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Effect of Modification and Expansion on Emergence of Cooperation in Demographic Multi-Level Donor-Recipient Game

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***Abstract*—**It is known that the mean investment evolves from a very low initial value to some high level in the Continuous Prisoner's Dilemma. We examine how the cooperation level evolves from a low initial level to a high level in our Demographic Multi-level Donor-Recipient situation. In the Multi-level Donor-Recipient game, one player is selected as a Donor and the other as a Recipient randomly. The Donor has multiple cooperative moves and one defective move. A cooperative move means the Donor pays some cost for the Recipient to receive some benefit. The more cooperative move the Donor takes, the higher cost the Donor pays and the higher benefit the Recipient receives. The defective move has no effect on them. Two consecutive Multi-level Donor-Recipient games, one as a Donor and the other as a Recipient, can be viewed as a discrete version of the Continuous Prisoner's Dilemma. In the Demographic Multi-level Donor-Recipient game, players are initially distributed spatially. In each period, players play multiple Multi-level Donor-Recipient games against other players. He leaves offspring if possible and dies because of negative accumulated payoff of him or his lifespan. Cooperative moves are necessary for the survival of the whole population. There is only a low level of cooperative move besides the defective move initially available in strategies of players. A player may modify and expand his strategy by his recent experiences or practices. We distinguish several types of a player about modification and expansion. We show, by Agent-Based Simulation, that introducing only the modification increases the emergence rate of cooperation and introducing both the modification and the expansion further increases it and a high level of cooperation does emerge in our Demographic Multi-level Donor-Recipient Game.

***Keywords*—**Agent-based simulation, donor-recipient game, emergence of cooperation, spatial structure, TFT, TF2T.

I. Introduction

We present multiple levels of cooperation into the usual one-level Donor-Recipient (DR) Game and investigate the effect of modification and expansion of strategy on the emergence of cooperation in the Demographic Multi-level DR Game.

The Continuous Prisoner's Dilemma with a spatial structure in [1] is described as follows: A square lattice of cells is fully filled with players. In each period, a player plays against his 8 immediate neighbors (known as Moore neighbors). A Continuous Prisoner's Dilemma is a two-person game where two players can invest non-negative real number I_1 and I_2, respectively. The payoffs of player 1 and player 2 are $B(I_2)-C(I_1)$ and $B(I_1)-C(I_2)$, respectively, where $B(I)$, $C(I)$, and $B(I)-C(I)$ are increasing functions of I and $B(I)-C(I)$ takes its maximum at $I=I_{\text{Max}}$. If we restrict investments to only two investments, I_{low} and I_{high}, then I_{low} and I_{high} can be regarded as Defect and Cooperate, respectively, in the usual Prisoner's Dilemma (PD) if $0 \le I_{\text{low}} < I_{\text{high}} \le I_{\text{Max}}$. Thus, the Continuous PD is a generalization of the usual PD to a continuous quantity. Since a player in the lattice of cells plays 8 games in a period, his payoff in the period is the sum of the payoffs of the 8 games. In the next period, the player adopts a new investment level used by the player that has the highest payoff among the 8 immediate neighbors and himself. If the mutation occurs, a player invests a value normally distributed with the mean of his original investment (in case of no mutation) and the variance equal to 10% of the mean. It is shown in [1] that the mean investment level (the mean level of cooperation) evolves from a very low initial value (cooperation) to some high level (a significant fraction of the maximum level of cooperation, I_{Max}).

A demographic model is introduced in [2]. There are randomly dispersed AllC and AllD initially in a square lattice of cells. AllC and AllD always use Cooperate and Defect, respectively. In each period, players move locally and play PD game(s) against local player(s). Here "local" means his von Neumann neighbors (his immediate neighboring 4 cells). A player has his lifespan and negative wealth (accumulated payoff) of him means his death. He leaves offspring if he gets enough wealth to do it and he has an unoccupied cell in his von Neumann neighbors. It is shown in [2] that the cooperation emerges in this setting. The local move and play in the spatial structure makes cooperative strategies, that is, AllC's happen to cluster together around them, to play PD games against them, to earn positive payoff, and to leave their offspring. Thus, the local move and play in the spatial structure is a major factor in the emergence of cooperation. The Epstein’s original model discussed above is extended in [3] by introducing global move, global play, and Reluctant players into a demographic PD game. Reluctant players delay replying to changes and use extended forms of tit for tat (TFT). Here TFT Cooperates at the first game and at later games uses the same move as the opponent did in the previous game. It is shown that the reluctance promotes the emergence of cooperation. Thus, the

