Emergence of cooperation and patterns of move-play in Demographic Donor-Recipient Game[1]

Tsuneyuki Namekata[1] and Yoko Namekata

[1] Department of Information and Management Science, Otaru University of Commerce, Midori 3-5-21, Otaru, Hokkaido, 047-8501, Japan

Abstract. We examine distribution of strategies in demographic Donor-Recipient game where patterns of move-play are restricted to simple structure. Players are initially randomly distributed in square lattice of cells. In each period, players move locally to random cell in neighbors or globally to random unoccupied cell in the whole lattice, and play multiple games against local neighbors or against randomly selected global players. We restrict patters of move (play) to local or global; local (global) means with high probability the player moves (plays) locally (globally). If wealth (accumulated payoff) of player becomes negative or his age becomes greater than his lifetime, he dies. If his wealth becomes greater than some amount and there is unoccupied cell in neighbors, he has an offspring.
Players consist of TFT-like strategies; TFT uses Defect if the state is 0, Cooperate if it is 1 and the smallest state number that prescribes Cooperate is regarded as threshold. We allow up to three states and assume players may change their threshold at most once depending on their experience.
We show, by Agent-Based Simulation, for example, Cooperative strategies evolutionarily tend to move and play locally, Defective do not, and AllC and AllD are abundant unless all strategies initially play locally.

Keywords: demographic game, Donor-Recipient game, emergence of cooperation, generalized reciprocity, Agent-Based Simulation

1 Introduction

Emergence of cooperation in repeated dilemma game is a very fascinating and important topic. This paper investigates the effect of move-play pattern and repetitions of games per period on the emergence of cooperation and distribution of strategies in demographic Donor-Recipient game. Donor-Recipient (DR) game is a two-person game where one player is randomly selected as Donor and the other as Recipient. Donor has two moves, Cooperate and Defect. Cooperate means Donor pays cost c in order for Recipient to receive benefit b ($b>c>0$). Defect means Donor does nothing. Note that Recipient has no move.

Epstein [1] introduces demographic model. He shows the emergence of cooperation where AllC's and AllD's are initially randomly distributed in a square lattice of cells. In each period, players move locally (that is, to random cell within the neighboring 4 cells, that is, north, west, south, and east cells; von Neumann neighbors, if unoccupied) and play Prisoner's Dilemma (PD) game against local (neighboring) player(s). If wealth (accumulated payoff) of a player becomes negative or his age becomes greater than his lifetime, he dies. If his wealth becomes greater than some amount and there is an unoccupied cell in von Neumann neighbors, he has an offspring and gives the offspring some amount from his wealth. Namekata and Namekata [2] extend Epstein's original model discussed above by introducing global move, global play, and a player called Referential who uses tag-based TFT with connections. They show cases where the cooperation emerges in some frequency between Referential and AllD, while it is almost impossible between AllC and AllD. Also Namekata and Namekata [3] introduce Reluctant players, who delay replying to changes and use extended forms of TFT, into demographic PD game and consider the effect of Reluctant players on the emergence of cooperation. Namekata and Namekata [4] further introduce variable-threshold strategies, which vary their threshold (tendency toward cooperation) at most once in their lifetime depending on their experience, into demographic DR and PD games and examine the effect of variable-threshold strategies on the emergence of cooperation.

Nowak and Sigmund [5] consider the emergence of cooperation in different setting where two players are randomly matched, one is selected as Donor and the other as Recipient at random, and play DR game at each period. Frequency of a strategy at the next period is proportional to the payoff of the strategy earned at the current period, which is different from that in our demographic model. The chance that the same two players meet again over periods is very small. Every player has his own image score that takes on some range, is initially zero, and increases or decreases by one if he cooperates or defects, respectively. Donor decides his

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move (Cooperate or Defect) depending on the opponent's image score. Riolo et al. [6] deal with similar repeated DR game setting where, instead of image score, every player has his own tag and tolerance and Donor cooperates only if the difference between his tag and the opponent's is smaller than his tolerance.

In general, reciprocity explains the emergence of cooperation in several situations [7]: Direct reciprocity assumes that a player plays games with the same opponent repeatedly and he determines his move depending on moves of the same opponent. If a player plays games repeatedly and the opponents may not be the same one, indirect (downstream) reciprocity assumes that the player determines his move to the current opponent depending on the previous moves of this current opponent, or indirect upstream reciprocity, or generalized reciprocity, assumes that the player determines his move to the current opponent depending on the previous experience of his own. Since a player in our model and Namekata and Namekata [2, 3, 4] determines his move depending on his own previous experience, we deal with generalized reciprocity. Nowak and Sigmund [5] deal with indirect (downstream) reciprocity because Donor determines his move to his opponent Recipient depending on the image score of the Recipient that relates to the previous moves of the Recipient. There is no reciprocity, either direct or indirect in the model of Riolo et al. [6] because Donor's move does not depend on the opponent's previous moves as well as his own previous experience.

