The Multi-Agent Public Goods Challenge

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Abstract

In the realm of multi-agent systems, the simulation of N-Person Public Goods Games represents a strong approach for exploring cooperative behaviors, strategic decision-making under uncertainty, and social dynamics among autonomous agents. This report presents a simulation study based on Public Good Games, using personality traits like risk willingness and adaptability in a multi-agent system. The agents adjust their risk appetite based on observed actions and received rewards, simulating real-world decision-making processes. The results of the simulation are analyzed to understand the dynamics of agent behavior in different scenarios as well as the optimal personality traits.

Keywords: Public Good Game, Risk Willingness, Adaptability, Common Pool, Strategy

1 Introduction

Public good games are a fundamental experimental paradigm in economics and social science, used to investigate the dynamics of cooperation and collective action among individuals. These games provide a controlled environment to explore how people balance personal interests with the benefits of contributing to a common resource. In a typical public good game, participants decide how much of their private resources to allocate to a communal pot, which is then augmented by a certain factor and redistributed among all players, irrespective of their contributions. This setup inherently presents a social dilemma, where individual rationality can lead to suboptimal outcomes for the group, thereby highlighting the tension between personal incentives and collective welfare.

In this report, we delve into an extended version of the public good game that incorporates elements such as punishment and personality traits, specifically risk appetite and adaptability, to understand how these factors influence cooperative behavior and decision-making. By integrating these traits and punishment, we aim to simulate a more realistic social environment where individuals' behaviors are shaped by inherent characteristics and responses to their peers' actions.

Public Good Games can be implemented in a multiplicity of real-world problems, such as collective funding for infrastructure or community services, Contributions to collective efforts to reduce pollution or preserve natural resources.

2 Approach

Our environment will be a classical N-Person Public Goods Game, played with 4 players, each starting with 10 coins, in 10 rounds, with the goal being to be the person with the most money. Each agent can decide to place some coins in the community box(which at the end of the round, multiplies all the money by a factor of 1.5 and splits it amongst every player). The environment also has a scoreboard that displays the rank of every player after each round, the amount of coins they possess and the contributions to the common box (this is done so agents can learn from what happened in previous rounds). To promote cooperation and complexity between agents psychological parameters were added, making it so every agent has a predefined "personality" that will be shaped each round and is influenced by the actions other players took on previous rounds:

- **Risk willingness:** a personality trait that indicates how little an agent is willing to contribute at the risk of getting punished. Free riders have high risk willingness.

- **Adaptability:** a personality trait that indicates the capacity of a given agent to adapt its behaviour depending on the evolution of the game and on his perception of other agents behavior, in other words, it indicates the degree to

which the agent is willing to change its strategy, to change its risk willingness in order to better adapt to the game; unlike risk willingness, the adaptability doesn't change during the game since it is an intrinsic trait of the agent.

To reduce the free-riding behavior of risk willing agents, we implemented a mechanic in which, if you are the person with the least amount of money contributed to the community box, you will be punished by not receiving your share of the split money. This way, the agent that will have the highest profit in a given round will be the one who put the second smallest quantity in the pool (the agent that put less won't receive money and the agents that put more, will receive the same, having a smaller profit).

By adding the psychological aspect and also the mechanic to prevent people from keeping money, the game has gained a lot of complexity. Every agent should have a "perceived personality" for each one of the other agents based on the actions they took (at the start of the game every agent, to the eyes of one agent, will have a "blank-personality" but with every action, they should start to mold they perception to match as best as they can the reality). This is what will be used to in combination with their own actions to determine the expected play for an agent of a specific type of a personality.

In order to model agents' behaviour and actions, our implementation presents traits of bayesian games adjusted to the needs of the game being studied:

- **A set of players:** our agents that will put money in the common pool.
- **A set of actions:** the amount of money each agent places in the pool.
- **Types:** corresponds to the personality traits of the agents, in our context, the risk willingness is a value between 0 and 1 just like the adaptability.
- **Payoff:** the money that each agent receives from the pool after performing a given action.

Every player optimizes their strategy in order to maximize their expected payoff given their beliefs about other agents' risk willingness: each round, and according to their observations, they adjust the belief they have regarding every other agents' risk willingness, they average the beliefs they have, obtaining an overall belief of the game and adjust their own risk willingness accordingly. The adjustment is proportional to the agent' own adaptability - agents with high adaptability will change their strategy a lot more than agents with low adaptability.

