

Stochastic punishment by authorized third-parties in a public goods game: The role of reputation-based migration

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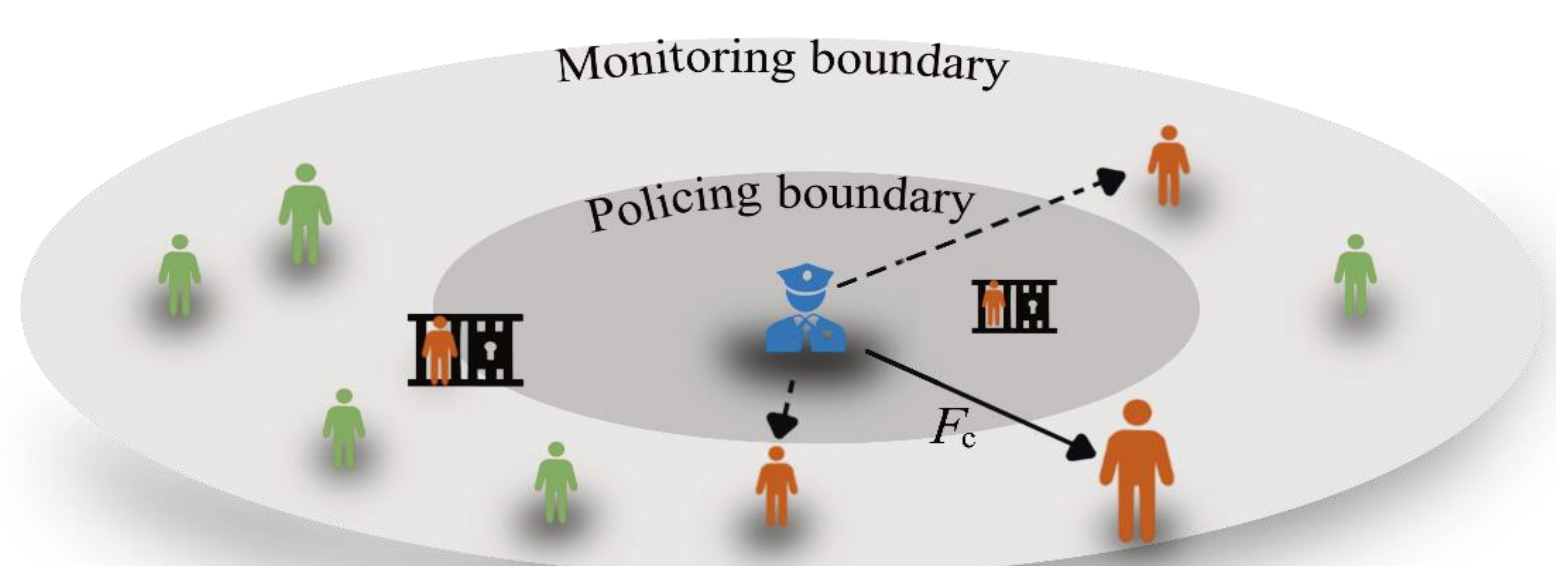
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INTRODUCTION & AIM

This study examines how delegating a third-party punishment can sustain cooperation in large-scale, mobile societies facing public goods dilemmas. Specifically, we explore the effectiveness of delegated punishment in more realistic scenarios (e.g., free-riders are not equally likely to be punished) when formal sanctions are neither certain nor immediate. Furthermore, we examine whether informal sanctions, such as reputation-based "voting with one's feet", can complement or substitute third-party punishment mechanisms, especially in the presence of mutant defectors.

