Normative conflict and history dependence in repeated coordination games

Julian Romero*[1] and Huanren Zhang†[2]

[1]Eller College of Management, University of Arizona

[2]Department of Business and Economics, University of Southern Denmark

October 8, 2018

Abstract

We study equilibrium selection in indefinitely repeated coordination games with and without payoff asymmetries. In the symmetric games, repeated interactions make it possible to achieve outcomes that are both efficient and egalitarian. In the asymmetric games, however, equality is at odds with efficiency, giving rise to a *normative conflict*. We design an experiment where subjects play a series of repeated coordination games where the degree of payoff asymmetry is gradually changing, which allows us to investigate how experience in one game influences behavior in later games. The experimental results show that normative conflict makes it difficult to achieve coordination. Overall, players successfully achieve coordination in less than half of the cases in the presence of normative conflict: a majority of them coordinate on the equal payoff outcome or strike a compromise between equality and efficiency; very few coordinate on the efficient outcome. History is shown to play an important role in equilibrium selection. We find evidence that the use of a normative principle can spillover across different games, even if the strategies implementing this principle change.

Keywords: Coordination; Normative conflict; Turn taking; History dependence; Laboratory experiment.

JEL Classification: C72, C73, C92.

*Email: jnromero@email.arizona.edu

†Email: huanrenzhang@gmail.com

1 Introduction

Repeated interactions can drastically change the incentives of economic agents. In the indefinitely repeated prisoner's dilemma, for example, the long-run benefits of cooperation enable credible punishments and rewards that can overcome the short-run temptations for opportunistic behavior (Friedman, 1971; Fudenberg and Maskin, 1986; Aumann and Shapley, 1994; Dal Bo and Frechette, 2018). In many situations that require coordinated actions, repeated interactions can also increase efficiency by reconciling opposing interests. Consider a team of two members who must choose a project to work on that can benefit both of them. The project requires the effort of both to succeed, while the players have different preferences over which project to undertake. Their contrasting preferences may easily lead to disagreement and coordination failure.[1] The above situation can be modeled as the battle of the sexes game. Figure 1 shows one version of the game with integer parameter $\theta > 0$. In terms of the above example, T (Tough) represents insisting on one's preferred project, and S (Soft) represents choosing the project preferred by the other. Two pure strategy Nash equilibria exist: (T,S) and (S,T).[2] The row player clearly prefers (T,S), while the column player prefers (S,T). Because of the opposing preferences, a miscoordination rate as high as 60% has been observed in the one-shot games (Cooper et al., 1994; Straub, 1995).

Repeated interactions allow the players to reconcile opposing interests intertemporally in the battle of the sexes. Theoretical analysis has shown that players can achieve the efficient and egalitarian outcome using the turn taking strategy (Bhaskar, 2000; Lau and Mui, 2008, 2012; Kuzmics et al., 2014). In the laboratory, the turn taking strategy has been consistently observed to resolve conflict and increase efficiency (Cason et al., 2013; Ioannou and Romero, 2014a; Kuzmics et al., 2014). Kuzmics et al. (2014), for example, find turn taking is used in more than 80% of their repeated battle of the sexes games.

These studies, however, have only investigated symmetric games where efficiency and equality can be perfectly aligned. This is rather a special case. In many instances with payoff asymmetries, efficiency and equality are in stark conflict.[3] Moreover, disagreements may arise

[1] Similar conflicting interests exist whenever role assignment is needed in a team or organization, for example, the appointment of leaders in a team, allocation of territories for a sales team, and assignment of duties on an assembly line. In daily life, we also experience similar situations, such as assigning unpleasant chores in a household or on a camping trip, choosing positions in a pickup soccer game, and deciding whose car to drive when carpooling.

[2] There is also a mixed-strategy Nash equilibrium where the row player plays T with probability $\frac{11}{12}$ receiving a payoff $-\frac{10\theta+1}{10\theta+2}$, while the column player plays T with probability $\frac{10\theta+1}{10\theta+2}$ receiving a payoff $-\frac{1}{12}$. We find no evidence that subjects play this mixed-strategy equilibrium from the experimental data.

[3] Efficiency here is defined as the sum of payoffs, not in the sense of Pareto efficiency (Charness and Rabin,

as to what it is that must be equalized: some people may understand equality as Equal Payoff that leads to the egalitarian outcome, while others may interpret it as Equal Opportunity where players are granted the same opportunity to choose their preferred outcome (Konow, 2003, pp. 1194-1196). Consider the game shown in Figure 1 with $\theta = 2$. Efficiency concerns would require players to choose the outcome that gives rise to the highest total payoff, so the players would always play (T,S). Equal Payoff would give rise to the egalitarian strategy—playing (T,S) once, and (S,T) twice—so that players receive the same payoff. Equal Opportunity would prescribe alternation between the two equilibria (T,S) and (S,T). Therefore, at least three normative principles–Efficiency, Equal Payoff, Equal Opportunity–exist in the asymmetric games.[4] These normatively appealing rules prescribe different behaviors and strategies, giving rise to a *normative conflict* (Nikiforakis et al., 2012; Gangadharan et al., 2017).

In comparison to the other settings, normative conflict is a more serious issue in coordination games: it is not enough for a player to recognize and use a specific normative principle in order for that principle to be implemented; she also needs to have faith that other people recognize the same principle, and at the same time are willing to coordinate with her using that principle. What complicates things more is the strategies that implement these principles have different levels of complexity[5]: the strategy required to achieve the Equal Payoff outcome is more complex, making it less likely to emerge.

Based on the current literature, it is unclear how individuals would deal with the tension between different normative principles in repeated coordination games. Yet this is an important empirical question as the tension between efficiency and equality arises naturally in situations where individuals derive different benefits from a collective action. We aim to address this question in this paper: using a lab experiment, we study equilibrium selection in the presence of normative conflict in repeated battle of the sexes games.

History is one factor that can affect equilibrium selection. Evidence suggests that players often use experience and precedents to form expectations of how others will behave (Van Huyck et al., 1997; Romero, 2015).[6] In the presence of normative conflict, previous experience is

2002; Engelmann and Strobel, 2004).

[4]Throughout this paper, we use capitalized terms–Efficiency, Equal Payoff, Equal Opportunity –to represent the normative principles, as well as the corresponding outcomes that are consistent with these principles.

[5]See the appendix for a detailed discussion of strategy complexity.

[6]Van Huyck et al. (1997) provide a classical example of path dependence in the "continental divide" game. The history dependence observed in our study, however, differs greatly from the continental divide in their study. In their experiment, the payoff structure is held constant and behaviors in later plays are endogenously determined by players' initial beliefs and actions. In our experiment, the payoff structure changes from supergame to supergame, and expectations and behaviors in later supergames are influenced by the payoff structure of the

		Column player	
		T	S
Row player	T	-1 , -1	10θ , 0
	S	0 , 10	-1 , -1

Figure 1: Battle of the sexes where actions are labeled as "Tough" (T) and "Soft" (S). The parameter $\theta \geq 1$ is a measures of the degree of payoff asymmetry.

especially important in shaping people's expectations on the normative principles to use. Our experiment allows us to investigate history dependence across games with different levels of payoff asymmetry. In one treatment (I), players start with the symmetric game, followed by games with increasing payoff asymmetry. In the other treatment (D), players start with an asymmetric game and payoff asymmetry is gradually decreasing across games. In games with high payoff asymmetries, both Efficiency and Equal Opportunity give rise to substantial payoff inequality. If individuals care for payoff equality as shown in numerous studies (Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000; Dawes et al., 2007; Cooper and Kagel, 2013), or simply believe others do, the principle of Equal Payoff is more likely to be implemented in these games. In contrast, all normative principles point to the same strategy and outcome in the symmetric games, so none of these principles are more prominent than others. Successful coordination using the simple turn taking strategy in the symmetric games is consistent with both Equal Payoff or Equal Opportunity, so when payoff asymmetry is imposed, neither principle is more normatively attractive than the other. However, it requires a more complex strategy to implement Equal Payoff. As simplicity is the natural focal criterion for selecting a strategy (Kuzmics et al., 2014), Equal Opportunity is more likely to be selected. We therefore hypothesize that Equal Payoff outcomes are more likely to emerge in the treatment D than in the treatment I, while Equal Opportunity outcomes are more likely to occur in the treatment I .

As the first to explore how normative conflict and history may affect equilibrium selection in the asymmetric battle of the sexes, our study shows that the presence of normative conflict significantly increases the likelihood of miscoordination. Overall, players successfully achieve coordination in less than half of the cases: a majority of them achieve the Equal Payoff outcome or strike a compromise between equality and efficiency, while very few coordinate on the Efficient outcome. Many players have coordinated or tried to coordinate on the Equal Payoff outcome,

first, which is determined exogenously.

even though doing so requires using complex strategies. History and previous experience have been shown to be important in shaping expectations and guiding behaviors: subjects with previous experience of successful coordination on the equality principle are more likely to converge to the same behavioral patterns. Compared to the treatment I, players in the treatment D are more likely to achieve the Equal Payoff outcomes and less likely to achieve the Equal Opportunity outcomes.

2 Related literature

We have abundant experimental evidence that people care about both equality and efficiency (Andreoni and Miller, 2002; Charness and Rabin, 2002; Konow, 2003; Cooper and Kagel, 2013). Individuals tend to take actions to achieve more even distribution of income (Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000; Dawes et al., 2007), and many of them sacrifice their payoffs in order to increase efficiency (Andreoni and Miller, 2002; Charness and Rabin, 2002; Engelmann and Strobel, 2004). In particular, Andreoni and Miller (2002) find that 30% of the subjects in their study demonstrate egalitarian preferences, while more than 20% of the subjects in the same study aim to maximize efficiency even if doing so lowers their own payoffs. These studies show that both equality and efficiency are normatively appealing rules in decision making.

Conflict between different normative principles has been studied in bargaining games (Roth and Murnighan, 1982; Kagel et al., 1996) and social dilemmas (Nikiforakis et al., 2012; Gangadharan et al., 2017). Kagel et al. (1996) study an ultimatum game where players bargain over 100 chips that are worth different values to the two players ($0.10 vs. $0.30), giving rise to a normative conflict (cf. Roth and Murnighan, 1982). Their data demonstrate that players use one of the two norms (equal chip vs. equal money) and they select the norm in a self-serving manner. Nikiforakis et al. (2012) and Gangadharan et al. (2017) study public goods games where some players receive higher returns. The heterogeneous returns generate a tension between efficiency and equality. Nikiforakis et al. (2012) observe that retaliatory punishments are much more likely to arise in the presence of normative conflict. Gangadharan et al. (2017) find that most groups either prioritize equality over efficiency or strike a compromise between the two. The literature, however, has largely overlooked the tension between equality and efficiency in repeated coordination games.

