Model Title: The role of heterogeneity and the dynamics of voluntary contributions to public goods

The following model description follows the ODD (Overview, Design concepts, Details) protocol for describing individual- and agent-based models (Grimm et al. 2006[1], 2010[2]).

1. Purpose

This model simulates the behavior of different cooperation preference types observed in a repeated linear public goods game and how the interaction between the different types affects the dynamics of voluntary contributions. The model is based on the results from an experiment that was done with real human subjects by the researchers.

Briefly, the public goods game is an environment where a group of N agents are given a certain endowment and have to make the decision of allocating this endowment between private consumption and the production of a public good. The utility an agent gets from one unit kept for private consumption is different from the utility an agent gets from one unit contributed towards a public good which is shared among all agents.

For more information about the experiment from which this model is originated, contact the authors.

2. Entities, state variables, and scales

At the beginning, the user selects the number of agents of each preference type and sets the common parameters for all agents. At each tick, each agent receives a fixed endowment, then places a contribution to the public account according to its preference type and the average contribution of other agents in the previous tick. After each tick, the total and average contributions are calculated and tabulated. Also, the contribution and payoff of each preference type is calculated.

State variabes

- Profit-Factor-PublicGood: is the return from each unit contributed to the public good.
- Profit-Factor_PvtGood: the return from each unit kept for private consumption.
- Initial-Endowment: the initial endowment each agent receives at the beginning of each tick.
- Number-of-Agents: the number of agents that will be assigned to preferences randomly if the Random Setup is used.

Entities (types of agents):

- Number-of-Freeriders: the number of agents with a preference to free-ride.
- Number-of-PerfectConditionalCooperators: the number of agents with a preference to contribute the same amount as their peers.
- Number-of-Above-Diagonal-ConditionalCooperators: the number of agents with a preference to contribute more than their peers.

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[1] Grimm, V. et al. (2006) A standard protocol for describing individual-based and agent-based models. *Ecological Modelling* 198:115-126.

[2] Grimm V, Berger U, DeAngelis DL, Polhill G, Giske J, Railsback SF. 2010. The ODD protocol: a review and first update. *Ecological Modelling* 221: 2760-2768.

- » Number-of-Below-Diagonal-ConditionalCooperators: the number of agents with a preference to contribute less than their peers.
- » Number-of-Alt-ConditionalCooperation: the number of agents with a preference to contribute more than their peers when the average contribution is less than half the endowment and a preference to contribute less than their peers when the average contribution is more than half the endowment.
- » Number-of-TriangularContributors: the number of agents with an increasing monotonic trend of contributions up to a certain level then a decreasing monotonic trend of contributions.
- » Number-of-RandomContributors: the number of agents with a preference to contribute a random amount.

Scales:
Each tick represents one decision period where interaction between agents takes place.

3. Process overview and scheduling

Pseudo code of the dynamics of the simulation model.

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Create an artificial environment of N agents according to contribution preferences set by user
Set common parameters for all agents (return from public good and endowment)
Create a memory for each agent to store average contribution of other group members
Calculate and plot statistics

For each time period
    For each agent
        Receive endowment for time period
        Place contribution according to an agent's strategy
        End for

Calculate total contribution and average contribution to public good

For each agent
    Calculate own payoff
    Calculate average contribution of other group members
    Update memory
End for

Calculate and plot statistics
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4. Design concepts

Basic principles.
The main assumption underlying this model is that the different cooperative preference types of agents in a public goods setting have a major effect on the overall level of contribution to the public good. The model incorporates these different types of preferences by a set of programmed strategies based on experimental data.

The payoff function for each agent *i* is represented by:

$$\pi_i = p\,(z_i - y_i) + (a / N) * Y$$

In the equation, *p* is the is the return from each unit kept for private consumption; z_i is the endowment given to each agent at the beginning each time period; y_i is the amount an agent decides to contribute to the public good; *a* is the return from each unit contributed to the public good; *N* is the number of agents; and finally, $Y = \sum_{i=1}^{n} y_i$ is the total contribution to the public good by all agents.
There are seven preference types an agent can follow: free-riding, perfect conditional cooperation, above-diagonal conditional cooperation, below-diagonal conditional cooperation, alternating-diagonal conditional cooperation, triangular contribution, and random contribution.

Consult authors or paper under publication for more information on how preference types were elicited.

