Evolution of Cooperation in Multi-level Public Goods Game with Mobility

Dian Gu, Haoran Yang, Kaiyu Ye, Ziyue Zhu

Barcelona Graduate School of Economics

Contents

1. Introduction

2. Model & Methods

3. Simulation Results

4. Conclusion

5. Questions

Introduction

Research Question

Research Question

Does mobility in multi-level public goods game allow for the survival of altruistic strategies?

Multi-level Public Goods Game

About Multi-level Public Goods Game:

1. Community and Nation;
2. National-level or Community-level public good;
3. Individuals contribute to either of them, or free-ride.

Mobility

Involving Mobility, e.g., labor mobility in Schengen Area.

Multi-level Public Goods Game

Common Discussions

- A classic conflict between individual interest and social optimality;
- Dominant Strategy is to free ride and Nash Equilibrium is at zero-contribution;
- Experimental Economics: Voluntary contribution steadily decrease

Explainations

- Confusion, altruism;
- Rationality, common knowledge

$\Rightarrow$ **Evolutionary Game Theory**

Agent-based Modelling

Complexity of the model setting

- Heterogeneous individuals;
- Movement across communities;
- Contribution strategies;
- Repeated competitive interactions between agents

Agent-based Modelling (ABM)

ABM models agents' automatic decision-making process.

Advantages of using ABM

- Can simulate large number of simple reactions superimposed on each other;
- Can simulate the dynamic evolution process with conditions closer to reality;
- More flexible settings

Model & Methods

Model: Evolutionary Game Theory Approach

Evolutionary Game Theory

- DO NOT assume of rationality and common knowledge
- Fixed Strategy
- Utility is perceived as survival fitness
- The organisms with the best interaction strategy has the highest fitness, ability to reproduce and thus will be favoured by natural selection
- Evolutionary Stable Strategies
  - Cannot be invaded by a small number of individuals playing a different strategy (Maynard Smith and Price 1973)
  - Corresponds to a strategy adopted by fully informed rational players

