From Tragedy to Win-win
Transforming Social Dilemmas in Commons

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Abstract: Prisoner's Dilemma, Chicken, and Stag Hunt games provide elementary two-person models of social dilemma situations that can be at the heart of a tragedy of the commons, where individual incentives discourage cooperation that could be better for everyone. Looking at the outcomes of mutual cooperation or mutual defection helps distinguish between different social dilemmas, which pose different challenges for crafting governance solutions. Changes that switch the ranking of different outcomes can transform Prisoner's Dilemma into a Stag Hunt and then into a fully-aligned game of Concord/No Conflict; similarly, Chicken can be turned into Concord. The Robinson-Goforth topology of payoff swaps in 2x2 games maps potential transformations in social dilemmas and other 2x2 games, offering insights into pathways and mechanisms for turning tragedy into cooperation. The potential transformations in social dilemmas help understand opportunities for "changing the game," crafting governance to improve collective action in commons and turning social dilemmas into win-win cooperation.

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Introduction

At the heart of the tragedy of the commons (Hardin 1968, 1998; Ostrom 2008) is a social dilemma situation where cooperation could be better for everyone, but individual incentives may lead people to not cooperate. This potentially results in a tragedy where everyone is worse off than they might have been. Each may use a common, a shared resource, in a way that seems to serve their individual best interest, at least in the short term, but misses opportunities for cooperation that would be better for all, at least in the long term. Even if they are aware of the potential benefits of cooperation, each may prefer to add another animal to the pasture, catch more fish, cut more trees, litter, discharge effluent, or engage in activities that emit more carbon dioxide. And so, they may end up trapped in an inferior outcome such as overgrazed grasslands, depleted fisheries, degraded forests, dirty streets, polluted rivers, or an overheated atmosphere. Similarly, reluctance to contribute could prevent people from providing themselves with shared goods and services that would make everyone better off. The incentive structures in game theory models of the Prisoner's Dilemma, Chicken, and Stag Hunt provide elementary models of social dilemmas, conflicts between self-interest and collective interest in situations with a choice to cooperate or not (Dawes 1980; Taylor and Ward 1982; P. Kollock 1998; Peter Kollock 1998; Dawes and Messick 2000; P. Van Lange et al. 2013; P. A. Van Lange, Rockenbach, and Yamagishi 2014). While real life often involves many actors and many other complexities, such simplified models can still help to understand some of the key challenges and opportunities for solving social dilemmas and crafting institutions for cooperation in governing commons.

This paper begins by looking at how changes in payoffs link the three social dilemmas of Chicken, Prisoners' Dilemma, and Stag Hunt with the no-conflict game of Concord, illustrating the potential to "change the game" to get better outcomes in such elementary models of social dilemmas. The Robinson-Goforth topology of payoffs swaps in 2x2 games provides a unified map of the relationships between 2x2 games, their potential transformations, and the diversity of elementary action situations (Goforth and Robinson 2004; Robinson and Goforth 2005; Bruns 2015). The topology shows how different games are linked by payoff swaps, including asymmetric games that show more detailed potential steps in transforming social dilemmas. While free riding and tragedy of the commons are usually discussed in terms of Prisoners' Dilemma, other games including Chicken and Stag Hunt also offer useful models of challenges for collective action, and different potential pathways to solutions. The topology of 2x2 games shows the potential transformations linking the 2x2 games that may be relevant as models for climate change negotiations about governing global commons, including the changes that could transform social dilemmas such as Prisoner's Dilemma, Stag Hunt, and Chicken into Concord and other incentive structures more favorable to win-win outcomes.

Transforming Social Dilemmas

Three famous game theory models and accompanying stories illustrate key characteristics of social dilemmas. Box 1 presents stories for Prisoner's Dilemma, Stag Hunt, and Chicken, (also discussed as Hawk-Dove and Snowdrift) (Rapoport, Guyer, and Gordon 1976; Tucker 2001;

Straffin 2001; Luce and Raiffa 1957; Rousseau 2004; Skyrms 2004; Poundstone 1992; Kümmerli et al. 2007). Figure 1 shows the corresponding payoff matrices ranking the possible outcomes when two people each have a choice of two moves. It shows the payoff structures for row and column players in the three social dilemmas, with moves to defect or cooperate labelled (D or C).

A key difference for distinguishing between the three social dilemmas concerns what happens if people defect and cooperation fails:

- In Chicken mutual defection leads to the worst outcome for both.
- In Prisoner's Dilemma, mutual cooperation could get second-best, but incentives lead to mutual defection where they get second worst.
- In Stag Hunt, rather than the win-win outcome where they both get the best result, they instead may get stuck at second-worst.

In Chicken and Prisoner's Dilemma, cooperation is unstable, since each person is tempted to get a better payoff if they defect. By contrast, in Stag Hunt, win-win is a Nash equilibrium from which neither can do better. However, mistrust and playing it safe to avoid the worst outcome could lead to getting stuck at the alternative second-worst outcome. In the harmonious game of Concord, both get their best outcome, which is stable. If such an incentive structure can be established, a win-win outcome is reached even if each only considers their own benefits and ignores the payoffs and potential strategies of the other.

These games pose somewhat different challenges for promoting cooperation. For Prisoner's Dilemma, the key challenge is how to overcome the temptation to defect from cooperation. Stag Hunt poses an assurance problem, how to create trust that the other will cooperate. Chicken risks either disaster or getting stuck in an unequal outcome, unless some kind of cooperation can be stabilized. Much work on solutions has focused on repeated interactions, and on the assumption in non-cooperative game theory that there is no government or other third-party enforcement, and so no way to credibly commit to enforceable contracts.

In a repeated Prisoners' Dilemma, the expected results from a strategy of cooperation actually create a Stag Hunt payoff structure, essentially turning a static single play game of Prisoners' Dilemma into a dynamic repeated play game of Stag Hunt (Skyrms 2014). However, even for single shot games, played only once, changes in payoffs can change one game into another, providing a structural solution to "change the game" (Dawes 1980; Ostrom, Gardner, and Walker 1994). From the point of view of some game theory researchers, solutions that come from structural changes in payoffs may seem obvious, uninteresting, or trivial. However, in terms of social dilemmas in real life, changing payoffs is often central to solutions. That makes it useful to have a systematic way of understanding what kinds of solutions may be more feasible and more stable.

Furthermore, game theory research has also shown the willingness of people to pursue cooperative solutions, starting as "conditional cooperators" rather than narrowly opportunistic, willing and able to cooperate if at least some communication is possible ("cheap talk"), and ready to apply norms and make agreements, including inflicting punishment on those who are seen as acting unfairly, and rewarding cooperation (Nowak and Highfield 2011; Ostrom, Gardner, and Walker 1994; P. A. Van Lange, Rockenbach, and Yamagishi 2014). Research on commons has often found that rather than being trapped in tragedy, commoners have been able to craft rules for cooperating to sustainably govern commons (Ostrom 1990, 2008).

Box 1. Stories for Three Social Dilemmas

Chicken: Two cars driving towards each other, if one swerves away, the other wins, but if both keep going straight, crashing is the worst for both. Brinksmanship can go bad. An aggressive hawkish strategy gets the best payoff when playing against a "dove" that prefers cooperation, but two hawks do worst when playing against each other. Drivers could cooperate to clear a snowdrift blocking the road, one person trying alone would waste their effort, and without cooperation, everyone stays stuck.

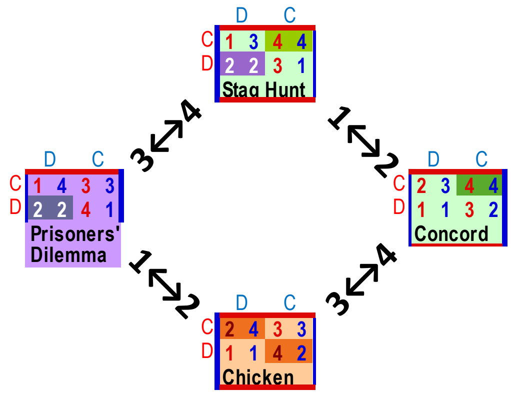
Stag Hunt: Hunters working together could share a feast, but safer to catch a rabbit and avoid the risk that others won't cooperate (Rousseau 2004). Two rowers, each with an oar, can only move the boat if both row (Hume 2003; Skyrms 2004).

