation with a person winning the game.

We used a survey (Appendix 6) to derive information on the cultural orientations of participants (Kahan et al. 2007). The survey of Kahan et al. is based on a cultural theory developed by Douglas and Wildavsky (1982) and Thompson et al. (1990). This theory assumes that people have different views of how the world works and how to manage risk. It identifies four types of world views defined by two dimensions (**Figure 10**). The "group" dimension represents the degree to which the individual's life is sustained by group membership. The "grid" dimension measures the significance of social differentiation within a worldview. Persons with a high grid orientation expect resources, opportunities, respect and the like to be distributed on the basis of explicit public social classifications, whereas low grid orientations value a more egalitarian distribution.

Based on the relative scores on the survey, we classified each participant in one of four categories (**Table 3**). Some individuals could not be classified since their scores were on the border of two categories. We identified eleven participants as individualist and hierarchical, eight participants as communitarian and egalitarian, twenty-six participants as individualist and egalitarian, and thirty-three participants as communitarian and hierarchical.

We recorded when a dirty card was available for players to purchase, and whether or not they played it when it was available. Thus, we were able to calculate, for each category of player, the probability they would use an available dirty card. We found that those identified as more communitarian/egalitarian were least likely to use the dirty card, while those identified as individualist/hierarchical were nearly twice as likely to use it. This is consistent with the observation that using a dirty card can be considered a selfish act, hurting the collective interest. Similarly, we identified the probability of a player winning. This was highest among those who are individualists and egalitarian. The number of groups was too small to identify compositions of cultural views that would perform better as groups.

