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Third party interventions mitigate conflicts on interdependent networks

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ABSTRACT

Interventions from third parties, such as governmental agencies or organizations, play an important role in mitigating conflicts in modern human societies. The goal thereby is to pacify disputants, although this is subject to failure on account of self-interest from all involved. To study how relationships between disputants and third parties evolve, we propose an interdependent network model, where one layer is occupied by disputants and the other layer is occupied by third parties. Disputants play a prisoner's dilemma game, where defection is the dominant strategy, whereas third parties play a snowdrift game, where cooperation and defection coexist more commonly. Moreover, third parties have the ability to mediate a conflict on the other layer by enforcing a snowdrift game onto disputants, for which they can receive a fee. We show that third party interventions improve the evolution of cooperation between disputants, and also, that the improvement of cooperation in turn promotes interventions. Nonetheless, non-intervention does not go extinct, which enables defectors to survive, thus creating a feedback loop between the two networks layers. The evolutionary dynamics is characterized by fascinating spatial pattern formation, which we explore by means of Monte Carlo simulations and via replicator equations.

1. Introduction

The conflicts between individuals or groups in societies are often tackled by third parties, be it government agencies, service groups, or organizations. Whether motivated by selfishness or altruism, these third parties are often capable of resolving strife, thus greatly benefiting the society [1,2]. Theoretical and experimental studies demonstrate that third parties enforce intervention, such as punishment or reward, to tackle uncooperative behavior or the violation of social norms, in order to enforce collective cooperation and improve the relationship between disputants [3–7].

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Generally, the conflict between players is most commonly studied by the means of prisoner's dilemma, a simple game theory model wherein two players chose between cooperating or defecting [8,9]. In such a setup, conflict arises because defecting player, under the condition that the other player is cooperating, receives a greater payoff than what either player would receive through mutual cooperation. Hence, defection by both players emerges as rational yet harmful self-interested solution. Defection, however, can be mitigated by various cooperation promoting mechanisms. For example, kin selection, group selection, direct reciprocity, indirect reciprocity, and network reciprocity are generally considered as general mechanisms that enable the evolution of cooperation [10]. Additional mechanism [11], such as willingness [12,13], memory [14,15], learning [16,17], and collaboration [18,19] are also suggested as being beneficial for the cooperation.

One of the most significant developments in the research on cooperation came from the merger of game theory and network science. Since individuals do not exist in vacuum, but instead communicate and form relationships, networks can be used to model such phenomena by using vertices to represent individuals and edges to represent relationships between them. Initially, expanding the standard two-player game to n-players game revealed the importance of spatial structure for the evolution of cooperation [20], and was followed by numerous studies on the effects of network topology, such as small world [21–23], scale-free networks [24,25], and interdependent networks [26–28].

Third parties can be implemented intrinsically, by driving game transitions [29] or being one of strategies forming a cyclic dominance with other strategies [30–32]. They can also be implemented independently via interdependent networks [7]. Here, we devise a multilayered, interdependent network model consisting of layer of disputants and layer of third parties. In disputant layer, players play a prisoner's dilemma game, while in third-party layer players play a snowdrift game. However, third-party players also have the option to intervene by forcing players in disputant layer them to play a snowdrift game. Because parameterization in snowdrift game is less rewarding to defection, cooperation is more likely [33,34], meaning that third-party players basically have a role of peacemakers. To make the model more realistic, third-party players get paid for their peacemaking activities, and they also can choose not to intervene.

Our results show that third-party intervention alleviates conflict in disputant layer and makes cooperation widespread. However, depending on temptation and intervention strength variables which control the payoff and the cost of defection in the environment, cooperation is either dominant, extinct, or coexists with defection. There is a monotonous trend between the frequency of cooperation and intervention strength, with cooperation being dominant at high values of intervention strength and low values of temptation, and defection being dominant at low values of intervention strength and high values of temptation. At intermediate values of both variables, coexistence between cooperation and defection emerges, with interesting spatial dynamics where cooperators are able to maintain cooperation, but cannot maintain clusters, as they scatter in patches throughout the environment together with defectors.

