15. Social Games (2026)

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These are tumultuous times! With the reelection of Donald Trump, the official political strategies in the United States have shifted from the more cooperative and egalitarian approaches of the Democrats to the competitive and skewed economy favored by the Republicans. How can an entire nation change so quickly? I have suggested some answers in earlier essays but would like in this one to develop those ideas further and summarize more recent research on what determines the outcome of the perpetual battle between cooperation and selfish defection.

Social Games: Earlier essays in this series described a simple evolutionary game in which all members of a society can either **cooperate** to enhance the common good or **defect** to pursue selfish interests. We saw that this game and its outcomes could be summarized in a simple table:

Opponent Plays

You Play	**Cooperate**	**Defect**
Cooperate	A	B
Defect	C	D

Here A, B, C, &D are the payoffs to you of playing the strategy in a particular row given what the opponent plays (options given in the columns).

Remember that this table summarizes not just one contest between two players, but in unlimited number of interactions between you and all possible opponents. In a sense, the player on the left is playing against the whole population.

Using a dot to indicate the best strategy for you given what your opponent does, there are four possible outcomes to this game (Hoffbauer & Sigmund, 1998):

	Cooperate	**Defect**
Cooperate		
Defect	●	●

Prisoner's Dilemma

	Cooperate	**Defect**
Cooperate	●	●
Defect		

Coordination

	Cooperate	**Defect**
Cooperate		●
Defect	●	

Snow Drift

	Cooperate	**Defect**
Cooperate	●	
Defect		●

Stag Hunt

In the literature, each of these outcomes has acquired its own name based on a short story. The challenge in each case is to find the strategy or mix of strategies that evolution will favor (called the evolutionarily stable strategy or ESS):

- **Prisoners' dilemma:** Two prisoners who committed a crime together are captured. They are kept separate and each given a chance to squeal on the other (**Defect).** They could of course keep their mouths shut and not say anything. (**Cooperate**). If they both cooperate, they both get a medium sentence. If one cooperates and the other defects, the one who defected goes free and the one who kept his mouth shut has a very long sentence. Using the payoff letters in the first matrix, $A<C$ and $B<D$. The ESS is for both criminals to **defect.** This is a case where one strategy is best, no matter what your opponent does. A completely selfish and unregulated economy would be a human example.

- **Coordination Game:** Here, it again pays for you to do the same thing no matter what the other person does. In this case, it is to always **cooperate.** $A>C$ and $B>D$. Strict religious sects and communist groups might be examples.

- **Snow Drift Game:** Two car passengers encounter a snow drift blocking the road. It will only take one to shovel the snow (**cooperate)** while the other sits in the car (**Defect.).** The best strategy is to do the opposite of the other individual. $A<C$ and $B>D$. Note that this has the same dynamics as a Hawk-Dove game in which the interactions are aggressive instead of cooperative. In that game, you should play Hawk if your opponent plays Dove and Dove if your opponent plays Hawk. Again, you should adopt the opposite strategy to your opponent.

  The ESS is a **stable equilibrium** in which a fraction X of the players adopt one strategy and (1-X) adopt the other. Mathematically, it does not matter whether X of the players always do one strategy and (1-X) always do the other, or for each player to do one strategy X of the time and the other strategy (1-X) of the time. In case you needed it sometime,

  $$X= (B-D)/(B+C-A-D).$$

  An example might be a hunter gatherer group in which the men hunt, and the women forage for vegetables and fruit. In fact, any stable division of labor would fit snowdrift economics.

- **Stag Hunt Game:** Two hunters set out for the day. If they both decide to **cooperate,** they should be able to capture a stag. If one of them wants to hunt rabbits instead (**defect),** it does not pay for the other to try to hunt a stag. So, they both end up hunting rabbits. In this game, the best strategy is to do whichever strategy your opponent selects. ($A>C$ and $D>B$). There are two ESS's: either both hunt stags or both hunt rabbits.

