Systems Engineering Master's of Engineering Report: Studying Conflict and Cooperation in Incentivized Rowing Tests

Ethan Suttner
Professor Reeve Kern
Fall 2011

Introduction

While much research has been performed on the topic of the individual's investment in group-settings, most of the data in the field of cooperative game theory has been collected through an artificial/computer interface as either survey responses or game-play strategies (Kummerli, Stark). As relevant to behavior in today's internet-driven society is this type of information, physical investment must have been to the development of intrinsic human behavior over the past millennia; human behavior via physical exertion, in regards to serving a role in a group, likely represents a set of decisions that have been made by the individual throughout our environment of evolutionary adaptation. Our goal is to investigate the individual's trade-off between physical cooperation and conflict through the medium of team sport, specifically (for reasons discussed below) rowing. Though physicality, on average, is quite unimportant in predicting one's wealth in today's society, professional and recreational sport provide opportunities to investigate the psychology otherwise (Baruch).

Model

Models for factors explaining investment have recently been presented and studied in insect societies (Reeve). Such scenarios have been defined by group size, number of groups, total investment capacity of the individual, relatedness between group members and between groups, and the total amount of resource available in the society. Thus, to apply these models to a sporting environment, we need to ensure the sport of interest has clear definitions for each of these terms.

Total Investment Capacity

Total investment capacity relates to the individual's ability to contribute to the team's performance in a given event, therefore defining and measuring it in some sports (soccer, hockey) is more difficult than doing so in others (rowing, relay races). It is possible to compute an individual's performance statistics within a team sport (batting average, number of home runs, etc. in baseball) and then to fit a relationship between the statistics and the team's performance, attempting to isolate the individual's direct contribution to the team. However, a competition in which team performance is mostly related to the summation of each individual's performance enables a more clear definition of investment capacity. For example, in a 4x100 meter relay race, a dominant team- in which each member is faster at completing 100 meters than each member of any another team- would most likely win the race; however, this dominant team can still get disqualified should they drop the baton or fault start. Similarly, in an eight-person-boat rowing race, a team that would otherwise be considered dominant could lose if they didn't row well together. We want to minimize the factors regarding how well group members work together for the purpose of isolating investment decisions.

Further insights into physical investment capacity may require specific physiological definitions of capability pertaining to the sport in question. However, we can mostly neglect the biological mechanisms behind the capacity; rather, general intensity (power) of the action (running, rowing, swimming, etc.), and durations thereof, suffice for our intended models.

Group Definition

Clearly defined groups are not always visible in sport. In cycling, alliances amongst riders bunched together on the road can lead to definitions of ever-changing spatial groups, whereas teammates and compatriots can define political groups. Most other sports have one constant definition of a group (perhaps less interestingly so).

Resources and Payoff

In order to distinguish between self-interest and group investment, we must be able to incentivize situations that promote both opposing sets of behavior. For example, payoffs for physical investment related to the Public Goods Game should differentiate between conflict and cooperation (Kummerli). Besides the negative utility associated with the pain of physical exertion, monetary incentives can be used to persuade the individual towards either behavior.

Relatedness

According to Hamilton's rule, relatedness between group members should increase cooperation levels. These features can be controlled and measured in our experiments.

Selecting a Sport

From these components of the Reeve model, we drafted the following requirements to select a sport:

- Each individual in the team shall perform the same role.
- The output of each individual invested towards his team shall be simply and quickly measured.
- The output of each individual invested towards himself shall be simply and quickly measured.
- The teams shall be clearly defined at all stages of competition.
- The incentives shall be clearly defined at all stages of competition.
- The research shall have access to test facilities/equipment.
- The research shall have approval/exemption for testing human subjects.
- The testing shall minimize the risk of injury to the participants.