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reluctance to respond the opponent's change is also an important element in the emergence of cooperation. Reference [4] examines the effect of move-play pattern on the emergence of cooperation and the distribution of strategy. It restricts patters of move and play of a player to simple structure; local or global, where local or global means that with a high probability the player moves (plays) locally or globally, respectively. It is shown in [4] that players using cooperative strategies finally move locally and play locally but those using defective strategies move globally or play globally if some players initially play globally. Role of Optimists against Pessimists on the emergence of cooperation in Demographic Multi-attribute DR game is considered in [5]. A player plays, instead of the usual single DR game, a Multi-attribute DR game where each attribute corresponds to a single DR game. Optimists focus on the best outcome of the Multi-attribute DR game whereas Pessimists on the worst outcome. It is shown that the emergence rate of cooperation with the initial population including both Optimists and Pessimists is higher than that including only Optimists.

In this paper, we present multiple levels of cooperation, L(ow), M(iddle), and H(igh) levels, into the usual one-level DR Game. We start with TFT as a strategy of a player which is a two-state automaton, DL. The initial state of TFT is L and the next state after one game as a Recipient is the right or the left of the current state if the opponent Donor uses L or D, respectively. We allow two identical moves in his strategy, for example, DLL or DLLMM. We introduce the following five types of a player, "f", "moe", "mse", "mon", and "msn" to modify and extend, for example, from DL to DLL and to DLLMM:

1. Type "*f*" (*f*ixed) does not modify his strategy.
2. Type "*moe*" *m*odifies and *e*xpands his strategy by means of his experiences as a Recipient by *o*ther players.
3. Type "*mse*" *m*odifies and *e*xpands his strategy by means of his practices by himself as a Donor.
4. Type "*mon*" *m*odifies his strategy by means of his experiences as a Recipient by *o*ther players but does *n*ot expand his strategy.
5. Type "*msn*" *m*odifies his strategy by means of his practices by him*s*elf as a Donor but does *n*ot expand his strategy.

For example, suppose that type "moe" experiences, as a Recipient, move L by other players most frequently. If he uses DL or DLL, then he changes his strategy to DLL or DLLM, respectively. Suppose also that type "msn" takes, as a Donor, move L most frequently. If he uses DL or DLL, then he changes DL to DLL but does not change DLL to DLLM. Type "moe" and "mon" learn from others' moves, whereas type "mse" and "msn" from their own moves.

We investigate the effect of modification and expansion of strategy on the emergence of cooperation in the Demographic Multi-level DR Game.

In Section II, we explain our model in detail. In Section III, results of simulation are discussed. And Section IV concludes the paper.

II. MODEL

A. Multi-level DR Game

A Multi-level DR game is a two-person game where one player is selected as a Donor and the other as a Recipient randomly. The Donor has four moves, D(efect), L(ow), M(iddle), and H(igh) level of Cooperate. L, M, and H mean the Donor pays cost c_{L}, c_{M}, and c_{H} in order for the Recipient to receive benefit b_{L}, b_{M}, and b_{H}, respectively ($b_{\mathrm{H}}-c_{\mathrm{H}}>b_{\mathrm{M}}-c_{\mathrm{M}}>b_{\mathrm{L}}-c_{\mathrm{L}}>0$, $b_{\mathrm{H}}>b_{\mathrm{M}}>b_{\mathrm{L}}>0$, and $c_{\mathrm{H}}>c_{\mathrm{M}}>c_{\mathrm{L}}>0$). D means the Donor does nothing. The Recipient has no move at all. The Multi-level DR game is a generalization of the usual one-level DR game in the sense that any two moves in the Multi-level DR game, for example, D and M constitute the usual one-level DR game. It is common in a demographic PD game that payoffs of opponent's cooperative move and those of opponent's defective move are treated symmetrically, that is, *R*+*P*=*T*+*S*=0 in the usual notation of PD, which means that the Reward for mutual cooperation plus the Punishment for mutual defection and the Temptation to defect plus the Sucker's payoff accruing to a sole cooperator are equal to 0. Thus, the original payoffs of our Demographic Multi-level DR game must be converted those where the worst sum of payoffs of a player, in two successive games once as a Donor and once as a Recipient, is equal to the best sum in absolute value. The converted payoffs are obtained by subtracting constant $x=(b_{\mathrm{H}}-c_{\mathrm{H}})/4$ from the original payoffs of the Multi-level DR game. We set $b_{\mathrm{H}}=9$, $b_{\mathrm{M}}=7$, $b_{\mathrm{L}}=4$, $c_{\mathrm{H}}=3$, $c_{\mathrm{M}}=2$, and $c_{\mathrm{L}}=1$ in this paper. Thus $x=1.5$. Table I shows the converted payoff matrix of the Multi-level DR game.