This paper examines the effect of move-play pattern and repetitions of games per period on the emergence of cooperation and distribution of strategies. Following Namekata and Namekata [4], players with their variable-threshold strategies move and play at each period. They play DR games 8 times as well as 2 at each period. We restrict patters of move and play of a player to simple structure; *local* or *global*, where local or global means that with high probability the player moves (plays) locally or globally, respectively. For example, a player with global move and local play (abbreviated as gl) moves globally with high probability and plays DR games against (possibly different) local opponents with high probability at each period. As in [4] we deal with two ways of varying threshold. Players may have different ways of varying threshold that are determined by initial distribution and are inherited from their parent in this paper, although they all have the same way of varying threshold in [4]. We show, by Agent-Based Simulation, that cooperation emerges more frequently with 8 games per period than with 2 games, Cooperative strategies evolutionarily tend to move and play locally, Defective do not, and AllC and AllD are abundant unless all strategies initially play locally.

In Section 2, we explain our model in detail. In Section 3, results of simulation are discussed. And Section 4 concludes the paper.

2 Model

We start with extending TFT as follows in order to introduce reluctant and variable-threshold strategy: Let m=0,1,2; t=0,…,m+1; s=0,…,m. *Strategy component* (m,t;s) is illustrated in Fig 1. It has m+1 inner states. The inner states are numbered 0,1,…,m; thus m is the largest state number. State i is labeled D_i if $i<t$ or C_i if not. If current state is labeled C or D, then the strategy component prescribes using C or D, respectively. In other words, the strategy component prescribes using D if the current state $i<t$ and using C if not; thus the value t is the threshold which determines the move of a player. Initial state in period 0 is state s; its label is D_s if $s<t$ or C_s if not. If current state is i, then the next state is $\min\{i+1,m\}$ or $\max\{i-1,0\}$ given that the opponent uses C or D, respectively, in this period. If m>1, then the strategy component may delay replying to its opponent's change. How to vary threshold is given shortly in this section. Note that TFT is expressed as (1,1;1) in this notation if threshold is fixed and we regard the strategy component as a strategy. We abbreviate fixed threshold case as fTh. Thus strategy component (m,t;s) is an extended form of TFT. To sum up, our strategy components are expressed as (m,t;s); m is the largest state number, t is the threshold, and s is the initial state number. We omit the initial state like (m,t;*) if it is determined randomly. We also omit the initial state like (m,t) if we have no need to specify it.

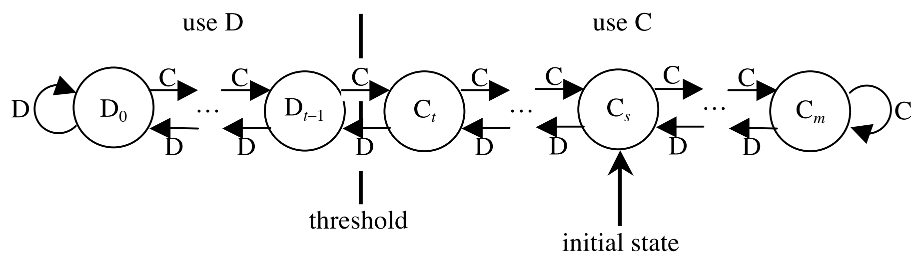

Fig. 1. Strategy component (m,t;s) in case of $t<s<m$. Circles denote inner states. Initial state is the state pointed by arrow labeled "initial state". Threshold divides states into two subclasses; one prescribes using D and the other using C. The transition between states occurs along the arrow labeled C or D if the opponent uses C or D, respectively.

We now explain how to vary threshold in detail. A player has, as his inheritable property, ageOfChange (abbreviated as ageCh) at which he may vary his threshold in accordance with his experience in encounter with others if he is still alive at his ageOfChange, and wayOfVaryingThreshold (abbreviated as wayVTh). wayVTh takes one of fTh, vCr, or vTend, which indicates fixed threshold, varying threshold by expected cooperation rate (vCr), or varying threshold by cooperation tendency (vTend), respectively. We define *experienced cooperation rate* (abbreviated as erCr) of a player as the number of move C used by the opponents divided by the total number of games played by him as Recipient until his ageOfChange. If the denominator of erCr is 0 and thus it is not defined, then nothing does happen. How does a player vary his threshold in accordance with this objective erCr if it is defined? We deal with two ways of varying threshold; one is based on player's cooperation tendency that is firmly related to his strategy component, and the other on a subjective idea of a player, expected cooperation rate of the society, that is independent of his strategy component.