Prisoner's Dilemma: Cooperation could get second-best, but temptation to get the best outcome and avoid the worst, leads to defection and getting second-worst. Two prisoners offered a lesser sentence for confessing, and a longer sentence for the one who stays silent while the other confesses and goes free. Cooperation to stay silent could get second-best for both, but the logic of the dilemma is that confession is the best option, whichever choice the other makes. A degraded commons yields poorly, but rather than restrain their usage ("stint") each would be tempted to defect from cooperation that could make things better for everyone.

Figure 1 also shows how the four games are linked by changes in payoffs that switch the ranking of different outcomes (Goforth and Robinson 2004; Robinson and Goforth 2005; Goforth and Robinson 2012).[1] Switching the top two payoffs (3⟷4) turns Prisoner's Dilemma into a Stag Hunt or Chicken into Concord. Switching the lowest two payoffs (1⟷2) turns Prisoner's Dilemma into Chicken, or Stag Hunt into Concord.

Thus, institutional changes that switch the ranking of the best and second-best outcomes, such as rules with enforceable sanctions making defection less worthwhile or cooperation more rewarding, could turn Prisoner's Dilemma into a Stag Hunt, where cooperation is a stable equilibrium outcome with everyone getting their best result. However, Stag Hunt is still a social dilemma with an assurance problem where choosing the cooperative option risks getting the worst outcome, if the other person does not also cooperate. So, distrust and a desire to avoid the worst outcome (maximizing the minimum payoff, a maximin strategy) could lead to an inferior equilibrium where everyone is worse off than they might have been. Changes that switch the ranks of the two lowest-ranked outcomes turn Stag Hunt into a harmonious game of Concord, also known as No Conflict, where all the incentives align to encourage cooperation. By contrast, Chicken is only one high swap away from Concord, and thus may be easier to solve.

Figure 1: Social dilemmas linked to Concord by payoff swaps

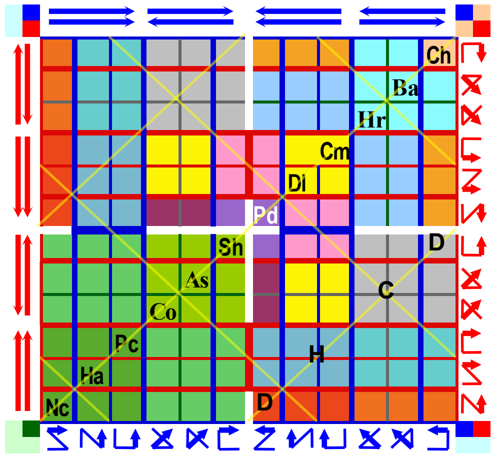


A Map for Changing Games

The previous section showed how social dilemmas are linked to the harmonious game of Concord by changes that switch the ranking of outcomes. This section discusses how such swaps in payoff ranks provide a unified way to understand the relationships between social dilemmas and other 2x2 games and their potential transformations. Most research on game theory and collective action has focused on Prisoner's Dilemma, and to a less extent on Stag Hunt and Chicken. While these are particularly interesting and challenging for organizing collective action, they are far from the only possible situations, even for two-person two-move games (Rapoport, Guyer, and Gordon 1976). The Robinson-Goforth Topology of 2x2 games provides a systematic and elegant way to understand the full range of possible games with two persons and two moves (Robinson and Goforth 2005; Bruns 2015).

In the "Periodic Table" of 2x2 games, twelve strict symmetric games, including Prisoners' Dilemma, Chicken, Stag Hunt, and Concord, form a diagonal, from lower-left to upper right, as shown in Figures 2 and 3. Payoffs from these symmetric games combine to form asymmetric games. Adjoining games are linked by swaps in payoff ranks.

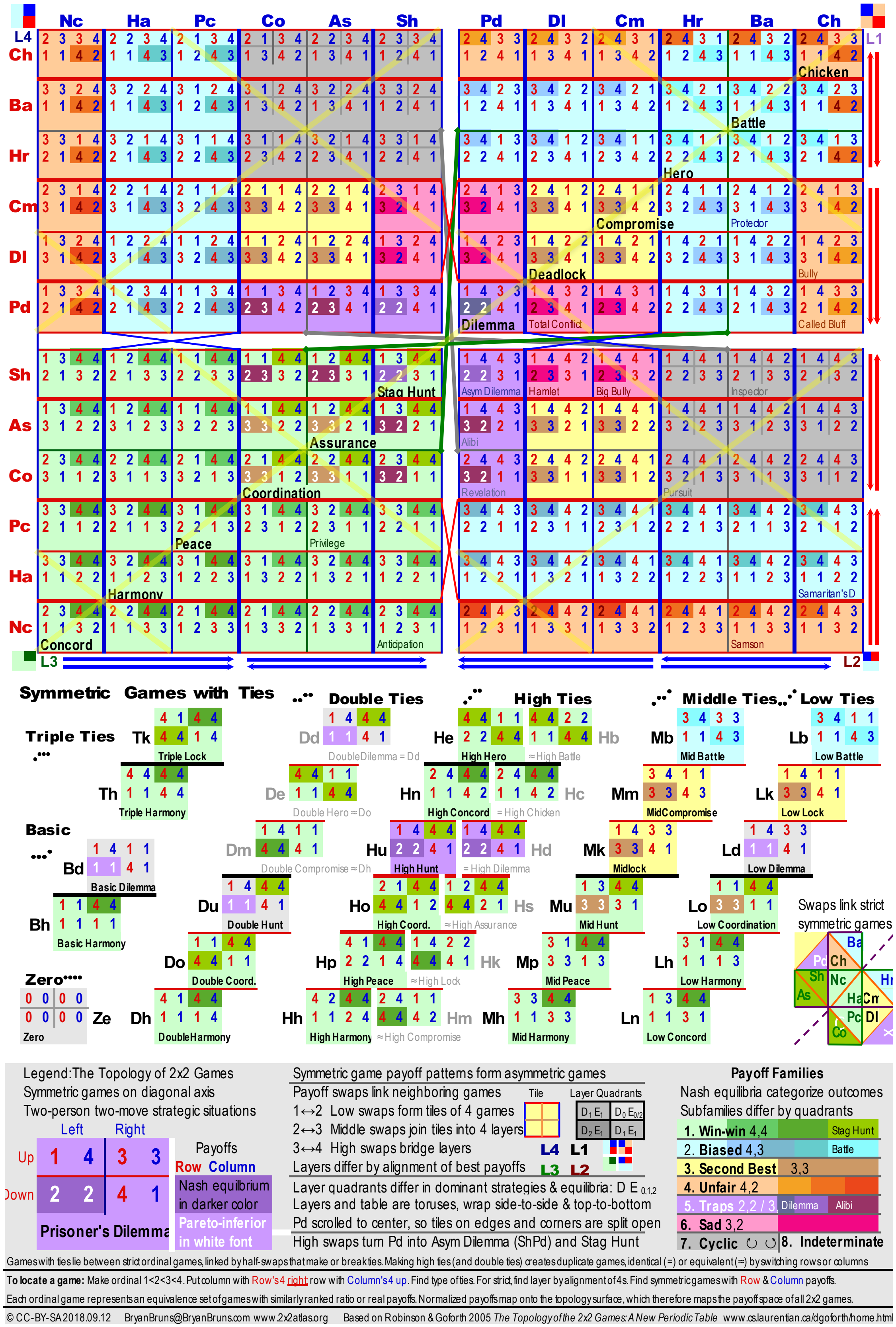
Figure 2. Schematic Visualization of the Topology of 2x2 Games with 12 Strict Symmetric Games on the Diagonal



Chicken
Battle
Hero
Compromise
Deadlock
Prisoners' Dilemma
Stag Hunt
Assurance
Coordination
Peace
Harmony
No Conflict/Concord

The topology of 2x2 games elegantly organizes the diversity of 2x2 games.[2] Between and beyond the three famous social dilemmas are an array of other games. The Appendix provides a more detailed description of how the topology of 2x2 games maps many different kinds of relationships between 2x2 games.[3] The key point for this paper is that the topology provides a map for "changing games," particularly transforming social dilemmas so incentives are realigned to lead to win-win cooperation.