  As with the snow drift game, there is an equilibrium mixture of cooperators and defectors where the payoffs of playing either strategy are the same. But unlike the snow drift game, the equilibrium is **unstable** and is in fact a **tipping point**! If the fraction of cooperators in a cooperator ESS population drifts below the tipping point, it suddenly becomes better to defect than cooperate. This can drive the population all the way to the defector ESS. And the same thing can happen if a population of defectors drifts across the tipping point leading to a shift to the cooperator ESS.

In most situations, the likelihood of drifting across the tipping point and changing strategies is not equal. Usually one strategy, called **the risk dominant strategy,** is the more likely ESS to find in nature. It is the strategy in which an individual pays the greatest cost by picking the wrong strategy in that environment. In other words, if A-C < D-B, it is easier for a cooperator population to turn into a defector population than the reverse and we are more likely to see defector populations in nature. If A-C > D-B, then cooperator populations would be more robust and more likely to be encountered.

Given a Stag Hunt economy, what could a society do to promote the cooperator ESS? The problem is that cooperation usually entails a cost that defectors do not need to pay. In a population of defectors, cooperation can be promoted most often by increasing the value of B and thus **reducing** D-B. Mechanisms for doing this include:

- **Allometric Cooperation**: As discussed in *Essay 13*, there may be synergistic benefits to doing something cooperatively instead of each individual doing their own thing. Examples include group hunting, building a structure that one person cannot build, and a trained military.
- **Selective Assortment:** Cooperators selectively interact with or choose to live with other cooperators and shun defectors. Favoring interactions with genetic relatives is one example (Hamilton 1964).
- **Direct Reciprocity**: I help you now at some benefit to you and cost to me, and later you help me at some cost to you and benefit to me. As long as the benefits are greater than the costs, it pays to have such a relationship (Trivers 1971).
- **Indirect Reciprocity**: Individuals who are frequently cooperative acquire a sufficient reputation that strangers who know about their reputation help them. (Nowak & Sigmund, 2005).
- **Network Proximity:** Cooperation can spread given a sufficient number of adjacent neighbors in a structured (network) population (Oksuki et al. 2006).

There are two primary mechanisms advanced to help sustain an existing cooperator ESS given Stag Hunt economics:

- **Punishment of Defectors:** This reduces the value of C and thus **increases** the value of A-C. But punishment is a bit complicated because *somebody* has to punish the defectors and that person has to pay the cost of doing so. This mechanism is favored when there are enough cooperators to spread the task around. Similarly, the less abundant the defectors, the fewer cooperators who have to engage in punishment (Boyd et al. 2003).
- **Social Norms:** Instructing children in proper standards of behaviors, putting social pressure on defectors, and using other psychological pressures can both increase A in our payoff matrix and decrease C to help maintain cooperation (Heinrich & Heinrich 2016; Wei et al. 2025).

It may be difficult to determine whether a defector society is stuck in a Prisoner's Dilemma game, or just currently at the defector ESS in a Stag Hunt game. For humans, history may provide an answer. Ancient Athens cycled repeatedly between democracy and oligarchy. Rome went from a relatively cooperative republic to a largely defector empire. And even the United States has cycled between a heavy emphasis on cooperative democracy and selfish oligarchy (Richardson 2023). This sounds more like a Stag Hunt than a permanent Prisoner's Dilemma. Also, once one society evolves a cooperative democracy, it becomes a "template" for other societies which are currently locked into the Prisoners' Dilemma. At least in principle, the ensemble becomes a Stag Hunt situation.

Multilevel Selection: While the evolutionary games above provide some interesting insights into social evolution, they are based on simplifying assumptions that may not be true. For example, they all assume that everyone who adopts a given strategy when their opponent adopts a given strategy will get the same payoff. What if payoffs are unequal for different players? This is often the case in animal and human societies. These game models are also deterministic: nature is rarely that reliable and chance often plays an important role. Finally, it has proved difficult to demonstrate that the mechanisms listed for the promotion of cooperation in a Stag Hunt game are sufficient to change a defector population into a largely cooperative one. Yet, there are many animal and human groups that are largely cooperative. What are these simple models missing?