(vTend): We define *cooperation tendency* of (m,t) as $\mathrm{CT}(m,t) := \frac{m+1-t}{m+1}$, that is, the number of states labeled C divided by the total number of states in Fig 1. This value is interpreted as the tendency toward cooperation. AllC, AllD and TFT have 1, 0 and 1/2 cooperation tendency respectively. If a player with (m,t) experiences erCr at his ageOfChange, then he tries to adjust his cooperation tendency (actually adjust his threshold) to be as near the erCr as possible by at most one increment or decrement, that is, adjust his threshold to a new threshold t^* which is given by

$$\left|\mathrm{CT}(m,t^*) - \mathrm{erCr}\right| = \min\left\{\begin{array}{l}\left|\mathrm{CT}(m,\max\{t-1,0\}) - \mathrm{erCr}\right|,\\ \left|\mathrm{CT}(m,t) - \mathrm{erCr}\right|,\\ \left|\mathrm{CT}(m,\min\{t+1,m+1\}) - \mathrm{erCr}\right|\end{array}\right\}$$

where t^* is given to be the smallest t if the minimum of the right hand side of the above equation is attained by multiple values of t. This way of varying threshold is based on two objective values, cooperation tendency and experienced cooperation rate of the player and is called varying threshold by cooperation tendency (abbreviated as vTend).

(vCr): We assume that a player has *expected cooperation rate* (abbreviated as ecCr) as his inheritable property. The ecCr is a subjective rate at which he expects the society is cooperative. If a player with ecCr experiences erCr at his ageOfChange, then he tries to adjust his threshold to erCr irrespective of his cooperation tendency as follows:

Decrease his threshold by one (try to be more cooperative) if possible
    in case of erCr≥ecCr+tolerance (since the society is more cooperative than expected),
increase his threshold by one (try to be more defective) if possible
    in case of erCr<ecCr−tolerance (since the society is more defective than expected),
do not vary his threshold
    in other cases,

where tolerance is set to be 0.05 in our simulation. This second way of varying threshold is based on two values; one is objective experienced cooperation rate and the other is subjective expected cooperation rate of the society and is called varying threshold by expected cooperation rate (abbreviated as vCr). This second way of varying threshold is our attempt to incorporate some subjective property of a player which is not directly related to strategy component into decision process; his subjective property affects not his moves directly but his pattern of behavior.

We have fully defined a variable-threshold strategy by specifying strategy component (m,t;s), way of varying threshold (fTh, vTend or vCr), ageOfChange, and ecCr in case of vCr. Thus strategy component (m,t;s) of a variable-threshold strategy of a player may vary to another strategy component (m,t') (t'=t+1 or t'=t−1) at his ageOfChange. Note that we need not to specify all elements of the latter strategy component (m,t') because they are determined automatically. Thus we can say variable-threshold strategy (m,t;s). Usual TFT, AllC, and AllD are (1,1;1), (m,0;s), and (m,m+1;s), respectively if their threshold is fixed. We also use TFT, AllC, and AllD to call strategy components (1,1), (m,0), and (m,m+1), respectively. Strategy and its strategy components are not the same in the strict sense, but we do not distinguish these terms strictly unless there is any confusion. So we say, for example, variable-threshold TFT varies to AllC. Notations (m,t;s), (m,t;*), and (m,t) are used to indicate both strategy and strategy component. Note that we deal with indirect upstream reciprocity, that is, generalized reciprocity since moves of the strategy are determined only by the previous experience of the strategy.

We restrict our model to satisfy the following condition:

(AllCneverAllD): If a player (m,0) (AllC) before his ageOfChange belongs to the first generation, then his all descendants are never (m,m+1) (AllD). And if a player (m,m+1) (AllD) before his ageOfChange belongs to the first generation, then his all descendants are never (m,0) (AllC).

Note that AllC of the form (0,0) is always AllC and AllD of the form (0,1) is always AllD because of this condition.

We deal with Donor-Recipient (DR) game as a stage game. DR game is a two-person game where one player is randomly selected as Donor and the other as Recipient. Donor has two moves, Cooperate (C) and

Defect (D). C means Donor pays cost c in order for Recipient to receive benefit b ($b>c>0$). Defect means Donor does nothing. Note that Recipient has no move. We assume that each player plays 2 or 8 games against (possibly different) players at each period. Since Donor is selected at random in each DR game, it is expected that at each period each player plays 4 or 16 DR games as Donor 2 or 8 times and as Recipient 2 or 8 times, respectively. Since it is common in demographic dilemma game that the sum of payoffs of a player, in two successive games once as Donor and once as Recipient, to be positive if the opponent uses C and negative if D and the worst sum of a player is equal to the best sum in absolute value, we transform the original payoffs to new ones by subtracting constant x. Table 1 shows the transformed payoff matrices of DR game.