Figure 3. The Topology of 2x2 Games

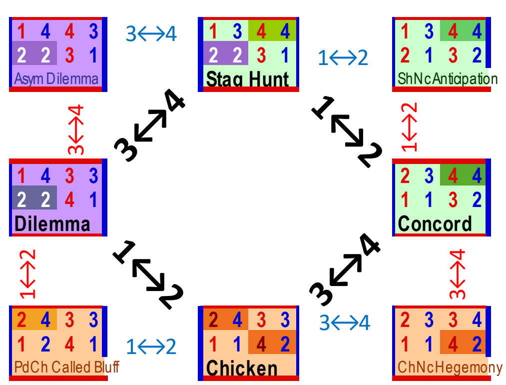


The entire table wraps around from top to bottom and from left to right, as does each of the four layers within the table. So, switching the top two payoffs in Chicken, in the upper-right corner, transforms it into Concord, in the lower-left corner. In the middle of the table, switching the top two payoffs turns Prisoner's Dilemma into a Stag Hunt. Switching the bottom two payoffs turns Stag Hunt into Concord. Chicken is closer to Concord, only one swap step for each person, while getting from Prisoner's Dilemma to Concord takes two steps for each person, first switching the top two payoffs and then the bottom two.

Figure 4 shows intermediate games where payoff ranks change only for one player.

- Switching the ranks of the lowest two outcomes in Prisoners' Dilemma or Chicken creates a game of Called Bluff (*PdCh*)[4]. One person has the payoffs of Prisoner's Dilemma and the other has the payoffs of Chicken. One person has a dominant strategy, better whatever the other does. The other then has a choice only between worst and second-worst, while the player with a dominant strategy gets their best outcome. The incentive structure thus leads to a Nash equilibrium with a very unequal outcome.
- Switching the top two payoffs in Chicken creates a game, *ChNc,* sometimes called *Hegemony* (Brams 1994) where the player with a dominant strategy gets second worst. In a sense the other player can take advantage of the dominant strategy to get the best outcome, a kind of reverse exploitation.[5] Switching the top two payoffs for the other player would create a game of Concord.
- From Stag Hunt, switching the lowest to payoffs creates a game of Anticipation (*ShNc*) where one player has a dominant strategy. If the other player realizes or learns this, then their incentives lead to the move resulting in both getting the best result.[6]

Figure 4. Transforming Social Dilemmas with intermediate games



The table, in Figures 2 and 3 provides a way to understand the full set of 2x2 games, while Figures 1 and 4 focus on the detailed connections between the three social dilemmas and Concord. The display with Prisoner's Dilemma and Stag Hunt at the center offers an ingenious way to show many important connections, including high swaps that link layers. However, having Prisoner's Dilemma and Concord at opposite corners fails to show how closely they are connected, as better shown in Figures 1 and 4.

The diagram including asymmetric games between social dilemmas offers additional models, showing intermediate states where payoffs only change for one person. In the social dilemma, both players have an interest in getting to an outcome that would be better for both. However, in these intermediate games, if one person is already getting the best outcome, then that person lacks an incentive to change the game. The intermediate outcome is not a social dilemma. Thus, there is the potential and risk of getting "stuck" in a transition. Or, one person might act deceptively or in bad faith to create an intermediate situation that would be to their advantage.

The map of 2x2 games can also be used to think about what happens if conditions change so cooperation is less rewarding or penalties weaker or less likely to be enforced. Thus, Concord could "decay" into Chicken, and Stag Hunt could decay into Prisoners' Dilemma. This is particularly relevant if people have created rules, governance institutions, that change payoffs to reward cooperation or punish defection, but then violations become harder to detect, enforcement of these rules become less effective, and so forth. So, the map can help to understand the risks and vulnerabilities of different social situations and governance institutions.

A more complete map of potential transitions may help in analyzing and understanding which transformations may be more feasible and lead to more stable results, not just in theory but in practical terms of the transactions costs of negotiating and implementing new arrangements, including characteristics such as the extent to which a new arrangement may considered understandable, credible, enforceable, and acceptable.

Free Riding

If too many people take a bus or other public transport without paying, then the service could collapse. In the two-person model, if only one contributes and the service is not provided, so they pay a cost but don't get the benefits, then cooperating when the other does not is the worst outcome, while neither contributing is second-worst, so the situation is like a Prisoner's Dilemma.

In discussing the *Logic of Collective* Action (Olson 1971), Mancur Olson's core concern was that voluntary contributions would not be sufficient to ensure provision of a public (non-excludable) good, since each person would "logically" choose not to pay, even though everyone would be better off if the good was provided. In thinking about solutions to provide a "public" good from which it would be hard to exclude non-contributors, Mancur Olson used the academic example of scholarly journals, discussing how funding for the journal could be tied to an excludable good such as insurance available only to members of a scholarly society. Game theory research has often looked at provision of public goods, where everyone (or at least a critical mass of people) have to contribute, or else it will not be provided, for which the three main social dilemmas may provide useful models.

Such situations can be described as "give-some" since there is an initial costly payment which leads to benefit later on (Cross and Guyer 1980; Dawes 1980; P. Van Lange et al. 2013). This can be used to model the provision of public goods, where once the goods are provided, they will be available for all, and non-payers cannot be excluded (or at least exclusion is difficult). This contrasts with "take-some" situations with an initial benefit, such as extracting resources (water, fish, timber, grass, etc.) from a shared resource, a commons, with the risk of later loss. Give-some situations with an initial loss and later gain through provision of a shared good can be described as "social fences," in contrast to "social traps," take-some situations, with an initial gain and later loss, such as the use of shared resources in a commons. So, you take something from a commons to use, or give something to provide a collective good.

Free riding is commonly discussed as a social dilemma and major concern for institutional design.

- Using Prisoners' Dilemma to model free riding implies that cooperation is second-best, since each would prefer to get the benefits without paying, but that mutual defection results in the second-worst outcome, an outcome they each still prefer to the outcome of paying but getting no benefits.
- If mutual defection results in the worst outcome, a bad situation which both dislike more than acting cooperative without getting benefits, then the situation may be more like Chicken. This could be a situation of brinksmanship turning into open conflict, two aggressive hawkish strategies that stumble into disaster.
- If cooperation would actually result in the best outcome, the best provision of a public service or good, then Stag Hunt may offer a better model, particularly if the key challenge seems to be developing sufficient assurance that the other person (or a critical mass of others) will contribute.

Therefore, free riding is not necessarily a Prisoners' Dilemma. Instead it may be important to see if the noncooperative outcome, mutual defection results in the second worst, or worst outcome, and whether cooperation yields the second-best or best outcome. Or, there may be an intermediate asymmetric situation that combines the payoffs from different social dilemmas, with an equilibrium that gives the advantage to one or the other.

Tragedy of the Commons

Garrett Hardin's story of a "pasture shared by all" suggests that each person would follow the logic of adding more animals (Hardin 1968). Each gains all the benefits from an additional animal, while the costs in terms of degraded pasture are spread among all those using the pasture. Earlier models of fisheries showed how such individualistic decisionmaking could prevent achieving a "maximum sustainable yield" and instead result in a collapse of the fishery (Gordon 1954; Scott 1955). Another fisheries example concerns how inappropriate regulation could encourage overinvestment in boats and equipment attempting to get as much as possible during a limited fishing season. Individually, the incentive would be to invest more, buying a bigger, faster boat, even though collectively everyone could have been better off with a smaller investment. The underlying incentive structure is that of an arms race (Schelling 1960), where each feels forced to invest more, even though ultimately no one may end up gaining an advantage, and everyone would have been better off with a lesser level of investment.

These examples of tragedy of the commons again raise the question of which model of a social dilemma may be most appropriate.