Model

Payoff Function

Utility =

Wealth - Contribution - Consumption

+ (Total Contribution to National Public Goods) x $\frac{x^N}{n^N}$

+ (Total Contribution to Community Public Goods) x $\frac{x^C}{n^C}$

- Consumption : Energy spent

Flow of Simulation

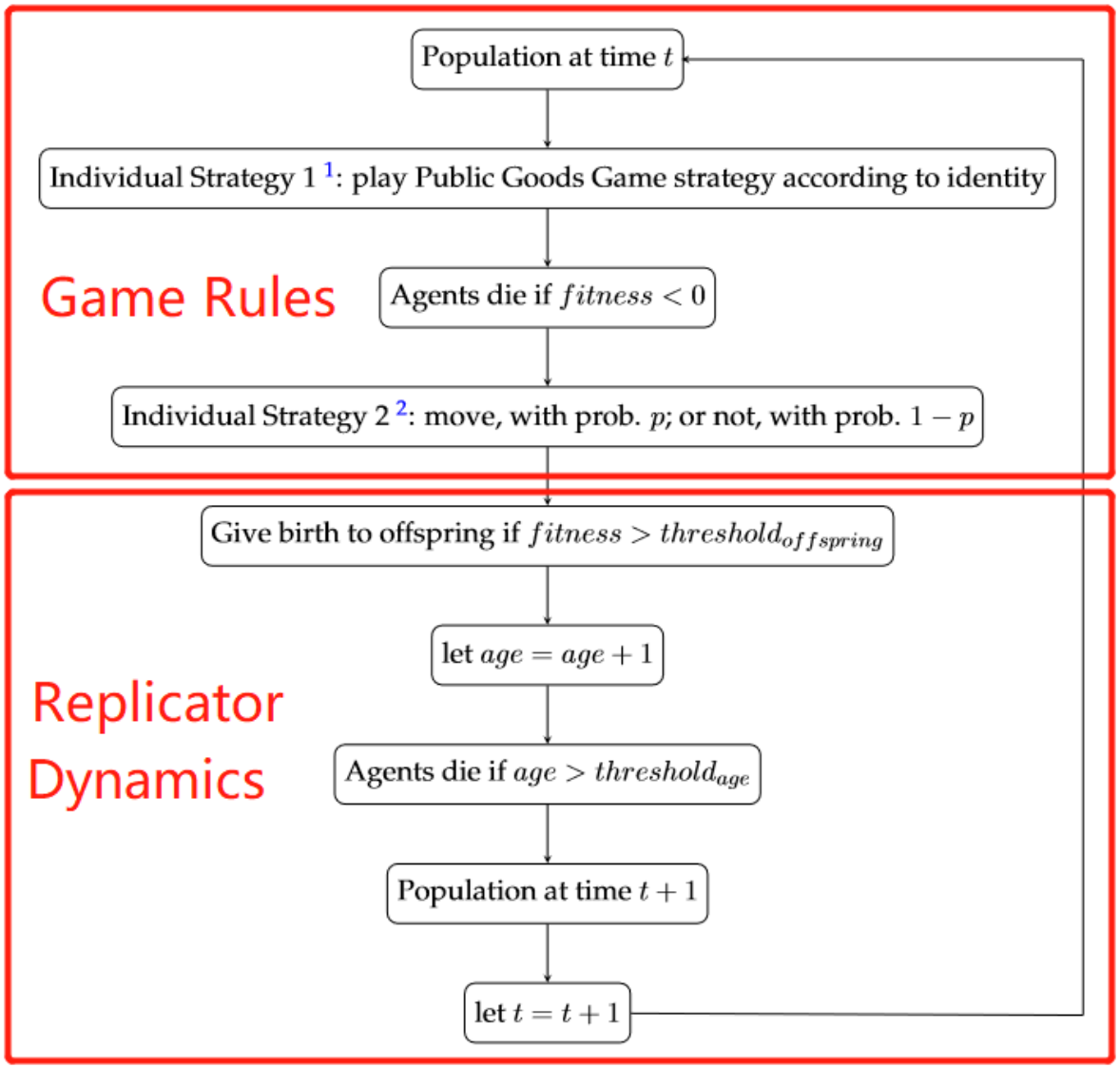


Figure 1: Model Working Flow

Notes: 1: For all kinds of agents; 2: Only for community-level contributors

Individual Strategy 1

Agents are born with a strategy

- free-riding (F)
- investing in national level public good (N)
- investing in community level public good (C)