Table 1. Payoff matrix of DR game. Constant x is given by $x=\frac{b-c}{4}$. We set b=2.5, 4, or 5 and c=1 in this paper.

		Recipient
Donor	C	$-c-x\ ,b-x$
	D	$-x\ ,-x$

In period 0, N (=100) players are randomly located in 30-by-30 lattice of cells. The left and right border of the lattice are connected. If a player moves outside, for example, from the right border, then he comes inside from the left border. So are the upper and lower border. Players use strategies of (m,t;s) form. Initial distribution of strategy components is described in Table 2. Initial wealth of every player is 6. Their initial (integer valued) age is randomly distributed between 0 and deathAge (=50).

Table 2. Initial distribution of inheriting properties.

property	initial distribution
strategy component	We deal with 4 types of populations, 1ALL, 2ASYM, AllCAllD, and TFTAllD with the specified initial distribution as follows: 1ALL:={(1/6)(0,0;0), (1/6)(1,0;*), (1/3)(1,1;*), (1/6)(1,2;*), (1/6)(0,1;0)}, 2ASYM:= {(1/8)(0,0;0), (1/8)(2,0;*), (1/4)(2,1;*), (1/4)(2,2;*), (1/8)(2,3;*), (1/8)(0,1;0)}, AllCAllD:= {(1/2)(0,0;0), (1/2)(0,1;0)} (fixed-threshold case), TFTAllD:= {(1/2)(1,1;1), (1/2)(0,1;0)} (fixed-threshold case). The notation, for example, of 1ALL, means that with probability 1/6 strategy component (0,0;0) (AllC) is selected, with probability 1/3 strategy component (1,1;*) (indicating initial state is selected randomly) is selected, and so on. Note that initially 50% of players use C on the average since both ((0,0;0) or (1,1;1)) and (0,1;0) are included with the same probability and so are both (m,t;*) and (m,m−t+1;*).
(rGM,rGP)	We deal with 11 distributions, ll, gl, ml, GL, lllg, llgl, llgg, -lg, -gl, -gg, and all. For example, gl means rGM is distributed in interval g and rGP in interval l, where l:=(0.05,0.2), m:=(0.4,0.6), g:=(0.8,0.95), L:=[0.0,0.0], G:=[1.0,1.0]. lllg:={(1/2)ll, (1/2)lg} means rGM and rGP are selected randomly as ll or lg. -lg:={(1/3)ll, (1/3)gl, (1/3)gg}, and all:={(1/4)ll, (1/4)lg, (1/4)gl, (1/4)gg}.
ageCh	Takes one randomly from {15, 16, 17, 18, 19, 20}.
wayVTh	Is fixed threshold (fTh) with probability 1/2, varying threshold by expected cooperation rate (vCr) with probability (1−rVTend)/2, and varying threshold by cooperation tendency (vTend) with probability rVTend/2, where rVTend = 0.5 or 0.9.
ecCr	Uniformly distributed at interval (0.35,0.55) (=vCr).

In each period, each player (1^{st}) moves, and (2^{nd}) plays DR games given by Table 1 against other players. Positive payoff needs opponent's C. (The detailed description of (1^{st}) move and (2^{nd}) play is given in Table 3.) The payoff of the game is added to his wealth. If the resultant wealth is greater than fissionWealth (=10) and there is an unoccupied cell in von Neumann neighbors, the player has an offspring and give the offspring 6 units from his wealth. His age is increased by one. If his age is equal to his ageOfChange, then follow the varying-threshold process discussed above. If the resultant wealth becomes negative or his age is greater than deathAge (=50), then he dies. Then next period starts.

Table 3. Detailed description. (1) describes move and (2) describes play in detail.

(1)	With probability rateOfGlobalMove (abbreviated as rGM), a player moves to random unoccupied cell in the whole lattice. If there is no such cell, he stays at the current cell. Or with probability 1−rGM, a player moves to random cell in von Neumann neighbors if it is unoccupied. If there is no such cell, he stays at the current cell.
(2)	With probability rateOfGlobalPlay (abbreviated as rGP), the opponent against whom a player plays dilemma game is selected at random from all players (except himself) in the whole lattice. Or with probability 1−rGP, the opponent is selected at random from von Neumann neighbors (no interaction if none in the neighbors). This process is repeated 2 or 8 times. (Opponents are possibly different.)