- If the pasture still yields grass and each commoner gets more milk or meat than if they limited their own livestock, then Prisoners' Dilemma would be an appropriate model. If an arms race to buy better boats still leaves fishing somewhat profitable, or better weapons still leave enough other goods ("butter") to live on, then that may be more desirable than investing less.
- However, if mutual defection would mean that the fishery would collapse to the point that there are no profits or the pasture becomes too degraded to support grazing, then Chicken may offer a better model, particularly if power or other factors allow some to gain a larger (lions') share of the benefits while other gets much less. Thus, in thinking about strategic choices, it matters whether global warming risks risks pushing past thresholds, tipping points, that could result in systemic collapse, whether the potential costs are modest or catastrophic.
- If cooperation offers the best for both, for example if access can be controlled and carefully managed grazing is much more productive, then Stag Hunt may offer a better model.

While this paper has focused on three major models of social dilemmas, there are other games that may also offer useful models. If noncooperation gets a second-best outcome, then an Assurance game would be the appropriate model rather than a Stag Hunt where non-cooperation leads to second-worse. Stag Hunt offers a more perilous situation than Assurance, and perhaps stronger motivation to change rules so that playing it safe to avoid the worst outcome is less attractive. Changes could transform Stag Hunt into Concord, where both have dominant strategies and incentives are fully aligned. By contrast, in the milder challenge of an Assurance situation, switching the lowest two payoffs instead leads to a game of Coordination, where avoiding the worst payoffs leads to the win-win outcome. So, the most feasible pathways and destinations for a solution may differ between Stag Hunt and Assurance.

Diverse Solutions

Even within the diversity of elementary games, different games can illuminate potential challenges and solutions for governance, including overcoming free riding, tragedy of the commons, and other social dilemmas. There has been a vast amount of research on individual games. The literature on social dilemmas has offered insights on common issues and differences between social dilemmas (Dawes 1980; P. Kollock 1998; P. Van Lange et al. 2013).

Distinguishing between different social dilemmas can help understand and respond in ways that can adapt to the different challenges posed by different kinds of games. The focus of this paper is on the potential transformations that link social dilemmas to win-win solutions.[7]

- A key example of the difference in challenges posed by different social dilemmas is the difference between building trust to solve assurance problems in a Stag Hunt versus changing incentives to discourage defection in a Prisoner's Dilemma.
- Trying to have rules that punish non-cooperative behavior in turn raises questions of how to detect violations and ensure that penalties are enforced.
- Building trust to assure cooperation may depend on building confidence that benefits and costs will be equitably shared.
- Repeated games allow options for taking turns enjoying the benefits, and using strategies such as tit-for-tat (Axelrod 1984) to reward cooperation and discourage defection.

Goforth and Robinson found the topology provided a unified way to understand relationships between different kinds of games. However, they found that it did not necessarily reveal any unified set of solutions, particularly if there is repeated play and payoffs are not just crudely ranked outcomes but can be measured well enough to calculate tradeoffs. Even within variations of a single ordinal game, such as Prisoner's Dilemma, the best strategy for repeated games may depend on whether taking turns "alternately cooperating and defecting" yields greater overall benefits than both "cooperating" every time, (Robinson and Goforth 2005; Goforth and Robinson 2012). Similar issues apply to the relative payoffs between cooperation and taking turns in Chicken. The benefits and risks of cooperating or playing it safe in a Stag Hunt also depend on the magnitude of the different payoffs. The topology of 2x2 games offers a useful map of the diversity of 2x2 games but does not offer a unified solution to 2x2 games, at least in terms of the boundaries between ordinal games.[8] It does offer a way to understand relationships between games, similarities and differences in the challenges they may pose, such as conflicts between individual and collective interest in social dilemmas.

Just as there are a diversity of 2x2 games, and diverse solutions that may be relevant, comparative research on commons has found there is no single solution, no "one best way" to manage a forest, fishery, irrigation system or other shared solution (Ostrom 1990).The specific rules created by users reveal instead an enormous diversity, often crafted to take advantage of particular characteristics of the resource and local conditions. What Elinor Ostrom did discover was that it was possible to identify more general "design principles" that tended to occur in long-enduring locally-governed commons (Ostrom 1990; Cox, Arnold, and Tomás 2010; Tarko 2017). Many of these principles can be linked to the key challenges for collective action illustrated by elementary games, such as building mutual understanding and trust; creating confidence that benefits and costs will be equitably shared; making and enforcing rules that discourage defection, and the need to customize rules to fit local conditions in terms of boundaries, resources, and other conditions. The principles for institutional design can help transform social dilemmas into situations that encourage successful cooperation in commons.

Transforming Climate Games

DeCanio and Fremdstad (2013) use the topology and Periodic Table of 2x2 Games to identify 25 elementary game situations relevant for climate negotiation. They look at situations where both abating pollution is preferred to both polluting, and pollution harms the other (imposes a negative externality). They find that "assessment of the magnitude of the global climate risk is the key determinant of the kind of 'game' being played. This in turn affects the feasibility of reaching an agreement, and the possible role of equity considerations in facilitating an agreement."

Transformations in such situations could result from changes in the ranking of expected outcomes (a result of new scientific findings, better understanding of existing science, or actual climate changes), side payments as part of negotiated agreements and other factors that switch payoff rankings.

While DeCanio and Fremdstad use the periodic table of 2x2 games to identify relevant games, they do not use it to show the connections between the games they identify and the potential for transforming one game into another. Visualizing the ways in which these games are linked by payoff swaps shows that these games form a closely connected region within the topology, a subset of the total of 144 games in the topology.[9]

Figure 5 shows the 25 games. The twenty-five games include five symmetric games: Chicken, Prisoner's Dilemma, Stag Hunt, Concord (No Conflict), and Harmony. As with the Periodic Table display of the Topology of 2x2 games, symmetric games form a diagonal from lower left to upper right. Ten pairs of games can be formed by combining payoffs from these symmetric games.

Sixteen of the games make up a quartet of four tiles, what Robinson and Goforth call a "pipe." Internally, each tile is linked by low swaps (1↔2) such as those that turn Prisoner's Dilemma into Chicken. The four tiles are linked by high swaps (3↔4). In the visualization, the four tiles form a torus, so the high swap links in the quartet of tiles not only link across tiles in the middle, but also wrap from top to bottom, and left to right. Middle swaps, such as those that turn Concord into Harmony, then link the sixteen tiles to eight more games (four pairs).

As discussed in the paper, key potential transformations include those that might turn a Prisoner's Dilemma into Stag Hunt and then Concord, or turn Chicken into Concord. However, if the change in payoffs only affects one side rather than being symmetric, there is the potential to get stuck in an intermediate situation, where one side does much better than the other.

- As identified by DeCanio and Fremdstad, eight of the climate relevant games are harmonious games with no inherent conflict. Both players have dominant strategies, better whatever the other does, that would lead to a win-win Nash Equilibrium.

- Three games, Prisoner's Dilemma and two asymmetric siblings that combine Prisoner's Dilemma and Stag Hunt payoffs, have dominant strategies that lead to a pareto-inferior outcome.
- In the two Called Bluff games adjoining Prisoner's Dilemma, the person with the dominant strategy gets their best outcome, while the other gets second-worst.
- One pair of games has a cyclic preference structure, where one or the other would always prefer to move to another outcome.
- In two pairs of games, the player with a dominant strategy gets their second-worst outcome.
- DeCanio and Fremdstad also identify a Samaritan Dilemma kind of situation (Buchanan 1977; Schmidtchen 2002), and an adjoining game (PdHa), in both of which one party with a dominant strategy could end up getting second best.

The situations where a dominant strategy leads to getting second-best or second-worst could represent the "exploitation of the weak by the strong" (Schelling 1960). Such an outcome is not strictly a social dilemma, in that there is no cooperative outcome that would be better for both, at least in a single-shot game where taking turns is not an option. So, the dominant strategy just affects who gets best versus second best or second-worst. Nevertheless, such an outcome may be distasteful and make the side with the dominant strategy reluctant to come to agreement unless they can find a way to do better, for example by changing the game. High swaps have the potential to transform Samaritan's Dilemma (and its neighbor) into harmonious games with aligned incentives (Bruns 2010b). This could occur through mechanisms that ensure that the side without the dominant strategy will fulfill its commitments to sharing in investment, rather than acting opportunistically to free ride. Change could also occur through compassion, other-regarding preferences, creating more willingness to provide assistance (as with the Samaritan in the original story or through a more compassionate acceptance that the other side is already investing as much as they reasonably can within the limits of their capabilities) (Stone 2008).