TABLE I
PAYOFF MATRIX OF MULTI-LEVEL DR GAME

		Recipient
Donor	H	$-c_{\mathrm{H}}-x=-4.5, b_{\mathrm{H}}-x=7.5$
	M	$-c_{\mathrm{M}}-x=-3.5, b_{\mathrm{M}}-x=5.5$
	L	$-c_{\mathrm{L}}-x=-2.5, b_{\mathrm{L}}-x=2.5$
	D	$0-x=-1.5, 0-x=-1.5$

B. Strategy, Basic Structure

A strategy in this paper is an extended form of TFT and is expressed as strings of letters, D(efect), L(ow), M(iddle), and H(igh). The number of the identical letter included in a strategy is 0, 1, and 2, that is, at most two repetitions. A less cooperative letter comes first from the left to the right in the order of letters. Examples of them are DL, DLL, DLLM, DDLLMMHH, and so on.

A strategy has its current state with an initial value. For example, TFT (DL in our notation) has its initial state L, meaning that TFT uses L initially as a Donor. Initial states of our strategies will be specified in later subsections. A player uses the move that the current state of his strategy points to when he plays a game as a Donor. A current state of a strategy changes as follows: Suppose that a strategy plays a Multi-level DR game as a Recipient. If the move of the opponent Donor is less cooperative than the current state, then the current state changes to the immediate left (unless the current state is the leftmost state). If the move of the opponent Donor is more cooperative than the current state, then the current state changes to the immediate right (unless the current state is the rightmost state). If the move of the opponent Donor is the same as the current state, then the current state changes to the immediate left or right (unless the current state is neither the leftmost nor the rightmost state) if the move of the opponent is D or not, respectively. For example, the current state L of DL changes D if the move of the opponent Donor is D. The current state L of DLM changes D if the move of the opponent Donor is D, and it changes M if the move of the opponent Donor is L, M, or H. We will explain the part of modification and expansion of strategy later in this Section.

C. Inheriting Properties of a Player

A player has the following properties that are inherited from parents to offspring; rateOfGlovalMove (*rGM*), rateOfGlobalPlay (*rGP*), strategy, type of modification and expansion (tME); whose initial distributions are summarized in Table II.

TABLE II
INITIAL DISTRIBUTION OF INHERITING PROPERTIES

Property	Initial Distribution
(*rGM*, *rGP*)	(*rGM*, *rGP*) is selected randomly from ll, lg, gl, and gg. For example, lg denotes *rGM* is selected uniformly from interval l:=(0.05, 0.2) and *rGP* from g:=(0.8, 0,95), which indicates to move locally and play globally.
strategy	We deal with the following 3 distributions, DL, 1D9DL, and 1D4DL5DLL. DL:={(1)DL}, 1D9DL:={(0.1)D, (0.9)DL}, and 1D4DL5DLL:={(0.1)D, (0.4)DL, (0.5)DLL}. The distribution DL selects strategy DL with probability one. 1D9DL means that D is selected with probability 0.1 and DL with probability 0.9. 1D4DL5DLL means that D, DL, and DLL are selected with probability 0.1, 0.4 and 0.5, respectively. The initial state of DL is basically determined randomly. The initial state of D is, of course, D. The initial state of DLL is the rightmost L. Initial states of the other strategies are determined so that D and L are used with the same probability 0.5. Note that all these three initial distributions do not have M nor H moves, that is, the middle and the high levels of Cooperate.
tME	We deal with the following 22 distributions, f:={(1)f}, msn:= {(1)msn}, m5n:={(0.5)mon, (0.5)msn}, mon:={(1)mon}, 5msn:= {(0.5)msn, (0.5)f}, 5m2n:={(0.1)mon, (0.4)msn, (0.5)f}, 5m5n:= {(0.25)mon, (0.25)msn, (0.5)f}, 5m8n:={(0.4)mon, (0.1)msn, (0.5)f}, 5mon:={(0.5)mon, (0.5)f}, 5mse:={(0.5)mse, (0.5)f}, 5m2e:= {(0.1)moe, (0.4)mse, (0.5)f}, 5m5e:={(0.25)moe, (0.25)mse, (0.5)f}, 5m8e:={(0.4)moe, (0.1)mse, (0.5)f}, 5moe:={(0.5)moe, (0.5)f}, mse:={(1)mse}, m5e:={(0.5)moe, (0.5)mse}, moe:={(1)moe}, ms8:= {(0.8)mse, (0.2)msn}, m28:={(0.16)moe, (0.04)mon, (0.64)mse, (0.16)msn}, m58:={(0.4)moe, (0.1)mon, (0.4)mse, (0.1)msn}, m88:= {(0.64)moe, (0.16)mon, (0.16)mse, (0.04)msn}, mo8:={(0.8)moe, (0.2)mon}. For example, the distribution f selects type f with probability one. 5m2e selects moe with probability 0.1=0.5*0.2, mse with 0.4=0.5*0.8, and f with 0.5. m88 selects moe with probability 0.64=0.8*0.8, mon with 0.16=0.8*0.2, mse with 0.16=0.2*0.8, and msn with 0.04=0.2*0.2. We can specify the distribution of type of modification and expansion (tME) of a player depending on his strategy as explained in the main text.