The first requirement is satisfied in a few sports including rowing, tug-of-war, weightlifting, and relaying racing since of these sports can test individual ability. We performed a concept selection process to pick a sport:

		Rowing (Indoor)		Tug-of-War		Weightlifting		Relay Racing	
Metric	Weighting	Score	Weight*Score	Score	Weight*Score	Score	Weight*Score	Score	Weight*Score
Measurement Capability	0.3	9	2.7	5	1.5	9	2.7	6	1.8
Team Component/Model	0.3	9	2.7	9	2.7	7	2.1	5	1.5
Injury Risk	0.1	9	0.9	5	0.5	4	0.4	7	0.7
Access to Facility/Equipment	0.15	8	1.2	4	0.6	5	0.75	9	1.35
Access to Participants	0.15	10	1.5	5	0.75	4	0.6	8	1.2
SUM	1	45	9	28	6.05	29	6.55	35	6.55

Since we have sufficient experience with the sport of rowing, we decided to work with designing experiments to test cooperative game theoretic behavior. Furthermore, the Concept2 rowing machine enables precise data collection and test control.

Experimental Design 1

We plan to treat this initial test as a proof-of-concept for rowing as a scientific tool in human behavior research. Before attempting to design scenarios in which we observe a change in behavior depending on the incentives as a function of group and individual performance, we can first determine to what extent incentives affect decision making in individual workouts. The initial hypothesis we want to test is:

Hypothesis 1: Rowers work harder based on monetary incentives.

Monetary incentives based on rowing performance will be a function of the individual's energy expenditure over a given time. All information regarding the payoffs for the entire test will be presented to the rower before rowing begins. In this study, for a given interval, the constant reward function, $r_{i_{individual}j}$, will be defined:

$$r_{i_{individual}j} = c_{i_{individual}} p_{ij} t_i$$

where $c_{i_{individual}}$ is the amount of money rewarded to the *j*-th individual per unit energy burned, p_{ij} is the average power produced for the interval, and t_i is the duration of the interval. For multiple intervals each with different constant reward functions, the total reward function for the test will be:

$$R_{individual_j} = \sum_{i}^{N} r_{i_{individual}j} = \sum_{i}^{N} c_{i_{individual}} p_{ij} t_i$$

The rower's goal is, then, to maximize $R_{individual_j}$ over the set of constraints defined as functions of p_{ij} and t_i (invest energy stores to maximize money won).

If we assign t_i constant throughout the experiment (constant duration intervals), the hypothesis is proved when p_i is observed to have statistically significant, positive correlation with $c_{i_{individual}}$.

Procedure

The reward function values for this study are:

$$c_1 = 0.5c;\ c_2 = c;\ c_3 = 0;\ c_4 = 2\text{c};\ c_5 = c;\ t_i = 4\ minutes \text{ for all } i$$

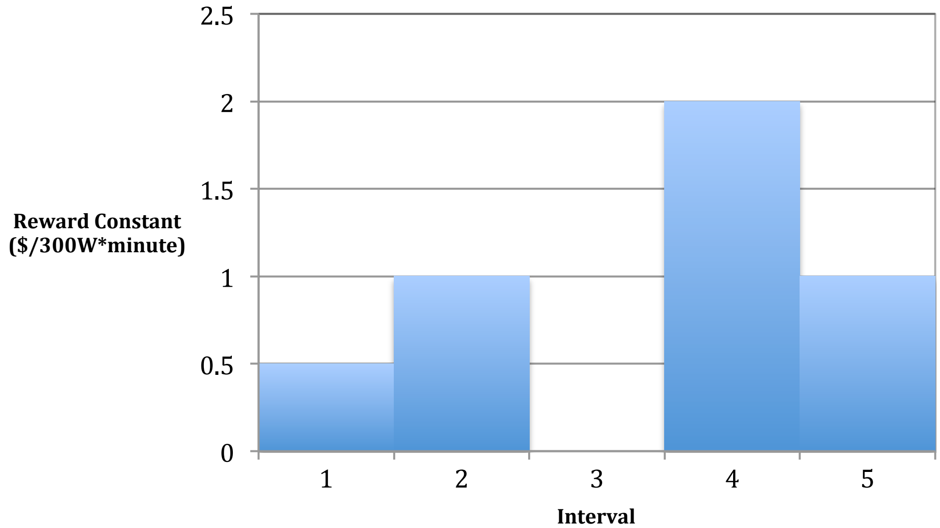
with $\text{c} = \frac{\$1}{300\ W*minute}$ (Figure 1). For example, if the rower averages 280W, 320W, 100W, 330W, and 290W for the each of the 4-minute intervals, respectively, the total reward for the test is then:

$$R_{individual_j} = \sum_{i}^{N} c_{i_{individual}} p_{ij} t_i$$

$$= \frac{\$1 * 4\ minutes}{300\ W * minute}(0.5 * 280W + 320W + 0 * 100W + 2 * 330W + 290W)$$