2. Methods

We consider a game on an interdependent network with disputant and third-party layers. Both layers are $L \times L$ square lattices with a periodic boundary and a von Neumann neighborhood. Vertices represent players who interact with nearest neighbors along edges. Players in disputant layer are playing a prisoner's dilemma game (*PDG*), with each player having to choose between cooperation (C) and defection (D). Their payoffs are denoted by a two-dimensional bilateral matrix, wherein R stands for reward, P for punishment, T for temptation, and S for sucker's payoff:

$$\begin{array}{ccc} & C & D \\ C & R & S \\ D & T & P \end{array} \tag{1}$$

In prisoner's dilemma, parameters satisfy $T > R > P > S$ in order to encourage defection and discourage cooperation. Furthermore, in repeated games it is assumed that $2R > T + S$ in order to make mutual cooperation ($2R$) more beneficial for the group than defecting against a cooperative player [35].

In third-party layer, players are playing a snowdrift game (*SDG*), with the same parameterization as aforementioned *PDG*. However, in *SDG* parameters follow $T > R > S > P$ condition, which encourages higher levels of cooperation than in *PDG*.

Players in both layers interact with one of their four nearest neighbors, updating strategies following the imitation rule, a mechanism commonly used to model selection [36,37]. Imitation probability is given by the Fermi function:

$$f = \frac{1}{1 + \exp[(\pi_x - \pi_y)/K]} \tag{2}$$

, where π_x and π_y are payoffs of focal player x and their randomly selected neighbor y, while the parameter K denotes the selection intensity [36–38].

However, players in third-party layer have an additional option, as they can choose whether to interact with the players in disputant layer too. Specifically, every player in third-party layer supervises corresponding player in disputant layer (Fig. 1), and can choose intervention (I) or non-intervention (N). In the case of intervention (I), corresponding player in disputant layer plays with its neighbors *SDG* instead of *PD*G, while third-party player gets additional payoff depending on the result of interaction between players in disputant layer. Alternatively, if third-party player chooses non-intervention (N), they receive a default payoff regardless of the strategy of their corresponding player in disputant layer. In other words, play-

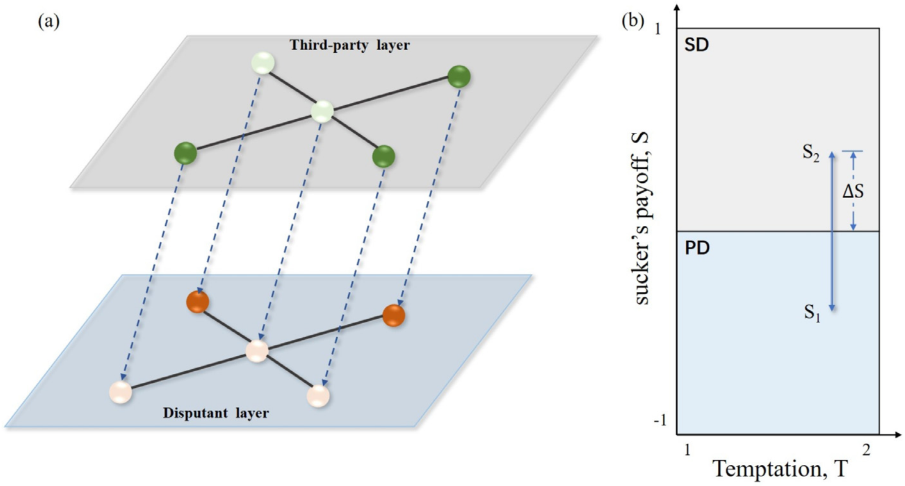

Fig. 1. Interdependent network. (a). Players in third-party layer can choose intervention (I) or non-intervention (N), and players in disputant layers can play cooperation (C), represented by dark orange, or defection (D), represented by light orange. In third-party layer, dark green represents player who choosing intervention and the corresponding player in disputant layer playing a snowdrift game, and light green represents player choosing non-intervention and the corresponding player in disputant layer playing a prisoner's dilemma game. **(b).** T-S space. For simplicity, we set $R = 1$, $P = 0$, $T_1 = T_2$, $S_1 = -S_2$, where ΔS denotes intervention strength. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

ers in third-party layer receive a payoff consisting of two parts; payoff earned from interactions with nearest neighbors in third-party layer, and payoff earned from interventions in disputant layer.