Flow of Simulation

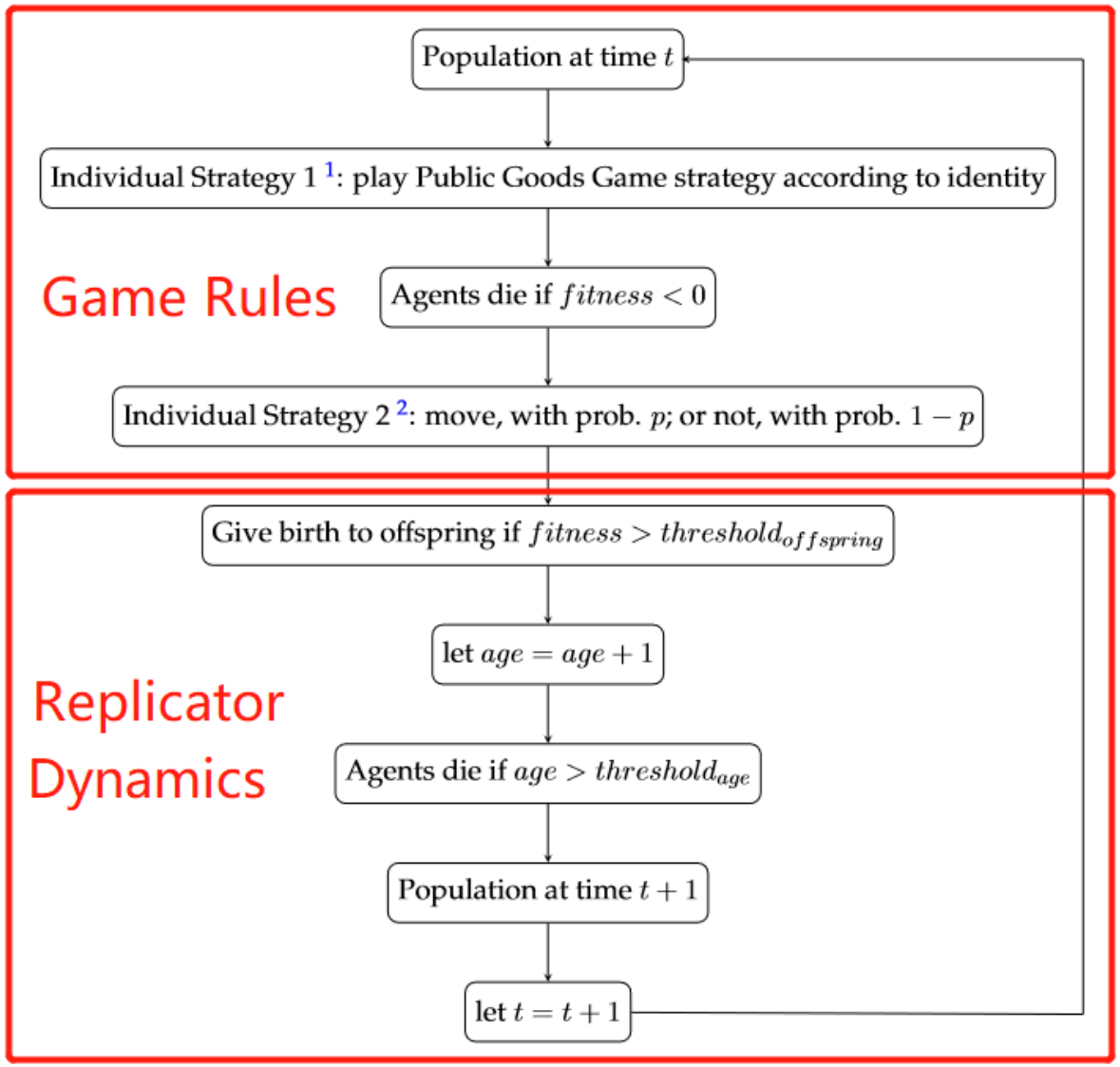


Figure 1: Model Working Flow

Notes: 1: For all kinds of agents; 2: Only for community-level contributors

Individual Strategy 2

Mobility of Community-level Contributors

- Community-level contributors will receive a private message that their current community is undesirable.
- This message is conditioned on the fact that his individual fitness level is decreasing.
- These contributors move to another community with a probability.
- Their destination of movement is random as they do not possess information about the population structure of other communities.

Flow of Simulation

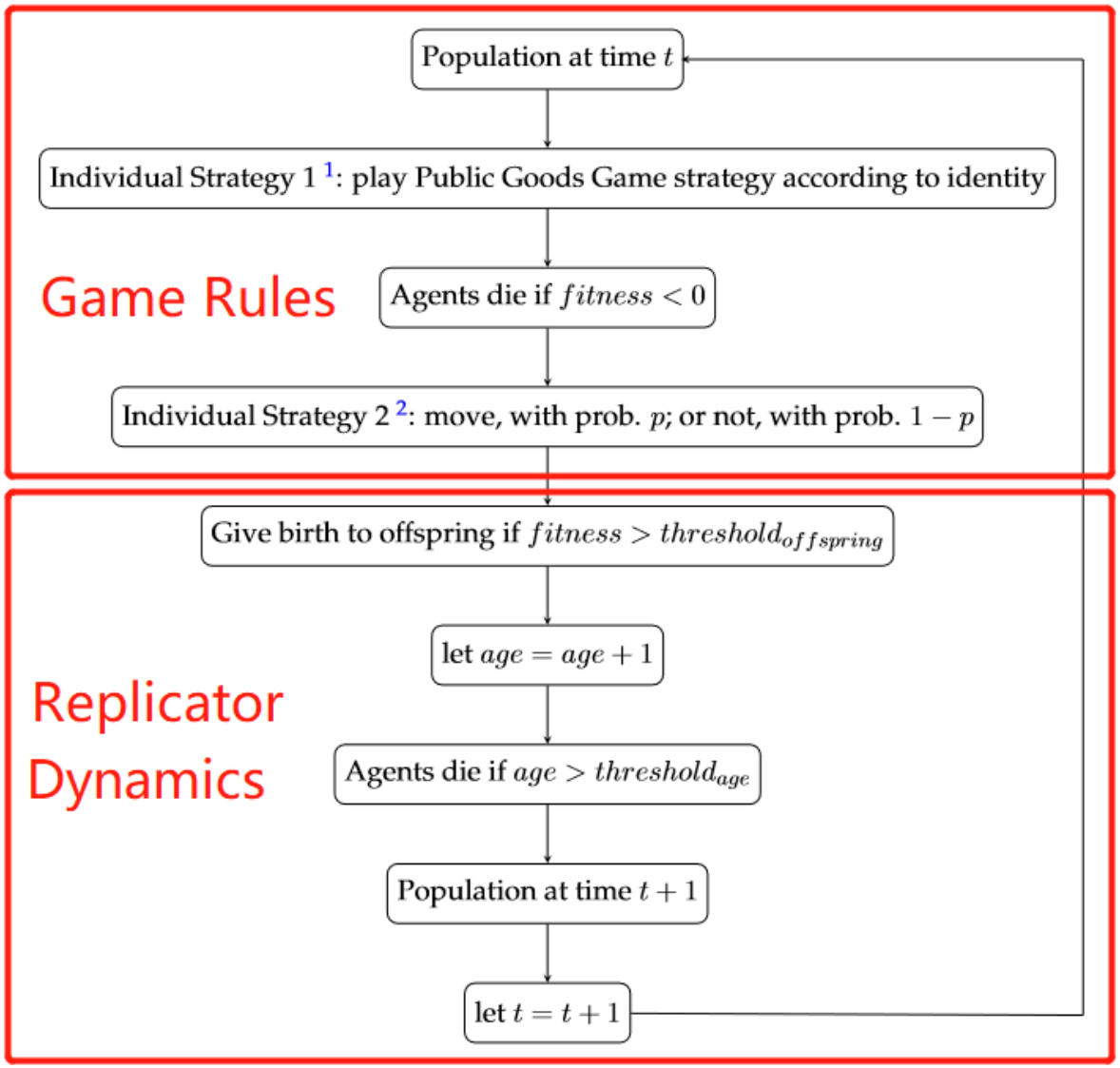
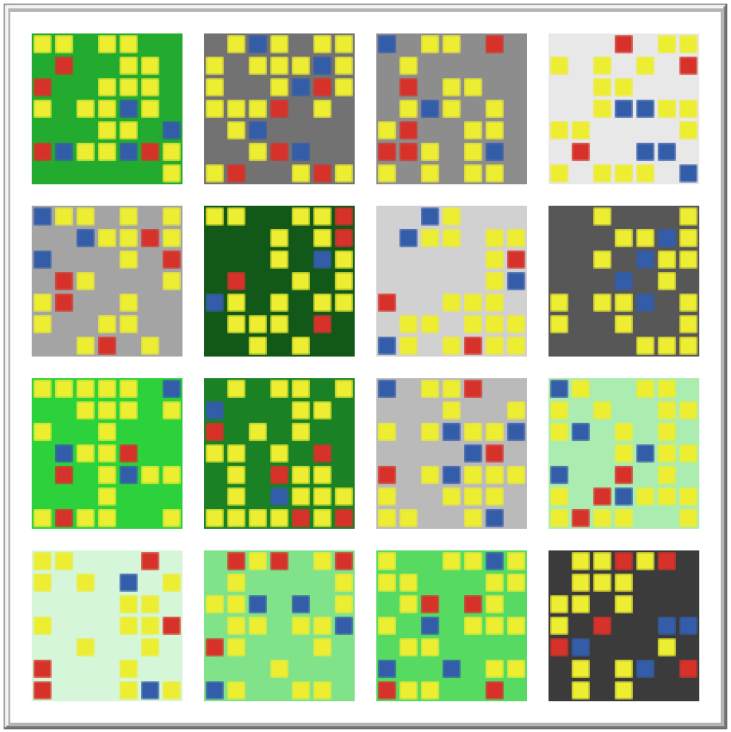