There are two potential high swap transformations to turn Samaritan's Dilemma and its neighbor (HaPd) into win-win games by changing the ranks of the top two outcomes. The other two games (Hegemony, NcCh, and NcPd) have less potential, with only one potential transformation leading to win-win.

As with any other use of game theory, there are limits to the suitability of simplified models, including risks of including invalid assumptions, and other limitations. Other solution concepts besides Nash Equilibria and avoiding the worst outcome (maximin) may be relevant, the structure of the game (payoffs) may evolve over time, and many other aspects may be better represented with more sophisticated models and techniques (Madani 2013). Nevertheless, the topology does show how the elementary models are potentially linked by transformations, such as could be achieved through better information, better understanding, or agreements with side payments that share benefits and costs more equitably.

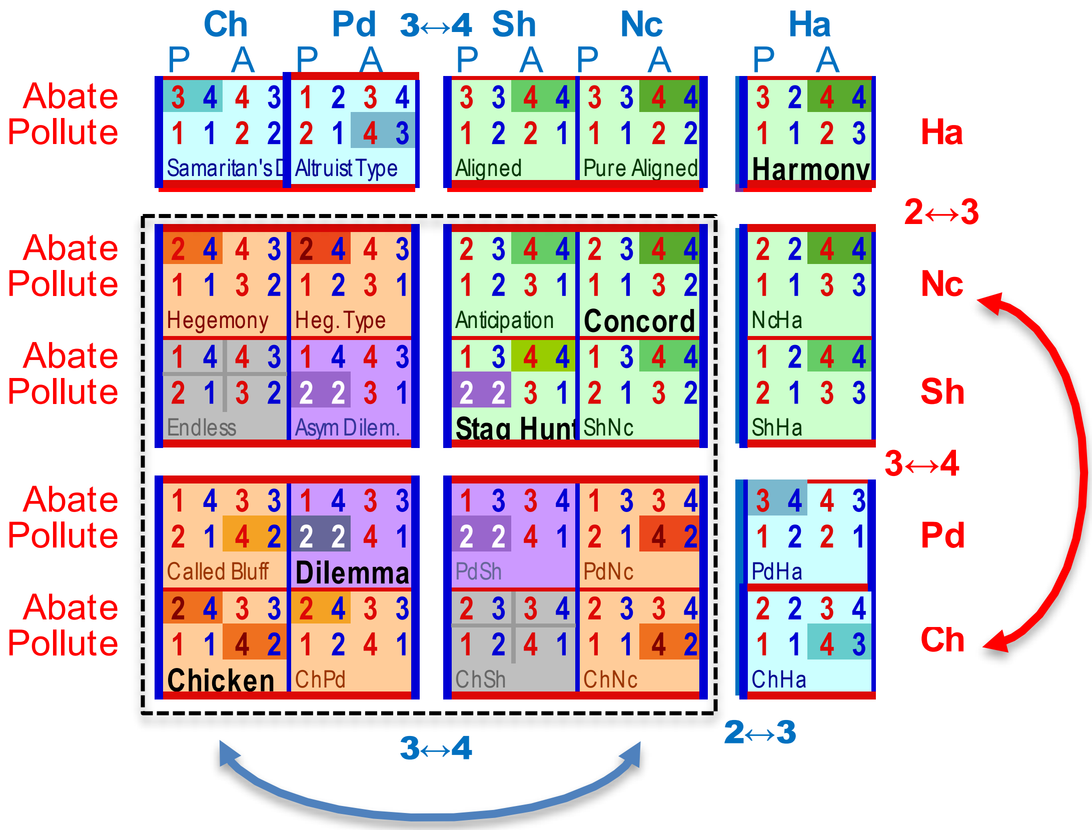


Figure 5. Twenty-five Climate Games and their Potential transformations

Conclusions

Payoff structures for the games of Prisoners' Dilemma, Stag Hunt, and Chicken offer elementary models of social dilemmas where individual interests conflict with collective interests. Changes in the ranking of the top two outcomes, best and second-best, can transform Prisoners' Dilemma into Stag Hunt. Changes that switch the ranking of the worst and second-worst outcomes change Stag Hunt into a game of Concord with fully aligned incentives. Swaps in the lowest two payoffs turn Prisoners' Dilemma into Chicken, and high swaps turn Chicken into Concord. Thus, the three social dilemmas are linked by transformations, showing potential pathways for changing discord into concord.

The Robinson-Goforth topology of payoff swaps in two-person two-move games provides a unified framework for understanding the relationships between 2x2 games. The Periodic Table of 2x2 games provides a map visualizing these relationships, including potential transformations to turn tragedy into win-win outcomes best for both. The Table also shows the asymmetric games, combining payoffs from symmetric games, which may represent intermediate steps between two situations, based on changes in the ranking of outcomes for one person. This offers models of situations that combine payoffs from different social dilemmas.

Discussion of free riding and tragedy of the commons often assume a particular kind of tragedy, as in Prisoners' Dilemma, where both have dominant strategies, a move which is better regardless of what the other does. However, for theoretical models, and for the analysis of practical situations it may be important to look more carefully at which model is more appropriate. If noncooperation leads to the worst outcome for both, Chicken may offer a better model. If cooperation would actually be best for both, then Stag Hunt may be a better model. Other situations may combine payoffs from different symmetric games. Different games pose different challenges for collective action, and so may be susceptible to different structural solutions for "changing the game," whether rewarding cooperation or punishing defection in Prisoners' Dilemma, building trust that others will cooperate in Stag Hunt and Assurance, or reducing the rewards for aggression/free riding iand increasing the benefits from cooperation in Chicken/Hawk-Dove.

The topology of 2x2 games helps provide a systematic understanding of the different types of social dilemmas that pose challenges for cooperation in governing shared resources and the potential for transformations that promote cooperation. Distinguishing between different social dilemmas can help understand which kind of solutions may be more feasible, and so more likely to be worth pursuing.

Appendix A: The Periodic Table of 2x2 Games

This appendix provides additional description of the topology of 2x2 games and its visualization in the Periodic Table of 2x2 Games. For a systematic and more formal introduction to the topology, see Robinson and Goforth *The Topology of 2x2 Games: A New Periodic Table*.

Twelve symmetric games on the diagonal. There are only twelve possible strict symmetric two-person two-move games, where each person can assign different ranks to the four possible outcomes.[10] For each game, the payoff matrix shows the preferences for the outcomes resulting from each move by each player. For simplicity, the ranks can be shown by numbers, payoffs, from one to four. Payoffs from twelve symmetric games on the diagonal combine to create payoff structures for asymmetric games.

Generating the Periodic Table. Starting from any 2x2 game, switching the two lowest-ranked payoffs creates a *tile* of four games. Swaps in the middle-ranked payoffs create new games, which also form tiles of four games linked by payoff swaps. If the two highest-ranked payoffs stay in the same position there are nine possible tiles and thirty-six possible games, which form a *layer.* Swapping the top two payoffs then starts a new layer.

Four Layers. The four layers are distinguished by the location of the top two payoffs, which is fixed within each layer. Harmonious concord reigns in Layer 3, where both can get their best outcome with the top-two payoffs in the same cell. Fundamental discord exists in Layer 1, containing Prisoner's Dilemma and Chicken, where the top payoffs are in diagonally opposite cells. In Layer 2, the top two payoffs are in the same row, while they are in the same column on Layer 4.

