How Social Structure and Institutional Order Co-evolve Beyond Instrumental Rationality

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ABSTRACT
This study proposes an agent-based model where adaptively learning agents with local vision who are situated in the Prisoner's Dilemma game change their strategy and location as well. Besides both the copying-highest-scoring strategy and the tie dissolution among defectors as the instrumental rationale, two other heuristics are considered: following-the-majority in the influence process; and the tie dissociation between cooperators and defectors in the selection process. Under the overall setting which is not favorable to cooperation, it turned out that cooperative culture is less likely to emerge and its transmission is more unstable when more agents stick to follow the trend on the fixed network. Given the same set of conditions but with the small amount of social plasticity, cooperative culture is much more likely to emerge and sustain on a hierarchical network where the average clustering coefficient is higher and the average path length is still similar compared to those of the equivalent random network when the small degree of freedom from defectors is allowed to defectors only; much higher and slightly longer, respectively, when cooperators also have that freedom.

Categories and Subject Descriptors
J.4 [**Computer Applications**]: Social and Behavioral Sciences – *Sociology*

General Terms
Algorithms

Keywords
Prisoner's Dilemma Game, Instrumental Rationale, Homophily, Coordination, Emergent Order, Emergent Structure, NetLogo

1. INTRODUCTION
There has been growing scholarly concern in institutions and institutional analysis across the social science disciplines over the past decades, but it seems that there are still divergent views on two interrelated issues: First, how to conceptualize institution? Is that institutional system or shared belief? Second, how to bridge the macro-micro gap in view of the structure-agency duality?

One answer is the macro approach with a structural functionalistic flavor. This approach places institutions in the classical systems theory and attributes causal forces to reified structure independently from agent's course of actions. It assumes the particular tendency at the global level such as differentiation and integration as the master trend of socio-cultural evolution: differentiation of the society engenders the problem of cooperation or coordination among human agents, but regulatory norms function to hold it together. The system-dynamics simulation has a strong affinity with this macro-oriented evolutionary theorizing. In contrast, agent-based simulation modeling of evolutionary games on social dilemmas, although it has only rarely been the focus of attention among sociologists, has great potentials for inquiring into how institutions as shared beliefs or regularities of behavior emerge and maintain at the global level as the outcome of local interactions among heterogeneous agents with bounded, retrospective, and algorithmic rationality, without assuming a set of normative values as the system-level parameter.

Agent's adaptive learning, not to mention social interaction and economic exchange, proceeds in social networks, however. In this sense, spatiality has been a missing link in the analysis of the behavior-institution co-evolution [16]. Institutional structure (e.g., cooperation, coordination, solidarity) and relational structure (e.g., segregation, hierarchy, small-world networks, scale-free networks) have been studied under the distinctive categories: dynamics on networks (i.e., emergent order) and network dynamics (i.e., emergent structure), respectively [9]. Suffice to say here: it is hard to handle territoriality with the system dynamics approach in which random interaction is implicitly assumed; and local variables (e.g., clustering) cannot be distinguished from global ones (e.g., density).

2. LITERATURE REVIEW
Recent research on spatialized evolutionary Prisoner's Dilemma game [1, 2, 6, 10, 11, 14, 17, 18] has rekindled the attention to the network embeddedness: social structure matters. Nevertheless, there seem to be still several drawbacks: some assume random matching at the global level; the space in most approaches is the lattice; most works focus more on dynamics on networks (i.e., strategy change on exogenous networks) while bypassing the question of where networks come from; some others deal with the selection process through voluntary participation, exit, or viscosity, but this is an indirect approach to network dynamics; and some others adopt stochastic modeling of network dynamics, but agents are hyper-rational. For instance, agents in the scale-free network model should be able to calculate the number of others' links across the population, but human agents are neither statisticians nor mathematicians. It would be more reasonable to model how networks change as the outcome of local interaction among

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actors when their vision is restricted by local information as common knowledge.

