EFFECT OF DECLARATION ON EMERGENCE OF COOPERATION IN DEMOGRAPHIC DONOR-RECIPIENT GAME

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ABSTRACT

We consider effect of declaration on emergence of cooperation in demographic Donor-Recipient game. 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. In Donor-Recipient game, one player is selected at random as Donor and the other as Recipient. Donor has two moves Cooperate or Defect; Cooperate means Donor pays cost for Recipient to receive benefit. Defect means Donor does nothing. We introduce one option for Recipient; Recipient can declare that he is cooperative before Donor's move. We show, by Agent-Based Simulation, declaration promotes emergence of cooperation, but some players need to distinguish true declaration from false one if Donor can punish suspicious declaration.

INTRODUCTION

This paper investigates the effect of declaration on the emergence of cooperation and the distribution of strategies in demographic Donor-Recipient game (DR). We introduce one option for Recipient into usual DR game. Recipient can declare that he is cooperative before Donor's move.

Epstein (2006) introduces demographic model. He shows the emergence of cooperation where AllC and AllD are initially randomly distributed in a square lattice of cells. Here AllC always Cooperate and AllD always Defect. 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 (2011) extend Epstein's original model discussed above by introducing global move, global play, 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, and show cases where the reluctance promotes the emergence of cooperation. Here TFT Cooperates at first period and at later periods uses the same move as the opponent did in the previous period. Namekata and Namekata (2012) examine the effect of move-play pattern on the emergence of cooperation and the distribution of strategies. They 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. They show that cooperative strategies evolutionarily tend to move and play locally, defective do not, and AllC and AllD are abundant unless all strategies initially play locally.

Nowak and Sigmund (1998) consider the emergence of cooperation in different non-demographic setting where two players are randomly matched, and play DR game at each period. Rate of a strategy at the next period is proportional to the payoff of the strategy earned at the current period, which is also 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 move (Cooperate or Defect) depending on the opponent's image score. Riolo et al. (2001) 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 (Nowak and Sigmund

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2005): 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 Namekata and Namekata (2011, 2012) determines his move depending on his own previous experience, they deal with generalized reciprocity. Nowak and Sigmund (1998) 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. (2001) 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 declaration on the emergence of cooperation and the distribution of strategies. In real life cooperative player is willing to cooperate if the opponent is expected also to be cooperative. In our Donor-Recipient game setting, the cooperative Donor is willing to cooperate if Recipient is expected also to be cooperative. Therefore the Recipient has an incentive to make the Donor believe the Recipient to be cooperative. We introduce a costless option for Recipient; Recipient can declare that he is cooperative before Donor's move. Donor tries to distinguish true declaration from false one by his ability and make his move based on his distinction. Some do not have any ability to distinguish but believe the declaration as it is with high probability or with low probability. Some do distinguish true declaration from false one with high probability. Further we introduce Donor's punishment for suspicious declaration, which means Donor defects if he judges Recipient's declaration to be suspicious. We show, by Agent-Based Simulation, that declaration promotes the emergence of cooperation, but some players need to have ability to distinguish true declaration from false one if Donor's punishment for suspicious declaration is allowed.

MODEL

We start with extending TFT as follows in order to introduce reluctant strategy: Let m=0,1,2; t=0,…,m+1; s=0,…,m. Strategy (m,t;s) is illustrated in Figure 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 prescribes using C or D, respectively. In other words, the strategy 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 may delay replying to its opponent's change. Note that TFT is expressed as (1,1;1) in this notation. Thus strategy (m,t;s) is an extended form of TFT. To sum up, our strategies 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. Note that reluctant strategy (m,t;s) by itself decides its move to the current opponent depending on the previous experience of its own, meaning indirect upstream reciprocity. Also that AllC is denoted by (m,0) and AllD by (m,m+1).