No group or society exists in a vacuum. For a given country, such as the United States, there are hundreds, if not thousands of subgroups based on religion, politics, ethnic background, etc. It is well known that even within a nation, the subgroups interact in complicated and important ways (Alesina et al 2003; Duclos et al 2004; Estaban & Ray 2011; Guarneri 2021). In addition to humans, a wide variety of animal species exhibit conflict or even collaboration between different conspecific groups (De Driu & Triki 2022; Morris 2022).

The relative success of two interacting groups usually depends on the relative cooperative efforts within each group. If the interaction involves conflict, the winner will often be the one with the highest degree of internal cooperation. Similar arguments can be made for collaborative interactions between groups. These usually entail the synergistic (allometric) creation of some "public good" that would be more expensively created by independent groups. The result is then shared among the contributing groups. Higher cooperation increases the value or amount of public good and this increases the share each group and its members will receive. Whether interactions between groups involve conflict or collaboration, they provide another reason why members of a group should collaborate rather than defect. Can group interactions, either alone or in combination with the other mechanisms listed for Stag Hunt games, justify persistent cooperation within an initially all-defector population?

The relevant evolutionary models are complicated. We cannot just apply the simple games listed above to explain what happens within groups and then apply them again to group interactions, this time treating the groups as the players instead of individuals. The reason is that there will always be feedbacks between what happens within and between groups. The process by which evolution sorts out the many possible patterns of interaction is called **multilevel selection** (Sober & Wilson 1998). Given the potential complexity of multilevel selection, most models use some simplifying assumptions, but luckily models with different assumptions largely give the same predictions. Below, I summarize a sample of the recent literature:

- **Reeve & Hölldobler (2007)** consider a population of equally-sized groups that compete to acquire larger fractions of a limited resource. A group's chance of winning a larger fraction of the resource increases the more its members contribute to the intergroup competition

(**Cooperate**). However, the more time a group member spends contributing to the cooperative effort, the less time it has to compete for its share of its group's resource, tempting it to **Defect**. The authors assume the population has already evolved to an ESS where all groups exhibit the same level of defection, all groups get the same share of contested resource, and the ESS share is the most that can be obtained in a given context.

They find that the ESS is a stable mixture of cooperation and defection (Snow Drift Game). The ESS fraction of cooperators in each group increases with increases in within-group genetic relatedness, the number of groups competing in a patch, and the intensity of within patch competition. The fraction of cooperators decreases with increases in group size and increased genetic relatedness between groups.

- **Barker et al. (2015)** use the same model as Reeve and Hölldobler (2007), but divide each group into two classes, one very effective at competition for within-group resources and another that is less effective. Most of the predictions of the former model recur here. However, as the difference in effectiveness is increased, the less effective class takes on more of the task of competing with other groups while receiving less of the acquired resource. It does not take a very large difference in effectiveness before the more effective group is doing none of the intergroup competition and receiving most of the benefits. Such groups are very effective at competition because so many individuals in the group cooperate in contests with other groups. The most effective type of group has a single leader who does no work but receives most of the benefits! Interestingly, this is what is found in many social insects.

- **Cooney et al. (2023)** also model a population with groups of the same size. But unlike the prior two models, every individual is either a defector or a cooperator, and individuals in each group who adopt the same strategy all get the same payoff. Another difference is that these models are dynamic: they do not assume that the population is already at an ESS but allow the fraction of cooperators in groups to change over time. Random birth and death processes cause changes both in the fraction of cooperators within a group and the fraction of groups with a particular fraction of cooperators. The model thus tracks two concurrent processes: within-group competition that tends to decrease the fraction of cooperators, and between-group competition that tends to increase it. They introduce a parameter that specifies the strength of selection between groups relative to that within groups.