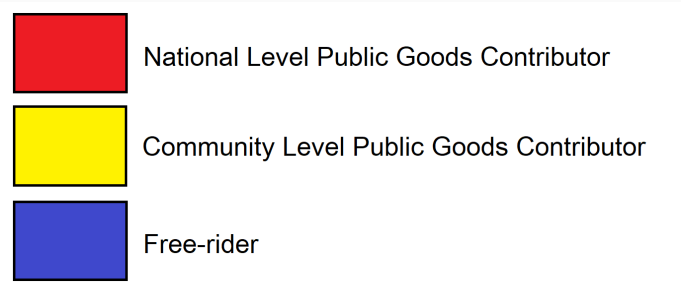
Figure 1: Model Working Flow

Notes: 1: For all kinds of agents; 2: Only for community-level contributors

Initial Settings



(a) Initial Settings



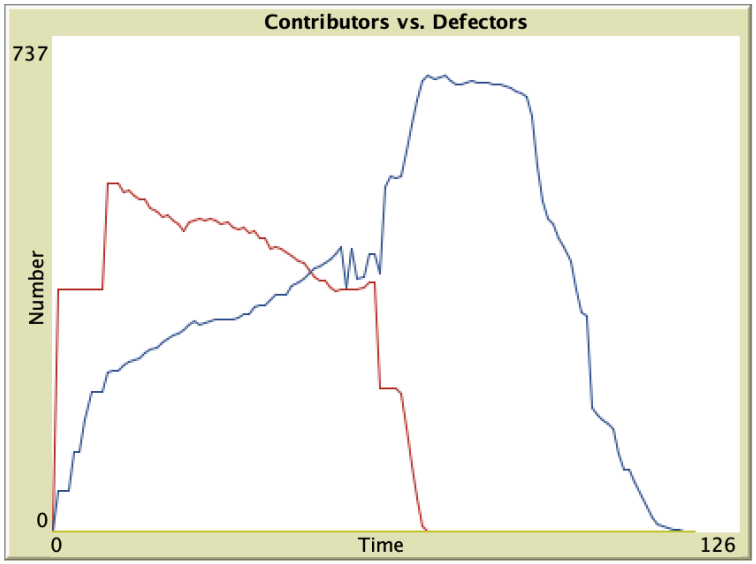
(b) Legend

Model Calibrations:

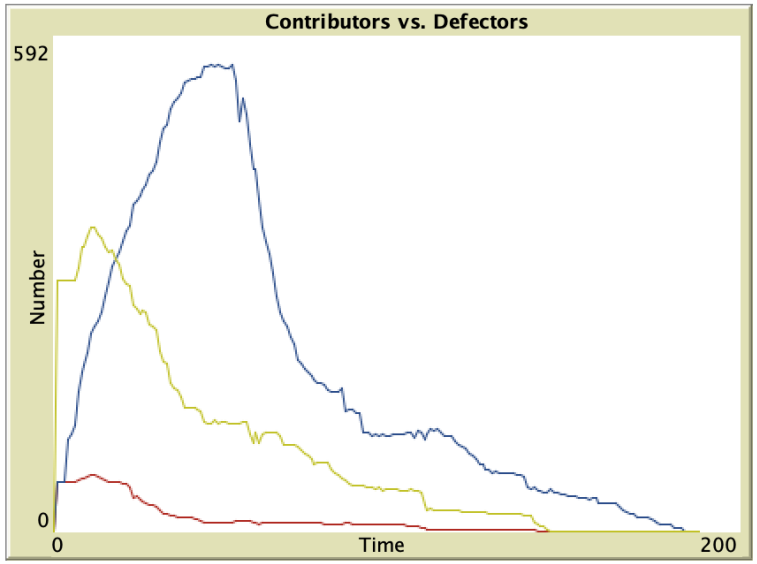
- Total number of agents= 420
- Max Age= 50
- Initial Fitness= 20
- Reproduction threshold = 40
- n-multiplier = 2.25
- c-multiplier = 2
- contribution = 5

Simulation Results

Baseline Results



(c) Classic Public Goods Game



(d) Multi-level Public Goods Game

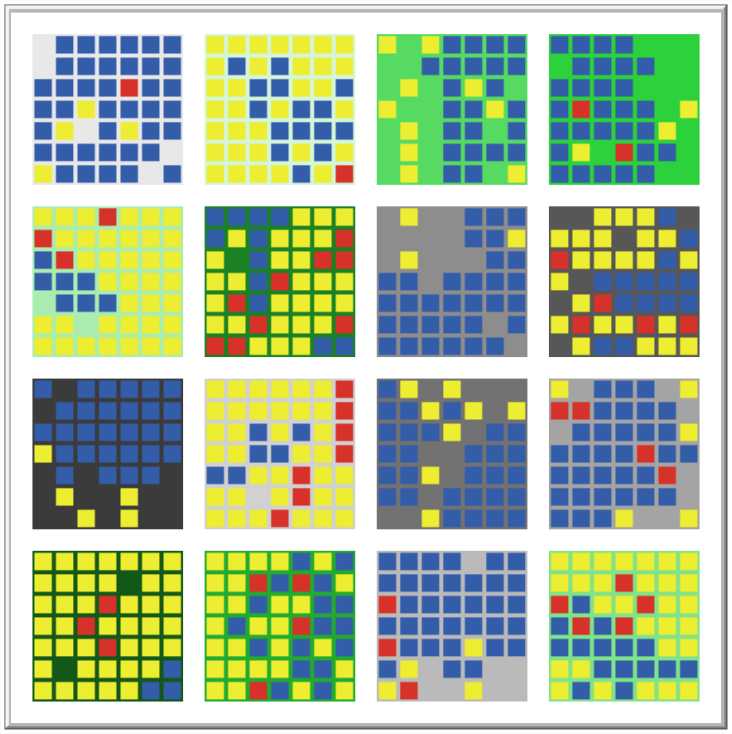
Population Distribution:

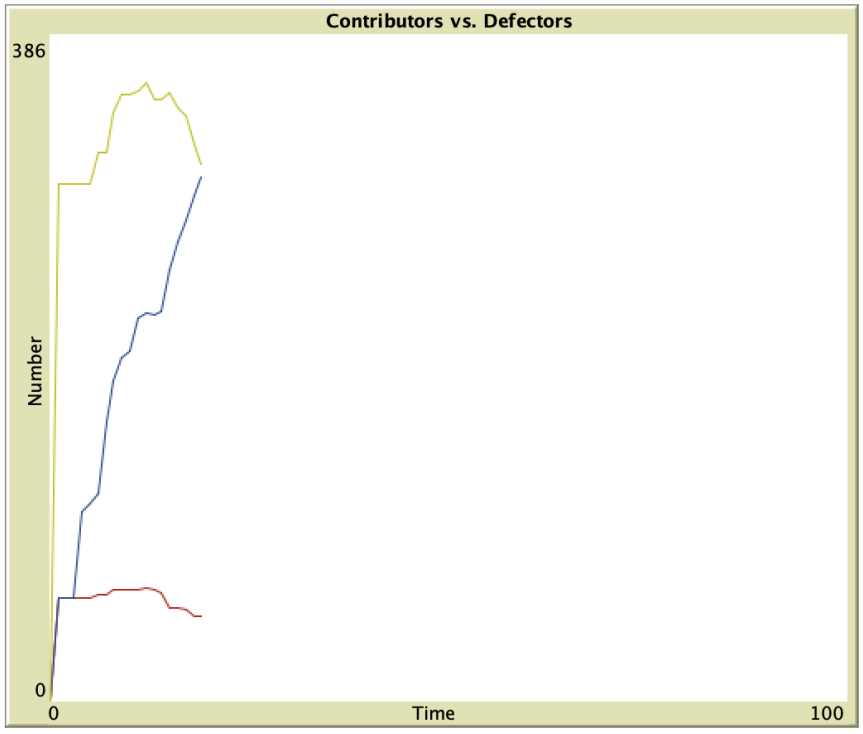
(c) N: 360, F: 60; (d) N: 60, F: 60, C: 300

Results:

- Both baseline models are incapable of sustaining contribution.
- All agents survive for longer period in Multi-level Public Goods Game.