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. 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. Constant

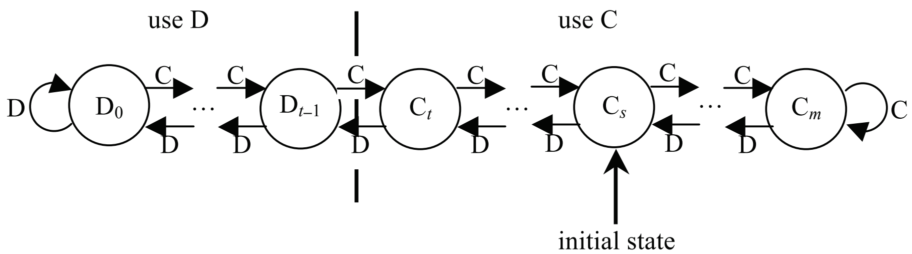

Figure 1: Strategy (m,t;s) in Case of $t<s<m$
Circles denote inner states. Initial state is the state pointed by arrow labeled "initial state". Threshold divides states into two subclasses; one prescribes using D and the other using C. The transition between states occurs along the arrow labeled C or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

x is given by $x = \frac{b-c}{4}$. We set b=4 and c=1 in this paper. Table 1 shows the transformed payoff matrix of DR game. We assume that each player plays 8 games against (possibly different) players at each period.

Table 1: Payoff Matrix of DR Game

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

In this paper, we introduce two costless moves for Recipient, Declare or not, one of which is made before Donor's move. Declare means that Recipient declares he is cooperative. Not declare means that Recipient does nothing. In case of Recipient's declaration, Donor (except AllC or AllD) tries to distinguish true declaration from false one by the Donor's ability. Donor uses C if he judges the Recipient's declaration to be reliable. We assume three types of Donor in this ability; High (H) has no ability to distinguish them but believes the declaration to be reliable with high 80% probability, Low (L) also has no ability to distinguish them but believes the declaration to be reliable with low 20% probability, and Good (G) has ability to distinguish true declaration from false one with about high 80% probability. We explain the ability of Good in more detail. The probability $\Pr_{\mathrm{Re|G}}(r)$ with which Good Donor judges Recipient's declaration to be reliable given that the Recipient has cooperation rate r, the number of move C used by the Recipient divided by the number of games played by the Recipient as a Donor until now, is given by

$$\Pr_{\mathrm{RelG}}(r) = \begin{cases} 1.2r + 0.2 & (r \le 0.5) \\ 0.8 & (r > 0.5) \end{cases}$$

If r=0 (the Recipient is AllD), then Donor judges the declaration to be suspicious with high probability 0.8. If $r > 0.5$ (including AllC), then Donor judges the declaration to be reliable with high probability 0.8. Thus Good Donor has ability to distinguish true declaration from false one with about 80%. In the same notation we have $\Pr_{\mathrm{RelH}}(r) = 0.8$ and $\Pr_{\mathrm{RelL}}(r) = 0.2$. Our model also deals with indirect downstream reciprocity because Good Donor decides his move by partial information about Recipient. Our way to introduce indirect downstream reciprocity is different from that of the second incomplete information model in Nowak and Sigmund (1998), where the result of one DR game is observable only a randomly selected subset of all players and thus every player may have different incomplete image score of the same player. Thus our results discussed later about the promotion of emergence of cooperation is the effect of our way of indirect downstream reciprocity in addition to our indirect upstream reciprocity in the form of reluctant strategy in the Demographic DR game.

We further introduce the possibility for Donor to punish suspicious declaration, which means Donor defect in case that the Donor judges the declaration of Recipient to be suspicious.

A player has the following properties that are inherited from parents to offspring; rateOfDeclaration (rDec), distinction, punishment, strategy, rateOfGlobalMove (rGM), and rateOfGlobalPlay (rGP); whose initial distributions are summarized in Table 2. Recipient declares with probability rDec. Donor (except AllC and AllD) distinguishes Recipient's declaration by his distinction if the Recipient declares. Donor uses his strategy if the Recipient does not declare or does declare but the Donor judges the declaration to be suspicious in case of non-punisher.

In period 0, N (=100) players (agents) are randomly located in 30-by-30 lattice of cells. The left and right borders 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 borders. Players use strategies of $(m,t;s)$ form. Initial wealth of every player is 6. Their initial (integer valued) age is randomly distributed between 0 and deathAge (=50).

