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Replicator dynamics and evolutionary game of social tolerance: The role of neutral agents[☆]

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HIGHLIGHTS

- We study the evolutionary game of tolerance including neutral agents.
- We show that neutral agents plays an important role in the dynamics of tolerance.
- Tolerance can be a natural consequence of economic integration.
- Evolutionary game with neutral agents is consistent with economic integration.

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ABSTRACT

The role of neutral agents on evolutionary tolerance between two differentiated groups is discussed based on the replicator game model proposed recently. We show that, very different from the pure opposing case studied previously, dynamics of social tolerance with neutral agents is more positive and exhibiting rich interesting effects. The full intolerance steady state $(0, 0)$ is unstable when neutral agents are taken into consideration and there are two type of evolution trajectory according to the population of the neutral agents. Especially, phase trajectories reach to the stable full tolerance steady state $(1, 1)$ at any starting point if the population of the neutral agents is large enough, and the tolerance between different social groups can be a natural consequence of economic integration in the present of neutral agents. We show that neutral agents may remove the contradiction between the traditional idea of economic integration and the evolutionary game point of view.

1. Introduction

Tolerance, which is defined as a generic attitude to accept diversity (Akerlof and Kranton, 2000; Darity Jr. et al., 2006), is seen as a vital element of a liberal political order from the philosophical viewpoint of the liberal political thought: shifting into a Hobbesian state of anticipation is unlikely in a tolerant society due to the tolerant behavior of accepting conflicting political values (Muldoon et al., 2012). Cross-country and cross-region differences with respect to tolerance have been studied by sociologists resorting to the theory of cultural modernization (Berggren and Elinder, 2012; Berggren and Nilsson, 2013). The conjecture that social tolerance is beneficial for population growth and technological performance has been demonstrated empirically (Bjørnskov, 2004, 2008), and social tolerance is shown positively related to social and economic development in many cases (Becchetti et al., 2010).

Recently, the discussion on tolerance at the individual level reveals that economic reasoning can offer original and unique insights into the determinants of tolerance (Corneo and Jeanne, 2009; Garofalo et al., 2010; Shi and Pan, 2017). It has been believed that the fairer distribution of wealth among people, which also means economic integration, is of great importance to tolerance between different social groups (Becchetti et al., 2010). However, from the evolutionary game point of view, tolerance requires an unequal distribution of aggregate wealth among people, and fairness without a corresponding balance in the perception of diversity leads to a society with full intolerance (Cerqueti et al., 2013). Here we study the evolutionary game of tolerance, where the neutral agents is taken into consideration. We show that the tolerance between different social groups can be a natural consequence

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of economic integration in the present of neutral agents, and in this case there is no contradiction between the traditional idea of economic integration and the evolutionary game point of view.

2. Coupled equations of tolerance dynamics

An evolutionary game model of social tolerance with two differentiated groups has been proposed recently (Cerqueti et al., 2013). The population of each group are N_1 and N_2, respectively, and assumed to be large enough and changeless with time. Each individual can be tolerant or intolerant towards the agents with the opposite group. If using the notation x_i and $\hat{x}_i$ be the share of tolerant and intolerant agents in group i respectively, then $x_i + \hat{x}_i = 1$ and $x_i, \hat{x}_i \in [0, 1]$, for each $i = 1, 2$. The replicator dynamics and the random pairwise matching assumption are used to discuss the tolerance dynamics, where two agents interact after being randomly matched (such economic interaction can be, for example, a business deal), producing aggregate wealth $R_{ij} = R_{ji}$ which depend on the contribution of capital of the two agents with $i, j = 1, 2$. The evolutionary game model implicitly assumes that tolerant and intolerant behavior spreads based on the payoff of the strategy. The relative contribution of capital of agents in group i when she interact with agents in group j is $\delta_{ij} \equiv k_i/(k_i + k_j)$ which determines the shares of the aggregate wealth with k_i the contribution of capital of agents in group i: the agent in group i shares $\delta_{ij}R_{ij}$ when she interact with the agent in group j. Based on the evolutionary dynamics of social tolerance, it has been shown that tolerance requires an unequal distribution of aggregate wealth among people, and fairness without a corresponding balance in the perception of diversity leads to a society with full intolerance (Cerqueti et al., 2013).