D. Demographic Model

In period 0, *N* (=250) players are randomly located in 50-by-50 lattice of cells. The borders of the lattice are connected as follows: A player comes inside from the upper (right) border if he moves outside from the lower (left) border, and vice versa. Every player has his initial wealth, 6. His initial integer valued age is randomly distributed between 0 and deathAge (=50).

In each period, each player moves and then plays 6 Multi-level DR games given in Table I. The detail of move and play is given in Table III. His wealth is increased by the payoffs of the games. Positive payoff needs cooperative moves, L, M, or H of the opponent Donor. If the resultant wealth is negative, then he dies. If it is greater than fissionWealth (=10) and there is an unoccupied cell in von Neumann neighbors, then the player leaves offspring and gives 6 units from his wealth to the offspring. His age is increased by one. If his age is larger than deathAge (=50), then he dies. Then the next period starts.

TABLE III
DETAILED DESCRIPTION OF MOVE AND PLAY

	Description
(1st) move	A player moves to a random unoccupied cell in the whole lattice if available with probability *rGM*. He moves to a random cell in von Neumann neighbors if available with probability 1−*rGM*. Otherwise he stays at the current cell.
(2nd) play	The opponent against whom a player plays the Multi-level DR game is selected globally and locally with probability *rGP* and with probability 1−*rGP*, respectively. "globally" means that it is selected randomly from all players except the player himself in the whole lattice. "locally" that randomly from von Neumann neighbors if available. The player plays 6 games by following this process. Thus, the opponents are possibly different.

E. Strategy, Modification and Expansion

We introduce types of players about the modification and expansion of their strategies, "f", "moe", "mse", "mon", and "msn". Type "f" does not change his initial strategy forever. For example, type "f" of DL uses DL forever.

Type "moe" and "mon" memorize the moves of his opponent Donors. In every three periods, they select the most frequent move of his opponent Donors (select the most cooperative move if a tie occurs) in the latest three periods and try to modify his strategy with the most frequent move. If the most frequent move is not in his strategy or the number of the most frequent move in his strategy is equal to one, then the most frequent move is added to his strategy (Inserting position is selected randomly from the left or the right of the same existing move in the latter case). If the number of the most frequent move in his strategy equals to two and the move is his most cooperative one but not H, then type "moe" adds one-level higher cooperative move than the most frequent move (extends his strategy to one-level higher cooperation), but type "mon" does not. For example, type "moe" and "mon" of DL with the most frequent move L modify their strategy to DLL. Type "moe" and "mon" of DL with the most frequent move H modify their strategy to DLH. Type "moe" of DLL with the most frequent move L extends his strategy to DLLM, but type "mon" does not.

Type "mse" and "msn" memorize their own moves as a Donor. In every three periods, they select the most frequent move of their own moves as a Donor (select the most cooperative move if a tie occurs) in the latest three periods. The rest of the modification and expansion process is the same as in type "moe" and "mon" cases.

Type “moe” or “mse” is necessary in order that initially a nonexistent move, for example, H, in the population comes into existence. If we do not distinguish "moe" and "mse" (or, "mon" and "msn"), then we use "me" (or "mn") instead.

F. Remark

In our simulation synchronous updating is used, that is, in each period, all players move, then all players play, and then all players leave offspring if possible. Initial state of a strategy in the initial population is defined in Table II. That of offspring is defined as the current state of the parent's strategy. The properties of a parent are not inherited to the offspring with mutationRate (=5%). The properties of the offspring are determined by the initial distributions of them given in Table II when the mutation occurs. We assume that with errorRate (=5%) a player makes a mistake when he makes his move, that is, he chooses a random one from the moves that the current state does not point to if the number of letters in his strategy is larger than one.

Note that the initial distribution of (*rGM*, *rGP*) in Table II has simple structures; with a high probability, a player moves and plays locally or globally, thus there are 4 move-play patters such as local move local play (ll), local move global play (lg), global move local play (gl), and global move global play (gg).

