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Evolutionary investor sharing game on networks

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ABSTRACT

Investors often co-invest in the same project together. As the payoff of the project realizes, how to share the total payoff is in consideration. With this inspiration, an investor sharing game is proposed in this paper, where investors' payoffs relate to their investing amount and the degree of monopoly in the industry market. Economically, the degree of monopoly in the market is introduced in the game by a parameter α that affects the evolutionary process. The distribution of investing amounts is assumed to satisfy the Pareto distribution in terms of the empirical wealth distribution. The simulation on WS small-world networks shows that cooperative behaviors will prosper by the union of investors who invest less amounts in a less monopolized market. The higher power of the Pareto distribution of investing amounts also results in more cooperators in equilibriums. Furthermore, as the degree of monopoly swings, the density of cooperators is higher and more stable in a more random small-world network. The findings may be helpful in understanding the effect of network structure on the emergence of cooperation.

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1. Introduction

Network is useful to describe interactions among agents in society [1–4]. Especially, relationships of economic agents attract more researchers. Depended on the network science, some essential features of social and economic networks are concluded, including small distance [5,6], high clustering [7,8], unequal distribution of links [9,10] and high assortativity [11]. With economic networks, most markets in the economics are studied, such as the labor markets [12,13], international trades [14,15], and financial markets [16–20]. The utilization of network narrows the gap between the economic theory and the economic real world.

However, behaviors of agents on network need the game theory, headed by Nash [21]. In his studies, the repetition of game would also lead to Nash equilibrium as time evolves. Axelrod and Hamilton [22] designed a game named repeated prisoner dilemma and built up a framework for studying evolutionary games. In what follow, many classical game models are used in this framework. As one of the most famous game model, prison dilemma games (PDG) are applied to analysis social dilemmas in our life. Hence, more evolutionary prison dilemma game models are proposed [23–27]. Essentially, researchers try to illustrate why cooperation emerges in social dilemma games and also to outline many different ways on how cooperation could evolve [28]. Wang [29] has studied how two interdependent networks affects the evolution of public cooperation by means of a utility function. He also provided other different kinds of cooperation-promoting mechanisms

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in social dilemmas such as costly punishment [30] and onymity [31]. Perc and Szolnoki also extended the prison dilemma game (PDG) with other mechanisms, including heterogeneous agents [32–34], heterogeneous investment [35], social diversity [36,37], compassion [38] and neighborhood diversity [39]. Certainly, there are more extension about prison dilemma game in academics [40,41]. In fact, the prison dilemma game could not explain all of the communications among agents. With this inspiration, more and more classical games are came out, including snowdrift games (SG) [42–44], public goods games (PGG) [45,46], stag hunt games (SH) and so on. Recently, Perc and Szolnoki make a review about evolutionary classical games [25,47] and group interactions [48]. Interestingly, Amaral and Javarone integrate four kinds of basic games in a networked game [49]. Actually, for the illustration of human behavior, new game models often begin with some phenomena in reality. For instance, Kamal et al. [50] considers an inspection game against the background of labor unions. Workers in the game can choose working and shrinking. They find that the union has significant effect on the productivity of a firm and the benefits of employees. Explaining investors' behaviors in the markets, Xu et al. [51] proposed an investors' power-based game which integrates the prison dilemma game and the stag-hunting game (SH). The effect of assortative network structure on the investors' power-based game is continued to study in [52]. Following the thought, an investor sharing game will be presented in this paper, which pays attention to the sharing of payoffs in the co-investment market.

In neoclassical economics, most assumptions are too strict to satisfy in reality. On the one hand, all of the agents are supposed to be of perfect rationality [53–56] which means they should be smart enough to make the best decisions all the time. Actually, agents in the real world especially in markets are easy to be influenced by others, which is defined as the bounded rational in academics. Fortunately, in the evolution process, every one on social networks is needed to be of bounded rational only [57,58]. To some extent, an agent in the evolution process are more similar to a human in real world.

On the other hand, in the microeconomic theory, monopoly is one of the most important factors that causes market failure. Market failure means that the resource allocation in equilibrium lacks Pareto efficiency, which cannot maximize the welfare of the population. Note that market failure does not exist in the economic of neoclassical theory. According to the definition, monopoly describes that the market is controlled by one or several businesses in the industry. To measure the degree of monopoly, Lerner has constructed the Lerner index [59,60]. In brief, it reminds us that the degree of monopoly is one of the key parameters that we should focus on.

Motivated by these references, we explore the behaviors of investors against the background of investment markets. To describe the sharing of payoffs between investors who join in the same project, an investor sharing game is exhibited in Section 2. The sharing is connected to investors' strategies in the investor sharing game. Section 3 will present the rule of strategy updating in our evolutionary process. Considering the structure of business network, simulations on WS small-world network are displayed in Section 4. Finally, Section 5 concludes.

2. Investor sharing game

Co-investing between the two companies is common in the market of investment. Investors from different companies capitalize the common project according to their own powers. For example, the agent from big companies or institutions always invests more than the agent from small business. Certainly, the more you pay, the more you gain, which is still held in the market of investment. In detail, we propose the investor sharing game, describing the game between the investors.

Suppose that amounts invested by investor i and investor j is I_i and I_j respectively. Our investor sharing game between investor i and j is depicted by the following rescaled payoff matrix:

$$\begin{array}{c} \\ C \\ D \end{array} \begin{array}{c} \begin{array}{cc} C & D \end{array} \\ \begin{pmatrix} \frac{I_i}{I_i+I_j} & 0 \\ \frac{I_i^\alpha}{I_i^\alpha+I_j^\alpha} & 0 \end{pmatrix} \end{array}$$

where α measures the degree of monopoly, $\alpha > 1$. If investor i and j cooperate with each other, the income from the project they invest will be shared according to the proportion they input. It is easy to see that, the income will be divided half-and-half when investor i and j input the same amount, $I_i = I_j$. For general, if $I_i > I_j$, investor i, who holds more shares of the project, will obtain more when cooperating with investor j that holds less.

But, under $I_i > I_j$, when investor i defects the cooperator j, he will get more payoffs $\frac{I_i^\alpha}{I_i^\alpha+I_j^\alpha}$, compared with the income of cooperation, $\frac{I_i}{I_i+I_j}$. On the contrary, for $\frac{I_j^\alpha}{I_i^\alpha+I_j^\alpha} < \frac{I_j}{I_i+I_j}$, investor j gains less when defecting the cooperator i. Apparently, defecting the cooperator is only beneficial for the investor with more investing amount. Also, investors always get half of the project's reward when meeting the cooperator with the same amount, no matter which strategy he applies. Economically, investors' defection is also called the moral hazard in corporate finance. By cheating his partner, companies with strong capital will get more payoffs while the small businesses always face the losses.

Importantly, the further explanation about α is as follow. Assume that $\alpha > 1$. Mathematically, α narrows the payoff of the defector with less amount, but amplifies the payoff of the defector with higher amount. On the perspective of economy, α reflects the degree of monopoly. In accordance with the theory of cooperation, monopoly means the control of the market

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