Given this discussion, [6, 18] is the exemplary reference for my study since they conducted simulation experiments of the Prisoner's Dilemma game on endogenous networks to explore the behavior-institution co-evolution. They found out that cooperators can coexist with defectors on a small-world network with the relatively high clustering coefficient, once those who choose to defect for the next round are allowed to break one of ties to one of neighbors who defected at the last round and then make a new friend in a random manner, given the influence rule by default that unsatisfied agents copy the highest-scoring strategy at the last round in their local neighborhood. They maintain that agents play the different roles on that network such as leaders (i.e., satisfied agents in the core), conformists (i.e., unsatisfied cooperators around leaders), and exploiters (i.e., defectors with larger payoff in the periphery). It should be added that they observed little change in the average path length and introduced another new parameter, the extent to which local selection of a new partner happens among the neighbors of the neighbors, to get the higher clustering coefficient than that of the equivalent random network. Suffice to stress here that some studies [8, 11] got the similar network which is conducive to the robustness of cooperation, but it looked like a scale-free network.

As another substantial issue, instrumental rationality together with the material reward is predominant in existing studies including [6, 18], with limited attention to psychological one. However, agents might want to coordinate their choices with the dominant one when the payoff structure is not built-in them. Indeed, the Coordination game is another core model of social dilemma [7]. In this aspect, the generalized Tit-for-Tat in the N-person Prisoner's Dilemma game indicates another type of heuristic (i.e., following-the-majority): each actor calculates the fraction of its neighborhood that cooperated at the last round, if this fraction is greater than a cut-off point, cooperate, and otherwise, defect [14]. Also, people might want to change their location for affectual reasons, as is implied in Schelling's model of residential segregation [12]. Collins puts forward the theory of interaction ritual market to contend that the common denominator for social interaction is emotional energy, not material reward [3-5]. Only defector-defector ties can be severed in [6, 18] because there is no material incentive for them to keep the relationship while cooperator-cooperator ties are reinforced and the net force in cooperator-defector ties is balanced. However, cooperators are likely to decrease heterophilous ties (i.e., to increase homophilous links indirectly through breaking ties to defectors) and more likely to do when they do not have clear ideas of the external material reward.

3. THE MODEL

3.1 Algorithms

N of cooperators and defectors are distributed at a certain ratio on a random network. Agents embedded differently in their local neighbors are supposed to gain differential economic capital (i.e., flow) per round based on the classical payoff matrix where 1 for Reward for Mutual Cooperation, α for Temptation to Defect, and 0 for both Sucker's Payoff and Punishment for Mutual Defection. Given that the level of relative deprivation is 1, if an ego's economic capital is less than the local maximum, she feels unsatisfied; otherwise, satisfied. Satisfied agents change neither their strategy nor their location. Synchronously, unsatisfied agents change their strategy first, and then their location.

Unsatisfied agents copy the strategy of the local neighbor of the greatest wealth (i.e., stock, not flow) or follow the strategy which was in the majority at the last round. When more than two neighbors happen to have the same maximum, one of them is randomly selected. Similarly, one strategy is randomly chosen if the local strategy distribution is bimodal. Which one between copying-the-highest and following-the-trend depends on what random integer number is generated. For example, if the percent of following-the-majority is 0 (or 100), always highest-copying (or majority-following). Given it is 10, if the random number is less than 10, majority-following; otherwise, highest-copying. Because the random number generator is based on the uniform distribution, the chance is that 10% of those who feel unsatisfied follow the trend while 90% copy the highest in the long run.

At a certain level of social plasticity [6, 18] (i.e., the degree of social mobility), rewiring is manipulated if it is above 0; otherwise, the influence procedure only. If it is 100, unsatisfied agents modify their strategy first, and then always change their location. In the same way above, when the level of plasticity is set as 10, if the random number is less than 10, unsatisfied ones change their strategy and then their location; otherwise, their strategy only. It should be added here: isolates may be generated in the middle of location change. Since either of influence processes cannot be applicable for those who do not have the local neighborhood, they always feel unsatisfied, but they keep their strategy at the last round for the next round. The same principle of plasticity is applied to their location change, however.

If the tie dissociation from defectors is allowed to cooperators as well as defectors, whether unsatisfied agents choose cooperation or defection for the next round, both can refuse the interaction with, if any, one of local neighbors that defected at the last round; otherwise, only one who will choose defection can break one of ties to, if any, one of defectors. It should be addressed that agents remember who was who at the last round in their local, but they do not have any ideas about who outside their neighborhood will be who at the next round. They make a new link to them randomly given this local vision. This assumption of no preference is reasonably applicable to the tie formation whether agents are isolates or not. Right after both the procedures of influence and selection, all of information is updated at the end of each round.