Repeated game strategies can be represented as finite automata, and a commonly used measure of strategy complexity in the literature is the number of states in its automaton representation (Neyman, 1985; Rubinstein, 1986; Kalai and Stanford, 1988; Aumann and Shapley, 1994). Using this measure of complexity, Kuzmics et al. (2014) provides theoretical and empirical evidence that simplicity is a natural criterion for strategy choice. Because players must use complex strategies to achieve the Equal Payoff outcome in the asymmetric battle of the sexes, the principle of simplicity makes it less likely for the Equal Payoff outcome to emerge. It remains unclear from the literature whether players would be able to coordinate on the Equal Payoff outcome. The literature has largely focused on relatively simple strategies (Fudenberg et al., 2012; Dal Bo and Frechette, 2018; Romero and Rosokha, 2018). Dal Bo and Frechette (2018), for example, find that most behaviors in the infinitely repeated prisoner's dilemma can be accounted for by three simple strategies: AllD, TFT, and Grim. These strategies have a complexity of 1 or 2 according to the state-number measure. In the asymmetric battle of the sexes, the strategy complexity for achieving the Equal Payoff outcome is $\theta + 1$, which is much more complex than these three strategies when for a big θ.[7]

Lab experiments have shown that social preferences can influence behaviors in one-shot social dilemmas (Peysakhovich et al., 2014) and one-shot coordination games (Bland and Nikiforakis, 2015). In the repeated games, however, strategic consideration can mask the effect of social preferences. For example, no direct effect of social preferences has been found in the repeated prisoner's dilemma (Dreber et al., 2014; Davis et al., 2014). It is unclear whether egalitarian preferences are sufficiently strong to be revealed in the asymmetric battle of the sexes. On the one hand, the strategy complexity required to achieve the Equal Payoff outcome makes it unlikely for it to occur. On the other hand, it is possible that, as in the repeated prisoner's dilemma, strategic considerations dominate the effect of social preferences. In our experiment, we explore whether egalitarian preferences demonstrated in dictator games can predict behaviors in the asymmetric coordination games.

Previous studies have shown that people with higher cognitive abilities exhibit behavior that is closer to the Nash equilibrium and receive higher earnings in the beauty contest games (Burnham et al., 2009; Gill and Prowse, 2016). In the settings of the repeated prisoner's dilemma, pairs of players with high IQs, which are measured by the scores of Raven's progressive matrices test (Raven, 2000), are better able to recognize the gains from cooperation and achieve a win-win outcome (Proto et al., 2014; Al-Ubaydli et al., 2016). If results from other settings can

[7]Refer to the Appendix for a detailed discussion of strategy complexity.

be carried over to the repeated battle of the sexes, we should find players with high IQs more likely to achieve coordination. Cognitive abilities are especially relevant in our setting as players need to understand and predict the strategies of the opponent in order to achieve coordination, which requires high IQs. We have a measure of IQs based on the score of Raven's progressive matrices test in order to investigate whether cognitive abilities predict the likelihood of successful coordination in repeated coordination games.

3 The experiment

3.1 Experimental treatments

The games studied in the experiment are captured by the payoff matrix shown in Figure 1 with the key parameter θ. The value of θ changes gradually in our two treatments. In each treatment, players in a group of 6 are divided into 3 pairs in each of the 5 supergames. In the treatment I, the value of θ increases from 1 to 5 across the supergames, while in the treatment D, its value decreases from 5 to 1. This design enables us to study history dependence in a changing environment. This gradual change maintains the similarity across games, making it likely for expectations and behaviors in one game to influence later games.

The summary of the treatments is shown in Table 1. A total of 144 subjects participated in 10 experimental sessions, with 12 or 24 subjects participating in each session. Subjects in each session were randomly divided into groups of 6 subjects, and each subject only interacted with his group members. To minimize the reputation effect, we used perfect stranger matching across different supergames, so no two players would play with each other more than once in the experiment. Subjects were informed that there were 5 supergames in total, but they only see the payoff matrix at the start of each supergame.

In each supergame, the interaction was indefinitely repeated with a continuation probability $\delta = 0.99$. The length for each match was pre-drawn before the experiment in order to hold the effect of match length constant across treatments.[8] In the asymmetric games, the roles of the players were randomly determined at the start of each supergame.[9]

[8]For the first 6 groups in each treatment, the pre-drawn lengths for the 5 supergames were 86, 122, 80, 67, and 142 respectively. For the second 6 groups, they were 142, 67, 80, 122, and 86; in other words, the order of the match lengths was reversed. This was done in order to make sure that the treatment effect is not caused by the particularity of the match length. This reversal of match length also makes the two treatments comparable in terms of both match length and θ.

[9]We also elicited beliefs in an incentive compatible way. Whenever a subject correctly predicted the action of her opponent, she received a raffle ticket. At the end of the experiment, one raffle ticket was randomly selected in each group and its owner received a $5 bonus.

Table 1: Summary of treatments

Treatment	Value of θ	Number of groups	Number of subjects
I	1,2,3,4,5	12	72
D	5,4,3,2,1	12	72

The computerized experimental program was developed by the authors using a Python server and JavaScript clients. Figure 2 shows the interface of the program. To avoid the influence of the game presentation, the two actions were neutrally labeled as "U" and "D", while the actions for the opponents were labeled as "L" and "R". The meanings of the labels were also randomized so that each label represented either T or S with equal probability, which means the stage Nash equilibrium could be in any of the four quadrants of the payoff matrix. In each period, subjects chose their actions and indicated their beliefs by clicking the corresponding labels, and proceeded to the next period by clicking on the cell in the payoff matrix corresponding to their action and the other player's action. After each period, the computer provided a summary showing both players' choices and payoffs in that period, as well as the total payoffs in the current match. Subjects had access to the full history of the current supergame at the bottom of the screen. The computerized program greatly facilitated decision making in the coordination games. Each pair of subjects could proceed at their own pace, and most pairs quickly converged to a repetitive pattern. Although there were about 500 periods of interactions in total, it only took a bit more than 20 minutes to finish all 5 supergames.

Earnings in the experiment were denominated by an experimental currency called Francs with the exchange rate at 20 Francs = \$1. In order to minimize the income effect, the payment from the repeated coordination games was determined by randomly picking 30 consecutive rounds, which may span two supergames.[10] The subjects did not know their realized payoff until the very end of the session.

The experiment was conducted at the Economic Science Laboratory at the University of Arizona. Volunteers were recruited from a subject pool of undergraduate students. Upon entering the lab, the subjects were randomly assigned to a computer and given a copy of the instructions (which can be found in the supplementary material). After all of the subjects had been seated, recorded video and audio instructions were played on a projector at the front of the lab and also displayed on each computer terminal. Subjects were asked to complete a twelve-question quiz

[10]We chose 30 periods because it is short enough so that the income effect does not play an important role, and it is long enough so that it does not favor short behavior patterns over longer ones.

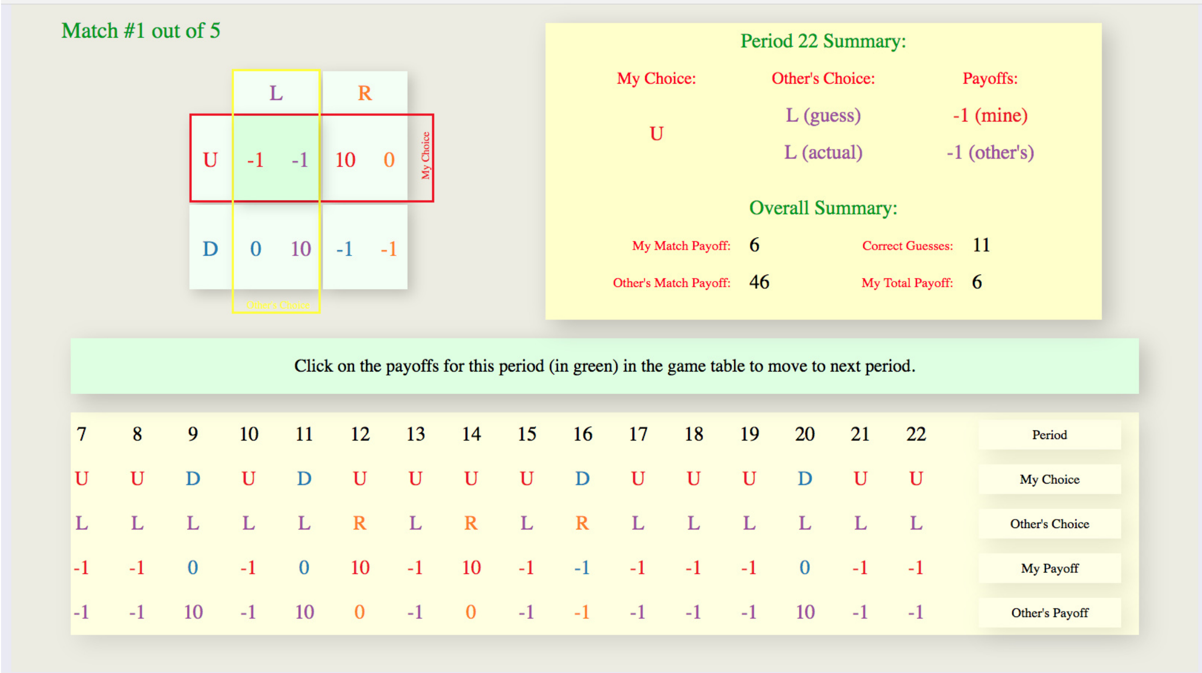


Figure 2: The experimental interface.

Table 2: Allocation tasks

Game	Distribution A (self,other)	Distribution B (self,other)
Prosociality	(40,40)	(40,20)
Costly prosociality	(40,40)	(64,16)
Envy	(40,40)	(40,72)
Costly envy	(40,40)	(44,76)

to make sure that they understood the format of the game and the interface. After the second incorrect attempt, the subjects were given an explanation to help them answer the question. The experiment did not start until all of the subjects had correctly answered all of the quiz questions.

After playing the repeated games, subjects were asked to make a decision for each of the four allocation tasks used by Bartling et al. (2009) to elicit social preferences. As listed in Table 2, the allocation tasks were binary dictator games with one distribution always giving the same payoff to the two players. The numbers shown in the table were the Francs the players can earn. The tasks were presented in a randomized order, and only one was randomly selected for the actual payment at the end of the experiment. In the analysis, subjects choosing the equal distribution in the prosociality and costly prosociality games are classified as aheadness averse, while those who chose equal distribution in the envy and the costly envy games are classified as behindness aversion.

In order to have a measure of cognitive ability, we asked the subjects to finish 6 Raven's progressive matrices questions (Raven, 2000) at the end of the experiment before collecting the demographic information. Subjects received \$0.5 for each correct answer. A typical experimental session lasted around 70 minutes including the time of going through the instructions and finishing the quiz questions. On average, subjects received a payment of \$20, including a \$5 show-up fee.

3.2 Hypotheses

Figure 3 shows graphically all the feasible payoffs of the repeated battle of sexes with and without payoff asymmetries. In the battle of the sexes, all feasible payoffs are individually rational. According to the folk theorems (Friedman, 1971; Fudenberg and Maskin, 1986; Aumann and Shapley, 1994), all these payoffs can be achieved as equilibrium outcomes. The dotted line represents the outcomes achieved by playing (T,S) and (S,T) the same number of times, while the dashed line in the graph represents the outcomes where both players receive the same payoff. All the points on the frontier of the individually rational payoffs—that is, all points on the line connecting $(0, 10)$ and $(10\theta, 0)$—are Pareto efficient.

To visualize the tension between different normative principles, the outcomes that are consistent with the three normative principles are indicated on the graph. In the symmetric game with $\theta = 1$, the outcome $(5, 5)$ is consistent with all three principles. With payoff asymmetries, the three principles—Equal Payoff, Equal Opportunity, and Efficiency—point to different outcomes: $(\frac{10\theta}{\theta+1}, \frac{10\theta}{\theta+1})$ is the Equal Payoff outcome, $(5\theta, 5)$ is the Equal Opportunity outcome, while $(10\theta, 0)$ is the Efficient outcome.