If a distribution has only one element with probability one in Table II, we indicate the distribution with the same notation as the element (abuse of notation). We deal with three initial distributions of a player's strategy, DL, 1D9DL, and 1D4DL5DLL in Table II. The initial state of DLL is the rightmost L. Initial states of the other strategies are determined so that D and L are selected with the same probability 0.5. All these three distributions do not have the middle nor the high level of Cooperate, that is, M nor H.

We consider 22 initial distributions of type of modification and expansion (tME) in Table II. We use the following notation *s*m*tu*, where "*s*"∈{"5", ""}, "*t*"∈{"s", "2", "5", "8", "o"}, and "*u*"∈{"n", "2", "5", "8", "e"}. "*s*"="5" and "*s*"="" means type "f" is selected with probability 0.5 and 0.0, respectively, and the rest is determined by m*tu* part. m*tu* means type "moe", "mon", "mse", and "msn" are selected with probability $(t/10)*(u/10)$, $(t/10)*((1-u)/10)$, $((1-t)/10)*(u/10)$, and $((1-t)/10)*((1-u)/10)$, respectively, where "s", "t", "n", and "e" are interpreted as "0", "1", "0", and "1", respectively. All events in the above process are independent events, that is, the probability of a product event of two events is the product of the probabilities of the two events.

III. Simulation and Result

We examine the effect of modification and expansion of strategy on the emergence of cooperation and the distribution of strategy by simulating our model by means of Repast Simphony 2.4.0 in [6].

Let us define some basic terms. HRate, MRate, LRate, and DRate at a period are the average of HRate, MRate, LRate, and DRate of a player over all players at that period, respectively. HRate, MRate, LRate, and DRate of a player at a period is defined as the number of moves, H, M, L, and D used by the player, divided by the number of games played as a Donor at that period, respectively, where 0/0 is interpreted as 0. The average Cooperation rate is defined as the sum of HRate, MRate, and LRate. An outside observer sees cooperative moves, L, M, or H at the average Cooperation rate.

We perform 300 runs of simulations in each different setting. We conclude that cooperation emerges in a run if there are more than 250 players (the initial number of population) and the average Cooperation rate is greater than 0.2 at period 500. We call a run in which the cooperation emerges as successful. Note that it is necessary for many players to use cooperative moves, L, M, or H so that the population does survive. We are interested in the emergence rate of cooperation (EC), that is, the rate at which the cooperation emerges.

A. DL(f) and DL(mn)

First, we compare the emergence rate of cooperation (EC) of type "f" and that of type "mn" if the initial distribution of strategy is DL. Their EC's are shown in Table IV, where, for example, DL(f) indicates that the initial distribution of strategy is DL and that of type of modification and expansion is "f".

TABLE IV
Emergence rate of Cooperation (EC): DL(f) and DL(mn)

Distribution of strategy and tME		EC	
		Average	EC
DL(f)		0.000	
DL(mn)	DL(msn)	0.520	0.547
	DL(m5n)		0.503
	DL(mon)		0.510

The first row (of the data part, similarly hereinafter) in Table IV indicates the emergence rate of Cooperation, EC is 0% if every strategy is initially DL and its type of modification and expansion (tME) is "f". That is, the cooperation never emerges if there are initially only two moves, D and L, and all players do not modify nor expand their strategies. The second and fourth columns in the second to fourth rows show the tME's of DL and their EC's. For example, the third row means that EC of DL(m5n) is 50.3%, that is, EC increases from 0% to 50.3% if tME of DL changes from "f" to "mon"(50%) and "msn"(50%). By averaging three EC's in the fourth column, we conclude that EC of DL(mn) is 52.0%, that is, EC increases from 0% to 52.0% if tME of DL changes from "f" to "mn" (since we do not distinguish "mon" nor "msn").

The average number of repetitions of D and L in DL of type "mn" are 1.009 and 1.988, respectively (not shown in any table or figure). Thus, DLL, a variant of TF2T, tit for two tats, emerges by introducing the modification of strategy but not expansion.

B. DL(5mn) and DL(5me)

We consider how the situation changes if 50% of DL is of type "f", that is, 50% of DL does not modify nor extend their strategies. Table V shows how the situation changes. The structure of Table V is the same as that of Table IV. Thus EC increases from 0% to 25.3% and to 47.3% if tME of the rest 50% of DL changes from "f" to "mn" and to "me", respectively. The modification and expansion of strategy promote the cooperation more compared with the modification but not expansion.

We further examine the effect of expansion of strategy in a typical case, DL(5m5e) of DL(5me) in Table V. We are interested in the Cooperation rate, the distribution of strategy, and the average number of repetitions of moves in DLMH at period 500 in DL(5m5e). Their graphs of DL(5m5e) are shown in Figs. 1-3.

