Journal of Theoretical Biology 450 (2018) 43–52

Contents lists available at ScienceDirect

Journal of Theoretical Biology

journal homepage: www.elsevier.com/locate/jtbi

# Bribery games on interdependent complex networks

Prateek Verma[1], Anjan K. Nandi[1], Supratim Sengupta*

*Department of Physical Sciences, Indian Institute of Science Education and Research Kolkata, Mohanpur, 741246, India*

ARTICLE INFO

*Article history:*
Received 7 December 2017
Revised 18 April 2018
Accepted 19 April 2018
Available online 26 April 2018

*Keywords:*
Corruption
Bribe
Evolutionary game theory
Asymmetric games
Social evolution
Networks

ABSTRACT

Bribe demands present a social conflict scenario where decisions have wide-ranging economic and ethical consequences. Nevertheless, such incidents occur daily in many countries across the globe. Harassment bribery constitute a significant sub-set of such bribery incidents where a government official demands a bribe for providing a service to a citizen legally entitled to it. We employ an evolutionary game-theoretic framework to analyse the evolution of corrupt and honest strategies in structured populations characterized by an interdependent complex network. The effects of changing network topology, average number of links and asymmetry in size of the citizen and officer population on the proliferation of incidents of bribery are explored. A complex network topology is found to be beneficial for the dominance of corrupt strategies over a larger region of phase space when compared with the outcome for a regular network, for equal citizen and officer population sizes. However, the extent of the advantage depends critically on the network degree and topology. A different trend is observed when there is a difference between the citizen and officer population sizes. Under those circumstances, increasing randomness of the underlying citizen network can be beneficial to the fixation of honest officers up to a certain value of the network degree. Our analysis reveals how the interplay between network topology, connectivity and strategy update rules can affect population level outcomes in such asymmetric games.



## 1. Introduction

Corruption involving bribery is an example of a social conflict scenario which affects the lives of many people particularly in developing countries. The conflict arises when a service provider (corrupt officer) withholds a service from citizens until they pay a bribe. The bribes are called harassment bribes when citizens are legally entitled to the service. Examples of such bribes include bribes paid for obtaining identification cards, electricity & gas connections, driver's license, etc. One way of discouraging such forms of corruption is by imposing a high penalty on such illegal transactions that are enforced by law. Punishment can be inflicted symmetrically on both bribe giver (who pays a bribe silently) and bribe taker (corrupt officer) or asymmetrically on only bribe taker (corrupt officer). Basu (2011) suggested punishing only bribe takers in the case of harassment bribe will encourage citizens to act as whistle-blowers and hence would cut down incidents of bribery incidents. Several experimental and theoretical studies have been carried out to test the validity of the proposal since it was first suggested (Abbink et al., 2014; Basu et al., 2016; Dufwenberg and Spagnolo, 2015; Oak, 2015; Ryvkin and Serra, 2013; Verma and Sengupta, 2015).

The act of demanding harassment bribes showcases a conflict between a harasser (corrupt officer) and a harassed citizen. A corrupt officer would like to maximize his gain from exploiting citizens while simultaneously attempting to minimize the risk of being punished. A citizen subject to a bribe demand is faced with a different kind of economic as well as ethical dilemma. She must weigh the cost of paying a bribe against the cost of denial of service should she refuse to pay. The decisions taken in this context will depend on the bribe amount, the likelihood of redress following a complaint against the extorting officer, the cost incurred in lodging a complaint as well as other factors. The strategies adopted by the protagonists and the manner in which they are updated over time under the influence of connected neighbours has significant consequences on the prevalence and spread of such forms of corruption in society.

Analysis of such types of social conflicts using evolutionary game theory can be insightful in several ways. Firstly, such a game provides a realistic model to explore the effects of punishment on reducing corruption and enabling ethical behaviour. Several recent studies (D'Orsogna et al., 2013; D'Orsogna and Perc, 2015; Helbing et al., 2010; Lee et al., 2017, 2015; McBride et al., 2016; Rand and Nowak, 2011; Short et al., 2010; Sigmund, 2007; Szolnoki and Perc, 2013a, 2015) have begun to address the impact of punishment and

* Corresponding author.
*E-mail address:* supratim.sen@iiserkol.ac.in (S. Sengupta).

[1] Equal contribution.

https://doi.org/10.1016/j.jtbi.2018.04.028
0022-5193/

reward on deterring criminal behaviour in mixed as well as structured populations. Such social conflicts characterized by competing interests and distinct strategies of interacting players also provides a natural framework for analysing evolutionary game dynamics on interdependent networks.

Initially, most studies on complex networks were focused on single networks (Barabasi and Albert, 1999; Barrat et al., 2008; Callaway et al., 2000; Cohen et al., 2000; Newman et al., 2006; Song et al., 2005; Watts and Strogatz, 1998). Networks in real life are often made up of interconnected and interdependent layers where each layer contains a network of nodes that can be different from those found in another layer (Danziger et al., 2014; Kenett et al., 2015). The interconnectedness of the two layers lead to their inter-dependence. The properties of such interacting networks can be quite different from that of a single network. A recent work on such interdependent infrastructure network reveals that small failures in a small part of one network may lead to catastrophic cascade of failures in another network (Buldyrev et al., 2010).