Whether players intervene or not in disputant layer depends on their behavior in third-party layer. If they decide to cooperate with their nearest neighbors, then as prosocial players, they will also intervene in disputant layer. Otherwise, they will choose non-intervention. Therefore, to separate them from cooperators and defectors in disputant layer, we dub cooperative players in third-party layer as intervenors and defecting players as non-intervenors.

In each time step and in random order, players in third-party layer decide whether to intervene or not in disputant layer. After that, players in disputant layer play a game with their nearest neighbors, followed by third-party players who play between themselves the last. In this order, strategies of third-party players influence the payoff of players in disputant layer and the interaction results between players in disputant layer affect the payoff of players in third-party layer.

We initialize simulations on a lattice of size $L = 200$ (we also test $L = 100$, 300, and 400 and find that size does not affect the results). Each player in disputant and third-party layer has an equal probability to start off as cooperator or defector regarding their strategy choice with nearest neighbors, thence, each player in third-party layer has an equal probability to start off as intervenor or non-intervenor regarding their strategy choice with corresponding players in disputant layer. For *PDG* and *SDG*, we set $R = 1$, $P = 0$, $T_1 = T_2 = T \in [1, 2]$, while for *PDG* we set $S_1 \in [-1, 0]$ and for *SDG* we $S_2 \in [0, 1]$. For intervention, third-party player receives payoff value of 1 if both corresponding player and their neighbor play cooperation, 0.5 if one of them plays cooperation and other defection, and 0 if both play defection [7]. For non-intervention, third-party players receive a default payoff of 0.5. Parameter K in Eq. (1) is set as 0.1.

In each simulation run, we observe cooperation and intervention frequencies as a function of parameters temptation T and intervention strength ΔS over the course of 50,000 steps of Monte Carlo simulation *MCS*, of which the last 5000 are taken to represent a steady state. In each time step, players are selected once on average to play a game and update their actions, To ensure accuracy, all results are averaged over ten independent simulation runs for a fixed set of parameter values.

3. Results

According to the previous researches [39–41], we rely on the concept of universal dilemma strength posed by, $D_g = (T - R)/(R - P)$ and $D_r = (P - S)/(R - P)$ to depicted the steady status of evolution in two layers. Based on the payoff matrix of *PDG*, we obtain $0 \leq D_r \leq 1$ and $0 \leq D_g \leq 1$. Apparently, positive D_r in *PDG* means negative D_r in *SDG* because of the opposite value of S_1 and S_2. As the parameters setting, $D_r = \Delta S$ and $D_g = T - 1$. In Fig. 2, we explore the cooperation and intervention in two layers under various dilemma strengths. Intervention by third-party players greatly enhances cooperation in disputant layer, especially at higher values of intervention strength ΔS (Fig. 2). However, increasing the value of temptation T decreases both intervention (Fig. 2a) and cooperation (Fig. 2b) frequencies. For example, around the diagonal the coexistence of intervention and non-intervention in third-party layer is mirrored by the coexistence of cooperation and defection in disputant layer, while at high values of T both intervention and cooperation become extinct (we also confirm these results mathematically, see Appendix). It is worthy noticing that, under the intervention of third-party players, players in disputant layer play *SDG*, which is not beneficial for the dominant of cooperation, and consequently, lead to the number