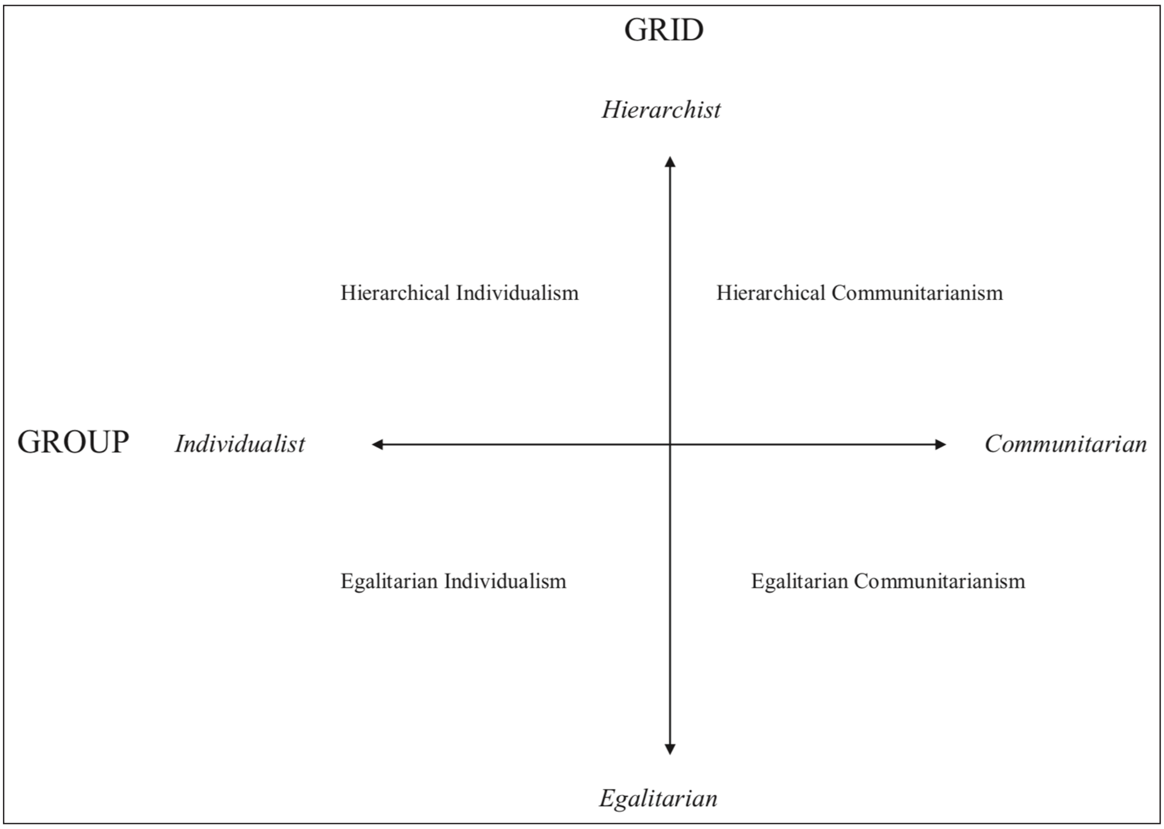

Figure 10: Cultural orientations according to Kahan et al. 2007.

Table 3: Using cultural views to identify types of behavior.

Cultural type	Number	% using a dirty card when available	Probability player wins
Individualist/hierarchical	11	14.3%	9%
Communitarian/egalitarian	8	8%	25%
Individualist/egalitarian	26	14%	31%
Communitarian/hierarchical	33	11.5%	18%

We also analyzed the communication information we collected but did not find a quantitative measure that explained the performance of the groups. We typically saw more discussion of game rules in the first few rounds. Each round, most groups discussed how much to invest and planned trades. There were differences in the amount and type of communication. Some groups were very inclusive, checked in on each other, and confirmed agreements. Others had minimal exchanges and rarely tried to confirm agreements. Group communication was also impacted by Events, and it is, therefore, no surprise that there is no obvious causal impact of the type of communication with the data we have collected.

Conclusions

In this study, we explored how groups of individuals perform in a system with shared resources in conditions of high uncertainty, high risk, and unknown unknowns. Our sample is too small to make firm conclusions, but the pilot study demonstrates that, in line with past experiments, informal communication allows most groups to successfully avoid resource overharvesting. We also find—again, in line with previous studies—that the existence of specific thresholds makes the participants more cooperative. Testing the specific roles of thresholds and types of communication for this specific game design will require larger sample sizes with alternative treatments.

Our study displays a new way of including uncertainty in commons dilemma experiments. More traditional experiments feature probabilities that identify the likelihood of specific events occurring (e.g. Milinkski et al. 2008). This follows the tradition of calculating the expected returns needed within the rational choice framework. Port of Mars is distinct from these experiments in its inclusion of unknown unknowns. Participants do not know what kind of events might occur in the game, leading them to form assumptions as to what those events might be.

We are now in the process of creating a digital version of Port of Mars that will allow us to run experiments with greater efficiency, increase our sample size to many hundreds of groups, collect survey data on the attributes of participants, and collect player discussion data accurately to derive objective measures of communication. Furthermore, since our pilot data suggested that leadership plays a role in group performances, our future work will use surveys and analysis of communication data to study what types of leadership makes groups more effective.

In the coming years, our governance of shared resources will increasingly experience new challenges due to humankind's disruption of the biosphere. We need new approaches to collaboration with shared resources in extreme environments. The Port of Mars experiment is a useful platform to study such situations, and a possible educational tool for students to experience collective action challenges under high uncertainty.

Data Accessibility Statement

The code of the NetLogo model that is used in this study is openly available at https://www.comses.net/codebase-release/90dac191-572a-48d3-ab80-2cbc2f566484/. The data that are used in the statistical analysis is openly available at https://osf.io/mqyux.

Additional Files

The additional files for this article can be found as follows:

- **Appendix 1.** List of event cards. DOI: https://doi.org/10.5334/ijc.1017.s1
- **Appendix 2.** List of accomplishment cards. DOI: https://doi.org/10.5334/ijc.1017.s2
- **Appendix 3.** PORT OF MARS Information sheet. DOI: https://doi.org/10.5334/ijc.1017.s3
- **Appendix 4.** Script. DOI: https://doi.org/10.5334/ijc.1017.s4
- **Appendix 5.** Interview questions. DOI: https://doi.org/10.5334/ijc.1017.s5
- **Appendix 6.** Survey. DOI: https://doi.org/10.5334/ijc.1017.s6
- **Appendix 7.** Recruitment Notice. DOI: https://doi.org/10.5334/ijc.1017.s7

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Competing Interests

The authors have no competing interests to declare.

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