TABLE V
EMERGENCE RATE OF COOPERATION (EC): DL(5MN) AND DL(5ME)

Distribution of strategy and tME		EC	
		Average	EC
DL(5mn)	DL(5msn)	0.253	0.240
	DL(5m2n)		0.267
	DL(5m5n)		0.263
	DL(5m8n)		0.250
	DL(5mon)		0.243
DL(5me)	DL(5mse)	0.473	0.477
	DL(5m2e)		0.503
	DL(5m5e)		0.450
	DL(5m8e)		0.467
	DL(5moe)		0.467

Fig. 1 indicates that DRate is not the maximum of the four rates. LRate is the maximum and HRate is the minimum of the four rates. Among the cooperative moves, the more cooperative, the less often observed.

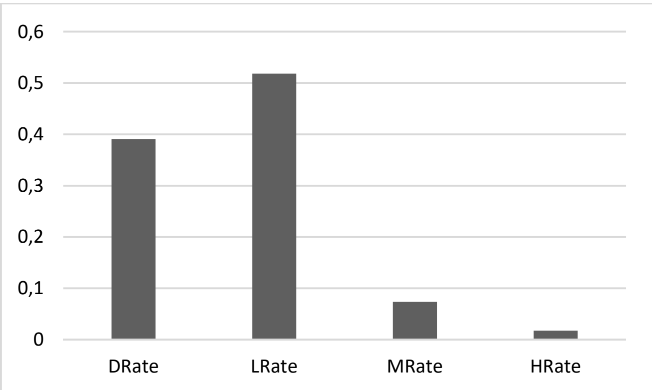

Fig. 1 (DL) Average rate of move, D, L, M, and H

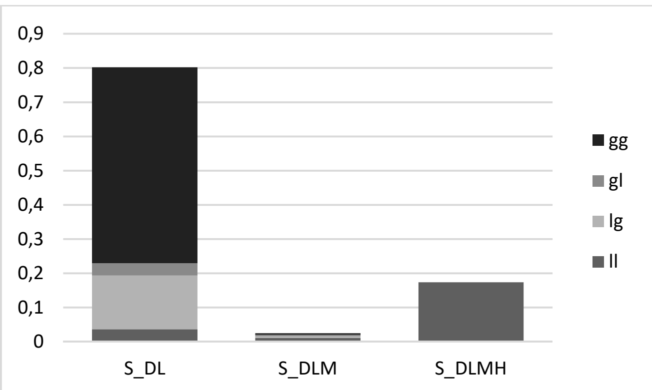

Fig. 2 (DL) Distribution of strategy and move-play pattern

In Fig. 2 the repetitions of moves are ignored. For example, S_DL (shortened DL) in Fig. 2 includes DL, DDL, DLL, and DDLL. S_DL is the largest part of the population (about 80%) and S_DLMH is a small but some part of the population (about 17.3%). The move-play pattern of S_DLMH is local move and local play (ll) and the ll pattern of S_DL is very small. This observation corresponds to that in [4].

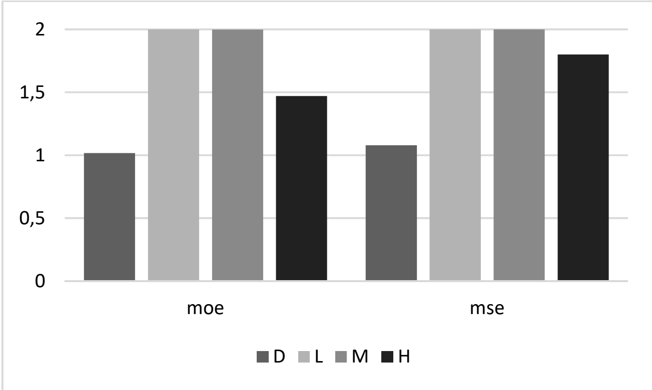

Fig. 3 (DL) Average number of repetitions of moves in S_DLMH

Fig. 3 shows the average number of repetitions of moves in S_DLMH of type "moe" and "mse". On the average, S_DLMH of type "moe" is actually DLLMMH and that of type "mse" is actually DLLMMHH. Thus, DLLMMH and DLLMMHH emerge. Note that the highest level of cooperation, H emerges because of the expansion of strategy even if the move H is not initially present.