Table 3 lists the total payoffs, payoff inequalities, and strategy complexities for outcomes that are consistent with the three normative principles in asymmetric games. As we move from "Equal Payoff" to "Equal Opportunity" and "Efficiency", both the total payoff and the payoff inequality increase, while the strategy complexity required to achieve the corresponding outcome decreases. Moreover, the payoff inequality in "Equal Opportunity" and "Efficiency" increases with θ, so does the strategy complexity required to achieve the "Equal Payoff" outcome. Therefore, the tension between these normative principles intensifies as θ increases.

Both efficiency concerns and strategy simplicity make Efficiency attractive, while people dislike inequality would be attracted to the Equal Payoff outcome. The principle of Equal

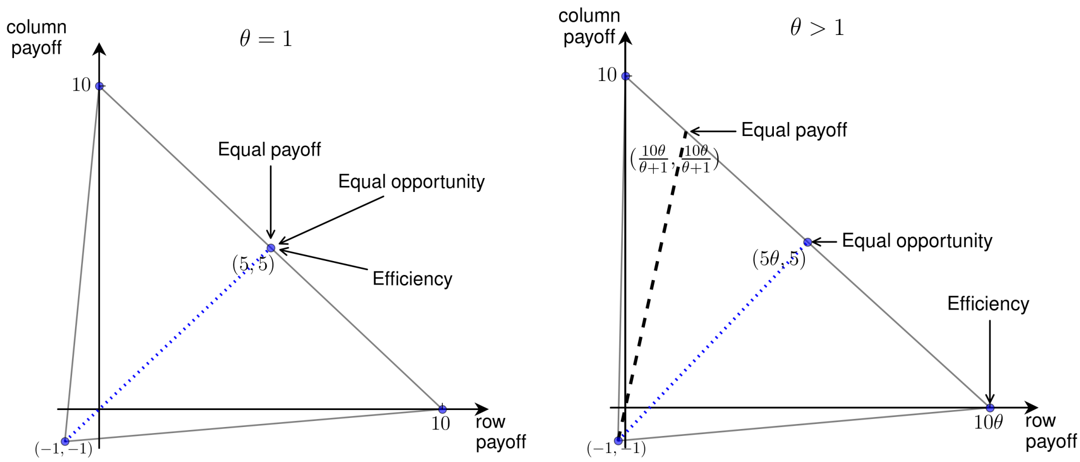


Figure 3: Illustration of payoff outcomes that are consistent with different normative principles.

Table 3: Comparison total payoff, payoff inequality, and strategy complexity for different normative principles($\theta > 1$).

	Equal Payoff	Equal Opportunity	Efficiency
Total payoff	$\frac{20\theta}{\theta+1}$	$5(\theta + 1)$	10θ
Payoff inequality	0	$5(\theta - 1)$	10θ
Strategy complexity	$\theta + 1$	2	1

Note: Strategy complexity is defined as the number of states needed to implement the strategy as a finite automaton. Refer to the appendix for a detailed discussion of strategy complexity.

Opportunity serves as a compromise between equality and efficiency/simplicity. This principle has been observed in other settings with normative conflict, such as the equal-contribution norm in heterogeneous social dilemmas (Nikiforakis et al., 2012; Gangadharan et al., 2017) and the equal-chip norm in asymmetric bargaining games (Roth and Murnighan, 1982; Kagel et al., 1996).

In the presence of the normative conflict, it is unclear whether players in the asymmetric coordination games can reconcile their expectations and coordinate their actions using one of the normative principles. Our first hypothesis focuses on the influence of normative conflict on coordination. To explore the effect of normative conflict, we compare the behaviors in the first supergames of the two treatments, where the effect of previous experience and learning is absent. We use the treatment label and the θ value to identify a supergame: D5, for example, represents the supergame with $\theta = 5$ in the treatment D, which is the first supergame in the treatment. The substantial payoff asymmetry in D5 generates a tension between different normative principles, which is absent in I1. We therefore expect the miscoordination rate is significantly higher in D5 than I1.

Hypothesis 1: *Disagreements on the normative principles and miscoordination are significantly more frequent in D5 than in I1.*

Previous research has shown that behavioral spillovers exist across games that are played sequentially (Knez and Camerer, 2000; Brandts and Cooper, 2006; Cason et al., 2012; Buser and Dreber, 2015). In coordination games, a gradual change in group size (Weber, 2006) or cost structure (Romero, 2015) can influence which equilibrium is selected. These studies focus on the spillover of "actions" in games with the same action space. In many games like the repeated battle of the sexes, however, learning behavior cannot be analyzed in terms of actions alone (Erev and Roth, 1998, p. 872). Our second hypothesis investigates whether behavioral spillovers exist at the level of repeated game strategies.

Hypothesis 2: *Players with previous experience of successful coordination using a normative principle are more likely to coordinate using the same principle.*

As previous experience can shape one's normative expectations, playing different games at first may lead to different expectations. Theoretical analysis based on inequality aversion shows that with a high degree of payoff asymmetry, inequality aversion makes the Equal Payoff outcome more attractive compared to the Equal Opportunity outcome or the Efficient outcome.[11] Therefore, starting from a game with a high degree of payoff asymmetry, people are more likely to use the principle of Equal Payoff and form their expectations correspondingly. In contrast, players in the symmetric games are likely to coordinate by alternation between the two stage-game equilibria. This alternation is consistent with both Equal Payoff and Equal Opportunity, so both principles are normative attractive when changing from the symmetric to an asymmetric environment. However, because achieving Equal Payoff requires an increase in the strategy complexity, and simplicity has been shown to be an important criterion for selecting a strategy (Kuzmics et al., 2014), we therefore hypothesize that players in the treatment I are more likely to achieve the Equal Opportunity outcomes in later games.

Hypothesis 3: *Equal Payoff outcomes are more common in the treatment D, while Equal Opportunity outcomes are more common in the treatment I.*

[11] See Appendix A for the analysis.

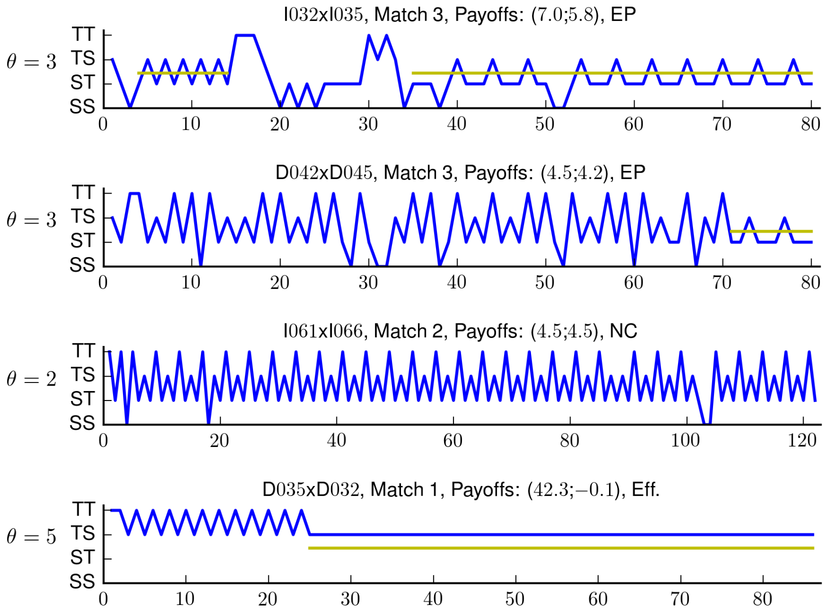


Figure 4: Examples of matches reflecting normative conflict. The IDs of the two players, the match number, the average payoffs of the two players, as well as the behavioral patterns they converge to, are shown at the top of each panel. The yellow line represents "coordinated spans" where players coordinate on one of the stage Nash equilibria.

4 Results

We start this section by providing evidence of normative conflict in the asymmetric games and demonstrating how the presence of potential normative conflict influence coordination. In order to measure the relative importance of different normative principles in coordinating actions, we categorize all the matches based on the principles they are consistent with. This categorization provides the basis for exploring history dependence.

In this paper, each subject is identified by a treatment letter I or D, followed by three digits: the first two digits ranging from 01 to 12 indicates the group while the last ranging from 1 to 6 specifies the subject in this group. Subject D016, for example, represents the sixth subject in group D01, which is the first group in the Treatment D.

4.1 Evidence of normative conflict

The experimental results show that, in more than 50% of the matches with payoff asymmetries, players fail to agree upon the normative principle to be used for achieving coordination. For those cases where coordination is achieved, most players struggle before they agree upon a principle. In some cases, we observe clear evidence of normative conflict: players switch between different principles within a match, or they insist on different principles and never achieve full coordination. Figure 4 provides some examples.

Each panel in this figure represents a match. The row player is always shown as the first player in these matches. At the top of each panel, it shows the IDs of the two players, the match number, the average payoffs of the two players, and the behavioral patterns they converge to. The y-axis represents the four possible outcomes; TS, for example, represents that the first player of the pair plays T and the other player plays S. The value of θ for each match is indicated to the left of the y-axis. In the plots, the yellow line represents "coordinated spans" where players coordinate on one of the stage Nash equilibria.[12]

The match between I032 and I035 is an example where players first coordinate using one normative principle, then the coordination breaks down before they switch to another principle. The two players first converge to Equal Opportunity within 3 rounds, but the column player I035 appears to be unsatisfied with the payoff inequality and tries to break the pattern. As a consequence, the established coordination breaks down. They both play T for several rounds then subject I032 realizes it hurts both to continue playing T, so she shows her willingness to coordinate by playing S and letting the other player get a higher payoff. After some rounds of interaction, they eventually coordinate on the Equal Payoff principle.

In the match between D042 and D045, the player D042 at the first 60 rounds or so keeps playing alternation between T and S, trying to signal to player D045 his intent to coordinate using the Equal Opportunity principle. However, D045 does not appear to accept this equilibrium—she is constantly signaling to D042 her intent to achieve Equal Payoff. After some miscoordination and some compromise, they eventually converge to the Equal Payoff equilibrium.

The match between I061 and I066 provides an example of unresolved conflict. Similar to the previous two matches, the player I061 constantly signals his preference for Equal Opportunity by alternating between T and S. The other player I066, however, insists on the Equal Payoff equilibrium. Both seem to expect the other to eventually conform to their principles, but neither does. In the end, they do receive the same payoff, but the frequent miscoordination has caused a loss of efficiency. If they were able to agree upon one of these two principles, both of them would have received a higher payoff: had they converged the Equal Payoff principle, they could both increase their payoffs by about 50 percent (6.7 vs. 4.5); had they used the Equal Opportunity principle, the row player would increase his payoff by more than 100 percent (10 vs. 4.5), while

[12] If we observe coordination consecutively for more than 10 rounds, then we consider those rounds as a coordinated span.

the column play could increase hers by 11 percent (5 vs. 4.5).

The players' descriptions of their strategies in the post-experiment survey clearly show the divergence of their normative expectations, one leaning towards Equal Payoff while the other choosing Equal Opportunity.

> I066: *"Try to make everyone earn equal money"*
>
> I061: *"... Regardless of the ratio of the positive payouts, I was willing to go back and forth with the payouts, so that they would earn whatever the computer had deemed as their positive earning for that match every other period. Even if they earned more than I did, I thought this the best way to maximize profits overall."*

More examples of similar conflict between Equal Opportunity and Equal Payoff can be found in the Online Supplementary Material where all match plays are listed (e.g., D012 vs. D014, D023 vs. D021, I041 vs. I044). These examples indicate the existence of self-serving bias in the asymmetric coordination games: while the row players are more likely to use and signal the Equal Opportunity principle, the column players prefer the Equal Payoff outcome.