$$R_{individual} = \$18.80$$

Figure 1: Reward Constant vs. Interval

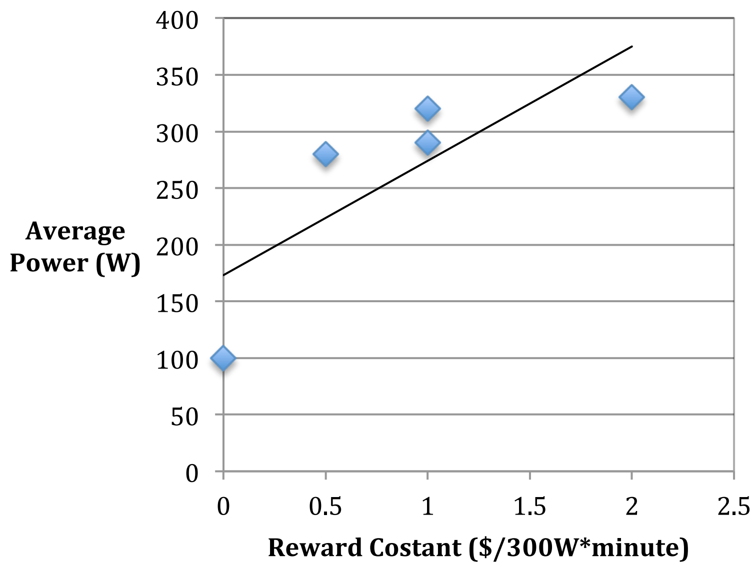


To test this reward function, we would like to conduct this 20-minute workout with 2 rowers. We will present the rowers with the test outline on the following page. If this test is successful, we may update the reward function and conduct the test with at least 20 more rowers.

Data Processing

The data that we will have from each rower in the test are p_{ij} for $i = 1 \ldots 5$. We must inspect the function $f(c_i) = p_{ij}$ which we can expect to not be linear. For example, in the third interval the rower will not get paid any money but he will still want to row for physiological reasons (stay warmed up and ready for the next intervals). Another example of nonlinearity would be the limitation on the total power output of the rower; if we gave the rower a time period in which we offered a very large payoff, he would produce as much power as possible which would not necessarily fit a linear model defined by lower power trends ($100/300W*minute may predict 3000W, for the interval using a linear model, which is impossible). We can rather fit a polynomial to this function and test it on further subjects to verify it (Figure 2). We will then use this function in the group behavior portion of the study.

Figure 2: Sample Average Power vs. Reward Function



Experimental Design 2: Public Goods Game

Once we have determined how rowers invest effort based on individual reward functions, we can study the group dynamics. Using the same structure for the reward functions as stated above, we define the *j*-th individual's contribution to the group in each interval as:

$$r_{i_{group}j} = c_{i_{group}} p_{ij} t_i$$

where $c_{i_{group}}$ is the amount of money rewarded to the group per unit energy burned by individual *j* and p_{ij} is the average power produced by individual *j* in interval *i*.

The reward to the group due to the investment by individual *j* is then:

$$R_{group_j} = \sum_{i}^{N} r_{i_{group}j} = \sum_{i}^{N} c_{i_{group}} p_{ij} t_i$$

and the total reward to the group over M group members is:

$$R_{group} = \sum_{j}^{M} R_{group_j} = \sum_{j}^{M} \sum_{i}^{N} c_{i_{group}} p_{ij} t_i$$

Dividing the resources equally among each group member results in each group member receiving:

$$R_{\frac{group}{individual}} = \frac{1}{M} \sum_{j}^{M} \sum_{i}^{N} c_{i_{group}} p_{ij} t_i.$$

Finally, the total amount of money each rower receives is:

$$R_{total} = R_{individual} + R_{\frac{group}{individual}}$$

$$R_{total_j} = \sum_{i}^{N} c_{i_{individual}} p_{ij} t_i + \frac{1}{M} \sum_{j}^{M} \sum_{i}^{N} c_{i_{group}} p_{ij} t_i$$

We can tune the payoff functions in this multiple stage Public Goods Game in order to refine our behavioral model. For example, some intervals can pay handsomely to the group's fund (high $c_{i_{group}}$), but individuals may not fully exert themselves in favor of saving energy for intervals with higher payoffs based on individual incentives ($c_{i_{individual}}$).