Results with full Mobility: Stage 1

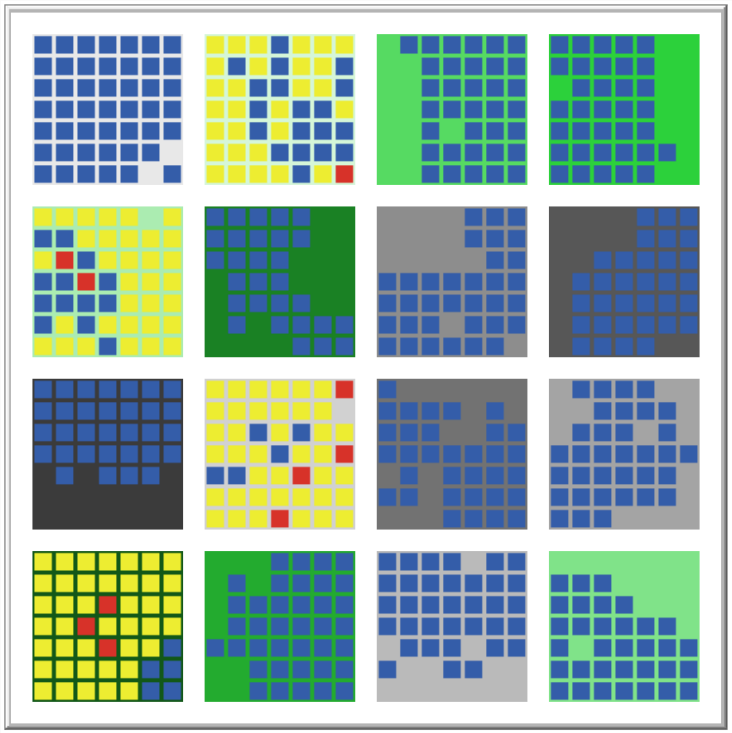


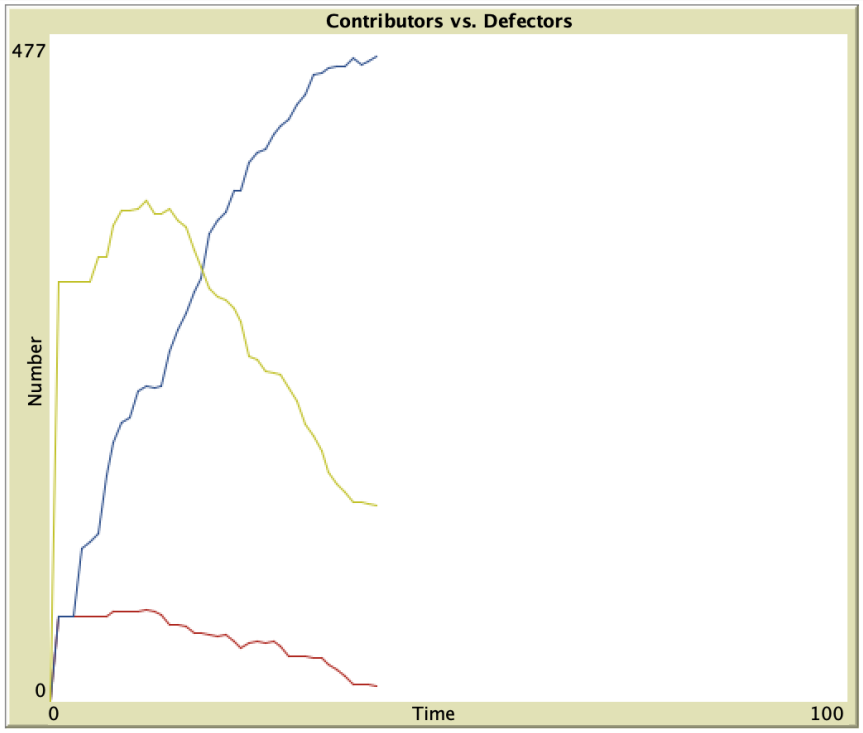


Characteristics:

- Benefiting from the dividends of the public goods, agents initially increase in population size;
- Free-riders grow faster than national-level contributors, although they have the same population in initial distribution.