In each period, each player (1st) moves, and (2nd) plays DR games given by Table 1 against other players. Positive payoff needs opponent's C. (The detailed description of (1st) move and (2nd) 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 gives the offspring 6 units from his wealth. His age is increased by one. If the resultant wealth becomes negative or his age is greater than deathAge (=50), then he dies. Then next period starts.

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. We remark that the strategy and its initial state of the offspring are set to the current strategy and its current state of the parent. There is a small mutationRate (=0.05) with which inheriting properties are not inherited. Initial distributions of inheriting properties given in Table 2 are 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 Recipient declares with low (L) or high (H) probability and Donor (except AllC and AllD) has no ability to distinguish Recipient's declaration (L or H) or partial ability to distinguish true declaration from false one (G), from Table 2. And that the initial distribution of strategy is 2ASYM (including AllC, (2,1), (2,2), and AllD) or AllCAllD. Also that the initial distribution of (rGM, rGP) has simple structures; with high probability a player moves and plays locally or globally, thus there are 4 move-play patters such as ll, lg, gl, and gg.

Table 2: Initial Distribution of Inheriting Properties

property	initial distribution
rDec	We deal with distribution {(1/2)L, (1/2)H}, which means rDec is uniformly distributed in interval L or H with equal probability 1/2. L:=(0.05,0.2) and H :=(0.8,0.95). In other words, a player declares with low probability (L) or high probability (H).
distinction	We deal with 12 distributions, Ig, LIg, HIg, GIg, HL, GL, GH, HLIg, GLIg, GHIg, GHL, and GHLIg, of Donor's distinction. For example, GHL:={(1/3)G, (1/3)H, (1/3)L}, which means the ability of a player to distinguish is determined randomly to be G, H, or L. L has no ability and believes the declaration to be suspicious with 80%. H has no ability and believes the declaration to be reliable with 80%. G has ability to distinguish true declaration from false one with about 80%. Ig ignores Recipient's declaration and uses his strategy as if the Recipient does not declare.
punishment	Donor (except AllC and AllD) can be punisher or non-punisher. He is punisher with probability rateOfPunisher (rP). rP takes 0, 0.5, or 1. rP=0 means there is no punishing Donor. rP=1 means every Donor (except AllC and AllD) punishes suspicious declaration. rP=0.5 means Donor (except AllC and AllD) is determined randomly to be punisher or non-punisher.
strategy	We deal with two populations, 2ASYM and AllCAllD as follows: 2ASYM:= {(1/4)(2,0), (1/4)(2,1;*), (1/4)(2,2;*), (1/4)(2,3)}, and AllCAllD:= {(1/2)(0,0), (1/2)(0,1)}. The notation, for example, of 2ASYM, means that with probability 1/4 strategy (2,0) (AllC) is selected, with probability 1/4 strategy (2,1;*) is selected, and so on, where * indicates that initial state is selected randomly. Note that initially 50% of players use C on the average since both AllC and AllD are included with the same probability and so are both $(m,t;*)$ and $(m,m-t+1;*)$.
(rGM,rGP)	We deal with distribution {(1/4)ll, (1/4)lg, (1/4)gl, (1/4)gg}. For example, gl means rGM is distributed in interval g and rGP in interval l, where l:=(0.05,0.2) and g:=(0.8,0.95). {(1/4)ll, (1/4)lg, (1/4)gl, (1/4)gg} means rGM and rGP are selected randomly among ll, lg, gl, and gg.

Table 3: Detailed Description of Move and Play
(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 8 times. (Opponents are possibly different.)

If population of strategy is AllCAllD, rGM=0, and rGP=0, then our model is similar to that of Epstein (2006). His model uses asynchronous updating while our model uses synchronous updating.