Experimental Design 3: Reeve Model Incentives

In the Reeve Model, multiple groups are in conflict over a fixed amount of a pooled resource. Simultaneously, individuals within a group are investing in either the group's effort to win resources or in their own individualistic efforts.

By having a constant reward function for each interval in the game, we can simplify the Public Goods Game model to design a test of game play behavior in the Reeve scenario. This game has a fixed resource, R. Out of M_k individuals in the k-th group, the j-th individual receives this fraction, S_{wjk}, of his group's share:

$$S_{wjk} = \frac{\sum_i^N p_{ijk_{individual}} t_i}{\sum_i^N \sum_j^{M_k} p_{ijk_{individual}} t_i}$$

and the k-th group gets this fraction, S_{bk}, of the total resource split among L groups:

$$S_{bk} = \frac{\sum_i^N \sum_j^{M_k} p_{ijk_{group}} t_i}{\sum_k^L \sum_i^N \sum_j^{M_k} p_{ijk_{group}} t_i}.$$

Thus, the individual receives:

$$R_{jk} = RS_{wjk}S_{bk} = R \frac{\sum_i^N p_{ijk_{individual}} t_i}{\sum_i^N \sum_j^{M_k} p_{ijk_{individual}} t_i} \frac{\sum_i^N \sum_j^{M_k} p_{ijk_{group}} t_i}{\sum_k^L \sum_i^N \sum_j^{M_k} p_{ijk_{group}} t_i}.$$

We can then look for correlations between relatedness, group numbers and sizes, and $p_{ijk_{individual}}$ and $p_{ijk_{group}}$(the average power in the i-th interval of the j-th rower in the k-th group contributed to the individual and the group, respectively).

Experimental Design 4: Hierarchal Incentives

The previous models have been designed with extra flexibility in terms of variable payoff rates and interval lengths, which might be unclear to a subject in the test. Instead, we would like to design an experiment in which only absolute performance relative to other individual and groups' determines one's payoff.

To each individual, we can reward performance over a given interval as F_i where i is place that individual finishes relative to everyone else. For example, first place receives $F_1 = \$100$, second place $F_2 = \$50$, and third place gets $F_3 = \$25$.

Similarly for the group, we can award G_j to the group where j is the place the group finishes.

After either of these first two possible stages of the game, another stage can be played in which the previous round's group payoff gets distributed between members of the group. We then define H_i as the fraction of the group's reward that the *i*-th finisher receives. For instance, first place in this round of the game gets half of his team's round 1 reward ($H_1 = \frac{1}{2}$).

This format of the game will still see the individual making trade-offs between conflict and cooperation, though with more simplicity than in previous designs. Only once we have begun testing will we be able to refine our design decisions to isolate the behavior we are trying to observe.

Conclusion

What we have developed is a system for testing cooperative game theoretic behavior with rowing exertion at each stage of the game as the decision variables. Rather than testing how an individual acts in a theoretical game by allocating money to himself or a group, we hope that testing via physical investment yields a more vivid image of human behavior and psychology. Incentivized rowing, or some alternative measurable exercise, as tool in this research, enables us to physically test current and future theories of group dynamics.

Sources:

Baruch, Yehuda, Ken Wheeler, and Xia Zhao. "Performance-related Pay in Chinese Professional Sports." *The International Journal of Human Resource Management* 15.1 (2004): 245-59. Web.

Kummerli, R., M. N. Burton-Chellew, A. Ross-Gillespie, and S. A. West. "Resistance to Extreme Strategies, Rather than Prosocial Preferences, Can Explain Human Cooperation in Public Goods Games." *Proceedings of the National Academy of* Sciences 107.22 (2010): 10125-0130. Web.

Reeve, H. K., and B. Holldobler. "The Emergence of a Superorganism through Intergroup Competition." Proceedings of the National Academy of Sciences 104.23 (2007): 9736-740. Print.

Stark, E., J. Shaw, and M. Duffy. "Preference for Group Work, Winning Orientation, and Social Loafing Behavior in Groups. " *Group & Organization Management* 32.6 (2007): 699-720. ABI/INFORM Global, ProQuest. Web.