Results with full Mobility: Stage 2

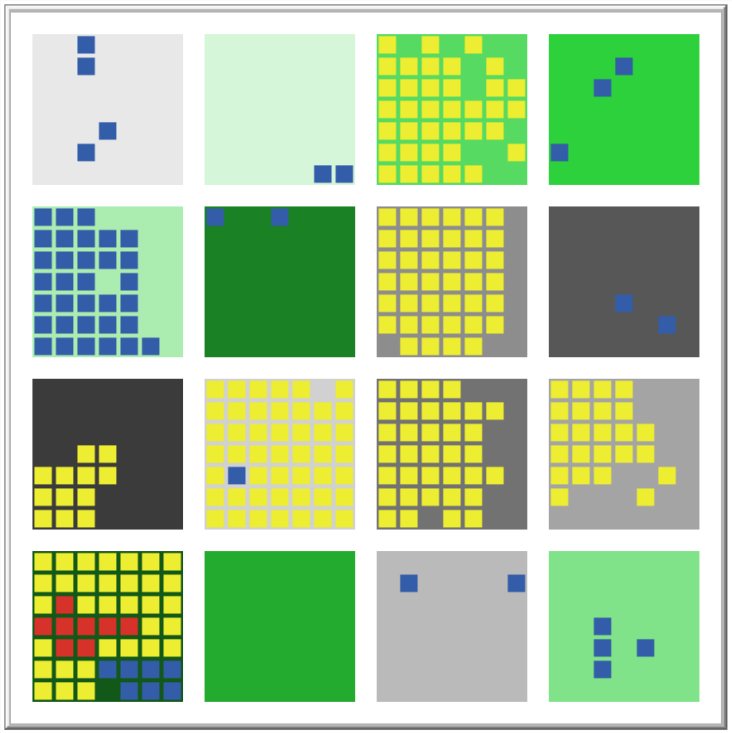


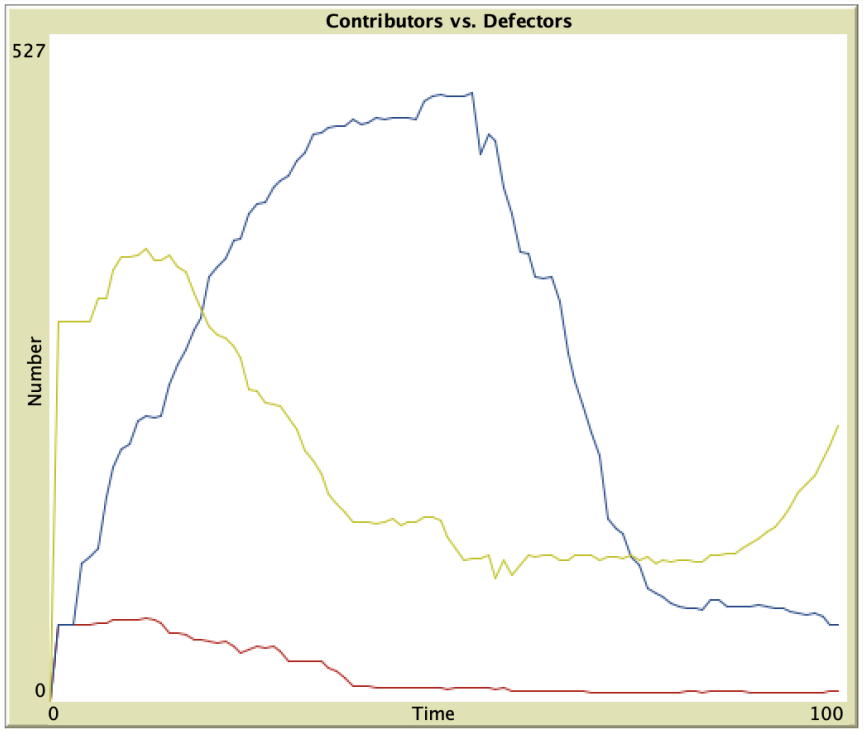


Characteristics:

- The number of free-riders overrides the contributors;
- The number of contributors decrease sharply and are gathered.