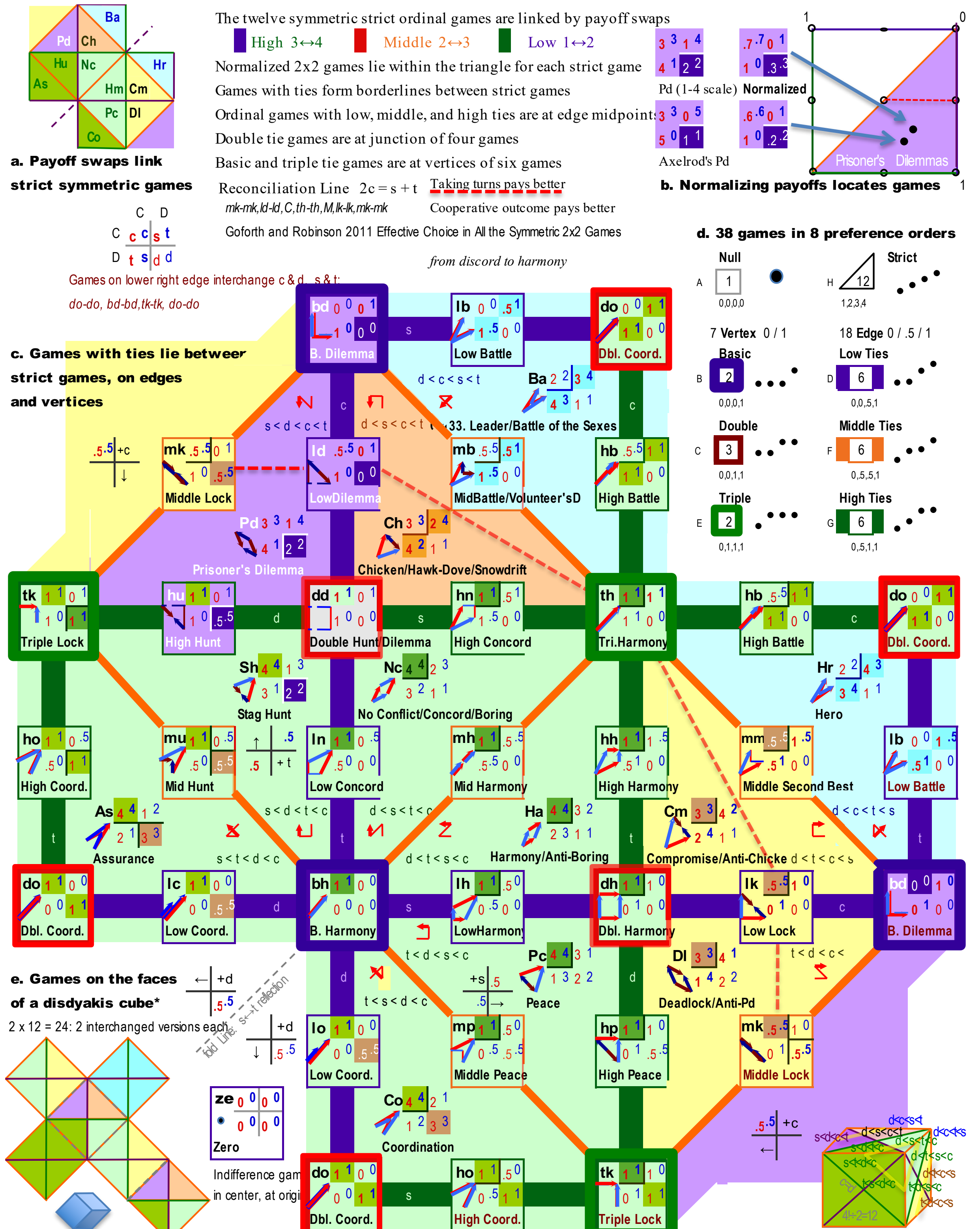
Dominant Strategies and Nash Equilibria. In the bottom half of each layer, the row player always has a dominant strategy, the best choice regardless of what the other player does. In the left half of each layer, the column player always has a dominant strategy. Thus, in the lower left quadrant, both have a dominant strategy which leads to a single outcome, a Nash Equilibrium from which neither can single-handedly improve their outcome. In the upper right quadrant, neither has a dominant strategy. On Layers 2 and 4, this creates cyclic games, where from any particular outcome, one person would always like to change their move to get a better payoff. The Stag Hunts on Layer Three have to two Nash Equilibria, one of which allows both to get their best result. Chicken and the battles on Layer 1 also have two equilibria, which offer unequal payoffs, with rivalry between outcomes where one or the other does better.

The Topology is a Torus. Each layer is like a doughnut, a torus, wrapping from top to bottom. Arranging the display so that Prisoner's Dilemma is in an inner corner provides a particularly useful way to see the connections between games on different layers.[11] Adjacent games are linked by payoff swaps, including high swaps (3↔4) across the gap between layers and between the top and bottom of the table.[12] As analyzed by Robinson and Goforth, the topology linking 2x2 games by payoff swaps is actually a torus with 37 holes. The periodic table structure with four layers provides a particularly elegant and convenient way to show many of the relationships between 2x2 games in the topology.

Payoff families. The table reveals families of games with similar equilibrium payoffs.(Bruns 2010a, 2015). In contrast to the pre-occupation of game theory research with Prisoner's Dilemma and other conflicts, one fourth of the games have win-win payoffs, shown with green shading. Prisoner's Dilemma has four asymmetric siblings and cousins, shown in lavender. There are more Stag Hunts (lime green, in the upper right quadrant of the win-win layer), nine in total. Several don't face the assurance problem, where maximizing the minimum payoff leads to an inferior equilibrium, and so the same move avoids the worst outcome and gets the win-win outcome. There are a dozen games where both get second-best at equilibrium (shaded yellow), which can help model situations where compromise is necessary, since it is impossible for both to get their best outcome. In eighteen cyclic games (shaded gray), one person would always prefer to move to a different outcome. In biased games (in various shades of blue), one gets best and the other second-best at equilibrium. In Unfair games, one gets best and the other gets second-worst, as in Chicken. Battles have two equilibria, where one player does best and the other gets second-best or second-worst.

Proportions. If payoffs occur randomly, then games will appear in the proportions in the Periodic Table of 2x2 Games (Simpson 2010; Bruns 2015). In practice, the frequency of different games is an empirical question. However, for a default distribution, the topology of games suggests that social dilemmas are relatively rare, and that situations that reward cooperation may be much more common. This supports other lines of argument that an excessive focus on "tragedy" may lead to distorted expectations about what the world may be like. Instead of pervasive tragedy, instead the world could be full of potential for successful coordination and cooperation. In most situations, both may be able to get at least get second-best, but often with asymmetric payoff structures or unequal payoffs. Situations often combine the potential for conflict and cooperation. Rather than being trapped in a particular situation, often the best solution is to "change the game," changing the rules and outcomes so that mutual understanding and incentives can lead to successful cooperation.

Appendix B: Mapping the Symmetric 2x2 Games onto a Cube



* Disdyakis Cube, aka. Tetrakis hexahedron v=14 f=24 e=36 74/2=37 games + Zero Game = 38 symmetric 2x2 games

see Goforth and Robinson 2012; Huertas-Rosero 2003, 2004; Robinson, Goforth & Cargill 2007; Fraser & Kilgour 1986; K&F 1988; Bruns 2012 Escaping Prisoner's Dilemma

The twelve strict symmetric games map onto faces of a cube (Huertas-Rosero 2003; Goforth and Robinson 2012). Each face of the cube divides into four triangles (a disdyakis cube or tetrakis hexahedron).

Payoffs can be labelled according to how they would affect decisions to cooperate or defect in Prisoner's Dilemma (c,d,s,t) including the temptation to defect, and the sucker payoff for choosing cooperation when the other defects. The possible combinations of different rankings for four payoff positions generate twenty-four games.

If games formed by switching rows or switching columns are considered equivalent, then each strict symmetric game appears twice, in northwest and northeast orientations (Row’s best outcome, 4 in the upper row, and Column’s four on the left or right). So, only half the cube is needed to show how the payoff swaps link games. This half cube can be cut open and flattened into a butterfly shape, (which in turn could be folded in half) to show the connections between the twelve symmetric games.

Normalized versions of symmetric games, such as the version of Prisoner's Dilemma studied by Axelrod (Axelrod 1984), map onto the triangle for each symmetric game (Goforth and Robinson 2012). Games with ties lie at the corners of each game's triangle, with the normalized strict game at the center. Games with pairs or triplets of ties form vertices on the cube: basic ties, double ties, and triple ties. Games with one pair of ties lie in the middle of edges connecting vertex games: low, middle, and high ties. Basic and triple ties games are linked to six edge games by payoff swaps for both players, while such swaps link double ties games to four edge games (Heilig 2012; Hopkins, Brian 2014). There eight preference orders (Fraser and Kilgour 1986; Kilgour and Fraser 1988) depending on the number of ties. Payoff swap connections, as mapped on the disdyakis cube, divide the thirty-eight symmetric games into seven vertex games, eighteen edge games, twelve strict games on faces, and the zero game at the origin.