We comment on the difference among Donor's distinctions (L, H and G) and Ig. Let us denote, for example, a strategy ((2,1) or (2,2)) with distinction L who is punisher by LP, and with distinction L who is not punisher by LN, respectively. We have the following basic relations among Donor's distinctions:

- LN=(20%-AllC, 80%-Ig; Ig), which means LN is equal to AllC with probability 20% and to Ig with probability 80% in case of Recipient's declaration; and LN is equal to Ig in case of no Recipient's declaration.
- LP=(20%-AllC, 80%-AllD; Ig).
- HN=(80%-AllC, 20%-Ig; Ig).
- HP=(80%-AllC, 20%-AllD; Ig).
- Ig<LN<HN, LP<LN, Ig<HN, LP<HP<HN, and GP<GN, where, for example, Ig<LN means that LN prescribes using C more frequently than Ig on the average.
- LN is similar to Ig with more than 80% probability but different from LP.
- HN is similar to HP with more than 80% probability but different from Ig.

Thus we expect that H promotes cooperation more often than L even if H and L have no ability to distinguish Recipient's declaration. Also that G promotes cooperation more often than L and H because G has some ability to distinguish true declaration from false one.

SIMULATION AND RESULT

Our purpose to simulate our model is to examine the effect of declaration and punishment for suspicious declaration on the emergence of cooperation and the distribution of strategies. We use Ascape (http://sourceforge.net/projects/ascape/) to simulate our model.

We execute 300 runs of simulations in each different 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 are interested in the emergence rate of cooperation that is the rate at which the cooperation emerges.

We summarize the emergence rate of cooperation, Ce, in Table 4. The second (rP=0), third (rP=0.5), and fourth (rP=1) columns contain Ce for the corresponding initial distribution (distinction in case of 2ASYM) such as AllCAllD, LIg or GHLIg of 2ASYM if all Donors do not punish, about half of Donors do punish, and all Donors do punish, respectively, for Recipient's suspicious declaration.

Table 4: Emergence Rate of Cooperation, Ce

population distinction	rP=0	rP=0.5	rP=1
AllCAllD	0.283	---	---
2ASYM			
Ig	0.407	---	---
LIg	0.517	0.356	0.273
HIg	0.647	0.520	0.497
GIg	0.807	0.797	0.820
HL	0.643	0.453	0.323
GL	0.763	0.677	0.567
GH	0.870	0.903	0.843
HLIg	0.600	0.433	0.407
GLIg	0.713	0.617	0.547
GHL	0.840	0.657	0.587
GHLIg	0.710	0.687	0.563

First we examine whether Recipient's declaration promote the emergence rate of cooperation or not in case of no punishment for suspicious declaration. The second (rP=0) column shows that the cooperation emerges 28.3% in AllCAllD population and 40.7% in Ig. Since Ig of 2ASYM ignores Recipient's declaration whose emergence rate of cooperation is 40.7%, the cooperation emerges 51.7% in LIg, and more than or equal to 60% in other distinctions, the increases of Ce from 40.7% by declaration are due to our way of indirect downstream reciprocity different from the second incomplete information model in Nowak and Sigmund (1998). We conclude the following observation:

1. Declaration promotes the emergence of cooperation. Furthermore, if initial distinctions contain G or contain H except G or contain L except H and G, then the emergence rate of cooperation is larger than 70% or 59.9% or 50%, respectively. Thus L, H, and G promote the emergence of cooperation roughly in this order.

Now we examine the effect of declaration on the emergence of cooperation if punishment for suspicious declaration is allowed. Let us judge declaration to promote the emergence of cooperation if the emergence rate of cooperation is larger than 50%. As the third (rP=0.5) and fourth (rP=1) columns of Table 4 show, we conclude the following observation:

2. Initial distinctions needs to contain G (except one case, HIg, rP=0.5) for declaration to promote the emergence of cooperation if punishment for suspicious declaration is allowed. Furthermore, the emergence rate of cooperation decrease as the rate of punisher increases except GIg and GH.

Next we examine the rate of players who declare with High probability (H). Table 5 shows them at period 500 if the emergence rate of cooperation is larger than 50% and the table concludes the following observation:

3. The rates of players who declare with H at period 500 are larger than the initial rate 50%. They decrease as the rate of punisher increases. Distinctions L, H, and G make these rates larger roughly in this order.