C. 1D(f)9DL and 1D(f)5DLL(me)4DL

In real life, there are inevitably undesirable AllD's (D in our notation) present in the world. We investigate how the cooperation emerges if 10% of the population is initially D of type "f", that is, D(f). We set the initial distribution of tME depending on the strategies. The rest (50%+40%) of the initial population consists of DL(me(80%)mn(20%)), that is, DL of type "me"(80%) and type "mn" (20%). And then 50%-portion of DL is replaced with DLL(me), that is, DLL of type "me". EC's are given in Table VI. The structure of the first row 1D(f)9DL(me(80%)mn(20%)) in Table VI is the same as that in Table V. The second row 1D(f)5DLL(me)4DL(me(80%) mn(20%)) in the first column averages the three averaged EC's in the fifth column over the sixth column. Thus, EC of 1D(f)9DL(me(80%)mn(20%)) is only 9.3%, but it increases to 38.9% by replacing 50%-portion of DL with DLL(me). Two repetitions of L (by adding one L initially) and type "me" in this 50%-portion really promotes the cooperation.

We also further investigate the effect of expansion of strategy. We pick up a typical case 1D(f)5DLL(m5e)4DL(m58) in Table VI. Since another typical case 1D(f)9DL(m58) has the similar results to those of 1D(f)5DLL(m5e)4DL(m58) shown in the rest of this subsection, we do not deal with 1D(f)9DL(m58).

We are interested in the Cooperation rate, the distribution of strategy, and the average number of repetitions of moves in DLMH at period 500 in 1D(f)5DLL(m5e)4DL(m58) of Table VI. Their graphs are shown in Figs. 4-6.

TABLE VI
EMERGENCE RATE OF COOPERATION (EC): 9DL AND 9DL(ME)

Distribution of strategy and tME			EC		
			Average		Average
			Average	Average	Average
1D(f) 9DL(me(80%) mn(20%))		DL(ms8)	0.093		0.110
		DL(m28)			0.060
		DL(m58)			0.110
		DL(m88)			0.100
		DL(mo8)			0.083
1D(f) 5DLL(me) 4 DL(me(80%) mn(20%))	DLL(mse)	DL(ms8)	0.389	0.393	0.390
		DL(m28)			0.393
		DL(m58)			0.433
		DL(m88)			0.357
	DLL(m5e)	DL(m28)		0.380	0.383
		DL(m58)			0.360
		DL(m88)			0.397
	DLL(moe)	DL(m28)		0.395	0.403
		DL(m58)			0.367
		DL(m88)			0.437
		DL(mo8)			0.373

In Fig. 4 DRate is the maximum and LRate is the minimum. HRate is the second maximum. Move D is most often observed. Among the cooperative moves, the more cooperative, the more often observed. The pattern of graph in Fig. 4, 1D(f)5DLL(m5e)4DL(m58), is quite different from that in Fig. 1, DL(5m5e), mainly because of the initial presence of 10% D(f).

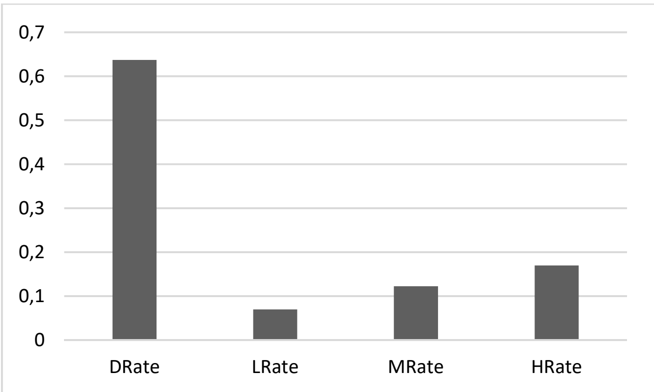

Fig. 4 (D) Average rate of move, D, L, M, and H

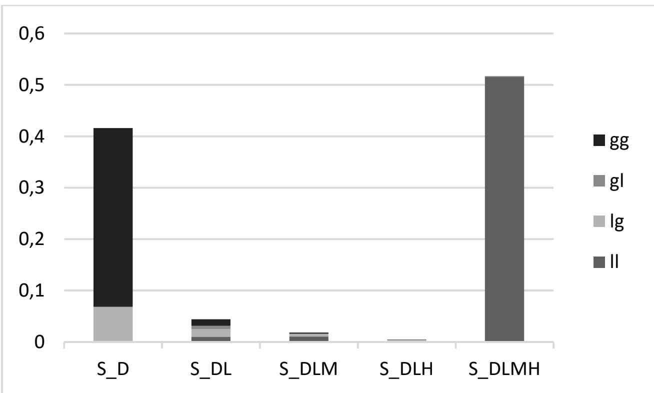

Fig. 5 (D) Distribution of strategy and move-play pattern

In Fig. 5 the repetitions of moves are ignored. For example, S_DL (shortened DL) in Fig. 5 includes DL, DDL, DLL, and DDLL. S_DLMH is the largest part of the population (just above 50%) and S_D (actually D because of type "f") is the second largest part of the population (just above 40%). The move-play pattern of S_DLMH is almost local move and local play (ll) and the ll pattern of S_D is negligible. This observation also corresponds to that in [4].