3 Empirical Evaluation

The empirical evaluation of the project will focus on assessing the effectiveness of various strategies - induced by different personality traits - in addressing collective action problems within our N-Person Public Good Game scenario. It should be shown how different scenarios with agents of different personality present different outcome:

- **Win Percentage over multiple simulations:** graph that shows the percenatge of wins by agents considering their personality traits.
- **Evolution of Risk Willingness:** graph that presents the change in risk willingness of each agent.
- **Evolution of Scoreboard:** graph that shows the evolution of the position of each agent in the scoreboard as well as their wealth at each moment.
- **Correlation between Adaptability and Final Money:** graph that shows the correlation between adaptability of a given agent with the money he ends up with in the final round.
- **Correlation between Risk Willingness and Final Money:** graph that shows the correlation between risk willingness of a given agent in the final round with the money he ends up with.

4 Simulations and Results

4.1 Case 1

The first question of relevance in this game is **'What personality contributes to success?'** This question, explores if risk willingness has a higher weight than adaptability or not in defining the success in the game; it also delves into some considerations like pondering if it's good or not to be risk willing and/or adaptable.

This question motivates the first simulation. As a first experiment, in order to find the traits of an agent with the optimal strategy and behavior, we selected 4 agents with diverse personality traits:

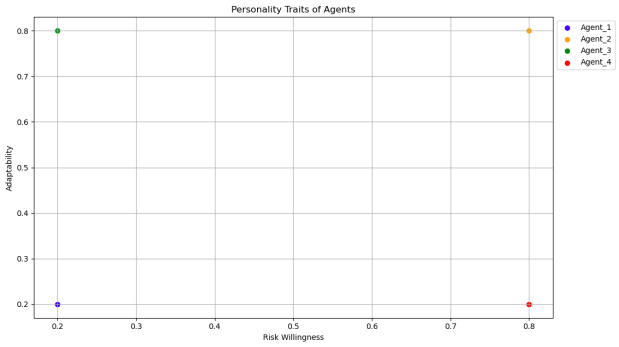

Figure 1: Simulation 1: Agents Personality traits

The behaviour of the agents, even though it's guided by their personalities, it is also guided by their perception of other agents, not being deterministic, therefore if we run this first simulation 100 times, we can see, in Figure 2, who tends to win.

To better understand why agent 2 tends to win, let's look at a single repetition of simulation 1. As can be seen in Figure 3 and Figure 4, Agent 1 starts with a low risk willingness and low adaptability and as he progresses through the game, he starts reducing the amount of money he puts in the pool since he notices that other agents are taking more risks. Agent 2 who has high risk willingness and adaptability, starts by taking a lot of risk but as he doesn't get rewarded in round 1, he quickly adjusts to a slightly more conservative strategy and progresses from there;

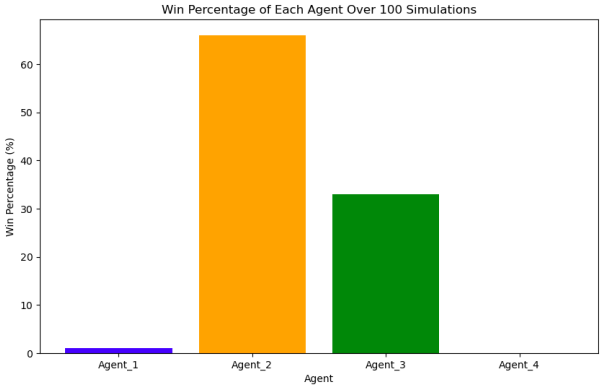

Figure 2: Simulation 1: Winner after repeating Simulation1 100 times

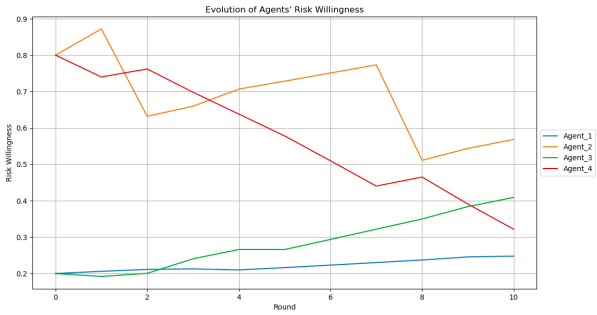

Figure 3: Simulation 1: Evolution Of risk willingness

later on, he loses money again but quickly adapts just like before ending up winning.

Agent 3 starts playing in a conservative manner and since he has a high adaptability, he starts adopting the optimal strategy by increasing his risk willingness gradually as he senses and analyzes the game.

Agent 4 having a high risk willingness and low adaptability, as he takes risks and doesn't get rewarded, he slightly changes his strategy, initially reducing his risk willingness in a small amount; since the agent didn't react properly, he still gets punished and reduces his risk willingness again in such a slow process that the lack of capability he has to change his risk willing behavior leads to his loss.