In our simulation we use synchronous updating, that is, in each period, all players move, then all players play, then all players have an offspring if possible, and then each player does the varying-threshold process if he is at his ageOfChange. Among properties of a player, strategy component, rateOfGlobalMove (rGM), rateOfGlobalPlay (rGP), ageOfChange (ageCh), way of varying threshold (wayVTh), and expected cooperation rate (ecCr) are inherited from parent to offspring. We remark that the strategy component and its initial state of the offspring are set to the current strategy component and its current state of the parent. But there is a small mutationRate (=0.05) with which they are not inherited. Initial distribution of these properties is given in Table 2 and this distribution is also used when mutation occurs. We assume that with errorRate (=0.05) a player makes mistake when he makes his move. Thus AllC may Defect sometime. Especially note that the initial distribution of strategy components is one of four distributions, 1ALL, 2ASYM, AllCAllD, and TFTAllD, listed in Table 2. And that the initial distribution of (rGM, rGP) is one of 11 distribution, ll, gl, ml, GL, lllg, llgl, llgg, -lg, -gl, -gg, and all that have simple structures.

If population of strategy components is AllCAllD, rGM=0, and rGP=0, then our model is similar to that of Epstein [1]. His model uses asynchronous updating while our model uses synchronous updating.

3 Simulation and Results

Our purpose to simulate our model is to examine the effect of repetitions of games played at every period and move-play pattern on the emergence of cooperation and distribution of strategies. We use Ascape (http://sourceforge.net/projects/ascape/) to simulate our model.

We consider the following range of parameters: Benefit for Recipient, *b* is basically 4, but changes to 2.5 or 5 for reasonable emergence rate of cooperation. rVTend is basically 0.5, but also changes to 0.9 for reasonable emergence rate of cooperation. Patters of move-play are restricted to simple structure, *local* or *global*; local or global means with high probability he moves or plays locally or globally, respectively. We set l:=(0.05,0.2), m:=(0.4,0.6), g:=(0.8,0.95), L:=[0.0,0.0] and G:=[1.0,1.0] (m, L, and G are included in order to focus on the role of local play). Local move or play means that rGM is in l or rGP in l, whereas global that rGM in g or rGP in g.

Table 4-1. Results of simulation (1).

move-play		ll *b*=2.5 rVTend=0.5		gl *b*=5 rVTend=0.9		ml *b*=4 rVTend=0.9		GL *b*=4 rVTend=0.9	
#games		2	8	2	8	2	8	2	8
Ce	2ASYM	0.000	0.923	0.000	0.560	0.000	0.557	0.000	0.900
	1ALL	0.000	0.493	0.000	0.023	0.000	0.000	0.000	0.343
	AllCAllD	0.000	0.087	0.000	0.000	0.000	0.000	0.000	0.000
	TFTAllD	0.000	0.003	0.000	0.210	0.000	0.090	0.040	0.977
M/m		---	10.6	---	2.67	---	6.19	0.00	0.92

Table 4-2. Results of simulation (2).

move-play		lllg *b*=5 rVTend=0.5		llgl *b*=2.5 rVTend=0.5		llgg *b*=4 rVTend=0.5	
#games		2	8	2	8	2	8
Ce	2ASYM	0.020	0.710	0.000	0.783	0.057	0.663
	1ALL	0.013	0.620	0.000	0.363	0.023	0.683
	AllCAllD	0.003	0.560	0.000	0.077	0.017	0.557
	TFTAllD	0.000	0.000	0.000	0.003	0.000	0.000
M/m		6.67	1.27	---	10.2	3.35	1.23

Table 4-3. Results of simulation (3).

move-play		-lg *b*=4 rVTend=0.5		-gl {ll/2,lg/4,gg/4} *b*=4 rVTend=0.5		-gg *b*=4 rVTend=0.5		all *b*=4 rVTend=0.5	
#games		2	8	2	8	2	8	2	8
Ce	2ASYM	0.060	0.720	0.037	0.640	0.043	0.760	0.017	0.450
	1ALL	0.043	0.607	0.020	0.620	0.017	0.573	0.013	0.390
	AllCAllD	0.027	0.563	0.007	0.563	0.023	0.540	0.010	0.283
	TFTAllD	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.003
M/m		2.22	1.28	5.29	1.14	1.87	1.41	1.70	1.59

We execute 300 runs of simulations in each parameter setting. We judge that the cooperation emerges in a run if there are more than 100 players and the average C rate is greater than 0.2 at period 500, where the average C rate at a period is the average of the player's average C rate at the period over all players and the player's average C rate at the period is defined as the number of move C used by the player divided by the number of games played as Donor at the period. (We interpret 0/0 as 0.) This average C rate is the rate at which we see cooperative move C as an outside observer. Since negative wealth of a player means his death in our model and he has a lifetime, it is necessary for many players to use C in order that the population is not extinct.