  The authors identify a threshold level of intergroup competition below which all groups are composed only of defectors. For levels of intergroup competition above the threshold, a population will converge to a hump-shaped distribution of groups, where the peak represents those groups that have a fraction of cooperators that maximizes group payoffs. As the strength of intergroup competition increases above the threshold, this peak moves to higher fractions of cooperators. However, it can never reach 100% cooperators based only on intergroup competition.

  The authors then explore the effects of the mechanisms listed earlier to promote cooperation in defector populations. While they find that assortment and the various forms of reciprocity can move the peak in the stable distributions to a higher fraction of cooperators, none of them lead to all-cooperator groups. Thus, as with the prior models, this model largely predicts a stable mixture of defectors and cooperators (Snow Drift Game), with the difference that the mixture is a distribution around a peak value and not a uniform level of cooperation.

- **Alexiou & Cooney (2025)** use a dynamic model similar to the prior example, but they replace the intrinsic replication process of groups with the outcomes of pairwise contests between groups: the winner is the group with the highest fraction of cooperators, and it replaces the loser with a copy of itself. As with the prior paper, the authors consider Prisoner's Dilemma economics for both within and between group competition, but also consider cases where that competition fits a Hawk-Dove model or a Stag Hunt model.

  As in the prior paper, **Prisoner's Dilemma** contests when intergroup selection is weak converge on populations where everyone is a defector, and when that selection is greater than a threshold, the steady state is a humped distribution of groups with different fractions of cooperators. Unlike the prior paper, these distributions are extremely broad with almost every fraction of cooperators present. As the strength of selection get stronger, the peak of the hump moves to higher values of cooperators and the spread of the distributions becomes narrower.

  Simple **Hawk Dove** games have the same dynamics as the **Snow Drift** game with an ESS that is a stable mixture of the two strategies. When applied to this dynamic model of multilevel selection, for low levels of intergroup competition, the population forms a peaked distribution with its maximum at the expected ESS mixture of cooperators and defectors predicted by the simple ESS game. However, as the strength of intergroup competition increases, the peak of the distribution moves to increasing fractions of cooperators and the spread of the distribution decreases.

  Simple **Stag Hunt** games have two ESS's: one in which all groups contain only defectors, and a second in which all groups contain only cooperators. When used in this dynamic model at low group competition levels, that is approximately what is seen, except that there is a peaked distribution of groups at each extreme, and a low level, but continuous smear between them. As the intensity of Intergroup competition is increased, the defector peak decreases in amplitude and the cooperator peak increases.

  Thus, replacing intrinsic birth/death processes between groups with frequency-dependent pairwise competition produces similar general outcomes, but instead of uniform ESS's, we get peaked distributions with greater variation in group compositions.

- **Tverskoi et al. (2010)** also examine a dynamic multilevel selection model, but they allow for both collaboration and conflict between groups. Each simulation of their model is broken into successive time periods. At the start of each period, three economic games are played concurrently: a) a within-group game in which individuals can decide whether or not to contribute to producing some shared public good such as a resource; b) a between-group economic game in which each group decides whether or not to contribute their produced public goods to a common pool; and finally) c), a between-group economic game in which groups compete for a larger share of the pooled public good.

At the end of a time period, each group divides its acquired public goods among all group members, including those who did not contribute to its production. Groups that did not contribute to the collaborative pool have whatever they managed to produce. Groups that did contribute have their share of the collaborative effort. A "**skew**" parameter determines the evenness with which these resources are divided among group members. A low value means everyone gets a fixed amount, whereas a high value allows for competition and unequal distributions.

A collaborating group's share of the pooled resource is determined by its current "power" (status) in the larger community. The model then updates the power of each group with a weighted combination of its current power and the fraction of this period's pooled public goods that it contributed. The higher a model parameter, called "**incumbency**", the larger the role of prior power in determining the next one. Low incumbency tends to equalize groups overtime, whereas high incumbency allows select groups to become dominant and wealthy. In human societies, limiting regulations, progressive taxes, and strong charity traditions all tend to keep the incumbency parameter low and thus reduce inequality between groups.