In some games, both playing the cooperative strategy yields the best payoff in repeated play, while in other games taking turns would earn more. These are separated by what Goforth and Robinson (2012) label a Reconciliation Line.

2x2 games have eight payoffs, eight dimensions on which they can differ. For symmetric games, normalized transformations map onto a cube (Huertas-Rosero 2003; Goforth and Robinson 2012)f. Similarly, for the payoff space of symmetric and asymmetric games, normalized games map onto the surface of the expanded topology. In the chart of 2x2 games, borderlines of games with ties form boundaries between games with strict ordinal equivalents. In the middle of each square is the strict ordinal game, where the second-worst payoff is halfway between worst and second-best, as with values of 1,2,3,4.

Moving the second-lowest payoff towards the worst or second-best payoff moves within the square, reaching the borderline when the values are equal, forming a tie, and then transforms into a different game. In the same way, on the game graphs, moving the payoff, where two lines meet, shifts within games that are ordinally equivalent, until reaching the point where one game changes into its neighbor. Shifts in the best payoff towards or away from the second-best payoff similarly move along the high swap "spacewarps" that link games across layers, though these are not as visible in the table. Each game has six neighbors. The Periodic Table display shows connections with four neighbors, linked by low and middle swaps. The additional swaps ca be visualized in terms of a cube formed by all six neighbors, including changes in the distance of the second-best payoff from the best and second-worst, than link games on different layers.

If payoffs are generated randomly, then just as with ordinal payoffs (Simpson 2010), the resulting games will be distributed evenly across the surface of the expanded topology. The flat projection in the chart will again show expected proportions, (for variations in the distance of the second-worst payoff between worst and second-best). Just as all normalized symmetric 2x2 games map onto a cube, all normalized 2x2 games map onto the topology of 2x2 games.

Endnotes

[1] It was already well known that there were only 12 "strategically non-equivalent [strict] symmetric games" (Rapoport, Guyer, and Gordon 1976, 17) and that changes in payoffs could turn Prisoner's Dilemma into Chicken or a Stag Hunt. Key contributions from Robinson and Goforth were to show systematically how games were linked by payoff swaps in a network with a particular topology, and to develop ways of visualizing these topological relationships (Robinson and Goforth 2005). In terms of Prisoner's Dilemma payoffs, the possible combinations of four strictly-ranked payoffs can be compared by the relative ranking of the payoffs for mutual cooperation and defection, the "temptation" payoff for a defector, and the resulting "sucker" payoff for a non-defector (Goforth and Robinson 2012).

[2] The topology can be extended to games with ties (non-strict), and to normalized versions of games with payoffs measured on interval or cardinal scales (ratio or real values) (Robinson, Goforth, and Cargill 2007; Goforth and Robinson 2012; Bruns 2010a; Hopkins, Brian 2011, 2014; Bruns 2015).

[3] DeCanio and Fremstad (2013) use the Periodic Table of 2x2 games to identify a variety of potential models for climate change situations. They discuss "nearness" in the topology and similar games, but not payoff families and not particular pathways through the topology.

[4] Asymmetric games come in two mirror-image versions, based on the payoffs of the Row or Column player. These lie on either side of the diagonal in the table. The convention used here is to refer to games by the combination of payoffs below and to the right of the diagonal of symmetric games (Bruns 2015). Thus *PdCh*, (Called Bluff) is the mirror image of *ChPd* (in other words, games are chiral, coming in left- and right-handed versions).

[5] NcCh (Hegemony) is similar to, and only one payoff swap away from Samaritan's Dilemma (Buchanan 1977; Schmidtchen 2002; Stone 2008; Bruns 2010b) where again having a dominant strategy leads to doing worse than the other player. This is the kind of situation that can be described as "the exploitation of the great by the small" (Olson 1971; Olson and Zeckhauser 1966; Petersen-Perlman and Fischhendler 2018).

[6] Win-win games of this type, with a dominant strategy for one leading to the best for both, can provide simple models of one form of what Olson talked about in terms of "privileged groups" where one person or a small group has sufficient incentive to contribute, so that the good will end up being provided. Olson discussed situations where one person's contribution would be sufficient, so that the others might make no contribution. However, these games could model a situation where the other is motivated to contribute, once they are sure how the one with a dominant strategy will act. Note that in the context of *cooperative* game theory, where enforceable agreements are assumed to be possible, there is the possibility for negotiation and threats of uncooperative behavior unless benefits are shared in a way acceptable to both players, especially if payoffs can be measured in terms of money and side payments are possible.

[7] Social dilemmas are not the only problems for collective action. For example, in simpler games, the key issue may be to identify a focal point that everyone could agree on, including creating a "convention," such as which side of the road to drive on, that allows coordination in the face of multiple alternatives (multiple equilibria) that might be feasible (Schelling 1960; Lewis 1969).

[8] Appendix B shows how the symmetric games can be mapped onto a cube, including mapping normalized payoffs for games with payoffs measured on ratio or real scales. It includes what Goforth and Robinson call the "reconciliation line" which marks the boundary where the total benefits of taking turns at "defecting" or "cooperating" become higher than mutual cooperation.

[9] See Perlo-Freeman (2006) for a similar analysis that pays more attention to the transformations between games. Perlo-Freeman's "Cooperate-Defect" (C-D) games include the five preference orderings (payoff structures) identified here: Chicken, Prisoner's Dilemma ("Prisoner"), Stag Hunt ("Deterrer"), No Conflict/Concord ("Appeaser"), and Harmony ("Pacifist") as well as Deadlock ("Warrior"). Deadlock/Warrior, and the games formed by combining its payoffs with the other five, did not satisfy DeCanio and Fremstad's first condition, for mutual abatement being preferred to both polluting. Therefore, DeCanio and Fremstad identified 25 games as relevant for modeling climate diplomacy, rather than the 36 in Perlo-Freeman's larger set of Cooperate-Defect games.

[10] For game theory models, games where columns or rows are switched are usually considered to be equivalent. In practice the way in which payoffs are presented may well influence decisions. The version shown in the table can be considered a primary version, while other versions are formed by switching rows or columns (Bruns 2015).

[11] The table shows the connections between the three social dilemmas and Concord, with the key potential transformation between Prisoners' Dilemma and Stag Hunt at the center. However, it puts Concord and Chicken at opposite corners of the layers and table, so that visually they appear far apart. Figures 1, 4, and 5 show how closely the four games are actually linked by changes in the ranking of outcomes (payoff swaps).

[12] Horizonal or vertical *bands* of twelve games, three tiles for four games each, (shown with thicker lines in the table) are linked by high swaps to equivalently located bands on other layers, as indicated by the colored lines that cross between layers (Bruns 2015).

- The central bands on each layer crisscross diagonally. Layers 2 and 4 are linked by central bands so high swaps turn cyclic games in each band into other cyclic games. Central bands on Layers 1 and 3 are also diagonally linked, so that high swaps join the Battle and Assurance tiles.
- The "Harmony" bands below and to the left of the central bands, rows or columns of three tiles, "slide," across or up/down, to the next layer. In the table, the links between bands are indicated by the diagonal lines between layers, since these links also switch the two rows or columns in the band.

Adding visualization of links between bands provides a way to use the Periodic Table of 2x2 Games to visualize the full set of six swap neighbors for each game, three swaps for each player: 1↔2, 2↔3, and 3↔4, and so to "see" and analyze the potential transformations for changing all the 2x2 games.

References

Axelrod, Robert. 1984. *The Evolution of Cooperation*. New York: Basic Books.

Brams, S. J. 1994. *Theory of Moves*. Cambridge Univ Pr.

Bruns, Bryan. 2010a. "Navigating the Topology of 2x2 Games: An Introductory Note on Payoff Families, Normalization, and Natural Order." *Arxiv Preprint ArXiv:1010.4727*.