We summarize our results in Tables 4-1, 4-2, and 4-3. In Tables 4-1, 4-2, and 4-3, the entity of the first row and the second to fourth or fifth column indicates initial distribution of patterns of move-play with additional information of *b* and rVTend. For example, gl means that rGM is selected uniformly at interval g and rGP at interval l. llgl:={(1/2)ll, (1/2)gl} means that with probability 1/2 rGM and rGP are selected like ll and with probability 1/2 rGM and rGP are selected like gl. -gl:= {(1/3)ll,(1/3)lg,(1/3)gg} and all:={(1/4)ll,(1/4)lg,(1/4)gl,(1/4)gg} have similar meaning. We add ml and GL in the initial distributions of patterns of move-play in order to focus on the role of local play. The second row (#games) indicates the number of games played at each period. "Ce" in the first column indicates this row gives the emergence rate of cooperation that is the frequency with which the cooperation emerges in the corresponding initial population like 2ASYM. The last row "M/m" indicates the rate between maximum Ce and the Ce of TFTAllD or AllCAllD (which is the larger of the two), for example, 10.6 = 0.923/0.087. This M/m shows the effect of reluctance and variable-threshold on the emergence of cooperation over the usual non-reluctant and fixed-threshold strategies such as AllCAllD and TFTAllD.

For example, Table 4-1 shows that the frequency with which the cooperation emerges is 92.3% when the initial population is 2ASYM, #games=8, initial distribution of patters of move-play is ll, *b*=2.5, and rVTend=0.5.

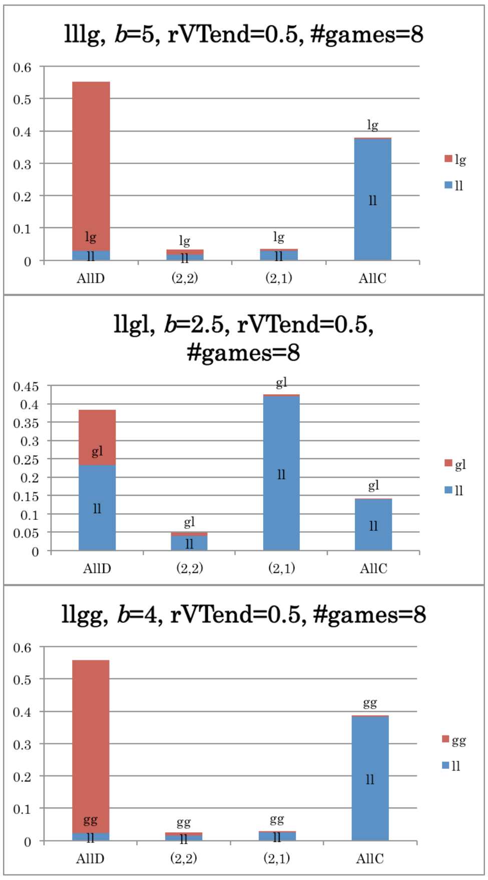

Fig. 2-1. Average frequency of strategy components and their patterns of move-play of 2ASYM for #games=8 at period 500 over 300 runs.

First note that in initial distributions (including ll, lg, gl, and gg), lg, gg, lggl, lggg, glgg, and -ll, which are not listed in Tables 4-1, 4-2, and 4-3 cooperation does not emerge. We set -gl:={(1/2)ll,(1/4)lg,(1/4)gg} instead of {(1/3)ll,(1/3)lg,(1/3)gg} since it needs more initial chance of playing locally than 1/3 to get reasonable emergence rate of cooperation Ce. We see that cooperation emerges easily in ll and llgl cases but with difficulty in gl and lllg cases since it needs smaller *b*=2.5 or larger *b*=5 to get reasonable Ce than usual *b*=4. We observe that in gl, ml, and GL cases (no local move and local play) cooperation dos not emerge in AllCAllD, but it does in 2ASYM (rVTend=0.9) and TFTAllD if #games=8, and it does more frequently in TFTAllD than in 2ASYM (rVTend=0.9). Thus with 8 games per period against local players, cooperation emerges in TFTAllD and 2ASYM (rVTend=0.9), but not in AllCAllD, and 2ASYM (rVTend=0.9; even though it needs high rate 0.9 of varying threshold by cooperation tendency) has better performance than TFTAllD since the initial distributions of patterns of move-play, ml and gl, are more probable than GL. In other cases than gl, ml, and GL, cooperation emerges in AllCAllD, but it does not in TFTAllD (we ignore 0.003) if #games=8. Ce's for #games=2 are zero or smaller than or equal to 6.0%, whereas Ce's for #games=8 are larger than 28% if corresponding Ce's are positive. We conclude that 8 games per period compered with 2 games increases the emergence rate of cooperation Ce if Ce's for #games=2 are positive. M/m's are larger than 2.6 if the initial distribution of move-play includes only local play, that is, it is one of ll, gl, ml, or llgl (here we exclude the unrealistic case GL), whereas other M/m's are larger than 1.13 (some are not so large but greater than 1.13). Thus we conclude that reluctance and variable-threshold increases emergence rate of cooperation Ce compared with non-reluctant and fixed-threshold strategies if M/m is defined. We summarize important results in the following two observations:

Observation (effect of repetition of games per period): 8 games per period compared with 2 games increases the emergence rate of cooperation Ce if Ce's for 2 games per period are positive. If 8 games are played per period, TFTAllD is favored over AllCAllD in gl, ml, and GL cases (no local move and local

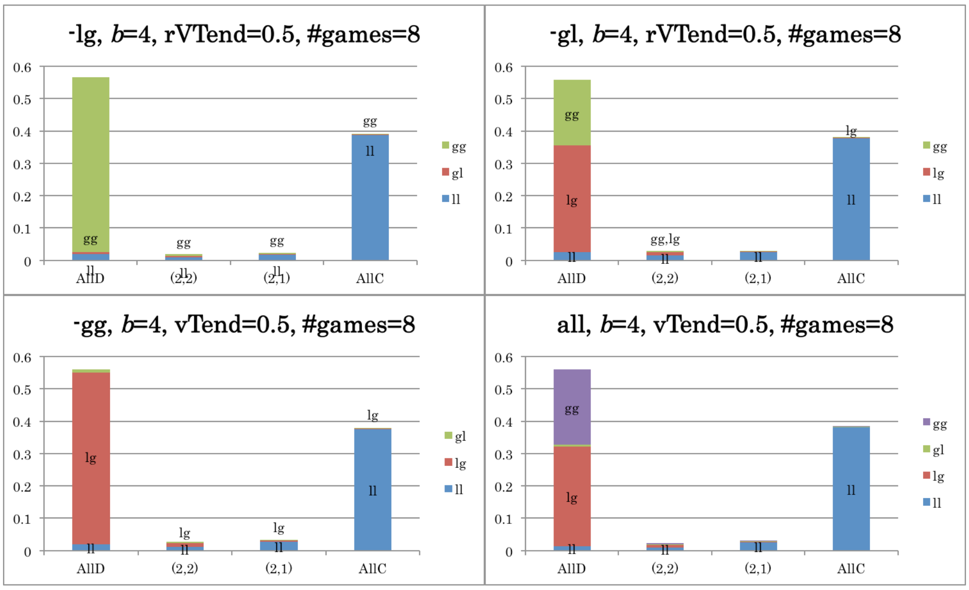

Fig. 2-2. Average frequency of strategy components and their patterns of move-play of 2ASYM for #games=8 at period 500 over 300 runs.

play) with respect to emergence of cooperation, whereas AllCAllD is favored over TFTAllD in other cases, that is, ll, lllg, llgl, llgg, -lg, -gl, -gg, and all; these cases include both local move and local play.

Observation (effect of reluctance and variable-threshold): The reluctant and variable-threshold strategy