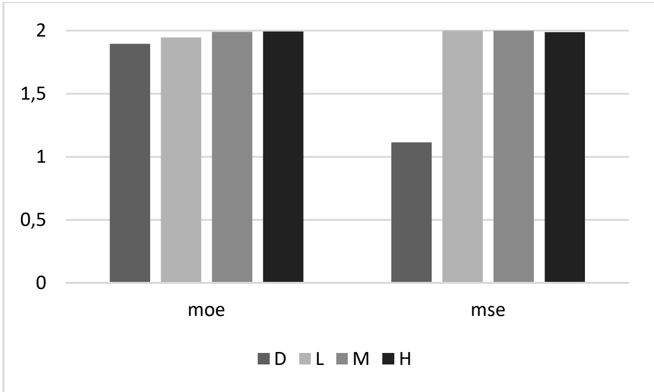

Fig. 6 (D) Average number of repetitions of moves in S_DLMH

Fig. 6 shows the average number of repetitions of moves in S_DLMH of type "moe" and "mse". On the average, S_DLMH of type "moe" is actually DDLLMMHH, which is different in Fig. 3 since the presence of D of type "f". And that of type "mse" is actually DLLMMHH. Thus, DDLLMMHH and DLLMMHH emerge. Note again that the highest level of cooperation, H emerges because of the expansion of strategy even if the move H is not initially present.

IV. CONCLUSION

We investigate the effect of modification and expansion of strategy on the emergence of cooperation in the Demographic Multi-level DR Game. We introduce five types of player about the modification and expansion, "f", "moe", "mon", "mse", and "msn".

We show, by Agent-Based Simulation, the following results:

(1-0) The emergence rate of cooperation is 0% if all players using DL are of type "f".

(1-1) It increases to about 50% and DLL emerges if all players are of type "mn".

(1-2) It increases to about 25% and to about 45% if 50% of all players are of type "f" and the rest of the players are of type "mn" and "me", respectively, and also DLLMMHH emerges in case "me".

(2-0) It is only about 10% but DLLMMHH emerges if 10% of all players use D and are of type "f" and the rest (50%+40%) use DL and are of type "me" (80%) and "mn" (20%).

(2-1) It increases to about 40% and DLLMMHH emerges if 50%-portion of DL are replaced with DLL of type "me".

The modification and expansion of strategy make our society more cooperative.

REFERENCES

[1] T. Killingback, M. Doebeli, and N. Knowlton, "Variable investment, the Continuous Prisoner's Dilemma, and the origin of cooperation," *Proc. R. Soc. Lond. B*, vol. 266, September 1999, pp. 1723-1728.

[2] J. M. Epstein, "Zones of Cooperation in Demographic Prisoner's Dilemma," in *Generative Social Science*. Princeton University Press, 2006, pp. 199-221.

[3] T. Namekata and Y. Namekata, "Effect of Reluctant Players in Demographic Prisoner's Dilemma Game," in R. Bartak (ed.): *Proceedings of the 14th Czech-Japan Seminar on Data Analysis and Decision Making under Uncertainty* (held in September 18-21, 2011, Hejnice, Czech Republic). Publishing House of the Faculty of Mathematics and Physics, Charles University in Prague, 2011, pp. 102-109.

[4] T. Namekata and Y. Namekata,"Emergence of cooperation and patterns of move-play in demographic donor-recipient game," in Masahiro Inuiguchi, Yoshifumi Kusunoki and Hirosaki Seki (eds.): *Proceedings of the 15th Czech-Japan Seminar on Data Analysis and Decision Making under Uncertainty* (held in September 24-27, 2012 Osaka, Japan), 2012, pp. 51-58.

[5] T. Namekata and Y. Namekata, "Role Of Optimist On Emergence Of Cooperation In Demographic Multi-Attribute Donor-Recipient Game," in *ECMS 2015 Proceedings* edited by: Valeri M. Mladenov, Petia Georgieva, Grisha Spasov, Galidiya Petrova European Council for Modeling and Simulation, 2015, pp. 35-41. doi:10.7148/2015-0035

[6] Repast Simphony 2.4.0 is an advanced, free, and open source agent-based modeling and simulation system downloadable in https://repast.github.io/.