Emergence.
In a public goods setting, group composition influences long-run contribution levels. We consider how each agent type (representing a social preference type) influences contributions by varying its proportion in the population. Our simulations are meant to address questions related to critical proportions of each agent that drive the population towards free-riding. For example, we ask whether a small proportion of free-riders can drive the population to a state where contributions cease.

Sensing and Adaptation.
Agents' actions depend on their pre-programmed preference type and the average contribution of other group members in the previous decision period.

Interaction.
Interaction is repeated among group members.

5. Initialization

State variables are set by the user. The initial contribution level is set at the average contribution in the first decision period in the repeated public goods game of the experiment.

6. Input data

Data from a laboratory experiment was used to program the behavior of agents and validate the model.

7. Submodels

Agents' behavior are programmed to act according to their predetermined type/strategy that is based on the average contribution of other group members in the previous time step. After an agent places its preferred contribution in a given time period, it is informed about the average contribution of its group peers, and adjusts its contribution behavior for the following period. Parameters used to program the behavior of the agents are based on the parameters obtained from the experiment in the previous chapter. The initial contribution is determined from data of the first decision period of the repeated public goods game of the conducted experiment Agents are programmed as follows.

Agents' behaviours functional form:

Let the average contribution of other group members in a previous time period be v_{t-1}; the initial endowment granted to each agent at each time period be T tokens.

» ***Free Riders***

The probability of not contributing to the public good at any given time period be l, where l follows a continuous uniform distribution from 0 to 1. Then the contribution function at time period t will be:

$$Contribution_t = \begin{Bmatrix} 0 & when\ \ l \leq 0.75\ \forall\, v_{t-1} \\ 1 & when\ \ l > 0.75\ \ \forall\, v_{t-1} \end{Bmatrix}$$

» ***Perfect Conditional Cooperators***

$$Contribution_{t=1} = \left\{ uniform\ (0, \frac{T}{2}) \right\}$$

$$Contribution_{t>1} = \{ v_{t-1} + Normal\,(0.04, 0.4) \qquad when\ 0 \leq v_{t-1} \leq T\ \ \}$$

» ***Above-diagonal Conditional Cooperator***

$$Contribution_{t=1} = \{ Normal\ (3.8, 4.2) \}$$

$$Contribution_{t>1} = \begin{Bmatrix} v_{t-1} + Normal\ (1.9, 4.84\ ) & when\ \ 0 \leq v_{t-1} \leq 0.2T \\ v_{t-1} + Normal\ (1.09, 3.24) & when\ \ 0.2T < v_{t-1} \leq T \end{Bmatrix}$$

» ***Alternating-diagonal Conditional Cooperator***

$$Contribution_{t=1} = \{ Normal\ (3.2, 3.61)\ \}$$

$$Contribution_{t>1} = \begin{Bmatrix} v_{t-1} + Normal\ (1.25, 5.07) & when\ 0 \leq v_{t-1} \leq 0.2T \\ v_{t-1} + Normal\ (-0.4, 4) & when\ 0.2T < v_{t-1} \leq 0.5T \\ v_{t-1} + Normal\ (-2.2, 6.76) & when\ 0.5T < v_{t-1} \leq 0.9T \\ v_{t-1} + Normal\ (-3.7, 14.44) & when\ v_{t-1} = T \end{Bmatrix}$$

» ***Below–diagonal Conditional Cooperator***

$$Contribution_{t=1} = \{ Normal\,(2.7, 4.84) \}$$

$$Contribution_{t>1} = \begin{Bmatrix} v_{t-1} + Normal\,(-0.7, 1.15) & when\ 0 \leq v_{t-1} \leq 0.3T \\ v_{t-1} + Normal\,(-2.3, 1.96) & when\ 0.3T < v_{t-1} \leq 0.5T \\ v_{t-1} + Normal\,(-4.07, 5.29) & when\ 0.5T < v_{t-1} \leq T \end{Bmatrix}$$

» ***Triangular Contributors***

$$Contribution_{t=1} = \{ Normal\,(2.4, 3.61) \}$$

$$Contribution_{t} = \begin{Bmatrix} v_{t-1} + Normal\,(-0.4, 2.25) & when\ 0 < v_{t-1} \leq 0.5T \\ v_{t-1} + Normal\,(-5.2, 12.96) & when\ 0.5T < v_{t-1} \leq T \end{Bmatrix}$$

» ***Random Contributors***

$$Contribution_{t} = \{ uniform\,(0,10) \quad when\ 0 \leq v_{t-1} \leq T \}$$