There are some matches that also shows the tension between Equal Opportunity and Efficiency. The match between D035 and D032 is one example: the column player D032 tries to implement the Equal Opportunity outcome, but the other player D035 is stubborn and plays T all the time.

4.2 Characterization of behavioral patterns

In repeated coordination games, coordination using a repeated-game strategy gives rise to a periodic behavioral pattern. We can therefore identify key aspects of the strategies used in each match based on the corresponding behavioral patterns. When a periodic pattern appears and lasts till the end of a match, we say the match has "converged". In this subsection, we categorize the match plays based on the behavioral pattern each match converges to. The categorization gives us a clear measure of the importance of each principle in coordinating behaviors in the repeated battle of the sexes. It also provides the foundation for the analysis of behavioral spillovers and history dependence.

Based on the corresponding normative principles, we define the following behavioral patterns:

1. **Equal Payoff**: (T,S) once followed by (S,T) θ times
2. **Equal Opportunity**: alternate between (T,S) and (S,T)

3. **Efficiency**: always play (T,S)
4. **Inefficiency**: always play (S,T)
5. **Attrition**: always play (T,T)
6. **No Convergence**

Although we are mainly interested in Equal Payoff, Equal Opportunity, and Efficiency, we also define two other behavioral patterns: Inefficiency and Attrition. "Inefficiency", which only occurs in asymmetric games, is the Pareto efficient outcome with the minimal total payoff.[13] "Attrition" refers to the case where both players play T, leading to the outcome $(-1, -1)$. If a match does not fall into any of the 5 patterns, we categorize it as No Convergence. Both of the two variants of the equality principle—Equal Opportunity and Equal Payoff—require using turn taking, so these two patterns together are referred to as Turn Taking. When $\theta = 1$, we cannot distinguish between Equal Opportunity and Equal Payoff, and we categorize the Turn Taking pattern as Equal Opportunity in the analysis. In contrast to the first four categories, Attrition is not Pareto efficient. In this sense, Attrition can be considered as a special case of No Convergence.

4.2.1 Criteria for convergence

To determine whether a play converges, we fit all the five patterns to the match play. The fitting should allow for behavioral mistakes. For Efficiency, Inefficiency, and Attrition, there is a predefined "correct" action, so the identification of these patterns can easily accommodate mistakes. It is tricky for the other two patterns, especially Equal Payoff, as there are multiple "states" in the cycle of the behavioral patterns: the fitting of the play needs to consider which state to start and which state to come back to after a mistake occurs. Allowing the fitting to start with any of these states and continue with any of these states after a mistake occurs, we use a brute-force search to find the pattern with the best fit for the match (Mathevet and Romero, 2014).

The outcome sequence is fitted backward, allowing for $d = 3$ possible discrepancies. If the pattern with the best fit matches more than 20 rounds of the interaction, we identify that interaction as converged to that behavioral pattern; otherwise we mark that play as No Convergence. The categorization is shown to be robust to the choice d: the best fitting pattern does not

[13] Note that Inefficiency is still Pareto efficient. We use the term to indicate the fact that it is the least efficient outcome among all the Pareto efficient outcomes.

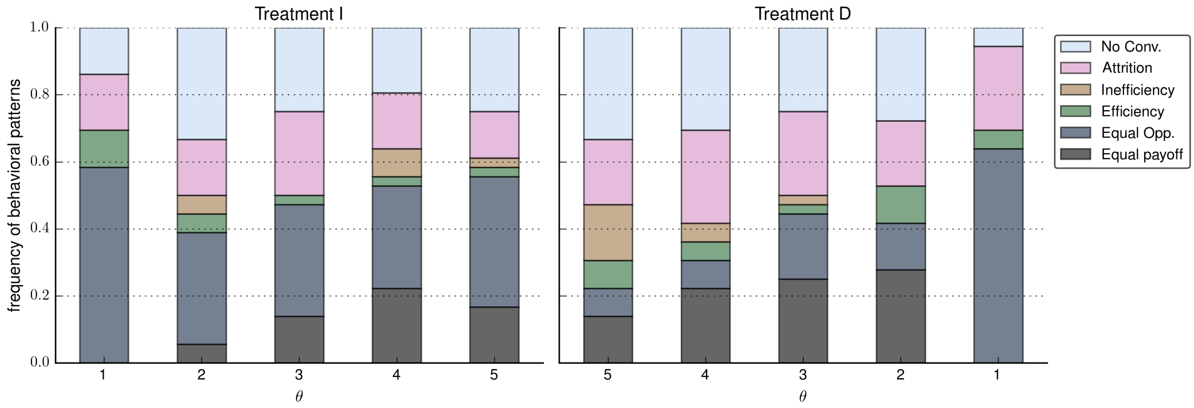


Figure 5: Frequencies of different behavioral patterns for different matches.

change with the value of d, and further increasing the value of d does not increase the number of convergence.

To check the robustness of the categorization, we compare the results with another categorization method that is based on coordination. In this alternative method, which is detailed in the supplementary material, we first determine whether a match has converged based on whether players have achieved successive periods of coordination, then use the share of different actions to identify the principle players have used to achieve coordination. These two methods provide similar results: only 6% of all the 360 matches are characterized differently. The following analysis is all based on the first method, although the results presented are robust to characterization algorithms.

4.2.2 Frequency of behavioral patterns

Figure 5 demonstrates the frequency of different behavioral patterns for each value of θ. Note that for $\theta = 1$ Equal Opportunity and Equal Payoff are indistinguishable—those two categories are pooled as Equal Opportunity.

Result 1: Overall, less than 50% of all the matches with payoff asymmetries resolve the normative conflict and converge to a pattern that is consistent with one of the normative principles. Most of these matches converge to either Equal Payoff or Equal Opportunity, while only a few converge to Efficiency.

Support: Table 4 shows the frequencies of convergence to different normative principles. Pooling all matches with payoff asymmetries in the two treatments, 18% have converged to Equal Payoff, 23% to Equal Opportunity, and 5% to Efficiency. There are also another 5% that have converged to Inefficiency. To control for the effect of match length across different matches, we

Table 4: Frequencies of convergence to different normative principles for matches with $\theta > 1$.

	Any Principle	Equal Payoff	Equal Opportunity	Efficiency	Inefficiency	Other
Treatment I	0.51	0.14	0.34	0.03	0.04	0.44
Treatment D	0.41	0.22	0.12	0.06	0.06	0.53
Overall	0.46	0.18	0.23	0.05	0.05	0.49

can look at only the first 67 periods (the minimal match length) of each match. The distribution of outcomes are quite similar: 17% Equal Payoff, 24% Equal Opportunity, 5% Efficiency, and 3% Inefficiency.

Pooling two treatments together, the most frequent outcome is Equal Opportunity, which serves as a compromise between equality and efficiency. This result is consistent with the findings in Gangadharan et al. (2017) where most groups prioritize equality over efficiency or strike a compromise between these two principles. However, we do find that Equal Payoff outcomes occurs more frequently in treatment D than in the treatment I, which is consistent with Hypothesis 3. We will postpone the analysis of this treatment effect till the discussion of history dependence.

Relatively few matches have converged to the Efficient outcome. Moreover, almost the same number of matches have converged to Inefficiency, and in some matches (e.g., I4 and D5), the frequency of Inefficiency is significantly higher than that of Efficiency. This is in stark contradiction to Efficiency. A close look at the players who end up converging to Efficiency reveals that these players' behaviors are not consistent with the principle of Efficiency in other matches they play. To be specific, all the column players who end up converging to Efficiency have experience of converging to Inefficiency or Attrition in other matches when they are the row players (see Figure 7), which cannot be the case if they have strong preferences for Efficiency.

In post-experiment survey, none of the subjects mention maximizing the total payoff as their goal, though many of them talk about maximizing their own payoff. All of these indicate that concerns for efficiency is weak compared to the preferences for equality. In contrast, players often mention "alternate", "back and forth", "even payoff", "equal chances" in the descriptions of their strategies, showing that both Equal Opportunity and Equal Payoff are important normative principles.

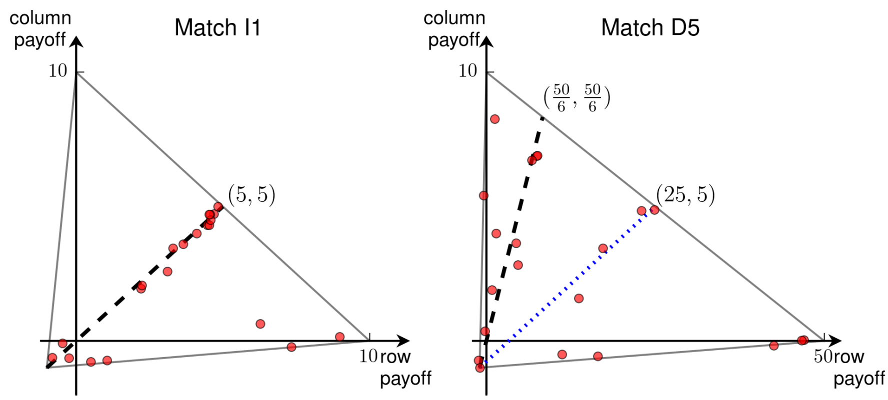


Figure 6: Scatter plots of payoff outcomes for the first match of each treatment.

4.3 Normative conflict and coordination

To clearly measure the effect of normative conflict, we compare the behavior and coordination rate between I1 and D5, which are the first supergames that are not influenced by previous experience. Figure 6 gives the scatter plots of payoff outcomes for the last 30 period of these two matches. We see that in I1, a majority of matches are along the Equal Payoff line, and many matches are near the efficient outcome $(5, 5)$. In comparison, outcomes in D5 are more scattered.

Result 2: Comparing D5 with I1, players are less to achieve coordination using a normative principle.

Support: Table 5 provides the statistics for I1 and D5. Because players in the first supergames do not have previous interactions with other group members, each match can be considered as an independent observation in the statistical analysis. A Mann-Whitney test shows that the overall coordination rate in D5 is marginally lower compared to I1 (0.64 vs. 0.57; $p = 0.096$, $m = n = 36$). Players in I1 are significantly more likely to achieve coordination using one of the three normative principles (0.58 vs. 0.25, $p < 0.01$, $m = n = 36$), and more likely to achieve coordination using the principle of Equality (Equal Payoff or Equal Opportunity) (0.67 vs. 0.33, $p < 0.01$, $m = n = 36$).

4.4 History dependence and equilibrium selection

The frequencies of behavioral patterns shown in Figure 5 mask the difference between individuals and groups. Figure 7 shows the individual behavioral patterns in each match. The top panel shows the patterns of the treatment I, and the bottom panel for the treatment D. Each column

Table 5: Comparison between I1 and D5.

Match	Overall Coordination	Convergence to Equality	Convergence to Any Principle
I1	0.64 (0.05)	0.58 (0.08)	0.67 (0.08)
	$\vee$*	$\vee$***	$\vee$***
D5	0.57 (0.05)	0.25 (0.07)	0.33 (0.08)

Note: Standard errors are shown in parentheses. Statistical significance is based on the Mann-Whitney test.

represents the evolution of behavioral patterns of one subject. Groups are separated by vertical lines.