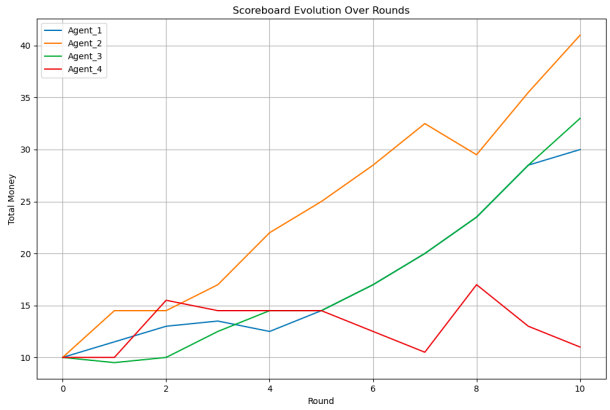

Figure 4: Simulation 1: Evolution Of Scoreboard

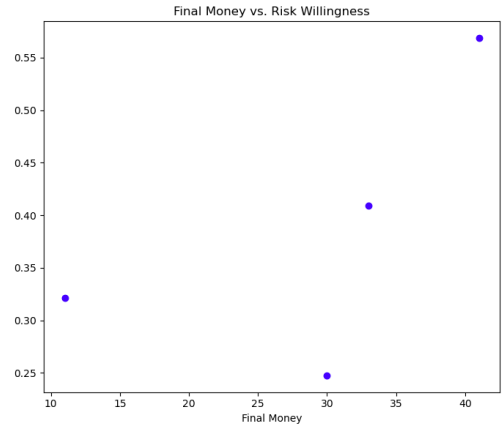

Figure 5: Simulation 1: Correlation between Final Money and Risk Willingness

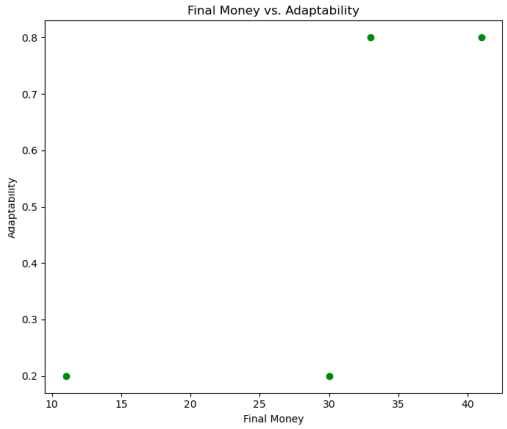

Figure 6: Simulation 1: Correlation between Final Money and Adaptability

From figure 5 and figure 6 it is easy to understand that agents with high adaptability and high risk willingness tend to win the game.

Now, let's look at a scenario where we have 3 agents that have, among them, similar personality traits. **When a fourth agent joins the game, what are the optimal personality traits he should adopt to guarantee success?**

4.2 Case 2

Let's consider for the case where 3 agents tend to risk a lot and have low adaptability (i.e. free riders):

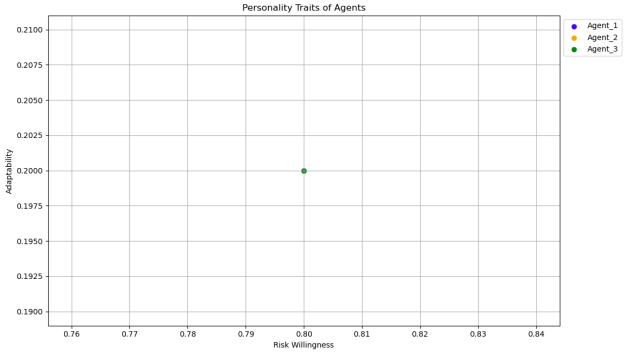

Figure 7: Simulation 2: Agents Personality traits

After running multiple simulations with different traits for the fourth agent and repeating them 1000 times, the personality traits that increase the likelihood of success for this scenario are those composed of high adaptability and low risk willingness, the adaptability having more relevance.

This makes sense since all the other agents, who aren't very adaptable and are very risk willing, tend to risk putting less money, since the fourth player

Table 1: Agent Performance in Simulation 2

Traits of fourth agent	Win Percenta
High risk willingness, Low adaptability	22.9%
Low risk willingness, High adaptability	34.5%
High risk willingness and adaptability	32.7%
Low risk willingness and adaptability	25%

starts with a conservative strategy, he gets rewarded and since the other agents are less adaptable than him, he can quickly understand the optimal values to bet - smaller values than that he is currently betting but that are still higher than the values bet by the remaining agents - while the others slowly change their behavior. This can be seen on the risk willingness of a single simulation, as shown in figure 8.