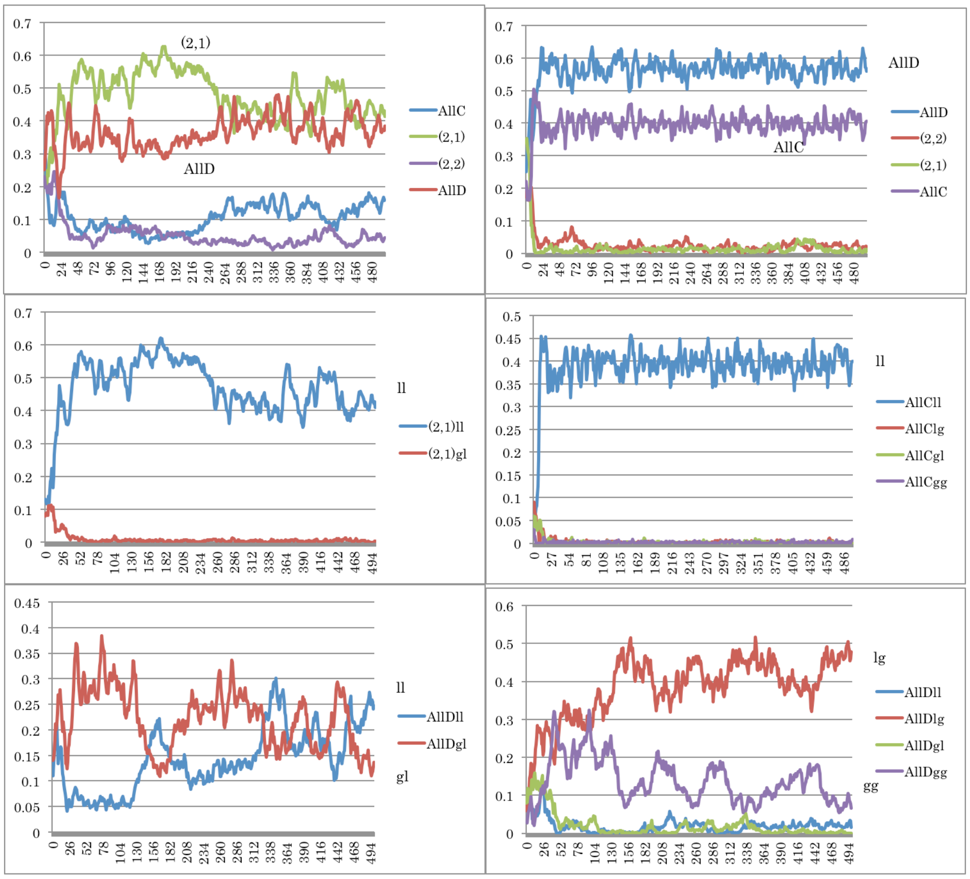

Fig. 3. Frequency of strategy components and their patters of move-play over periods. The left three graphs show one run of llgl case in Fig 2-1 and the right do one run of all in Fig 2-2.

compared with non-reluctant and fixed-threshold strategies increases emergence rate of cooperation Ce if M/m is defined.   (Here we exclude the unrealistic case GL.)

Next we consider the distributions of strategy components and patterns of move-play of 2ASYM for #games=8 at the final period 500.   Fig 2-1 and 2-2 show average frequency of strategy components and their patterns of move-play at period 500 over 300 runs.   First let us discuss distributions of strategy components. We observe in Fig 2-1 and 2.2 that AllC bar and AllD bar have large frequency but other (2,1) bar and (2,2) bar have very small frequency in all cases except llgl.   llgl case in Fig 2-1 has the following different structure: We observe that (2,1) and AllD bars have large frequency compared with other AllC and (2,2) bars.   This structure of llgl case is shared with ll, gl, ml, and GL cases (although their figures are not presented here).   Next let us discuss distribution of patterns of move-play.   We concentrate on the patterns of move-play that have at least 2 types such as lllg, -lg, or all.   We observe that AllC, (2,1), and (2,2) bars consist almost of the pattern of move-play ll in Fig 2-1 and 2-2.   AllD bar has the following different structure: It consists of both ll and gl in llgl case by Fig 2-1 but it does of few ll and few gl in other cases by Fig 2-1 and 2-2 even if ll or gl exits initially at period 0.   Especially, gl exists in the long run only if all players initially play locally in our simulation.   Lastly let us see two typical runs in Fig 2-1 and 2-2.   Fig 3 illustrates frequency of strategy components and pattern of move-play, of two runs in Fig 2-1 and 2-2, over periods.   The left graphs in Fig 3 show that in llgl case frequencies of (2,1) and AllD increase at early period and those of (2,2) and AllC decrease at early period.   And that (2,1) consists almost of the patter of move-play ll at early period and AllD consists of both ll and gl.   The right graphs in Fig 3 show that in 'all' case frequencies of AllC and AllD increase at fairly early period and those of (2,1) and (2,2) decrease at fairly early period.   AllC consists almost of ll at fairly early period and AllD consists of both lg and gg but of niether gl nor ll at early period.   Thus Fig 3 confirms our observations from Fig 2-1 and 2-2.   We summarize important results about 2ASYM for #games=8 in the following two observations:

Observation (more frequent strategy components): AllC and AllD have large frequency at period 500 unless initial patterns of move-play include only local play.   (2,1) and AllD have large frequency at period 500 if initial patters of move-play include only local play.

Observation (pattern of move-play): Cooperative strategy components (indicating AllC, (2,1), and (2,2) here) evolutionarily tend to move and play locally (ll).   AllD evolutionarily tends to play globally (lg or gg) unless initial patters of move-play include only local play.   If initial patters of move-play include only local play (lllg), then AllD moves both locally and globally (ll and gl); especially, the pattern of move-play gl exists in the long run.

4 Conclusion

We examine the effect of repetitions of games played at every period and move-play pattern on the emergence of cooperation and distribution of strategy components in demographic DR game.

We show, by Agent-Based Simulation, for example, that Cooperative strategy components evolutionarily tend to move and play locally, Defective one does not, and AllC and AllD are abundant unless all strategy components initially play locally.

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