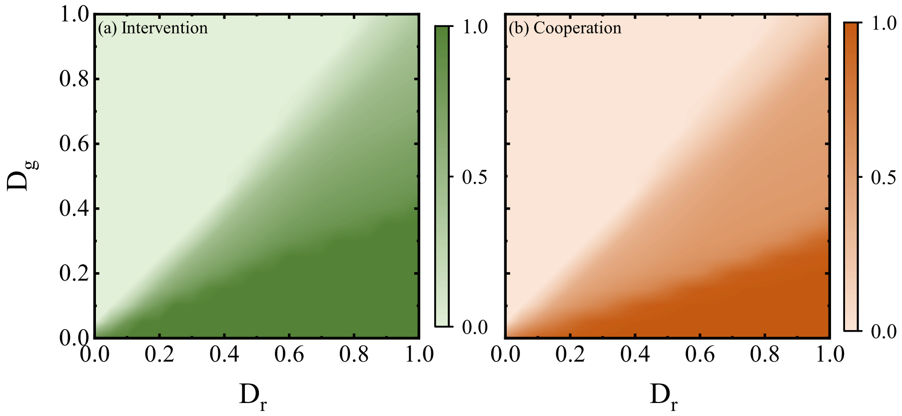

Fig. 2. Cooperation is more common under the supervision of third-party players. Shown are the steady state frequencies of intervention in third-party layer (left) and cooperation in disputant layer (right) as a function of dilemma strength D_r and D_g. **a).** As the parameters setting, we obtain $D_r = \Delta S$ and $D_g = T - 1$. Intervention frequency increases at higher values of ΔS and can reach a maximum as long as T remains below 1.45. **b).** The frequency of cooperation also increases at higher values of ΔS, maximum being achieved if T stays below 1.30. Furthermore, cooperation does not go extinct even at relatively high values of T, implying that strong enough intervention can maintain some level of cooperation even in extreme environments. We obtain simulation results on lattice network of size $L = 200$ with random initial distribution.

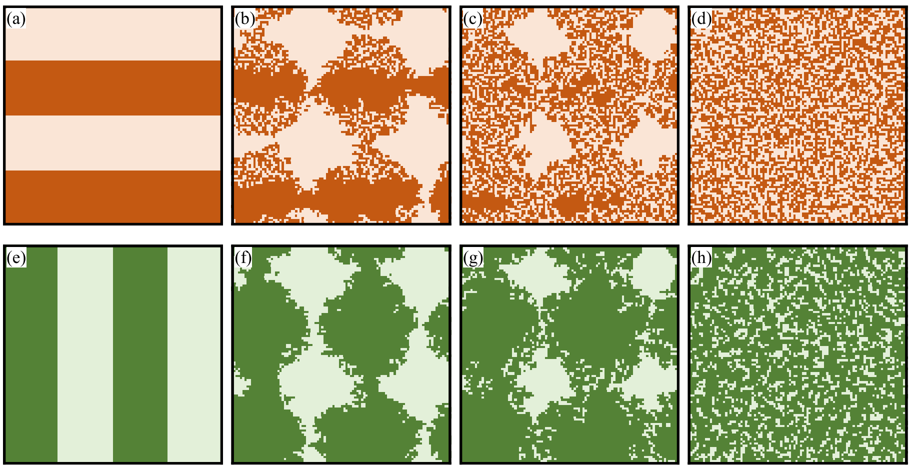

Fig. 3. Disputants and third parties are locked in a feedback loop. Fig. 3A-d. In the upper row, defectors (light orange) and cooperators (dark orange) initially interact on the boundary of clusters, which eventually causing fragmentation into tiny patches spread throughout the lattice. This is due to a different performance of cooperators, depending on whether they are supported by third-party players or not. Cooperators without third-party support easily get invaded by defectors, which in turn get invaded by third-party supported cooperators, the end result being coexistence of cooperation and defection in a fragmented environment. Fig. 3e,f. In the lower row, intervenors (dark green) and non-intervenors (light green) in third-party layer also follow the cluster fragmentation pattern. Clusters of non-intervenors gradually shrink in size because of the invasion of intervenors, but due to the equated payoffs resulting from mixing of cooperators and defectors, non-intervenors reemerge in the environment. For clarity, we present results for lattice network of size $L = 100$ with prepared initial distribution. To simulate the environment with coexistence of cooperation and defection, we use $T = 1.4$ and $\Delta S = 0.7$. From left to right, shown are the snapshots of strategies after 0, 20, 40, and 100 steps. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

of intervention who receive 1, even 0.5 unit extra payoff is small. Given this, non-intervention seems to be more competitive than intervention. However, compared with the traditional snowdrift game, extra payoffs benefited from disputant layer do increase the survive of intervention, though it is kind of trivial.

To explore the distribution of strategies during the evolution process, we take a look at coexistence phase and present snapshots of the lattice network over time with a prepared initial state (Fig. 3). Upper row shows disputant layer, with defectors represented in light orange and cooperators in dark orange, while lower row shows third-party layer, intervenors in dark green and non-intervenors in light green. By following the snapshot in the upper row from left to right (Fig. 3a–d), we can observe that defectors are not able to maintain initial cluster shape and are invaded by cooperators as soon as the simulation starts. Cooperators, however, do not maintain big clusters but instead fragment into patches scattered throughout the network. This patchiness emerges as a consequence of differing performance of cooperators supported by third-