This graph demonstrates an obvious heterogeneity across groups. Previous experience appears to have a significant influence on the behavioral patterns in later matches: subjects with Equal Opportunity or Equal Payoff experience are more likely to converge to the same pattern in later matches. However, it also matters which opponent one is matched with. For example, D041 always converges to the Equal Payoff pattern from match 1 to match 4. In match 5, however, she meets D043 who almost never plays S throughout the whole session. They eventually end up with Attrition.

Result 3: Prior experiences of Equal Opportunity or Equal Payoff pattern significantly increase the likelihood of convergence to the same pattern.

Support: Table 6 shows the random effects estimates of the likelihood of convergence to the Equal Opportunity and Equal Payoff outcomes. These models demonstrate how history and precedents influence coordination using the corresponding normative principle. In these regressions, each match is one observation, and the dependent variable takes 1 if a match converges to the corresponding principle in the first 67 periods. Only the first 67 periods (the minimum of all match lengths) are used to hold constant the effect of match length, although the results are essentially the same if we include all periods. Because none of the pairs in the first match have previous experiences, data in the first match is not included in the analysis, although including these observations (assuming no previous experiences exist for these observations) does not change the main results.

In the symmetric games we cannot distinguish Equal Opportunity from Equal Payoff. To prevent this complication in the symmetric games, only matches with $\theta \neq 1$ are included for the analysis of Equal Payoff. In order to investigate the effect of social preferences and cognitive abilities, the regressions also include the variables related to inequality aversion and IQs. Players

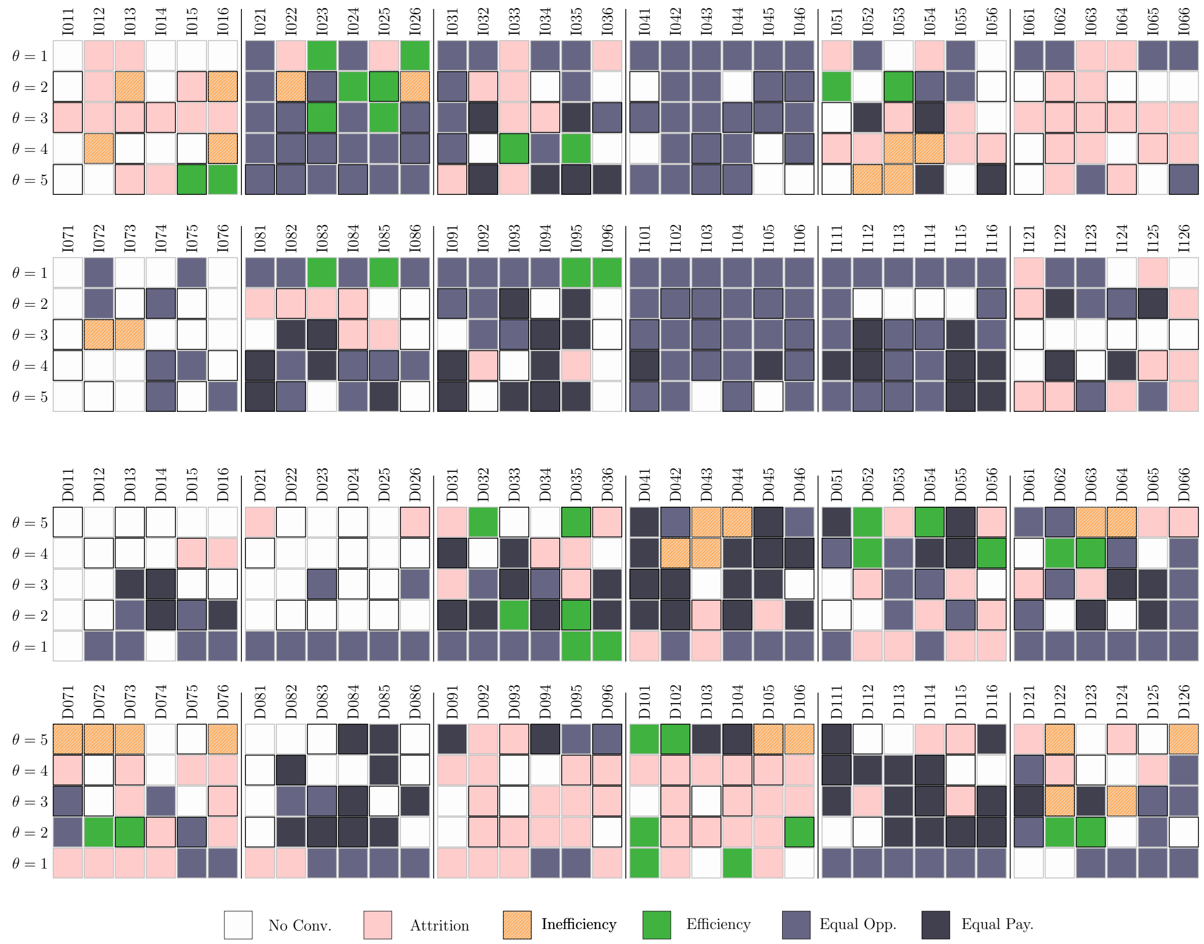


Figure 7: Individual behavioral patterns for all matches, separated by groups. The top panel shows the matches in the treatment I, and the bottom panel lists the matches in the treatment D. Boxes with darker borders represent the column players in the asymmetric games.

with scores higher than the median score in Raven's test are characterized as high IQ.

As the two variants of the principle of equality—Equal Payoff and Equal Opportunity—both involve turn taking that uses the principle of reciprocity, we pool Equal Payoff and Equal Opportunity behavioral patterns together and analyze them as Equality in the third columns. Equality shows the willingness of both players to discover and coordinate on a normative principle based on reciprocity.

The most significant effect in all these three models is previous experience, indicating a strong effect of behavioral spillovers. When one of the two players has previous experience of achieving an Equal Opportunity outcome, the likelihood for the pair to converge to the Equal Payoff pattern increases by 15 percentage points; if both players have previous experience, the likelihood increases by 48 percentage points. Similarly, when one of the two players has previous experience of achieving an Equal Payoff outcome, the likelihood for the pair to converge to the

Table 6: Regression analysis of convergence to behavioral patterns.

VARIABLES	(1) Equal Opportunity	(2) Equal Payoff	(3) Equality
Match	0.05**	0.00	0.03
	(0.02)	(0.01)	(0.02)
θ	-0.05**	-0.00	0.01
	(0.02)	(0.01)	(0.02)
One player with experience	0.15**	0.19***	0.18**
converging to the pattern	(0.06)	(0.06)	(0.08)
Both players with experience	0.48***	0.86***	0.58***
converging to the pattern	(0.08)	(0.05)	(0.09)
One aheadness-averse player	0.02	0.06	0.04
	(0.05)	(0.05)	(0.07)
Both aheadness-averse players	0.31***	-0.01	0.21
	(0.09)	(0.07)	(0.13)
One behindness-averse player	-0.03	-0.02	-0.04
	(0.05)	(0.04)	(0.05)
Both behindness-averse players	-0.06	-0.08	-0.16**
	(0.08)	(0.07)	(0.08)
One player with high IQ	-0.02	0.04	0.01
	(0.06)	(0.04)	(0.06)
Both players with high IQ	-0.05	0.07	0.06
	(0.09)	(0.09)	(0.10)
TD (treatment dummy)	0.04	-0.02	0.03
	(0.06)	(0.05)	(0.09)
Constant	0.05	0.06	0.00
	(0.13)	(0.07)	(0.12)
Observations	288	252	288
R-squared	0.258	0.287	0.310
Number of group	24	24	24

Note: Dependent variable=1 if the pair converges to the corresponding patterns. Models are estimated with group random effects.
Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Equal Payoff pattern increases by 19 percentage points; if both players have previous experience, the likelihood increases by 86 percentage points. We find similar results in Model (3) when we pooled these two behavioral patterns as Equality. The effect of previous experience is consistent with the results of the study by Cason et al. (2013) in the repeated assignment games.

We also find some evidence that inequality aversion influences convergence to these behavioral patterns. In general, pairs with both aheadness averse players are more likely to converge to these patterns, while pairs with both behindness averse players are less likely.[14] Whether the effect of inequality aversion is significant depends on the sepecificaiton of the model. Surprisingly, IQs do not influence convergence to Equal Opportunity or Equality in general, but pairs with high IQ players are less likely to achieve the Equal Payoff outcome.

The above analysis show that strategies and normative principles can spillover across games with different payoff structures. It is especially interesting to observe the spillover of Equal Payoff. Note that the strategy implementing Equal Payoff changes across games. We therefore find evidence that a normative principle is likely to persist after its emergence in a changing environment, even if the strategy implementing that principle changes.

One may argue that the significant effect of the previous experience is mainly the result of matching—players with certain characteristics are more likely to engage in turn taking. It is true that part of the effect may be caused by matching. If the effect is entirely caused by matching, however, the frequency of convergence to turn taking should be more or less constant over time. We find a significant increase in its frequency in the treatment D, indicating matching cannot be the only driving force.

We now investigate how the first supergame players play influences the strategies used for later games.

Result 4: Compared to the treatment I, players in the treatment D are more likely to coordinate on the Equal Payoff outcomes and less likely to coordinate on the Equal Opportunity outcomes.

Support: The most clean test of this treatment effect is to compare the third supergame in the two treatments where players in the two treatments face the same level of asymmetry and have experienced the same amount of learning. The statistical test is based on a clustered per-

[14]The results are similar if we distinguish whether it is the column player or the row player who is aheadness/behindness aversion as the explanatory variables. Random effects logit models give similar results. Here we present the results of linear regression for the ease of interpretation and for the easy comparison of the previous regression model on Equal Payoff patterns. For all these models, the Hausman test fails to reject the null hypothesis that the random effects estimator is consistent.

Table 7: Comparison between I3 and D3.

Match	Convergence to Equal Opportunity	Convergence to Equal Payoff	Payoff Inequality	Coordination Rate
I3	0.33 (0.12)	0.14 (0.05)	4.99 (1.02)	0.60 (0.09)
	$\vee$	$\wedge$*	$\vee$**	$\wedge$
D3	0.19 (0.05)	0.25 (0.07)	2.43 (0.62)	0.56 (0.05)

Note: Standard errors clustered at the level of groups are shown in parentheses. Statistical significance is based on the permutation test clustered at the level of groups.

mutation test on the payoff inequality at the match level. Permutation tests are non-parametric randomization tests where the distribution of the test statistic is obtained through permutations of labels for treatment among observations, and the p-value is obtained by comparing the actual test statistic with the constructed distribution (Good, 2013). Here we use *clustered* permutation tests that compare the difference between the statistics at the match level while taking into account the correlation between observations within a group—that is, when generating a permuted sample, observations in a group are always sampled together.