At the beginning of the next time period, randomly chosen individuals in each group estimate whether cooperating or defecting will yield the highest payoff and choose their subsequent effort accordingly. Similarly, randomly chosen groups decide whether to contribute to the next collaboration or not. Both processes add some stochasticity to the model. In addition, this model does not assume linear payoffs from increasing contributions. For example, the amount of public goods produced by a group is assumed to be an increasing but asymptotic function of the number of cooperators in the group. The limit is set by the environment in which the group lives. Similarly, the payoff to all members of a group is assumed to be an increasing, but again asymptotic function of its end-of-season resource. Both the stochasticity and nonlinearities make the mathematics more complicated but also make this a much more realistic model.

Happily, most of this model's simulations lead to stable equilibria. Many are mixtures of both cooperators and defectors *within* the groups and collaborators and non-collaborators *among* the groups. Equilibria are quite sensitive to the value of the incumbency parameter. For simulations in which all groups are equally sized, low incumbency leads to a large fraction of groups collaborating, but a low fraction of cooperators in collaborating groups. In fact, non-collaborating groups often have higher fractions of cooperators. As incumbency is increased past a threshold, the number of collaborating groups drops, the fraction of cooperators in the remaining collaborating groups rises, and the power of the few collaborating groups jumps to very high levels. A similar step-function change occurs as the maximal values of productivity and payoffs are increased. Note that similar step-function shifts in cooperation were seen in the Alexiou & Cooney (2025) model with variation in the intensity of between group selection.

Not surprisingly, given the non-linear functions built into this model (cf. Strogatz 2024), not all simulations lead to stable equilibria. Some produce limit cycles in which the fraction of collaborating groups stabilizes, but which groups join the coalition keeps changing. In some other cases, the fraction of groups collaborating also keeps changing.

This is a much more complicated model than the ones considered earlier, but interestingly, it also predicts both stable mixtures of cooperators and defectors (**Snow Drift** game) and systems that oscillate between alternative equilibria (**Stag Hunt** game).

Take-Home Messages: So, what does all this evolutionary modeling tell us? How is it relevant to our current circumstances? Here is my take on it:

- It is unlikely that evolution by itself will ever produce a stable population of 100% cooperators, whether in people or other organisms. Even in largely cooperative societies there will always be some defectors and "free riders" present (**Snow Drift** game**).**
- This is true even if there is strong multilevel selection (competition and/or collaboration), and all the ameliorating techniques (reciprocity, punishment, selective assortment) are activated.
- The mixtures of cooperators and defectors are only "quasi-stable". They are always at risk of shifting to largely defector societies (**Stag Hunt** game). Likely triggers:
    - The defectors in the mix typically pay fewer costs than cooperators but get the same benefits. It is in their interests to reduce any constraints on defecting. If they are successful, the fraction of defectors can increase, and if it passes the tipping point, the society will devolve to a selfish (defector) one.
    - Alternatively, conditions may change (e.g., there is a drop in the intensity of intergroup competition, environmental changes reduce within-group productivity, or there is a change in the within-group distribution of public goods). Any of these might reset the equilibrium past a threshold below which the society shifts to the defector alternative.

As I have pointed out in prior essays, I think we are now in such a shifting situation. The relaxing of regulations on business, the reductions of equalizing taxes, the abandoning of government-sponsored synergistic cooperation in favor of individual businesses, and the decline of charitable giving have all created a very strong **skew** in citizen wealth and well-being. When someone feels that the benefits of **cooperating** do not exceed the costs, they are going to **defect.** Once past the tipping point, this is an accelerating process.

At the group level, United States Republicans have decided to ignore the constraints built into the Constitution and current law to increase their **incumbency** and power. Gerrymandering, restricting access to voting, limiting what information can be shared publicly, extensive disinformation (now AI generated), and punishment of opponents are all designed to enhance incumbency and power. The models make it clear what happens next.