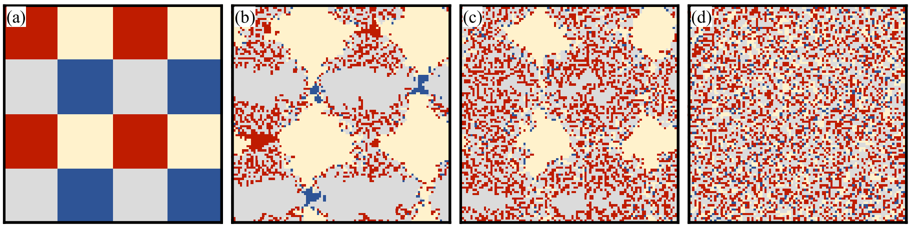

Fig. 4. Third-party players strongly influence the competition between cooperators and defectors. a). Players are categorized into four types, defectors supervised by non-intervenors (light yellow), cooperators supervised by non-intervenors (dark blue), defectors supervised by intervenors (dark red), cooperators supervised by intervenors (light grey). **(b-c).** Under the supervision of intervenors, cooperators easily spread into neighboring defectors, while defectors can barely maintain cluster form. On the contrary, defectors supervised by non-intervenors hold cluster form, although eventually they also get occupied by cooperators supervised by intervenors. Additionally, cooperators supervised by non-intervenors almost disappear as soon as the simulation starts and can only survive by clustering with cooperators supervised by intervenors. **d).** Eventually all clusters fragment and environment become patchy. For clarity, we present results for lattice network of size $L = 100$ with prepared initial distribution. To simulate the environment with coexistence of cooperation and defection, we use $T = 1.4$ and $\Delta S = 0.7$. From left to right, shown are the snapshots of strategies after 0, 20, 40, and 100 steps. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

party players and cooperates ignored by third-party players. Specifically, latter perform less well than former and are easily invaded by defectors. At the same time, however, invading defectors are in turn invaded by cooperators supervised by intervenors, which causes defector clusters to disappear. To summarize, regardless of third parties' strategy, cooperation and defection clusters fragment and scatter throughout the network evenly.

Taking a look at the lower row (Fig. 3e–h), we observe that spatial dynamics in third-party layer mirrors the pattern in disputant layer, i.e. large clusters fragment into numerous patches. This follows from the mixing of defectors and cooperators, which increases the frequency of cooperation-defection (*CD*) and defection-cooperation (*DC*) interactions, and in turn equates payoff from such interactions for both intervenors and non-intervenors. Hence, strategy updating in the third-party layer may occur randomly and lead to further fragmentation of clusters, meaning that intervenors help cooperators to become more competitive, but the coexistence of cooperation and defection allows for reappearance of non-intervenors.

To further reveal how players in the disputant layer update strategies when supervised by different third-layer players, we categorize players in disputant layer into four types, which are defectors supervised by non-intervenors (light yellow), cooperators supervised by non-intervenors (dark blue), defectors supervised by intervenors (dark red), and cooperators supervised by intervenors (light grey in Fig. 4), respectively. When supervised by intervenors, defectors are quickly invaded by cooperators supervised by intervenors, who do not form clusters, but instead remain scattered in patches mixing with the remaining defectors (Fig. 4b). However, when supervised by non-intervenors, defectors can not only preserve clusters, but they are also capable of invading cooperators (Fig. 4b, c). Clusters of cooperators supervised by non-intervenors diminish quickly, while clusters of cooperators supervised by intervenors manage to linger (Fig. 4b, c). Eventually, though, both clusters fragment and environment become patchy (Fig. 4d). These results demonstrate that third-party intervention makes cooperation competitive and able to hold against defection. This is especially evident when we see how fast cooperators supervised by non-intervenors go extinct (Fig. 4b).