Table 5: Rate of Players to Declare with High Probability at period 500

population distinction	rP=0	rP=0.5	rP=1
2ASYM			
Ig	---	---	---
LIg	0.631	---	---
HIg	0.864	0.814	---
GIg	0.947	0.832	0.734
HL	0.909	---	---
GL	0.965	0.815	0.672
GH	0.988	0.855	0.834
HLIg	0.858	---	---
GLIg	0.916	0.798	0.627
GHL	0.952	0.840	0.782
GHLIg	0.929	0.831	0.685

Next we investigate the effect of declaration on the distribution of strategies, distinctions, and declarations with Low probability or with High probability by focusing on 2ASYM, GHLIg, and rP=0.5 case. Figure 2-1 is scatter diagram of (rate of distinction G, number of population) at period 500 of successful runs. Figure 2-2 is scatter diagram of (rate of distinction H, number of population) at period 500 for the runs with rate of distinction G < 0.15. For convenience sake, let us divide all successful runs into three cases, A, B and C;

A for rate of distinction G, rG >= 0.15, B for rG < 0.15 (found that rate of distinction L, rL is also small) and rate of distinction H, rH < 0.3, and C for the others.

Figure 3-1, 3-2, and 3-3 show piled distribution (2,1)G, (2,2)L, and AllD of one run (circled in Figure 2-1; rG=0.42, rH=0.0014, rL=0.36) in case A over periods, respectively. The other strategies (distinctions) such as AllC, HP and HL almost vanish. Note that although there exist GP, GN, LP and LN, LP is fairly small. They declare with High probability (not shown here). AllD, who tends to declare with Low probability because of punishment by GP, diminishes as time goes.