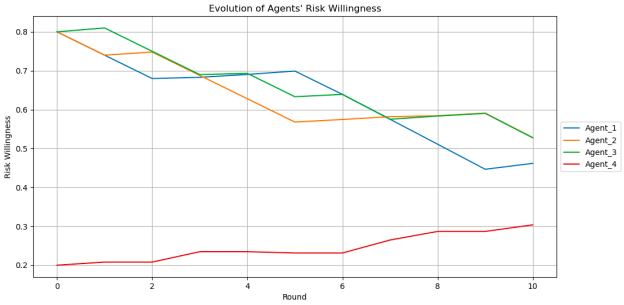

Figure 8: Simulation 2: Evolution Of risk willingness

4.3 Case 3

Let's consider for the case where 3 agents tend to risk as little as possible and have low adaptability (i.e. cooperative agents):

After running multiple simulations with different traits for the fourth agent and repeating them 1000 times, the personality traits that increase the likelihood of success for this scenario are those composed of high adaptability and low risk willingness, the risk willingness having more relevance.

In this case, the optimal traits correspond to Low risk willingness and High adaptability by a big margin since, most of agents are cooperative, if the fourth

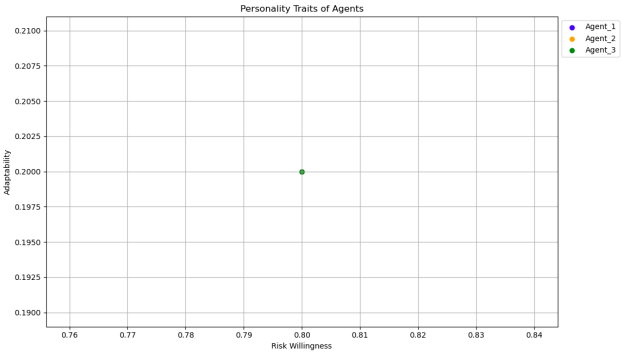

Figure 9: Simulation 3: Agents Personality traits

Table 2: Agent Performance in Simulation 3

Traits of fourth agent	Win Percentage
High risk willingness, Low adaptability	0%
Low risk willingness, High adaptability	64.4%
High risk willingness and adaptability	2.2%
Low risk willingness and adaptability	21%

agent isn't as cooperative as them and takes risk, he will be penalized. The high adaptability allows the additional agent to, once again, quickly understand the optimal values to bet, as can be seen in figure 9.

5 Discussion

Our findings suggest that agents with high adaptability tend to perform better in the game, allowing agents to dynamically adjust their strategies based on the observed actions of others and the outcomes of previous rounds. High adaptability enables agents to swiftly modify their risk-taking behavior, thereby optimizing their contributions to the communal pot and avoiding penalties. Conversely, agents with low adaptability struggle to adjust their strategies effectively, leading to suboptimal outcomes and frequent penalties.

In scenarios where agents possess similar personality traits, the adaptability of a new agent entering the game becomes crucial. Our simulations in-

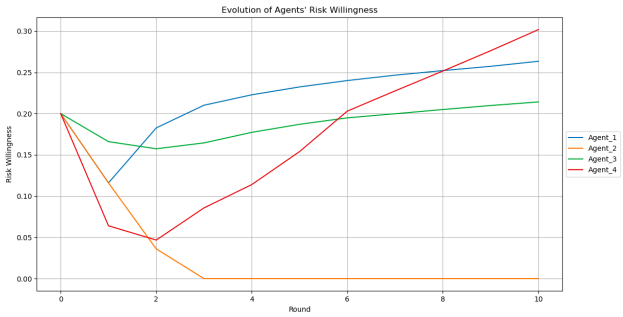

Figure 10: Simulation 3: Evolution Of risk willingness

dicate that a new agent with high adaptability and low risk willingness can achieve better results. This agent can quickly learn from the game dynamics and other agents' behaviors, while starting with a more conservative yet effective strategy. This adaptability enables the agent to outperform others who are more rigid in their approach.

Future work could explore the use of additional models towards finding more precise risk willingness and adaptability levels for very specific scenarios.

6 Conclusion

This simulation study highlights the significant role of personality traits, particularly risk willingness and adaptability, in shaping cooperative behavior and strategic decision-making in Public Goods Games. High adaptability emerges as a critical factor for success, enabling agents to effectively respond to the dynamic game environment. These findings contribute to a deeper understanding of social dynamics in multi-agent systems and offer practical insights for fostering cooperation in real-world collective action problems.