———. 2010b. "Transmuting Samaritan's Dilemmas in Irrigation Aid: An Application of the Topology of 2x2 Games." In *Capturing the Complexity of the Commons: International Association for the Study of Commons 2010 North American Regional Meeting*. Tempe AZ.

———. 2015. "Names for Games: Locating 2 × 2 Games." *Games* 6 (4): 495–520. https://doi.org/10.3390/g6040495.

Buchanan, James. 1977. "The Samaritan's Dilemma." In *Freedom in Constitutional Contract: Perspectives of a Political Economist*, edited by James Buchanan, 169–85. College Station: Texas A&M University Press.

Cox, Michael, Gwen Arnold, and Sergio Villamayor Tomás. 2010. "A Review of Design Principles for Community-Based Natural Resource Management." *Ecology & Society* 15 (4).

Cross, John G., and Melvin J. Guyer. 1980. *Social Traps*. University of Michigan Press.

Dawes, Robyn M. 1980. "Social Dilemmas." *Annual Review of Psychology* 31 (1): 169–193.

Dawes, Robyn M., and David M. Messick. 2000. "Social Dilemmas." *International Journal of Psychology* 35 (2): 111–116.

DeCanio, Stephen J., and Anders Fremstad. 2013. "Game Theory and Climate Diplomacy." *Ecological Economics* 85: 177–187.

Fraser, N. M, and D. M Kilgour. 1986. "Non-Strict Ordinal 2x2 Games: A Comprehensive Computer-Assisted Analysis of the 726 Possibilities." *Theory and Decision* 20 (2): 99–121.

Goforth, David, and David Robinson. 2004. "The Ecology of the Space of 2x2 Social Dilemmas."

———. 2012. "Effective Choice in All the Symmetric 2x2 Games." *Synthese*, 1–27.

Gordon, H. Scott. 1954. "The Economic Theory of a Common-Property Resource: The Fishery." In *Classic Papers in Natural Resource Economics*, 178–203. Springer.

Hardin, Garrett. 1968. "The Tragedy of the Commons." *Science*, no. 162: 1243–48.

———. 1998. "Extensions of 'the Tragedy of the Commons.'" *Science* 280: 682–83.

Heilig, Sarah. 2012. "When Prisoners Enter Battle: Natural Connections in 2 X 2 Symmetric Games." Honor's Thesis, Saint Peter's College. http://librarydb.spc.edu:8080/jspui/handle/123456789/14.

Hopkins, Brian. 2011. "Between Neighboring Strict Ordinal Games." In .

———. 2014. "Expanding the Robinson-Goforth System for 2x2 Games." In *The Mathematics of Decisions, Elections, and Games*, edited by Crisman, Karl-Dieter and Jones, Michael A, 177–87. Providence, RI: American Mathematical Society.

Huertas-Rosero, Álvaro Francisco. 2003. "A Cartography for 2x2 Symmetric Games." *ArXiv Preprint Cs/0312005*. http://arxiv.org/abs/cs/0312005.

Hume, David. 2003. *A Treatise of Human Nature*. https://www.gutenberg.org/ebooks/4705.

Kilgour, D. M, and N. M Fraser. 1988. "A Taxonomy of All Ordinal 2x2 Games." *Theory and Decision* 24 (2): 99–117.

Kollock, P. 1998. "Social Dilemmas: The Anatomy of Cooperation." *Annual Review of Sociology* 24 (1): 183–214.

Kollock, Peter. 1998. “Transforming Social Dilemmas: Group Identity and Cooperation.” *Modeling Rational and Moral Agents*, 186–210.

Kümmerli, Rolf, Caroline Colliard, Nicolas Fiechter, Blaise Petitpierre, Flavien Russier, and Laurent Keller. 2007. “Human Cooperation in Social Dilemmas: Comparing the Snowdrift Game with the Prisoner’s Dilemma.” *Proceedings of the Royal Society B: Biological Sciences* 274 (1628): 2965–2970.

Lewis, David. 1969. *Convention: A Philosophical Study*. http://philpapers.org/rec/LEWCAP.

Luce, Robert Duncan, and Howard Raiffa. 1957. *Games and Decisions: Introduction and Critical Survey*. Courier Dover Publications.

Madani, Kaveh. 2013. “Modeling International Climate Change Negotiations More Responsibly: Can Highly Simplified Game Theory Models Provide Reliable Policy Insights?” *Ecological Economics* 90: 68–76.

Nowak, Martin, and Roger Highfield. 2011. *SuperCooperators: Altruism, Evolution, and Why We Need Each Other to Succeed*. Free Press.

Olson, Mancur. 1971. *The Logic of Collective Action: Public Goods and the Theory of Groups*. Cambridge, MA: Harvard University Press.

Olson, Mancur, and Richard Zeckhauser. 1966. “An Economic Theory of Alliances.” *The Review of Economics and Statistics*, 266–279.

Ostrom, Elinor. 1990. *Governing the Commons: The Evolution of Institutions for Collective Action*. Cambridge: Cambridge University Press.

———. 2008. “Tragedy of the Commons.” *The New Palgrave Dictionary of Economics* 2.

Ostrom, Elinor, Roy Gardner, and James Walker. 1994. *Rules, Games and Common-Pool Resources*. Ann Arbor: University of Michigan Press.

Perlo-Freeman, S. 2006. “The Topology of Conflict and Co-Operation.” *U of the West of England, Dept of Economics, Discussion Paper* 609.

Petersen-Perlman, Jacob D., and Itay Fischhendler. 2018. “The Weakness of the Strong: Re-Examining Power in Transboundary Water Dynamics.” *International Environmental Agreements: Politics, Law and Economics* 18 (2): 275–294.

Poundstone, W. 1992. *Prisoner’s Dilemma: John von Neumann, Game Theory and the Puzzle of the Bomb*. Doubleday.

Rapoport, A., M. Guyer, and D. G Gordon. 1976. *The 2 x 2 Game*. Univ of Michigan Press.

Robinson, David, and David Goforth. 2005. *The Topology of the 2x2 Games: A New Periodic Table*. London: Routledge.

Robinson, David, David Goforth, and Matt Cargill. 2007. “Toward a Topological Treatment of the Non-Strictly Ordered 2x2 Games.” *Working Paper*.

Rousseau, Jean-Jacques. 2004. *A Discourse upon the Origin and the Foundation of the Inequality among Mankind*. http://www.gutenberg.org/ebooks/11136.

Schelling, T. 1960. “I960. The Strategy of Conflict.” *Cambridge, MA*.

Schmidtchen, D. 2002. “To Help or Not to Help: The Samaritan’s Dilemma Revisited.” In *Method and Morals in Constitutional Economics: Essays in Honor of James M. Buchanan*, 470.

Scott, Anthony. 1955. “The Fishery: The Objectives of Sole Ownership.” *Journal of Political Economy* 63 (2): 116–124.

Simpson, J. 2010. “Simulating Strategic Rationality.” Ph.D. Dissertation, Edmonton: University of Alberta.

Skyrms, Brian. 2004. *The Stag Hunt and the Evolution of Social Structure*. Cambridge Univ Pr.

———. 2014. *Social Dynamics*. Oxford University Press.

Stone, D. 2008. *The Samaritan's Dilemma: Should Government Help Your Neighbor?* Nation Books.

Straffin, Phillip. 2001. "The Prisoner's Dilemma." *Readings in Games and Information* 3: 5.

Tarko, Vlad. 2017. *Elinor Ostrom: An Intellectual Biography*. Oxford University Press.

Taylor, M., and H. Ward. 1982. "Chickens, Whales, and Lumpy Goods: Alternative Models of Public Goods Provision." *Political Studies* 30 (3): 350–370.

Tucker, A. 2001. "A Two-Person Dilemma." In *Readings in Games and Information*, edited by Rasmussen, E, 7–8.

Van Lange, Paul AM, Bettina Rockenbach, and Toshio Yamagishi. 2014. *Reward and Punishment in Social Dilemmas*. Oxford University Press.

Van Lange, Paul, Daniel P. Balliet, Craig D. Parks, and Mark Van Vugt. 2013. *Social Dilemmas: Understanding Human Cooperation*. Oxford University Press.