A study on evolutionary game theory and mathematical epidemiology

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論 文 内 容 の 要 旨
Thesis Summary

This thesis mainly focuses on investigating cooperative behavior through the lens of evolutionary game theory and applying it to the realm of mathematical epidemiology, more precisely to behavioral epidemiology. Each chapter of this thesis focuses on different yet closely related topics, which are already published in peer reviewed journals. Thus, each chapter includes a self-contained abstract, introduction, model description, results and discussion, conclusion, and reference list, which demonstrates that the chapters are largely independent. However, there are inherent connections among several chapters. Apparently, the thesis can be grouped into two parts: Chapters 2-5 are devoted to evolutionary games, whereas Chapters 6-8 concentrate on mathematical epidemiology. The structure of the thesis is as follows.

Chapter 2 studies the coexistence of two strategy update rules, namely imitation and aspiration, in pairwise evolutionary games. The chapter first discusses in detail about both update rules alone, and then proceeds to explore their coexistence and possible consequences in social dilemmas. Both rules have been coupled presuming two different cases: (i) individuals adopt either imitation or aspiration update rule with a specified probability, and (ii) the whole population is grouped into two parts according to update rules in which each group entirely obeys imitation (or aspiration) update rule. To get a more realistic picture, we investigate several scenarios. For instance, while combining both imitation and aspiration protocols, the level of aspiration or the population composition of two groups (i.e., the extent of the population following either rule) is considered to be time-evolving, besides strategies. At the end, strategies, aspirations as well as update rule choices are taken under evolutionary pressure to demonstrate more pragmatic scenario.

Chapter 3 discusses the strategy-environment feedback dynamics under the premise of imitation and aspiration dynamics. The basic idea of such a system is that individuals tend to act recklessly (i.e., defection) when the associated environment or resource is abundant, whereas the depleted environment or resource forces them to act more rationally (i.e., cooperation) to restore the environment. The notion of such an interplay between actions and environment is highly relevant in nature. The chapter fist presents an established strategy-environment coupled replicator dynamics which result in oscillatory dynamics between cooperation and defection with associated fluctuations between degradation and enhancement of the environment. Nonetheless, the oscillatory dynamics have not been observed when, instead of imitation dynamics, we employ the aspiration dynamics.

Chapter 4 addresses an interesting question on whether one's baseline payoff or income impacts the behavioral dynamics in competitive interactions. It is worth stressing that the classical replicator equation does not take into account the baseline fitness or payoff. Thus, we intend to incorporate people's greed or expectation or satisfaction on their baseline payoff which may influence their attitude (prosocial or egoistic) towards social interactions. We investigate both finite and infinite populations to explore the impact of the baseline payoff on evolutionary outcomes.

Chapter 5 presents a new index called 'social efficiency deficit (SED)' to demonstrate the existence of social dilemma in several game classes, ranging from pairwise games—in which SED and the dilemma strength are mathematically found to be inversely correlated—up to the complexity of multiplayer game (such as public goods game) and vaccination dilemma. SED is defined as the payoff gap between the evolutionary equilibrium and the social optimum. We observe that the dilemma strength of a game is not always calculable unless the game belongs to the simplest structure, such as pairwise interaction. Games having more complexity do not have the flexibility to estimate the associated dilemma strength. Since SED is always numerically foreseeable, it can illustrate the deficiency of stationary outcome, as compared with the social optimum. Thus, a nonzero SED, besides demonstrating the existence of social dilemma, can help identifying control parameters to improve the evolutionary outcome towards social optimum.

Chapter 6 layouts an instance of vaccination dilemma in which we model the dynamics of vaccination decision against a two-strain epidemic spreading. The mean-field equation for the evolution of vaccination decision is governed by the so-called imitation mechanism of population dynamics. The results show that a large-scale vaccination coverage may fail to control the epidemic if it cannot bestow a considerable efficacy against the mutant strain.

Chapter 7 takes into account a situation of vaccination game in infinite and well-mixed population where two types of vaccines, having different costs and efficacies, are available against a two-strain influenza spreading. In this case, individuals are encountered in a situation of choosing one of the two vaccines or remaining unvaccinated. This is a metaphor of investigating a context in which individuals can opt for a strategy among several options. The evolution of vaccination decisions has been governed by the mean-field equation of the population dynamics similar to that in Chapter 6. This chapter, in particular, shows the implications of SED in vaccination dilemma.

Chapter 8, motivated by the argument presented in Chapter 2, investigates the vaccinating behavior considering both imitation and self-assessment (i.e., aspiration) mechanisms, as the motivation for vaccination decision.

In Chapter 9, we summarize the thesis, giving some conclusive arguments, limitations of the study and indicating some links among several chapters. The chapter also provides a holistic notion for the further development of evolutionary game theory.