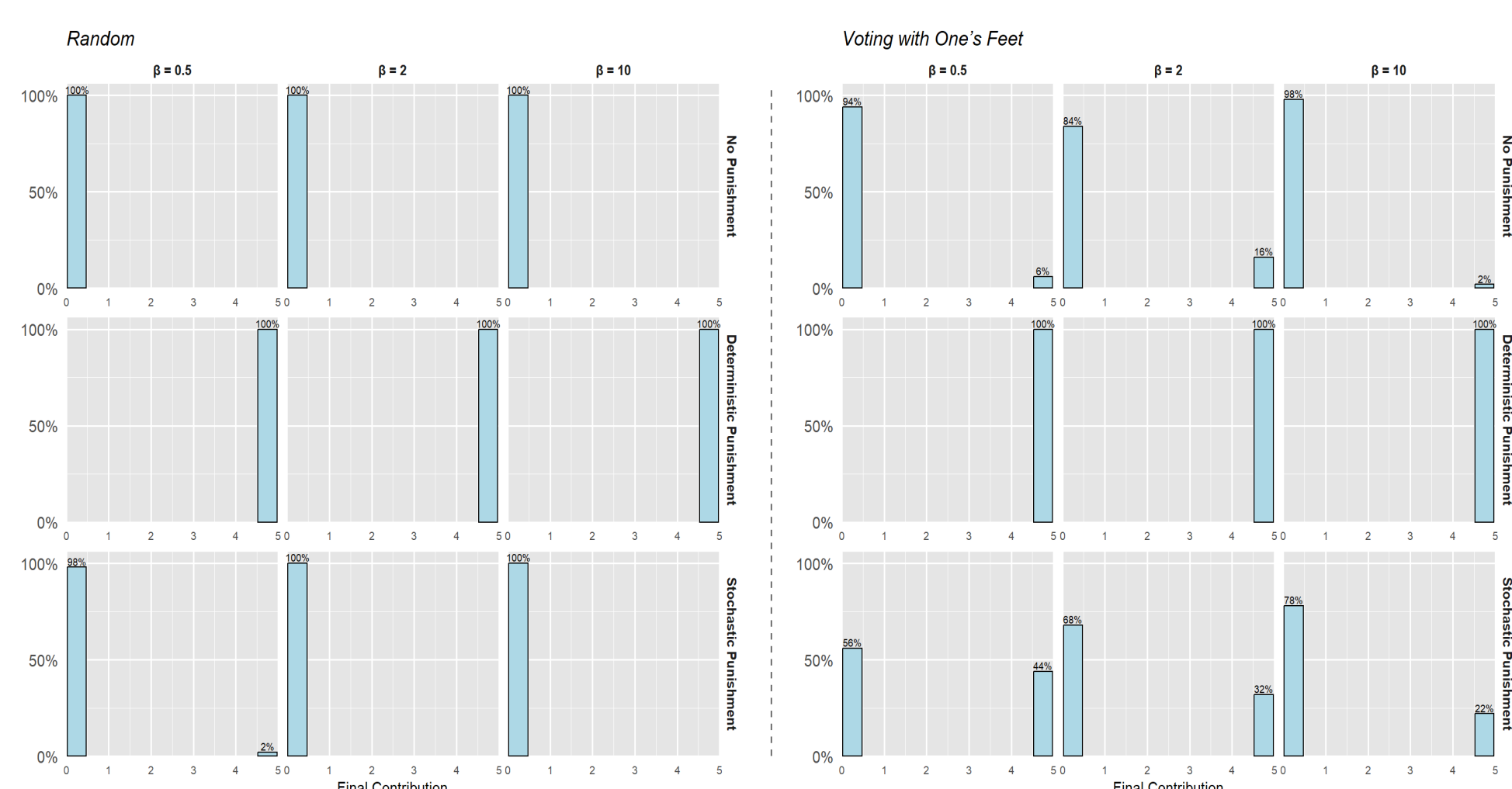
METHOD

We propose an agent-based model of stochastic third-party punishment in unstructured populations (e.g., during the Great Migration). Three types of players, unconditional cooperators, unconditional defectors, and conditional cooperators, are matched in a one-shot public goods game. Their contributions are mapped onto reputation scores that continuously accumulate up to fixed bounds. Under the "voting with one's feet" rule, reputation drives movement only for cooperators (unconditional/conditional)—toward positive reputation peers and away from negative reputation ones. For all types, punishment intensity is determined by each agent's own cumulative reputation. Agents update their strategies via payoff-based imitation to capture social learning dynamics. We assess the temporal and spatial dynamics of cooperation across scenarios combined by three factors: punishment type (none vs. deterministic vs. stochastic), migration rule (random vs. "voting with one's feet"), and mutation status (presence vs. absence).



The outer ring and the inner ring mark a monitoring boundary and a policing boundary, respectively. A third-party punisher (the police icon at the center) is assumed to be aware of reputation information within the outer ring and sanction agents with negative reputation scores only after moving into the inner ring to reach the target. The order of implementation is prioritized by reputation and distance, and the punisher follows paths such as arrow F_c . Consequently, some violators may escape sanction.