While history provides many examples where a largely cooperative society degenerated into oligarchy or autocracy, there are also examples where the people fought back and reconstituted a cooperative society. The French Revolution comes to mind. If we do experience such a major transition, I just hope it is nonviolent.

References:

I read a lot more material than I have cited in the discussion above. In case there are still readers interested in original materials instead of an AI generated summary, here are the references that I have read:

Starting Points:

Boyd, R., Gintis, H., Bowles, S., & Richerson, P. J. (2003). *The evolution of altruistic punishment*. www.pnas.orgcgidoi10.1073pnas.0630443100

Boyd, R., & Richerson, P. J. (2010). Transmission coupling mechanisms: Cultural group selection. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *365*(1559), 3787–3795. https://doi.org/10.1098/rstb.2010.0046

Hamilton, W.D. (1964). The genetical evolution of social behaviour. I & II. *Journal of Theoretical Biology*, 7(1), 1-16; 17-52.

Heinrich J. & Heinrich N. (2007). *Why humans cooperate: A cultural and evolutionary explanation*. Oxford University Press.

Hofbauer J, Sigmund K (1998) Evolutionary Games and Population Dynamics. Cambridge University Press.

Nowak MA, Sigmund K (2005) Evolution of indirect reciprocity. Nature 437(7063):1291–1298.

Ohtsuki, C. Hauert, E. Lieberman, &M. A. Nowak, (2006). A simple rule for the evolution of cooperation on graphs and social networks," *Nature*, 441 (7092): 502–505,

Sober, E. & Wilson, D. S. (1998) Unto Others: The Evolution and Psychology of Unselfish Behavior (Harvard Univ. Press, Cambridge, MA)

Strogatz, S.H. 2024. *Nonlinear Dynamics and Chaos. 3rd Edition. (*Chapman and Hall/CRC, New York, NY)

Trivers, R.L. (1971). The evolution of reciprocal altruism. Q Rev Biol 46(1):35–57.

Group Conflict:

Alberto Leschauwer. (2003). Alesina 2003. *Journal of Economic Growth, 8*, 155–194.

de Dreu, C. K. W., & Triki, Z. (2022). Intergroup conflict: Origins, dynamics and consequences across taxa. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *377*(1851), 332–342. https://doi.org/10.1098/rstb.2021.0134

Duclos, J. Y., Esteban, J., & Ray, D. (2004). Polarization: Concepts, measurement, estimation. *Econometrica*, *72*(6), 1737–1772. https://doi.org/10.1111/j.1468-0262.2004.00552.x

Esteban, J., & Ray, D. (2011). Linking conflict to inequality and polarization. *American Economic Review*, *101*(4), 1345–1374. https://doi.org/10.1257/aer.101.4.1345

Glowacki, L., & McDermott, R. (2022). Key individuals catalyse intergroup violence. In *Philosophical Transactions of the Royal Society B: Biological Sciences* (Vol. 377, Issue 1851). Royal Society Publishing. https://doi.org/10.1098/rstb.2021.0141

Guarnieri, E. (2025). Cultural Distance and Ethnic Civil Conflict. *American Economic Review*, *115*(4), 1338–1368. https://doi.org/10.1257/aer.20231087

Meijer, H. (2024). Janus faced: The co-evolution of war and peace in the human species. *Evolutionary Anthropology*, *33*(3). https://doi.org/10.1002/evan.22027

Morris-Drake, A., Kennedy, P., Goncalves, I. B., & Radford, A. N. (2022). Variation between species, populations, groups and individuals in the fitness consequences of out-group conflict. In *Philosophical Transactions of the Royal Society B: Biological Sciences* (Vol. 377, Issue 1851). Royal Society Publishing. https://doi.org/10.1098/rstb.2021.0148

Rusch, H. (2022). Modelling behaviour in intergroup conflicts: A review of microeconomic approaches. In *Philosophical Transactions of the Royal Society B: Biological Sciences* (Vol. 377, Issue 1851, pp. 947–962). Royal Society Publishing. https://doi.org/10.1098/rstb.2021.0135