As shown in Table 7, matches in the D3 are less likely to converge to Equal Opportunity (0.19 vs. 0.33, $p = .087$) and more likely to converge to Equal Payoff (0.25 vs. 0.14, $p = .053$). Moreover, payoff inequality in D3 matches is significantly lower compared to I3 (3.26 vs. 5.78, $p = 0.089$).[15]Table 7 compares the frequencies of convergence to Equal Opportunity vs. Equal Payoff. It may be more informative to compare the relative likelihood of convergence to these two different behavioral patterns. A multinomial logit model using the treatment dummy as the explanatory variable show that matches in D3 are 3 times more likely to converge to Equal Payoff rather than to Equal Opportunity (log-odds ratio 1.13, $p = 0.095$, with robust standard errors clustered at the level of groups). Note that in the above analysis, because the sample size is relatively small (12 groups in each treatment) the effects are only marginally significant, although the effect size is large,

Using only the third match in each treatment inevitably leaves out valuable information in the data from other matches. Table 8 gives the multinomial logit estimates of convergence to behavioral patterns that use all matches with $\theta > 1$. Matches with $\theta = 1$ are excluded because we cannot distinguish between Equal Opportunity and Equal Payoff. Only the first 67 periods in each match are used to hold the effect of match length constant. Here we investigate the factors

[15]Although miscoordination can lower the payoff inequality, this treatment effect is not caused by more miscoordination in the treatment D—indeed, the overall coordination rates do not differ significantly (0.60 vs. 0.56, $p = 0.335$).

Table 8: Multinomial logit estimates of convergence to behavioral patterns.

VARIABLES	(1) Efficiency	(2) Equal Opportunity	(3) Equal Payoff
θ	-0.46	-0.24**	-0.11
	(0.45)	(0.11)	(0.10)
Match	0.36	0.48***	0.60***
	(0.45)	(0.11)	(0.10)
TD	0.14	-1.10**	0.41
	(0.68)	(0.55)	(0.61)
Constant	-2.29	-1.10**	-2.93***
	(1.81)	(0.56)	(0.64)
Observations		252	
Pseudo R-squared		0.056	

Note: The base category is matches that have not converged to any of the three patterns. Matches with $\theta = 1$ are excluded from the analysis because we cannot distinguish between Equal Opportunity and Equal Payoff. Robust standard errors clustered at the level of group are shown in parentheses. *** p<0.01, ** p<0.05, * p<0.1

that influence the convergence to the three behavioral patterns: Efficiency, Equal Opportunity, and Equal Payoff. Matches that do not converge to any of these three patterns are left out as the base category. We see that the log-odds of converging to Equal Opportunity and Equal Payoff are significantly higher in later matches, demonstrating a learning effect. We also see that as the payoff asymmetry θ increases, it becomes significantly less likely for the matches to converge to Equal Opportunity.

Our interest here is the difference between the likelihood of converging to Equal Opportunity and Equal Payoff in the two treatments. The difference in the log-odds between convergence to Equal Payoff and Equal Opportunity is 1.51, giving rise to an odds ratio 4.52: holding other things equal, matches in the treatment D are 4.52 times more likely to converge to Equal Payoff rather than Equal Opportunity. This provides strong evidence that matches in the treatment D are more likely to converge to the equal payoff outcome.

To visualize what this odds ratio means, Figure 8 shows the predicted frequencies of these three behavioral patterns as a function of θ. Note there the x-axis also represents time: from left to right we have earlier matches to later matches. Compared to Figure 5, the predicted frequencies capture the general trend of changes in behavioral patterns over time.

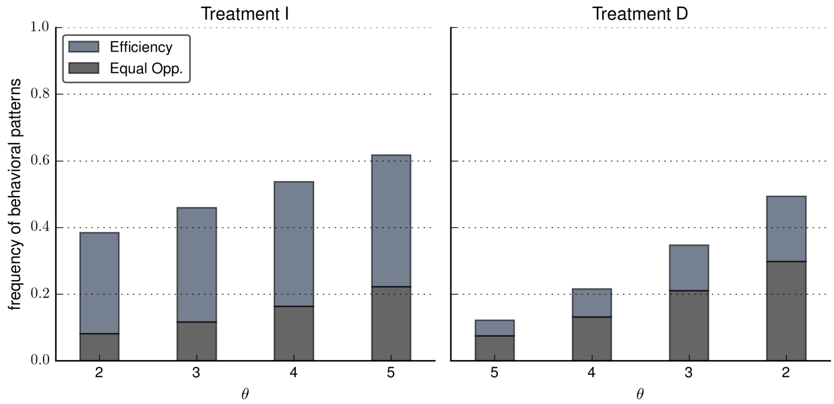


Figure 8: Predicted frequencies of behavioral patterns based on multinomial logit estimator.

$\theta = 2$	D031	0	20	0	0	20	0	0	20	0	0	20	0	0	20	0	0	20	0	0	20	0	0	20	0	0	20	0	0	20	0	0	20	0	0	20
	D032	10	0	10	10	0	10	10	0	10	10	0	10	10	0	10	10	0	10	10	0	10	10	0	10	10	0	10	10	0	10	10	0	10	10	0
$\theta = 3$	I054	0	0	0	30	0	0	0	30	0	0	0	30	0	0	0	30	0	0	-1	0	30	0	0	0	30	0	0	0	30	0	0	0	30	0	0
	I052	10	10	10	0	10	10	10	0	10	10	10	0	10	10	10	0	10	10	-1	10	0	10	10	10	0	10	10	10	0	10	10	10	0	10	10
$\theta = 4$	D031	0	0	40	0	0	0	0	40	0	0	0	0	40	0	0	0	0	-1	40	0	0	0	0	40	0	0	0	0	40	0	0	0	0	40	0
	D033	10	10	0	10	10	10	10	0	10	10	10	10	0	10	10	10	10	-1	0	10	10	10	10	0	10	10	10	10	0	10	10	10	10	0	10
$\theta = 5$	I032	50	0	0	0	0	0	50	0	0	0	0	0	50	0	0	-1	0	0	0	50	0	0	0	0	0	-1	50	0	0	0	0	0	50	0	0
	I034	0	10	10	10	10	10	0	10	10	10	10	10	0	10	10	-1	10	10	10	0	10	10	10	10	10	-1	0	10	10	10	10	10	0	10	10

Figure 9: Examples of Equal Payoff behavioral patterns with length $\theta+1$. The last 35 periods of the corresponding matches are shown. A blue box indicates the action S, and a red box indicates the action T. A red border indicates that subject has the wrong belief on her opponent's action, while green borders indicate correct beliefs.

4.5 Complex strategies and the Equal Payoff outcomes

It should be pointed out that our experimental results provide clear evidence that subjects are capable of using complex strategies. As shown in Figure 5, there are 52 out of 288 matches with payoff asymmetry that have converged to patterns of length $\theta + 1$, achieving the Equal Payoff outcomes. Figure 9 provides four examples, one for each value of $\theta > 1$. These examples show the last 35 periods of the corresponding matches. Infrequent mistakes still occur after convergence in some of these matches, but the players can successfully recover from them and come back to coordination.

Interestingly, we observe some subjects engage in really complex behavioral patterns to achieve the Equal Payoff outcomes. Figure 10 shows the match between D015 and D011 with $\theta = 3$ which has converged to a pattern with length 17. This is not the only match where player D011 coordinates with his partner on the Equal Payoff outcome using a strategy that is more complex than necessary: for his match with D015, they converge to a behavioral pattern with

0	-1	0	0	0	0	-1	-1	-1
30	-1	30	30	30	30	-1	-1	-1

-1	-1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

0	0	0	0	-1	10	10	10	10	10	10	10	10	10	10	10	10
30	30	30	30	-1	0	0	0	0	0	0	0	0	0	0	0	0

0	0	0	0	-1	10	10	10	10	10	10	10	10	10	10	10	10
30	30	30	30	-1	0	0	0	0	0	0	0	0	0	0	0	0

0	0	0	0	-1	10	10	10	10	10	10	10	10	10	10	10	10
30	30	30	30	-1	0	0	0	0	0	0	0	0	0	0	0	0

0	0
30	30

Figure 10: The match between subject D015 and subject D011 with $\theta = 3$, which has converged to a pattern with length 17. For a clearer presentation, the patterns are broken down into blocks of 17 where a consistent behavioral pattern is shown.

length 21, even though that match is a symmetric game with $\theta = 1$.[16] These provide further evidence that players are capable of coordinating using complex strategies.

5 Conclusions

The current literature has thus far overlooked the tension between different normative principles caused by payoff asymmetries in repeated coordination games. We provide the first study to investigate the effect of this normative conflict in repeated battle of the sexes with payoff asymmetries. Our findings and contributions are threefold. First, we show how players trade off between different normative principles in repeated coordination games. We find strong evidence that Equal Payoff is an important normative principle that players use. Many players have achieved or have tried to achieve the Equal Payoff outcomes, even though doing so requires the use of complex strategies. Some players coordinate by alternating between the two stage Nash equilibria, which is consistent with the principle of Equal Opportunity. Therefore, both Equal Payoff and Equal Opportunity are important normative principles people use in repeated coordination games. On the other hand, Efficiency, which has been shown to be a principle used by many subjects in dictator games, does not have an important influence in the strategic setting studies in this paper.

[16] Looking at D011's description of his strategy in the post-experiment survey may shed light on the reasoning underlying his strategy: *"I liked that it could be fair for both partners if both partners understood the strategy of helping each other. The first match, I didn't have a strategy and made a lot less francs. Then the second match based on what my partner was doing, I decided to do for the rest of the game. The partner would let myself make the money while they made 0 for a bit, then we would switch off while I made 0 and they would make money. Every time we were about at either 100 higher or around equal or equal currency, we would switch to the next partner to catch up."*

Second, we find evidence of behavioral spillovers and history dependence of normative principles and strategies across different games in the presence of normative conflict: players with successful coordination on Equal Payoff or Equal Opportunity are more likely to use the same normative principle in the future. Previous studies have documented behavioral spillovers across simple static games. Our paper shows that complex repeated games strategies can also spillover across different games. Moreover, we also observe the spillover of a normative principle across different games even when the strategies implementing that normative principle change across games. We therefore not only observe the spillover of repeated game strategies, but also the spillover of a class of similar but different strategies that are consistent with one normative principle. These results all show that history and prior experiences play an important role in equilibrium selection. Importantly, we find that Equal Payoff outcomes are more common when players start with a game with a high conflict level, so the first game players play could have a big impact on their behaviors and expectations.

Lastly, we find players use strategies that are more complex than those studied in evolutionary game theory and learning theory. In terms of the commonly used measure of complexity—the number of states in the automaton representation—some players in our experiment coordinate using strategies with a complexity measure of 6. Current literature in evolutionary games and learning models only considers simple strategies with a complexity measure of 2 (Imhof et al., 2007; Hanaki et al., 2005; Ioannou and Romero, 2014b; Zhang, 2018). Our experiment provides empirical evidence that evolutionary game theories and learning models should consider complex strategies, at least in the setting of the repeated asymmetric coordination games.

In many instances of social and economic interactions, normative conflict arises due to payoff asymmetry or heterogeneous preferences. Our study provides clear evidence that this normative conflict exists in the repeated coordination games, and it causes disagreement upon which normative principle should be used. Although further studies are needed for this important topic, our research provides a first step into understanding the nature and severity of such conflict.

References

Al-Ubaydli, O., Jones, G., and Weel, J. (2016). Average player traits as predictors of cooperation in a repeated prisoner's dilemma. *Journal of Behavioral and Experimental Economics*, 64:50–60.

Andreoni, J. and Miller, J. (2002). Giving according to garp: An experimental test of the consistency of preferences for altruism. *Econometrica*, 70(2):737–753.

Aumann, R. J. and Shapley, L. S. (1994). Long-term competition: a game-theoretic analysis. In *Essays in Game Theory*, pages 1–15. Springer.

Banks, J. S. and Sundaram, R. K. (1990). Repeated games, finite automata, and complexity. *Games and Economic Behavior*, 2(2):97–117.