To see how intervention and cooperation are intertwined, we observe the time evolution of cooperation and intervention frequencies (Fig. 5). Intervention indeed supports cooperation in the evolutionary process since intervention rises first and cooperation then follows (Fig. 5a). Interestingly, cooperation first drops due to the extinction of cooperators supervised by non-intervenors, but then it recovers to remain above initial levels. In both layers, the evolution processes can be divided into enduring (END) period and the expanding (EXP) period, where END period features the endurance of cooperation (intervention) when facing the invasion of defection (non-intervention), and EXP period features the areas expanding of cooperation (intervention) [42,43]. In disputant layer, *CC* pairwise interactions of cooperators are the most common, albeit closely followed by *DD* interactions (Fig. 5b). However, even this slight advantage in number of *CC* interactions in disputant layer is enough to keep *II* interactions the most abundant in third-party layer, where they account for more than half of all interactions (Fig. 5c). Clusters of players with same strategies play an important role in maintaining either cooperation or defection [20]. When supervised by intervenors, cooperative players are more successful at forming *CC* interactions than defectors supervised by non-intervention (Fig. 5d, e). Unlike cooperation, defection exists under both types of supervision, where, contrary to intuition, defection supervised by intervenors is more abundant (Fig. 5f).

Finally, we take a look at the influence of intervention strength ΔS on cooperation and intervention frequencies at fixed value of temptation T (Fig. 6). With values of ΔS lower than 0.35, the cooperation in disputant layer and intervention in third-party layer are non-existent (Fig. 6a), while defection and non-intervention are widespread (Fig. 6b). In this parameter space, ΔS is not sufficient to maintain intervention, which in turn results with the extinction of cooperation. In other words, intervenors are unable to protect themselves, let alone support cooperators. After ΔS passes the threshold value of 0.35, both cooperators supervised by intervenors (*IC*) and defectors supervised by intervenors (*ID*) become able to survive in the environment and eventually, at higher values of ΔS, they become dominant.

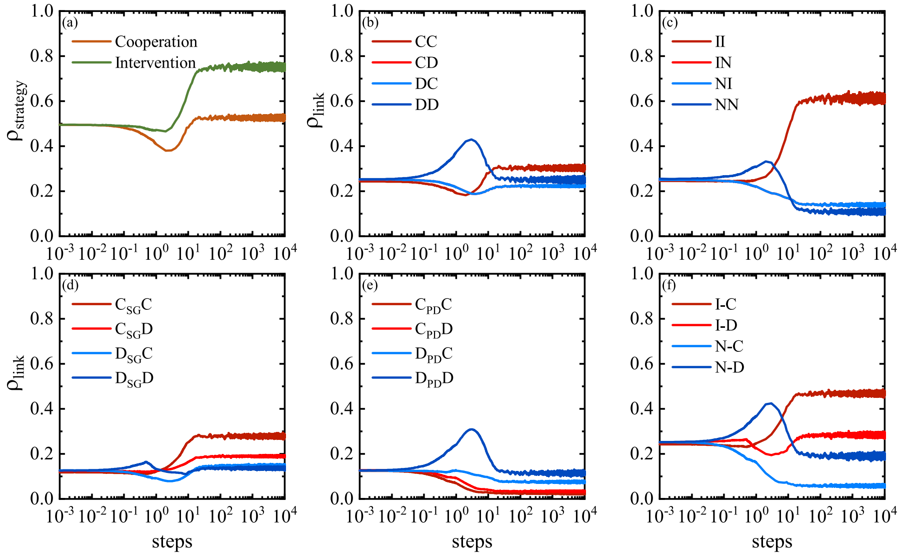

Fig. 5. Time evolution for cooperation and intervention frequencies. (a). Cooperation and intervention frequencies follow a similar pattern; they both first decrease and then increase above initial levels. However, intervention frequency experiences a slight dip followed by a strong growth, while cooperation frequency falls stronger due to the near-extinction of cooperators supervised by non-intervenors, and then recovers following the high levels of intervention. **(b).** In disputant layer, pairwise interactions between pairs of cooperators (*CC*) and pairs of defectors (*DD*) are the most abundant. However, before reaching the steady state, DD interactions are more common, with a high peak corresponding to the drop of cooperation in (a). However, the growth of intervention in (a) puts pressure on DD and the system stabilizes with *CC* as the most abundant type of pairwise interactions, followed by *DD* and *CD*/*DC*. **(c).**In third-party layer, pairwise interactions between pairs of intervenors (*II*) are by far the most common, accounting for around 60% of all interactions in the steady state. Initially, pairs of non-intervenors (*NN*) were the most common, but their frequency falls below and to become the least common in the steady state. **(d-e).**Frequencies of pairs radiating from the players in disputant layer supervised by intervenors and non-intervenors show that under the supervision of intervenors, *CC* are the most abundant, while under the supervision of non-intervenors, *DD* are the most abundant. **(f).**Frequencies of inter-layer pairs between intervenors and cooperators (*IC*), intervenors and defectors (*ID*), non-intervenors and cooperators (*NC*), and non-intervenors and defectors (*ND*) show that intervenors promote the frequency of cooperators. However, they also contribute to the defection as intervention accounts for almost 80% of inter-layer interactions. We present results for lattice network of size $L = 100$ with random initial distribution. To simulate the environment with coexistence of cooperation and defection, we use $T = 1.4$ and $\Delta S = 0.7$.