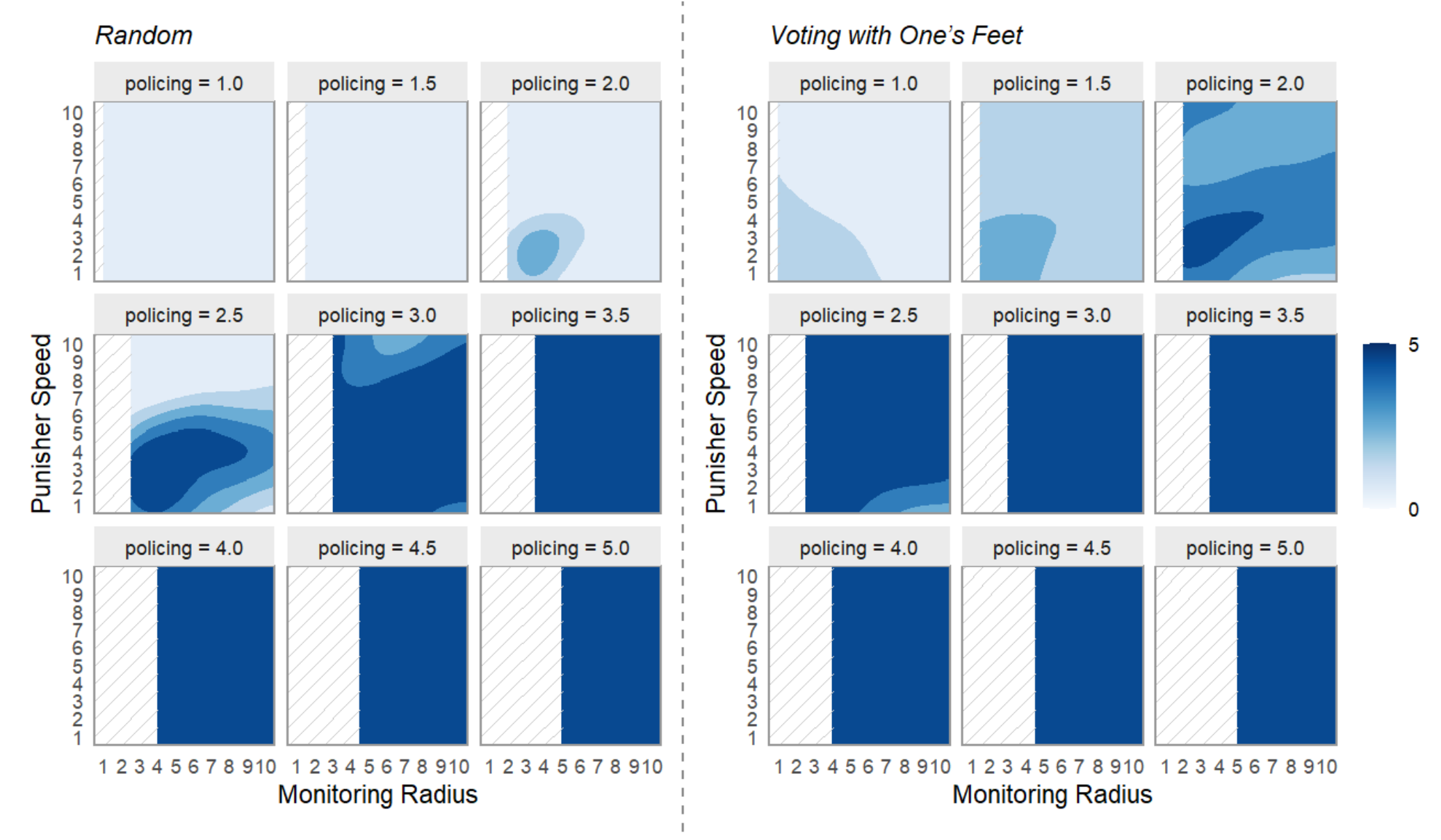
RESULTS & DISCUSSION



1. Deterministic punishment yields the highest level of cooperation across both migration rules. Given stochastic punishment, society-wide cooperation is more frequently reached in the presence of reputation-based movement at weaker selection pressures (β).



2. "Voting with one's feet" drives positive reputation agents to cluster while isolating negative reputation ones, reducing heterogeneous contact and preserving cooperators' survival space against the invasion of mutant defectors. Meanwhile, third-party punishers shift from "putting out fires everywhere" to "border management," lowering their enforcement burden. Due to the nature of stochastic enforcement (uncertainty and delays), emerging societies do not always transition toward full cooperation, however.



3. Overly narrow monitoring and slow speed reduce the productivity of formal sanctions, whereas overly broad detection and fast movement lead to enforcement redundancy. At moderate ranges of both parameters, stochastic punishment becomes more efficient when policing boundaries are smaller.

CONCLUSION & FUTURE WORK

Non-deterministic and non-immediate punishment in mobile societies, albeit similar to real-world settings, is less efficient than deterministic punishment. However, informal mechanisms, such as "voting with one's feet", partially fill the gaps left by imperfect formal sanctions through protecting clusters of cooperators. The main results also indicate a tension between sustainable cooperation and social inclusion. Future work for more policy insights is warranted to design governance systems that maintain cooperation while preserving opportunities for rehabilitation and social integration (e.g., restorative justice vs. retributive justice).