Bartling, B., Fehr, E., Maréchal, M. A., and Schunk, D. (2009). Egalitarianism and competitiveness. *The American Economic Review*, 99(2):93–98.

Bhaskar, V. (2000). Egalitarianism and efficiency in repeated symmetric games. *Games and Economic Behavior*, 32(2):247–262.

Blanco, M., Engelmann, D., and Normann, H. T. (2011). A within-subject analysis of other-regarding preferences. *Games and Economic Behavior*, 72(2):321–338.

Bland, J. and Nikiforakis, N. (2015). Coordination with third-party externalities. *European Economic Review*, 80:1–15.

Bolton, G. E. and Ockenfels, A. (2000). Erc: A theory of equity, reciprocity, and competition. *American Economic Review*, pages 166–193.

Brandts, J. and Cooper, D. J. (2006). A change would do you good....an experimental study on how to overcome coordination failure in organizations. *The American Economic Review*, 96(3):669–693.

Burnham, T. C., Cesarini, D., Johannesson, M., Lichtenstein, P., and Wallace, B. (2009). Higher cognitive ability is associated with lower entries in a p-beauty contest. *Journal of Economic Behavior & Organization*, 72(1):171–175.

Buser, T. and Dreber, A. (2015). The flipside of comparative payment schemes. *Management Science*.

Cason, T. N., Lau, S.-H. P., and Mui, V.-L. (2013). Learning, teaching, and turn taking in the repeated assignment game. *Economic Theory*, 54(2):335–357.

Cason, T. N., Savikhin, A. C., and Sheremeta, R. M. (2012). Behavioral spillovers in coordination games. *European Economic Review*, 56(2):233–245.

Charness, G. and Rabin, M. (2002). Understanding social preferences with simple tests. *The Quarterly Journal of Economics*, 117(3):817–869.

Cooper, D. and Kagel, J. H. (2013). Other regarding preferences: a selective survey of experimental results. *Handbook of Experimental Economics*, 2.

Cooper, R., DeJong, D. V., Forsythe, R., and Ross, T. W. (1994). Alternative institutions for resolving coordination problems: Experimental evidence on forward induction and preplay-communication. *Problems of coordination in economic activity*, pages 129–146.

Dal Bo, P. and Frechette, G. R. (2018). On the determinants of cooperation in infinitely repeated games: A survey. *Journal of Economic Literature*.

Davis, D., Ivanov, A., and Korenok, O. (2014). Individual characteristics and behavior in repeated games: an experimental study. *Experimental Economics*, pages 1–33.

Dawes, C. T., Fowler, J. H., Johnson, T., McElreath, R., and Smirnov, O. (2007). Egalitarian motives in humans. *nature*, 446(7137):794–796.

Dreber, A., Fudenberg, D., and Rand, D. G. (2014). Who cooperates in repeated games: The role of altruism, inequity aversion, and demographics. *Journal of Economic Behavior & Organization*, 98:41–55.

Engelmann, D. and Strobel, M. (2004). Inequality aversion, efficiency and maximin preferences in simple distribution experiments. *American Economic Review*, 94:857–869.

Erev, I. and Roth, A. E. (1998). Predicting how people play games: Reinforcement learning in experimental games with unique, mixed strategy equilibria. *American Economic Review*, pages 848–881.

Fehr, E. and Schmidt, K. M. (1999). A theory of fairness, competition, and cooperation. *Quarterly journal of Economics*, pages 817–868.

Friedman, J. W. (1971). A non-cooperative equilibrium for supergames. *The Review of Economic Studies*, pages 1–12.

Fudenberg, D. and Maskin, E. (1986). The folk theorem in repeated games with discounting or with incomplete information. *Econometrica: Journal of the Econometric Society*, pages 533–554.

Fudenberg, D., Rand, D. G., and Dreber, A. (2012). Slow to anger and fast to forgive: cooperation in an uncertain world. *The American Economic Review*, 102(2):720–749.

Gangadharan, L., Nikiforakis, N., and Villeval, M. C. (2017). Normative conflict and the limits of self-governance in heterogeneous populations. *European Economic Review*, 100(4):143–156.

Gill, D. and Prowse, V. (2016). Cognitive ability, character skills, and learning to play equilibrium: A level-k analysis. *Journal of Political Economy*, 124(6):1619–1676.

Good, P. (2013). *Permutation tests: a practical guide to resampling methods for testing hypotheses*. Springer Science & Business Media.

Hanaki, N., Sethi, R., Erev, I., and Peterhansl, A. (2005). Learning strategies. *Journal of Economic Behavior & Organization*, 56(4):523–542.

Imhof, L. A., Fudenberg, D., and Nowak, M. A. (2007). Tit-for-tat or win-stay, lose-shift? *Journal of Theoretical Biology*, 247(3):574–580.

Ioannou, C. A. and Romero, J. (2014a). A generalized approach to belief learning in repeated games. *Games and Economic Behavior*, 87:178–203.

Ioannou, C. A. and Romero, J. (2014b). Learning with repeated-game strategies. *Frontiers in neuroscience*, 8.

Kagel, J. H., Kim, C., and Moser, D. (1996). Fairness in ultimatum games with asymmetric information and asymmetric payoffs. *Games and Economic Behavior*, 13(1):100–110.

Kalai, E. and Stanford, W. (1988). Finite rationality and interpersonal complexity in repeated games. *Econometrica: Journal of the Econometric Society*, pages 397–410.

Knez, M. and Camerer, C. (2000). Increasing cooperation in prisoner's dilemmas by establishing a precedent of efficiency in coordination games. *Organizational Behavior and Human Decision Processes*, 82(2):194–216.

Konow, J. (2003). Which is the fairest one of all? a positive analysis of justice theories. *Journal of economic literature*, 41(4):1188–1239.

Kuzmics, C., Palfrey, T., and Rogers, B. W. (2014). Symmetric play in repeated allocation games. *Journal of Economic Theory*, 154:25–67.

Lau, S.-H. P. and Mui, V.-L. (2008). Using turn taking to mitigate coordination and conflict problems in the repeated battle of the sexes game. *Theory and Decision*, 65(2):153–183.

Lau, S.-H. P. and Mui, V.-L. (2012). Using turn taking to achieve intertemporal cooperation and symmetry in infinitely repeated 2× 2 games. *Theory and Decision*, 72(2):167–188.

Mathevet, L. and Romero, J. (2014). Predictive repeated game theory: Measures and experiments.

Neyman, A. (1985). Bounded complexity justifies cooperation in the finitely repeated prisoners' dilemma. *Economics letters*, 19(3):227–229.

Nikiforakis, N., Noussair, C. N., and Wilkening, T. (2012). Normative conflict and feuds: The limits of self-enforcement. *Journal of Public Economics*, 96(9):797–807.

Peysakhovich, A., Nowak, M. A., and Rand, D. G. (2014). Humans display a 'cooperative phenotype' that is domain general and temporally stable. *Nature communications*, 5.

Proto, E., Rustichini, A., and Sofianos, A. (2014). Higher intelligence groups have higher cooperation rates in the repeated prisoner's dilemma.

Raven, J. (2000). The raven's progressive matrices: change and stability over culture and time. *Cognitive psychology*, 41(1):1–48.

Romero, J. (2015). The effect of hysteresis on equilibrium selection in coordination games. *Journal of Economic Behavior & Organization*, 111:88–105.

Romero, J. and Rosokha, Y. (2018). Constructing strategies in the indefinitely repeated prisoner's dilemma game. *European Economic Review*, 104:185–219.

Roth, A. E. and Murnighan, J. K. (1982). The role of information in bargaining: An experimental study. *Econometrica: Journal of the Econometric Society*, pages 1123–1142.

Rubinstein, A. (1986). Finite automata play the repeated prisoner's dilemma. *Journal of Economic Theory*, 39(1):83–96.

Straub, P. G. (1995). Risk dominance and coordination failures in static games. *The Quarterly Review of Economics and Finance*, 35(4):339–363.

Van Huyck, J. B., Cook, J. P., and Battalio, R. C. (1997). Adaptive behavior and coordination failure. *Journal of Economic Behavior & Organization*, 32(4):483–503.

Weber, R. A. (2006). Managing growth to achieve efficient coordination in large groups. *The American Economic Review*, 96(1):114–126.

Zhang, H. (2018). Errors can increase cooperation in finite populations. *Games and Economic Behavior*, 107:203–219.

Appendix

A Payoff asymmetry and the principle of Equal Payoff

Severe payoff inequality exists in the Efficiency and the Equal Opportunity outcomes when the conflict level θ is high. If people have strong inequality aversion, or simply believe other people do, this payoff inequality would make the Equal Payoff outcome more salient. Using the model of inequality aversion proposed by Fehr and Schmidt (1999), we can show that Equal Payoff become more prominent with a high payoff asymmetry.[17] In the two-player version of the model, a player has the following utility function:

$$U_i = x_i - \alpha_i \max\{x_j - x_i, 0\} - \beta_i \max\{x_i - x_j, 0\}, 0 \leq \beta_i < 1, \alpha_i > \beta_i. \tag{1}$$

According to this functional form, player i's utility U_i depends on the monetary payoff of both player i and player j. The "evny" parameter α_i measures i's behindness aversion: a higher α_i indicates that player i experiences higher disutility from disadvantageous inequality. The "guilt" parameter β_i measures i's aheadness aversion: a higher β_i indicates higher disutility from advantageous inequality.

Inequality aversion influences players' preferences over different normative principles for $\theta > 1$. Row players with a strong aversion to advantageous payoff inequality would prefer Equal Payoff over Equal Opportunity. This happens when their β parameter satisfies the following condition:

$$\beta \geq \frac{\theta}{\theta + 1}.$$

[17]Using the ERC model proposed by Bolton and Ockenfels (2000) gives the same conclusion.

The column players always prefer the Equal Payoff over the Equal Opportunity outcome, but the Equal Opportunity outcome becomes less attractive to them as the value of θ increases. Column players with sufficiently strong disadvantageous inequality aversion would rather have attrition than the Equal Opportunity outcome. This would occur if their α parameter satisfies

$$\alpha \geq \frac{6}{5(\theta - 1)}.$$

Given the estimates of α in previous studies, a sizable number of players would prefer Attrition over Equal Opportunity.[18]

Normative conflict can influence coordination through two channels. First, players may prefer one normative principle over another. Second, if players do not have preferences over different normative principles, their beliefs on other people's preferences will also influence the strategy they choose. Therefore, if people have strong inequality aversion or simply believe others do, Equal Payoff becomes more salient in games with high payoff asymmetry.[19]

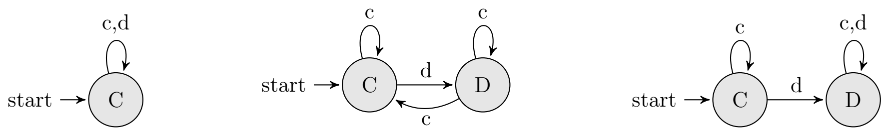
B Measure of strategy complexity

First introduced by Neyman (1985) and Rubinstein (1986), the most common measure of the complexity of repeated game strategies is the minimal number of states in any finite automaton that encodes the given strategy. Kalai and Stanford (1988) shows that this notion of complexity is equivalent to the number of continuation strategies this repeated game strategy can generate, so this measure of state-complexity can be calculated without reference to finite automata. Alternative measures of complexity do exist. Banks and Sundaram (1990) propose to incorporate the transitional structure into the measure of complexity, assigning greater complexity to strategies requiring more monitoring. We can also use the length of memory needed to implement a strategy as its complexity. No matter which measure is used, the Equal Payoff strategy is more complex than the Equal Opportunity strategy when $\theta > 1$.