3.2 Key Assumptions

My current model shares most assumptions with [6, 18]: I will be able to include stochastic elements in the near future, for examples, by making the probability of strategy change proportional to the difference between an ego's score and the local maximum and/or the probability of tie dissolution differ from one to another person depending on the duration of friendship or the strength of ties; any targeted agent, regardless of her preference, always accepts a new partner. The issue of whether undirected ties between two actors can be broken unilaterally could be circumvented through considering the direction of attraction and repulsion indirectly, though; why and under what conditions agents do not rely on the instrumental rationale: affectual (e.g., they want as many homophilous ties as possible for emotional stability) or herd-like (e.g., when the payoff structure is not recognizable, agents might regard the on-going game as an N-person coordination game)? Also, which heuristic is manipulated depends on what random number is generated, not on different types of algorithmic responses to different environments in which agents are embedded; my model is not about growing network; no cost for either strategy change or location change in a strict sense. The parameter of social plasticity takes such cost into account indirectly since it indicates the rate at which the network structure evolves, as compared to the timescale of strategy change; and synchronous updating is employed to test the findings in [6, 18].

4. METHODS

I took advantages of NetLogo 4.0 [15]. Given the experimental design (see Table 1), 100 runs for each setting, which amounted to 700 runs in total. In comparison to [6], the initial setting is not that favorable to cooperation: the population size (50 instead of 10,000); α as the defection award (0.8 instead of 0.2 through 0.8); and the proportion of cooperators (0.5 instead of 0.6). Indeed, it is reported that when α is 0.6 and the level of plasticity is 1%, only 6% get trapped in all-defector networks for N=10,000, while 80% get trapped for N=1,000 [6], which means that the smaller population, the higher chance of all-defector network. The initial density (mean: 0.151; standard deviation: 0.00608), the initial average degree (mean: 7.391; standard deviation: 0.298), and the level of relative deprivation (1.0) were controlled.

Table 1. Summary of Experimental Design

ID	Copy-highest	Follow-majority	DD broken?	CD broken?	Plasticity
1	100	0	N/A	N/A	0
2	90	10	N/A	N/A	0
3	80	20	N/A	N/A	0
4	100	0	Yes	No	10
5	100	0	Yes	No	20
6	100	0	Yes	Yes	10
7	100	0	Yes	Yes	20

5. PRELIMINARY FINDINGS

5.1 Institutional Order: 1 through 3

I found out that the more following-the-trend the less chance that cooperative culture survives. The association between the two was significant in the χ2 test (Type I Error=0.02), but the mean difference of the proportion of cooperators (Fig.1a) and the number of rounds needed for an equilibrium where cooperators and defectors coexist or it ends up with all-defector networks (Fig.1b) across the different level of following-the-trend is not significant at the alpha level of 0.05 according to the ANOVA test because of the big within-variance.

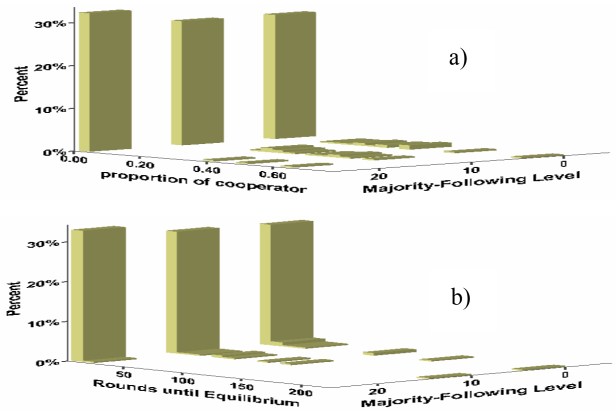

Figure 1: a) Proportion of cooperators. b) Number of rounds needed for an equilibrium

5.2 Institutional Order and Social Structure: 4 through 7

Whether cooperation as shared belief sustains or not was independent with the level of social plasticity according to the χ2 test at the alpha level of 0.05. Given two factors, social plasticity and the type of rationale for location change, the 2-way ANOVA test at the same alpha level indicates that the proportion of cooperators (Fig. 2a) increases and their culture diffuses faster (Fig. 2b) significantly when cooperators also have the small degree of freedom from defectors. It is not the case when defectors alone have that freedom.