Results with full Mobility: Stage 3

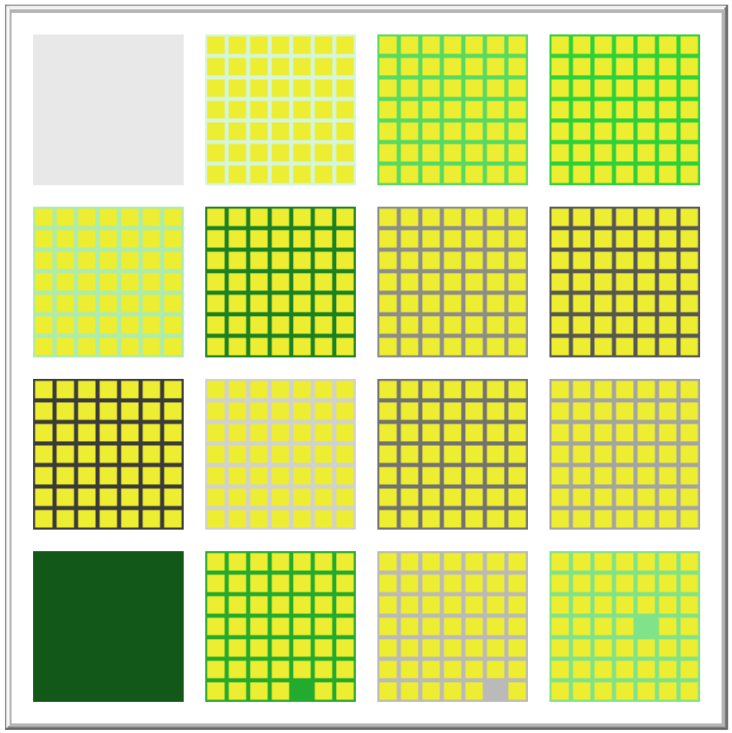


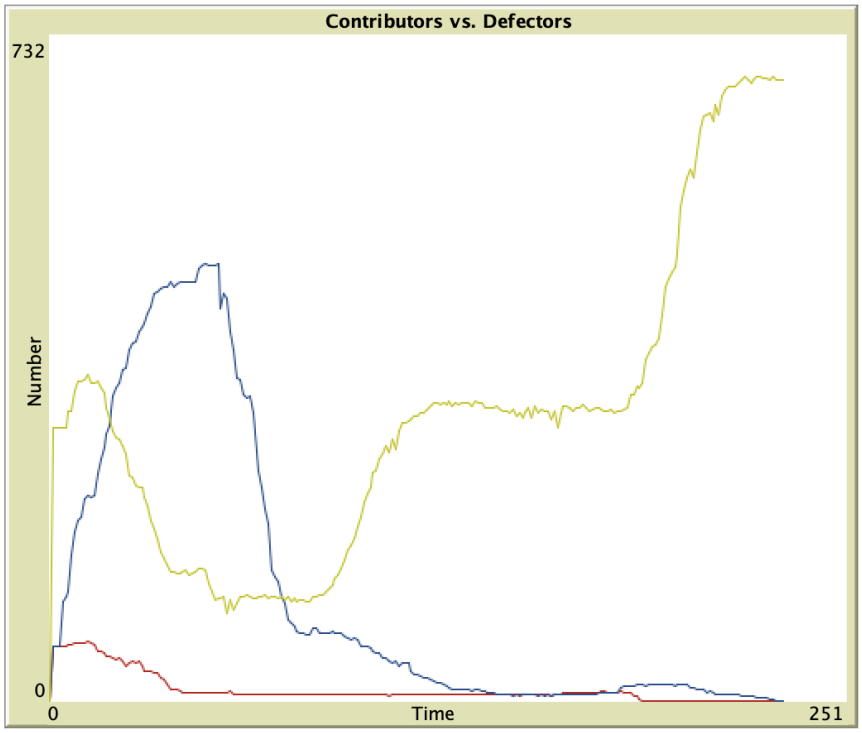


Characteristics:

- Free-riders living in communities with only free-riders are slowly eliminated;
- While those in communities with contributors continue to flourish.

Results with full Mobility: Stage 4





Equilibrium:

- Free-riders led to self-destruction;
- Cooperation can be sustained in this environment without free-riders.

Results with Probabilistic Mobility

Relax the assumption:

- Probabilistic Mobility $P(move) \in (0, 0.5]$;
- Movement cost: 5

Results:

This result provide evidence that despite having low mobility, contribution can still be sustained with the elimination of free-riders.

Prob	Free-riders	National Con.	Community Con.
1	0	29.7%	99.3%
0.5	0	31.3%	98.3%
0.4	0	30.0%	97.7%
0.3	0	30.3%	98.0%
0.2	0	27.0%	95.7%
0.1	0	31.7%	97.0%

Table 1: Statistics for Survival Rate

Mutation Results

Offspring Mutation

- The agents' offspring mutates with a probability of 10%

Improvements:

- Evolutionary stable strategy may be reached under lower movement cost and lower mutation rate;
- Set less harsh criteria for time period.

	Survival Rate				
Agent Type	Prob. = 0.5	Prob. = 0.4	Prob. = 0.3	Prob. = 0.2	Prob. = 0.1
Free-riders	59.0%	56.3%	50.0%	49.7%	58.3%
National	58.7%	56.0%	50.0%	49.0%	57.3%
Community	59.0%	56.3%	50.0%	49.3%	58.0%

Table 2: Statistics for Mutation

Conclusion

Policy Implications & Future Extensions

Policy Implication:

- In general, government-intervention in terms of rewards and punishment is unnecessary
- However, promoting free movement of labor may be beneficial to the total welfare of the society

Possible Extensions:

- Reduce movement cost and mutation rate.
- Conduct lab experiment on likelihood of individuals moving to another group, in the case of uncertainty.

Questions