In a survey paper, Dal Bo and Frechette (2018) find that three strategies–AllD, Grim, and TFT, which have at most two states in the corresponding automaton representation–account

[18]Blanco et al. (2011), for example, report the following estimated median values: α= 0.61 and β = 0.53.

[19]The model of inequality aversion does not take into account players' concerns for the social welfare. Column players with concerns for the social welfare would be less likely to choose Attrition over Equal Opportunity. (Charness and Rabin, 2002) show that when players consider being intentionally exploited by the other player, which is likely to be the case in repeated coordination games, they do not exhibit strong concerns for the social efficiency.



(a) AllD (b) TFT (c) Grim

Figure 11: Strategies that account for most of the behaviors in repeated prisoner's dilemma.

for most of the behavior in repeated prisoner's dilemma. Figure 11 shows the automaton representation of these three strategies. Fudenberg et al. (2012) study repeated prisoner's dilemma in the presence of implementation errors, and find some other strategies TF2T and Grim3 are also important in explaining behavior. However, there is no evidence that players use strategies that need automata with more than 4 states to implement.

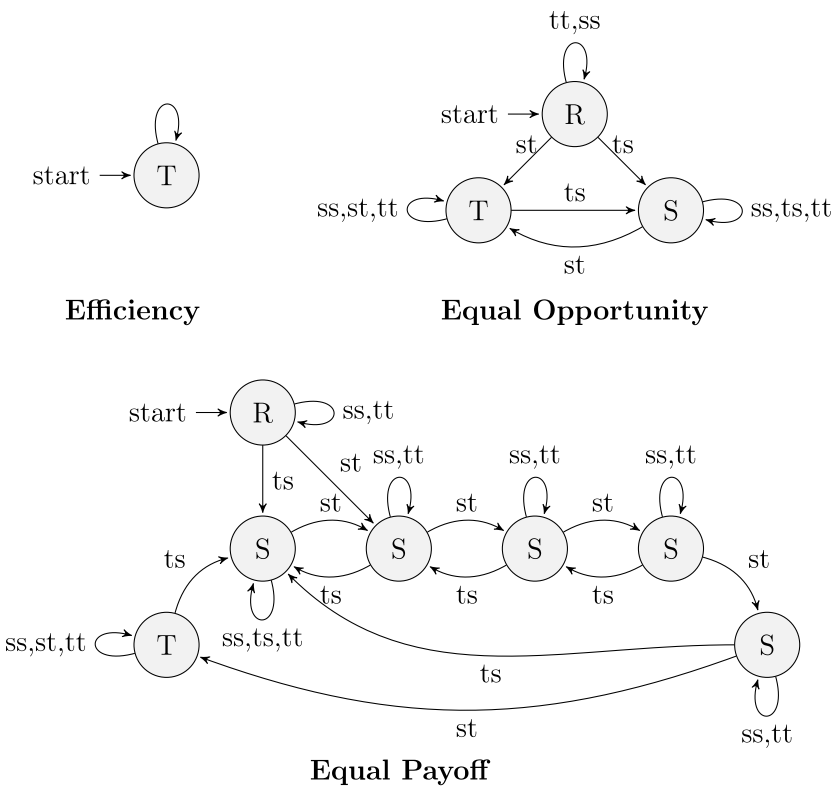


Figure 12: Strategies that implement each of the three normative principles.

In the asymmetric battle of the sexes, the strategies corresponding to different normative principles have different levels of complexity. Figure 12 shows that strategies for the row player that are consistent with the three normative principles. The corresponding strategies for the column player have similar representations (just need to change the labels of the state and make some other minor changes) and with the same level complexity. The automaton given is just one possible representation—there are many other strategies that can achieve the Equal Payoff outcome that differ only off the equilibrium path.

To implement Efficiency, a one-state automaton is enough. To implement Equal Opportunity, we need a three-state automaton. In contrast, at least $\theta + 2$ states are required for implementing the Equal Payoff principle, and the complexity of the strategy required is increasing with θ.

Because we have provided the information on both players' cumulative match payoffs in the experiment, players can use a simple heuristic to achieve the Equal Payoff outcome: play T when my cumulative payoff is lower than that of the opponent, and play S when it is higher. Investigation of the behavioral patterns reveals that, many Equal Pyaoff plays are consistent with this simple heuristic. One may argue that the strategies conditional on the difference in cumulative payoffs is not complex. However, 21% of the Equal Payoff patterns (11 out of 52 matches) do not use this simple heuristic, and two of them are with $\theta = 5$ (see the online supplementary information). This provides strong evidence that players do use complex strategies, and indicates that players are still able to achieve the Equal Payoff outcome even without this information on cumulative payoffs.

From the time series of the payoff difference in cumulative payoffs, many matches that do not converge to any of the 5 behavioral patterns are consistent with the heuristic of equalizing payoffs. However, many of these patterns do not use the simplest implementation of this heuristic as suggested by Bhaskar (2000) and Kuzmics et al. (2014). For example, the subject D16 with all his partners discover a pattern with where they coordinate on one stage equilibrium until one player's cumulative payoff is ahead by a certain amount (for the match between D16 and D11, for example, that amount is 100), then play the other stage equilibrium until the payoffs equalize. These matches provide examples of complex strategies that cannot be represented as finite automata.

C Payoff and coordination

Figure 13 provides the scatter plots of the payoff outcomes for different θ, distinguished by treatment. To make the outcome comparable across different matches, the payoffs shown are the averages of the first 67 periods, which is the shortest of all match lengths. When $\theta = 1$, no normative conflict exists, and a majority of outcomes are along the line of Equal Payoff, many of which are near the efficient and egalitarian outcome (5,5). Some observations cluster around the attrition point, while only a small number of the outcomes are along the line of exploitation.

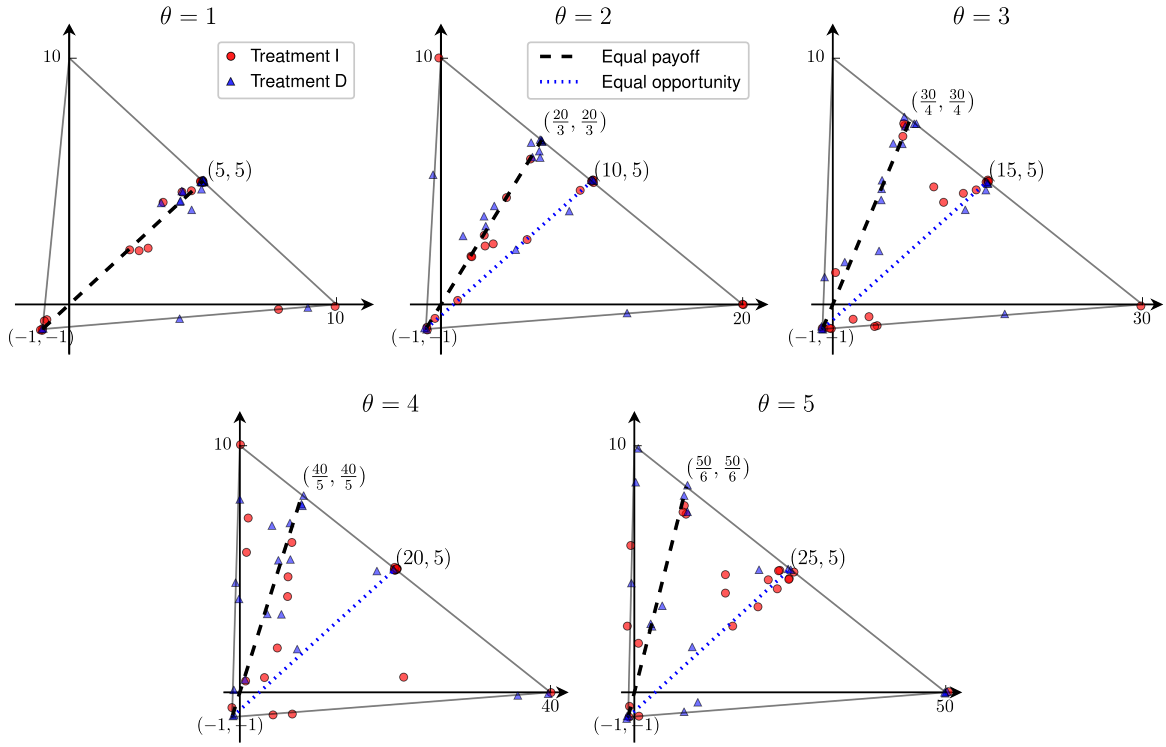


Figure 13: Scatter plots of the average payoffs of the first 67 periods in each match. Jittering is used to prevent overlaps of data points. All payoffs within the triangle are individually rational payoffs. Many outcomes are either along the line of Equal Payoff or Equal Opportunity.

When $\theta > 2$, most points are along the line of Equal Payoff or Equal Opportunity, indicating that both are important normative principles. Compared to the case with $\theta = 1$, many points are away from the Pareto efficient line. Miscoordination by reaching Attrition is still commonly observed. Some players reach Efficiency, but there are also others who reach Inefficiency, which is not consistent with any of three normative principles. The outcomes near Inefficiency imply that it may not be the concerns for social efficiency that cause people to coordinate on Efficiency—it is simply that some players are stubborn and try to force their preferred outcome. A crude look at the distribution reveals that except for $\theta = 5$, there are more points clustering around the Equal Payoff outcome in the treatment D.

Table 9 shows the average coordination rate, average payoff, payoff inequality, and the frequencies of different action pairs. The first letter of the action pairs represents the row player's action, and the second represents the column player's action. For symmetric games, TS and ST are pooled together. Note that across all supergames, miscoordination is almost always caused by both players choosing T. This is indicative of the mixed motives inherent in the battle of the sexes.

Table 9: Statistics of the results for different degree of asymmetry θ

θ	treatment	coordination rate	TS	ST	TT	SS	average payoff	payoff inequality
1	TI	0.64	0.64		0.33	0.02	2.83	1.19
	TD	0.72	0.72		0.26	0.02	3.23	0.80
2	TI	0.62	0.31	0.30	0.35	0.03	4.39	3.58
	TD	0.62	0.31	0.31	0.35	0.03	4.23	3.16
3	TI	0.60	0.27	0.33	0.37	0.03	5.35	5.28
	TD	0.56	0.20	0.36	0.39	0.05	4.38	2.95
4	TI	0.69	0.25	0.44	0.28	0.03	6.89	6.99
	TD	0.51	0.18	0.34	0.46	0.03	4.52	4.21
5	TI	0.67	0.27	0.40	0.30	0.03	8.43	9.50
	TD	0.58	0.19	0.39	0.38	0.04	6.32	8.69

The overall coordination rate is around 60% if we pool all the matches together. Note that as we move from match 1 to match 5, both the effect of conflict level and the effect of learning are at work. As players adjust their beliefs and learn the optimal strategies over time, learning would cause an increase in the coordination rate. But the increase in the conflict level would make it harder to achieve coordination. In the treatment D, the two effects work together, but in the treatment I the two effects work towards different directions. This explains why there is a statistically significant increasing time trend in coordination rate in the treatment D ($p = 0.044$, regression analysis with group random effects), but not in the treatment I ($p = 0.853$).

D Supplementary material

Supplementary material associated with this article can be found at

https://sites.google.com/site/huanrenzhang/research