Evolutionary, Game Models:

Amin, E., & Soliman, A. (2026). A semi-empirical evolutionary model for studying cooperation within and between groups. *Journal of Economic Interaction and Coordination*, *21*(1), 93–132. https://doi.org/10.1007/s11403-025-00446-2

Barker, J. L., Barclay, P., & Reeve, H. K. (2012). Within-group competition reduces cooperation and payoffs in human groups. *Behavioral Ecology*, *23*(4), 735–741. https://doi.org/10.1093/beheco/ars020

Barker, J. L., Loope, K. J., & Reeve, H. K. (2016). Asymmetry within social groups: Division of labour and intergroup competition. *Journal of Evolutionary Biology*, *29*(3), 560–571. https://doi.org/10.1111/jeb.12805

Kristensen, N. P., Ohtsuki, H., & Chisholm, R. A. (2022). Ancestral social environments plus nonlinear benefits can explain cooperation in human societies. *Scientific Reports*, *12*(1). https://doi.org/10.1038/s41598-022-24590-y

Maclean, R. C., Fuentes-Hernandez, A., Greig, D., Hurst, L. D., & Gudelj, I. (2010). A mixture of "cheats" and "co-operators" can enable maximal group benefit. *PLoS Biology*, *8*(9). https://doi.org/10.1371/journal.pbio.1000486

Reeve, H. K., & Holldobler, B. (2007). *The emergence of a superorganism through intergroup competition*. PMAS 104: 9736–9740.

Dynamic Game Models:

Alexiou, K., & Cooney, D. B. (2025). Steady-State and Dynamical Behavior of a PDE Model of Multilevel Selection with Pairwise Group-Level Competition. *Bulletin of Mathematical Biology*, *87*(7). https://doi.org/10.1007/s11538-025-01476-4

Arenzon, J. J., & Peliti, L. (2023). Emergent cooperative behavior in transient compartments. *Physical Review E*, *108*(3). https://doi.org/10.1103/PhysRevE.108.034409

Cooney, D. B. (2025). Exploring the Evolution of Altruistic Punishment with a PDE Model of Cultural Multilevel Selection. *Bulletin of Mathematical Biology*, *87*(4). https://doi.org/10.1007/s11538-025-01422-4.

Cooney, D. B., Levin, S. A., Mori, Y., & Plotkin, J. B. (2023). *Evolutionary dynamics within and among competing groups*. PNAS https://doi.org/10.1073/pnas.2216186120

Tverskoi, D., Senthilnathan, A., & Gavrilets, S. (2021). The dynamics of cooperation, power, and inequality in a group-structured society. *Scientific Reports*, *11*(1). https://doi.org/10.1038/s41598-021-97863-7

Refinements:

Allen, B., Khwaja, A. R., Donahue, J. L., Kelly, T. J., Hyacinthe, S. R., Proulx, J., Lattanzio, C., Dementieva, Y. A., & Sample, C. (2024). Nonlinear social evolution and the emergence of collective action. *PNAS Nexus*, *3*(4). https://doi.org/10.1093/pnasnexus/pgae131

Davis, D. S. (2024). Past, Present, and Future of Complex Systems Theory in Archaeology. *Journal of Archaeological Research*, *32*(4), 549–596. https://doi.org/10.1007/s10814-023-09193-z

Richardson, H. C. (2023). *Democracy Awakening: Notes on the State of America*. Viking Press.

Shao, S., & Wu, B. (2024). Value-behavior inconsistency is robust to promote cooperative behavior in structured populations. *Chaos*, *34*(12). https://doi.org/10.1063/5.0242898

Wei, H., Pu, X., Zhang, J., Zhang, C., & Cao, M. (2025). Moral Preferences Co-Evolve With Cooperation in Networked Populations. *IEEE Transactions on Evolutionary Computation*, *29*(5), 2188–2197. https://doi.org/10.1109/TEVC.2024.3486572