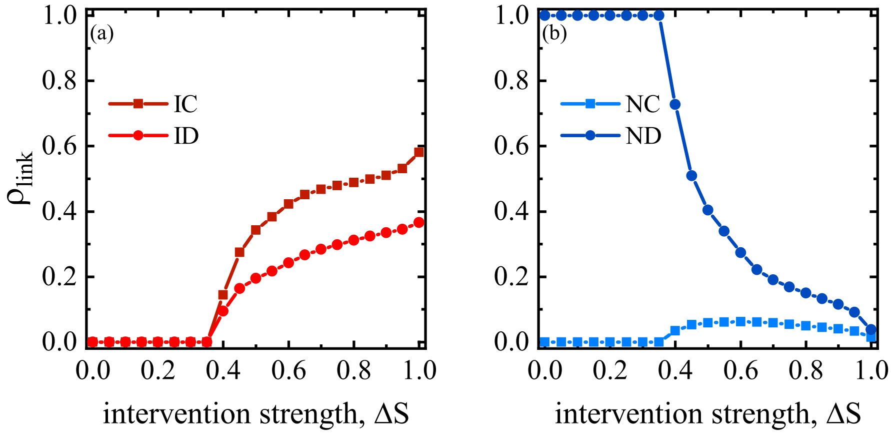

Fig. 6. Intervention strength ΔSinfluences inter-layer pairs monotonically. (a). Inter-layer pairs between intervenors and cooperators (*IC*) and intervenors and defectors (*ID*) go extinct at values of ΔS lower than 0.35. Above that threshold, *IC* and *ID* grow monotonically until they become dominant in the environment. Furthermore, *IC* growth rate is higher than *ID*, which demonstrates that at high enough values of the supervision of intervenors, cooperators are more competitive than defectors. **(b).** Inter-layer pairs between non-intervenors and defectors (*ND*) are the only one thriving at values of ΔS lower than 0.35. However, their numbers rapidly start to decrease as ΔS becomes higher, finally going extinct at highest value of ΔS. Interestingly, inter-layer pairs between cooperators and non-intervenors and defectors (*NC*) appear in the environment only at values of ΔS above 0.35 threshold, and remain at relatively low but stable numbers at all but highest value of ΔS, where they go extinct. As show earlier in Fig. 4, they are able to survive in small numbers by clustering with cooperators supervised by interventions *IC*. We present results for last 5000 steps (steady state), on a lattice network of size $L = 100$ with random initial distribution and fixed value of use $T = 1.4$.

4. Discussion

In this paper, we introduce an independent network model of third parties that intervene in conflict between disputants to mediate a social dilemma. For players in third-party layer, successful intervention brings additional payoff while failed intervention has no benefit. Non-intervention also brings additional payoff, albeit lower than for successful intervention to adjust for risk, and behavior of disputants has no effect on non-intervenor payoff.

Cooperation and defection are inevitable part of the evolution of human society, and as a consequence third parties evolved in order to mediate the competition between individual and group interests. We add to the existing literature on third parties [7,29] by demonstrating that the introduction of third-party layer greatly increases cooperation in disputant layer, especially at high values of intervention strength ΔS which enables cooperation to become dominant in the population. However, making defection more lucrative by increasing the value of temptation T creates an environment where cooperation and defection coexist. This coexistence evolves because cooperators supervised by intervenors are more competitive and they can survive in more hostile environments, but due to a high values of temptation T, defection and hence non-intervention still remain as viable strategies. Coexistence also spurs an interesting spatial dynamics, as cooperators in disputant layer supervised by players in third-party layer who adopt intervention are able to maintain cooperation, but cannot maintain clusters. Instead they scatter in patches together with defectors, confirming role-separating spatial pattern characteristic of *SDG* [44,45].