Evolutionary games, especially those dealing with the spread of cooperative behaviour, have been extensively analysed on a variety of networks with different topologies (Assenza et al., 2008; Fu et al., 2007; Gómez-Gardeñes et al., 2011, 2007; Kim et al., 2002; Lee et al., 2011; Masuda and Aihara, 2003; Peña et al., 2009; Poncela et al., 2011; J. 2007; Santos et al., 2006; Santos and Pacheco, 2005). These works established that heterogeneity in network connection positively impacts the spread of cooperation in social dilemmas though its effect is limited by payoff normalization (Masuda, 2007; Santos and Pacheco, 2006; Szolnoki et al., 2008; Tomassini et al., 2007). Recently, a number of studies have begun to focus on the conditions for spread of cooperation on interdependent networks (Gómez-Gardeñes et al., 2012; Jiang and Perc, 2013; Szolnoki and Perc, 2013b; Wang et al., 2012a,b; Wang et al., 2013a,b). For example, it has been found that an intermediate interdependence between two interacting networks promotes cooperation in the population (Jiang and Perc, 2013) and unbiased coupling of payoffs of two network leads to the emergence of interdependent network reciprocity (Wang et al., 2013a). Hence properties pertaining to interdependence among players of two networks can be exploited to promote cooperation in different social dilemmas.

A common theme of all these papers is the symmetric nature of interaction among players within and across the networks with the players being identified only by their strategies. In nature, however, intra and inter network interactions are mostly asymmetric. This asymmetry may arise due to intrinsic differences in the nature of two interacting networks, environmental and genetic factors, hierarchical social structure or because players have different social roles. Asymmetric interactions can be modelled through asymmetric games also referred to in the literature as bi-matrix games (Gaunersdorfer et al., 1991; McAvoy and Hauert, 2015). The bribery game is a typical example of an asymmetric game where citizens and officers interact with each other but can only imitate strategies of members belonging to their own populations. Thus, we have one interaction graph connecting officers & citizens and two replacement graphs, one each for citizen and officer populations, specifying the connections within those populations. This framework of interdependent network interaction and dynamics can be extended to other asymmetric social conflicts as well.

In our previous work we had employed the evolutionary game theoretical model to test the validity of the hypothesis for reducing bribery incidents, proposed by Basu in a mixed (Verma and Sengupta, 2015) as well as a structured (Verma et al., 2017) population represented by a regular interdependent network. In a mixed population scenario (Verma and Sengupta, 2015) we found that imposing the asymmetric punishment scheme may not suffice in reducing incidents of harassment bribery. Factors such as how players update their strategies, the cost of complaining incurred by harassed citizens and bribe amount demanded by corrupt officers plays a significant role in determining the prevalence of corrupt officers in the population at equilibrium. Subsequently, we also found (Verma et al., 2017) that incidents of bribery can be considerably reduced in a structured population represented by a regular inter-dependent network, in comparison to the mixed population scenario. Another key feature of such networks was the optimal range of connectivity of the nodes in the citizen and interaction networks that facilitated fixation of honest officers. While regular networks offer some insight into the role of underlying population structure and connectivity, real-world social networks are more complex and described by either small-world or scale-free networks. The main motivation of the current work is to understand how heterogeneity in network connections of both citizen and officer networks (implying differences in influencing individual behaviour by connected neighbours) together with asymmetry in the citizen and officer population sizes impact the spread of honest officers in the asymmetric penalty scenario. As in the previous work, we have focused primarily on varying two important parameters of the bribery game namely, bribe amount ($b$) demanded by the corrupt officer and cost of complaining ($t$) incurred by complaining citizens. This was based on the grounds that these two parameters are more easily controlled than the others. Parameters such as amount of punishment imposed and prosecution rates can vary across states and even jurisdictions and changes are more likely to depend on fickle political processes. Nevertheless, we have also analysed the effect of varying bribe amount ($b$) and punishment ($p_o$) on the equilibrium distribution of strategies in the population.

We find that a change in network topology from regular to small-world to random adversely affects the spread of honest officers in certain regions of parameter space. However, the extent of the decrease in dominance of honest officers and complaining citizens depends on the rewiring probability and the average number of links per citizen in the network. As in the case of regular networks, reduction in incidents of bribery over the parameter space is maximized for an optimal value of citizen network degree. However, this no longer holds for a completely random network.

The behaviour is reversed if an asymmetry exists in the population sizes of the citizens and officers. In this case, the success of honest officers is maximized when the network degree is minimum with an initial increase in degree leading to a sharp drop in the fixation of honest officers. Subsequent increase in the degree of the citizen network aids in the fixation of honest officers. Moreover, increasing randomness of the citizen network encourages the spread of honest officers.

## 2. Methods

### 2.1. Bribery game and update rule

We start with two sets of population, one of officers and the other of citizens as shown in the schematic Fig. 1. Officers are connected with citizens through a regular interaction network (network 3) of degree *IN*and with other officers through an intra-officer network (network 1) of average degree *ON*. Citizens, similarly are connected among themselves through intra-citizen network (network 2) of average degree *CN.IN* defines the number of officer(s) each citizen interacts with. The interaction network specifies how citizens play the bribery game with officers while the intra-citizen and intra-officer networks determine how a citizen and an officer updates their respective strategies by consulting connected neighbours in their corresponding networks. Depending upon their own strategies as well as strategies of opponents, players receive payoffs. The payoff matrix for the bribery game is given