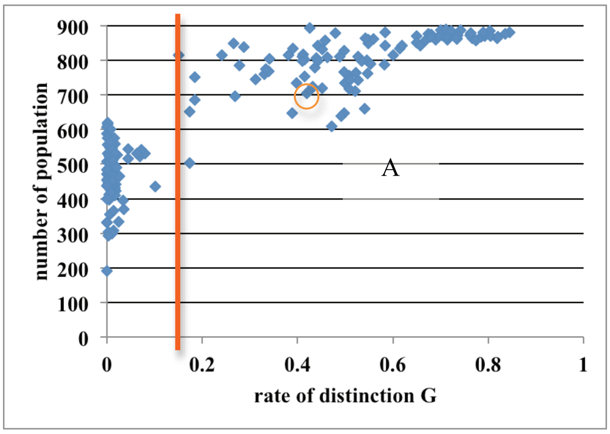

Figure 2-1: Scatter Diagram (rG,p) at Period 500

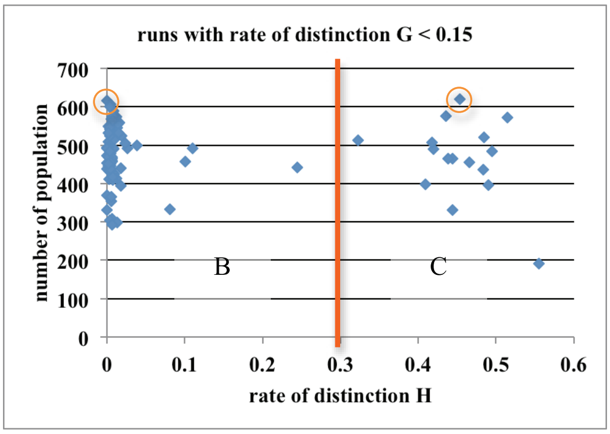

Figure 2-2: Scatter Diagram (rH,p) at Period 500

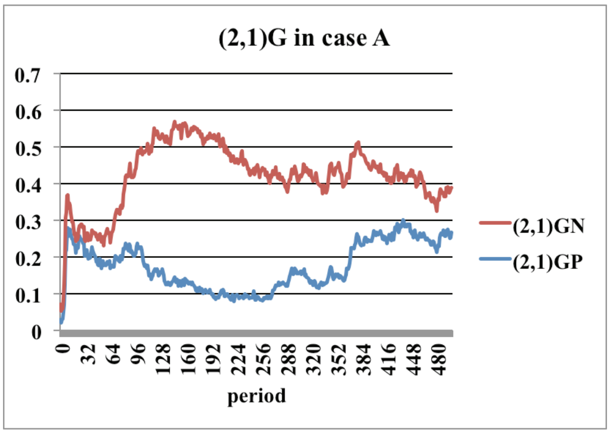

Figure 3-1: Distribution (2,1)G of One Run in Case A

Figure 4-1 and 4-2 are related to one run (circled in Figure 2-2; rG=0.0016, rH=0, rL=0.003) in case B. There exist AllC and AllD, who declare roughly with High probability. The other strategies (distinctions) such as (2,1) and (2,2) almost vanish.

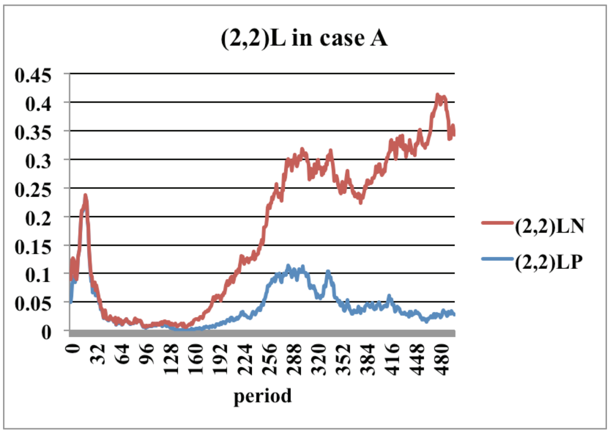

Figure 3-2: Distribution (2,2)L of One Run in Case A

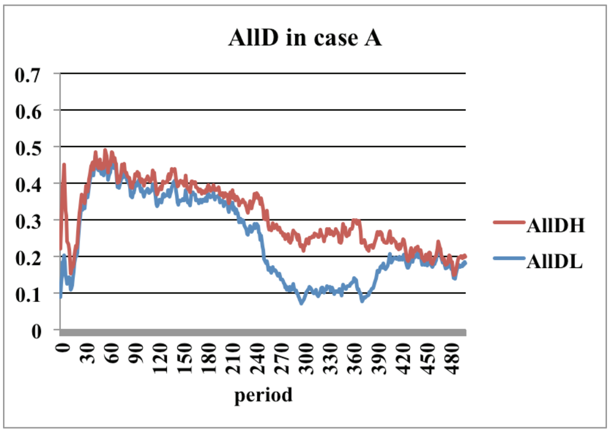

Figure 3-3: Distribution AllD of One Run in Case A

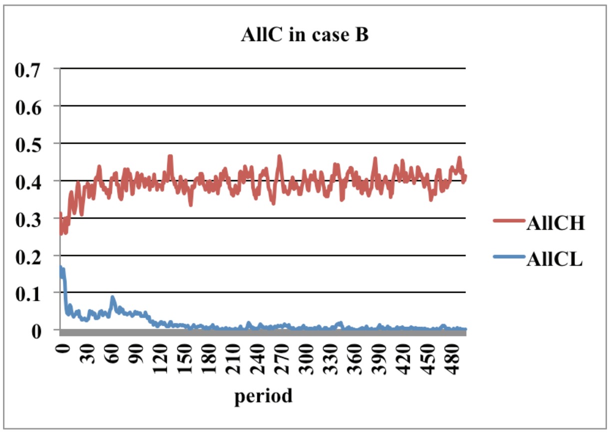

Figure 4-1: Distribution AllC of One Run in Case B

Figure 5 shows piled distribution (2,2)H of one run (circled in Figure 2-2; rG=0.0016, rH=0.45, rL=0.011) in case C over periods. HP (punisher) vanishes. The rest of the population consists almost of AllD. (2,2)HN and AllD declare with High probability because of almost no punisher (not shown graphically here).