Although our model shows that intervention of third parties promotes cooperation, there is still a room for improvement, as there is a wide parameter space where defection coexists with cooperation. In other words, by playing *SDG* third parties have an essential role in mediating social dilemma, but it is still not enough to make cooperation prevalent among the entire population. We demonstrate in this paper that although the introduction of third parties has a goal to relief conflict among disputants, players in third-party layer often take no action due to self-interest, which nourishes defection and causes pressure to cooperation. Reflecting on the real world, this phenomenon corresponds to various institutional and social failures where third parties do not fulfill their responsibilities and as a result, cause further deterioration of public trust and interests.

To further tackle social problems, it is worth to further explore cooperation promoting mechanism which could help third parties to improve their efficiency. Some examples could include the optimal occasion when third parties intervene and the method to encourage intervention and discourage non-intervention. Discovering how to improve the efficiency of third parties would, therefore, be helpful to policy makers and various volunteering institutions to better serve society and help to resolve disputes.

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Appendix

Here, we present a replicator equation method for our model. In disputant layer, a focal player i, can adopt either cooperation or defection. We calculate probability that focal player i in cooperation state equals to the frequency of cooperation p in the population based on mean-field approximation, therefore, the *ODE*:

$$\dot{p} = p(1-p)(\pi_C - \pi_D) \tag{A1}$$

where π_C (π_D) is the average payoff of a single cooperator (defector). Based on the payoff matrixes described in the model part,

$$\begin{aligned} \pi_C &= q(p*R+(1-p)*S_2)+(1-q)(p*R+(1-p)*S_1) \\ \pi_D &= q(p*T_2+(1-p)*P)+(1-q)(p*T_1+(1-p)*P) \end{aligned} \tag{A2}$$

In third-party layer, focal player j can be in state intervention or non-intervention, so we can calculate the probability that focal player j adopts intervention equals to the fraction of intervention q in the same way:

$$\dot{q} = q(1-q)(\pi_I - \pi_N) \tag{A3}$$

where $\pi_I(\pi_N)$ is the average payoff of a single intervenor (non-intervenor). Based on the payoff matrixes described in model part,

$$\begin{aligned} \pi_I &= qR+(1-q)S_2+1*q^2+2*0.5*q(1-q)+0*(1-q)^2 \\ \pi_N &= qT_2+(1-q)P+0.5 \end{aligned} \tag{A4}$$

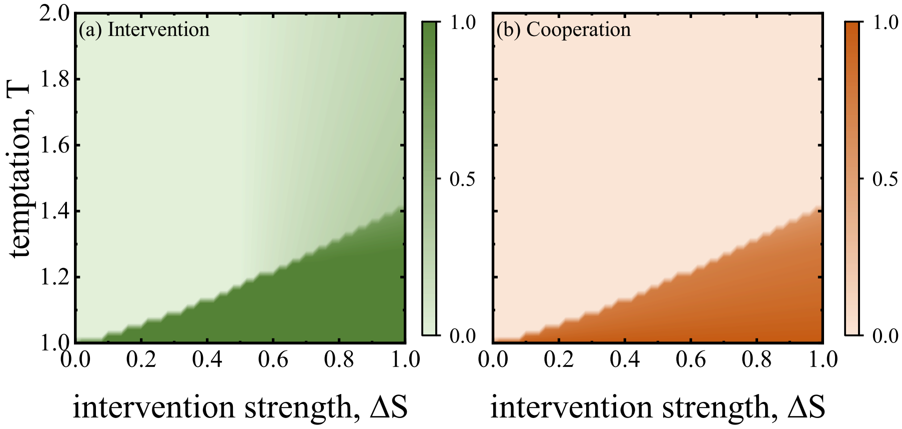

Fig. A1. Frequencies of intervention and cooperation as the function of temptation T and intervention strength ΔS. **(a).** Results obtained by replicator equation method for the intervention frequency of players in third party layer. **(b).** Results obtained by replicator method for cooperation frequency of players in disputant layer. All results are calculated when $K = 0.1$.

Initially, the frequency of cooperation p and intervention q are set to 0.5. Then we proceed with the numerical integration of the original replicator equation using the fourth-order Runge-Kutta method. The results of this method are shown in Fig. A1.

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