From the philosophical viewpoint of the liberal social thought, differences (such as ethnicity, religion, country of origin and social class) are only applied to specific groups and neutral agents which are always tolerant can exist in general. In the present work, we keep the two-group assumption while the neutral agents with population N_e is introduced in the evolutionary game model of social tolerance. We use an evolutionary game model of social tolerance similar to the model proposed by Cerqueti et al. (2013), where the replicator dynamics is used, to discuss the tolerance dynamics with neutral agents. We also use the random pairwise matching assumption that two agents interact after being randomly matched, producing aggregate wealth $R_{ij} = R_{ji}$ or $R_{ie} = R_{ei}$ with $i, j = 1, 2$, which depend on the contribution of capital of the two agents. We write the contribution of capital of agents in group i as k_i and the contribution of capital of neutral agents as k_e. The relative contribution of capital of agents in group i when she interact with agents in group j is $\delta_{ij} \equiv k_i/(k_i+k_j)$, which determines the shares of the aggregate wealth. Similarly, the relative contribution of capital of agents in group i when she interact with neutral agents is $\delta_{ie} \equiv k_i/(k_i+k_e)$. The agent in group i shares $\delta_{ij}R_{ij}$ when she interact with the agent in group j, while shares $\delta_{ie}R_{ie}$ when she interact with a neutral agent.

The social tolerance influences the net gain obtained by each agents in the following cases:

1. For the case that the two unneutral agents are of the same group, whether tolerant or not, $\delta_{ii} = 1/2$, and each of them obtains $R_{ii}/2$.

2. For the case that the two unneutral agents are of different group and both tolerant, them suffer a psychological cost $\alpha = R_{ii}/2$ and a social cost $c = \beta(1 - x_i x_j)$ with the exception of $\delta_{ij}R_{ij}$, with $\delta_{ij} + \delta_{ji} = 1$, for each $i, j = 1, 2$. The parameter β is greater than zero, and a higher β leads a higher social costs, so the parameter β describes the social reaction of intolerant agents adverse to the agents of the opposite group.

3. For the case that the two unneutral agents are of different group and if one or both of them is intolerant, which rules out any interaction between them, there is no wealth produced, and each of them obtains 0.

4. For the case that one of the agents is neutral while the another is of group i and tolerant, the neutral agent obtains $\delta_{ei}R_{ei}$ while the another agent of group i obtains $\delta_{ie}R_{ie}$.

5. For the case that one of the agents is neutral while the another is of group i and intolerant, which rules out any interaction between them, there is no wealth produced, and each of them obtains 0.

6. For the case that the two agents are both neutral, each of them obtains $R_{ee}/2$.

The evolutionary dynamics of social tolerance can be modeled by the theory of replicators in which the payoff functions described above serve as the fitness function, and the evolution of tolerant population in group i can be described by

$$\dot{x}_i = x_i\hat{x}_i(E[x_i] - E[\hat{x}_i]), \tag{1}$$

where $E[x_i]$ and $E[\hat{x}_i]$ are the expected net gain of tolerant and intolerant individuals in group i respectively, and can be calculated by using the following expression:

$$\begin{aligned}
E[x_1] &= P_{x_1x_1}R_{11}/2 + P_{x_1\hat{x}_1}R_{11}/2 + \delta_{1e}R_{1e}P_{x_1N_e}, \\
&\quad + [\delta_{12}R_{12} - R_{11}/2 - \beta(1 - x_1x_2)]P_{x_1x_2}, \\
E[\hat{x}_1] &= P_{\hat{x}_1x_1}R_{11}/2 + P_{\hat{x}_1\hat{x}_1}R_{11}/2, \\
E[x_2] &= P_{x_2x_2}R_{22}/2 + P_{x_2\hat{x}_2}R_{22}/2 + \delta_{2e}R_{2e}P_{x_2N_e} \\
&\quad + [\delta_{21}R_{21} - R_{22}/2 - \beta(1 - x_1x_2)]P_{x_2x_1}, \\
E[\hat{x}_2] &= P_{\hat{x}_2x_2}R_{22}/2 + P_{\hat{x}_2\hat{x}_2}R_{22}/2,
\end{aligned} \tag{2}$$

where $P_{x_ix_j}$ the probability for a tolerant agent of group i matches a tolerant agent of group j, and can be calculated as follows:

$$\begin{aligned}
&P_{x_1x_1} = \frac{x_1N_1 - 1}{N - 1}, \quad P_{x_1\hat{x}_1} = \frac{\hat{x}_1N_1}{N - 1}, \quad P_{x_1x_2} = \frac{x_2N_2}{N - 1}, \\
&P_{x_1\hat{x}_2} = \frac{\hat{x}_2N_2}{N - 1}, \quad P_{x_2x_1} = \frac{x_1N_1}{N - 1}, \quad P_{x_2\hat{x}_1} = \frac{\hat{x}_1N_1}{N - 1}, \\
&P_{x_2x_2} = \frac{x_2N_2 - 1}{N - 1}, \quad P_{x_2\hat{x}_2} = \frac{\hat{x}_2N_2}{N - 1}, \quad P_{\hat{x}_1x_2} = \frac{x_2N_2}{N - 1}, \\
&P_{\hat{x}_1x_1} = \frac{x_1N_1}{N - 1}, \quad P_{\hat{x}_1\hat{x}_2} = \frac{\hat{x}_2N_2}{N - 1}, \quad P_{\hat{x}_1\hat{x}_1} = \frac{\hat{x}_1N_1 - 1}{N - 1}, \\
&P_{\hat{x}_2x_1} = \frac{x_1N_1}{N - 1}, \quad P_{\hat{x}_2\hat{x}_1} = \frac{\hat{x}_1N_1}{N - 1}, \quad P_{\hat{x}_2x_2} = \frac{x_2N_2}{N - 1}, \\
&P_{\hat{x}_2\hat{x}_2} = \frac{\hat{x}_2N_2 - 1}{N - 1}, \quad P_{x_iN_e} = \frac{N_e}{N - 1}, \quad P_{\hat{x}_iN_e} = \frac{N_e}{N - 1},
\end{aligned} \tag{3}$$

with $N = N_1+N_2+N_e$. It is indeed possible that people develop tolerant attitudes for some reasons other than the tendency of mixed interaction in economic incentive. From natural continuation of economic studies on fundamentalism, here we assume that the behavior (tolerant and intolerant) spreads in the society often the selection process with higher payoff. Given the above probabilities produces a system of two differential equations which describes the evolution of tolerant populations in each groups:

$$\begin{aligned}
\dot{x}_1 &= \frac{x_1\hat{x}_1}{N - 1}\Big([\delta_{12}R_{12} - R_{11}/2 - \beta(1 - x_1x_2)]x_2N_2 + \delta_{1e}R_{1e}N_e\Big), \\
\dot{x}_2 &= \frac{x_2\hat{x}_2}{N - 1}\Big([\delta_{21}R_{21} - R_{22}/2 - \beta(1 - x_1x_2)]x_1N_1 + \delta_{2e}R_{2e}N_e\Big).
\end{aligned} \tag{4}$$

These differential equations give a complete description of the evolutionary dynamics of social tolerance. With payoff functions serve as the fitness function, the frequency of tolerance in a large, well-mixed society changes at a per capita rate equal to the difference between its expected payoff and the average payoff of the population. In the replicator dynamics, the rate of change in x_i, which describes the proportion of tolerant members in group i, is