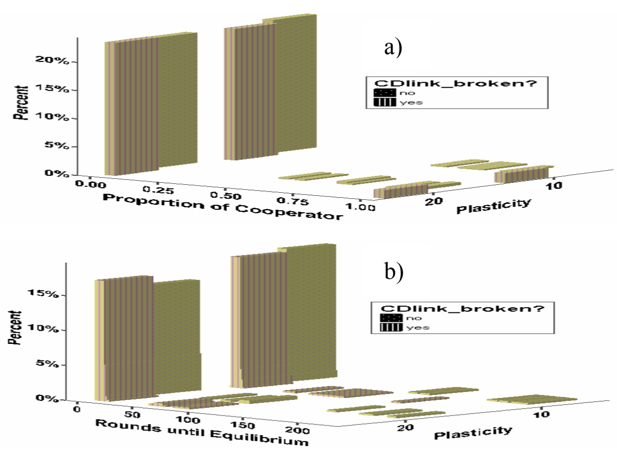

Figure 2: a) Proportion of cooperators. b) Number of rounds needed for an equilibrium. For both, left bars at each level of plasticity for the dissolution of CD-link as well as DD-link whereas right bars for the dissolution of DD-link only.

Once cooperators also can exit from defectors in their neighborhood, a network evolves with the significantly higher clustering coefficient (Fig. 3c) and the slightly longer path length (Fig. 3d) compared to both those when defectors alone can exit from defectors (Fig. 3a and 3c) and those when t=0 (i.e., the equivalent random network), without the help of additional parameter in [6, 18]. Together with the above result (Fig. 2), it is confirmed here that cooperative culture is more robust on the highly clustered network (Fig. 3a and 3c), but it is hasty to tell the path length effect (Fig. 3b and 3d). The overall result calls into question whether small-world networks are conducive to prosocial norms because the higher clustering less vulnerability of cooperation whereas the shorter path length the more effectively defection-prone culture traverses across the network. Also, hierarchical structure does not look like a small-world network given that the average path length does not change or becomes longer, not shorter. It might be a scale-free network, as is contended in [8, 11]. However, an in-depth analysis should be done of whether the overall regression residual of the log-log plot of degree distribution is small enough and how much that network is hierarchical through the blockmodeling technique.

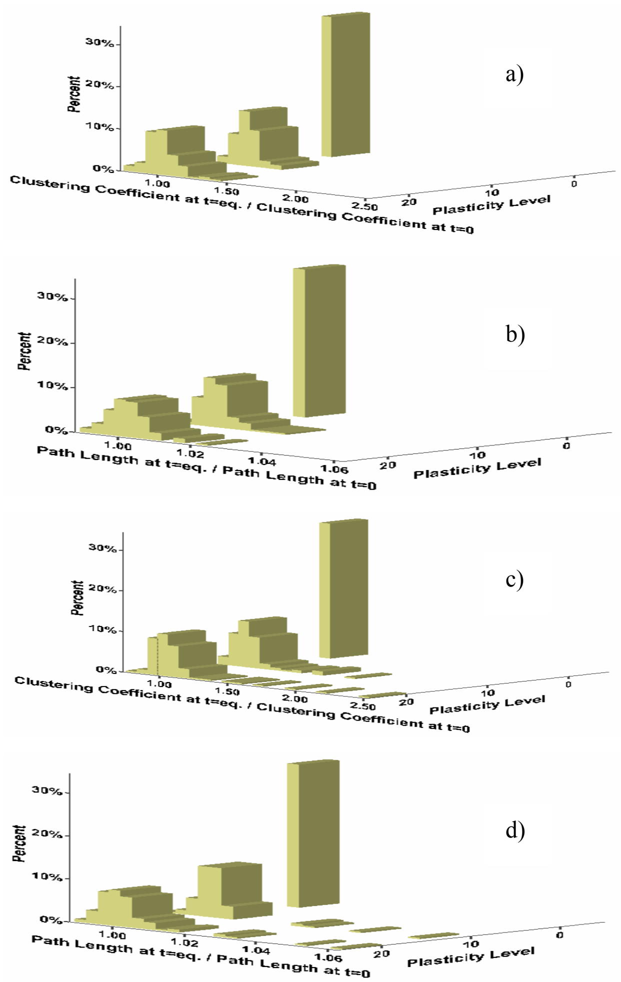

Figure 3: a) Average clustering coefficient. b) Average path length. Both from Exp 4 and 5. c) Average clustering coefficient. d) Average path length. Both from Exp 6 and 7.

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