Figure 6 shows the average distributions of strategies at period 500 for case A, B, and C, respectively. Large G (>0.15) makes (2,2) or (2,1) bar high and AllD bar low because of his ability to distunguish in case A. There is almost no effect of declaration and AllC and AllD bars are high in case B, which corresponds with Namekata and Namekata (2012). Large H (>0.3) makes (2,2) or (2,1) bar high but AllD bar is still high because of no ability of H's to distinguish in case C.

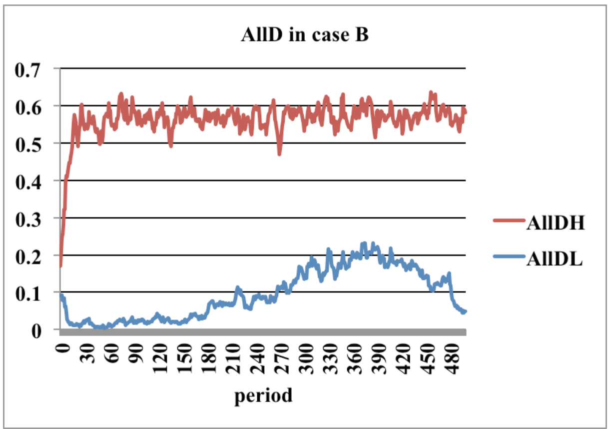

Figure 4-2: Distribution AllD of One Run in Case B

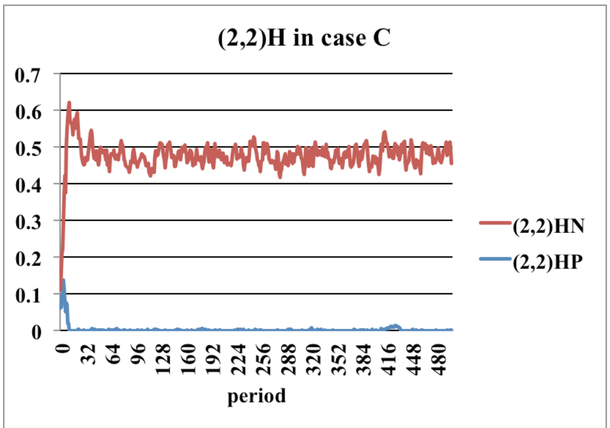

Figure 5: Distribution (2,2)H of One Run in Case C

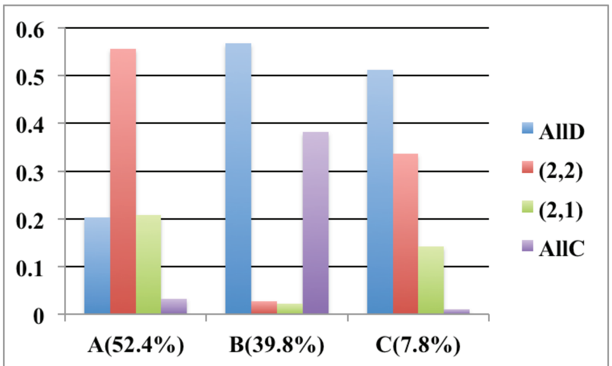

Figure 6: Average Distribution of Strategies at period 500

CONCLUSION

We investigate the effect of declaration on the emergence of cooperation and the distribution of strategies in Demographic Donor-Recipient game. We show, by Agent-Based Simulation, that Recipient's declaration promotes emergence of cooperation even if Donor has no ability to distinguish true declaration from false one in case of no punishment, but some Donors need to have some ability if punishment is allowed. We also show three types of distributions of strategies.

Suppose that you and another person come to the only one seat available, while you are a bit ahead of the person. You are Donor and the person is Recipient. Defect means you take the seat. The person may say "After you" to impress you that he is cooperative. Our results suggest that in order to promote cooperation it is effective for you to declare yourself cooperative, to trust declaration of others, and not to punish suspicious declaration if you cannot appreciate the declaration correctly.

Our future research is to find some feature of a player other than declaration or reluctance, which is oriented toward cooperation, and to investigate its effect on the emergence of cooperation.

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