

# Working with Your Neighbors: Incentives in Networked Coordination Games\*

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## Abstract

Coordination in groups often converges to the Pareto inefficient equilibrium. In this paper we test the effect of changes to the payoff structure, focusing on the effect of increasing versus decreasing the on- versus off-equilibrium payoffs, on equilibrium selection in coordination games. Our four treatments change the baseline coordination game payoff structure along two dimensions: 1) changing on- versus off-equilibrium payoffs and 2) increasing or decreasing payoffs relative to a baseline. We find that while the treatments do not increase coordination success on the Pareto efficient equilibrium significantly, changing payoffs, especially the on-equilibrium payoffs, deters inefficient coordination. However the on-equilibrium incentives also lead to more miscoordination and a lower level of play efficiency. We also find that individual strategy choices depend on the incentive structure. Although a significant fraction of subjects always choose the risk dominant strategy, the on-equilibrium incentives encourage more tit for tat strategies. We do not find that decreasing payoffs leads to different behaviors than increasing payoffs.

Keywords: Equilibrium Selection Coordination Success Incentives Strategy Estimation

## 1 Introduction

Coordination games with multiple pure Nash equilibria have been used to study coordination problems stemming from a variety of real world situations and organizational

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contexts (Coase, 1937; March and Simon, 1958; Milgrom and Roberts, 1992; Feri et al., 2010).<sup>1</sup> Of particular importance is the question of equilibrium selection when there are multiple Pareto-ranked Nash equilibria. Past experimental work shows that it is hard for subjects to coordinate successfully on the efficient equilibrium (Van Huyck et al., 1990; Cachon and Camerer, 1996; Berninghaus et al., 2002; Chaudhuri et al., 2009; Dugar, 2010), and that failure to coordinate on the efficient equilibrium is exacerbated in large groups (Knez and Camerer, 1994; Keser et al., 1998; Weber et al., 2001; Van Huyck et al., 2007). In this paper we test the effect of changes to the payoff structure, focusing on the effect of increasing versus decreasing the on- versus off-equilibrium payoffs, on equilibrium selection in coordination games.

Van Huyck et al. (1990, p.247) suggest that “coordination failure results from strategic uncertainty: some subjects conclude that it is too ‘risky’ to choose the Pareto-dominant action.” To decrease such strategic uncertainty, many interventions have been used to facilitate successful coordination. These interventions include communication (Cooper et al., 1992; Charness, 2000; Duffy and Feltovich, 2002; Blume and Ortmann, 2007), growing large groups from small groups (Weber, 2006) and enhancing group identity (Chen and Chen, 2011). Another commonly studied and more scalable intervention is to alter the incentive structure of the coordination game (Straub, 1995; Battalio et al., 2001; Schmidt et al., 2003; Dubois et al., 2012) and ask how these variations increase coordination success. However in most cases, the treatments involve changing multiple payoff cells at the same time. Thus, it is not possible to isolate the direct impact of, for example, increasing or decreasing a particular payoff cell, on equilibrium selection.

A concern with altering multiple payoffs is that behavior may change as a consequence of changes to the size of the basin of attraction of always choosing the efficient equilibrium strategy. The size of basin of attraction affects the limiting outcomes of related adjustment processes in coordination games with multiple equilibria (Crawford, 1991; Kandori et al., 1993; Young, 1993; Ellison, 2000).<sup>2</sup> Battalio et al. (2001) and Dubois et al. (2012) change payoffs holding the basin of attraction of always choosing the efficient equilibrium strategy constant. However their design does not provide a clean test of the impact of incentive structure as they alter multiple payoff cells at the same time.

It is important to understand how payoff structure affects individual strategy and equilibrium selection because incentives can inform subjects’ beliefs about future play

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<sup>1</sup>For example, preservation of biodiversity can be modeled as a coordination game with multiple equilibria. The multiple equilibria correspond to the land use decisions of private land owners (Banerjee et al., 2012). See the survey by Devetag and Ortmann (2007) for an in-depth literature review. Coordination on the inefficient outcome is undesirable because it causes efficiency loss. In an organization this might manifest as high production costs or difficulties to manage distributed expertise (March and Simon, 1958; Malone, 1987; Faraj and Xiao, 2006).

<sup>2</sup>Basin of attraction is also a key determinant in other classes of games such as Prisoner’s Dilemma. In an infinitely repeated Prisoner’s Dilemma game, Bó and Fréchette (2011) find that the size of the basin of attraction of a strategy can explain subjects’ behavior. Embrey et al. (2015) reach a similar conclusion by reviewing past lab studies on finitely repeated Prisoner’s Dilemma games.

and reduce the strategic uncertainty to facilitate coordination success (Van Huyck et al., 1993). For example, Van Huyck et al. (1993) auction the right to play a coordination game and find that the price of the right allows the players to eliminate certain strategies that do not justify the price. Such inference about an opponent’s play subsequently induces a different equilibrium refinement. Crawford et al. (2008) use subjects’ first period decisions as a proxy for strategic thinking. They find that first period strategies are sensitive to the magnitude of the payoff asymmetry in a coordination game. For this reason, it is important to understand how payoffs themselves affect strategy adoption and equilibrium selection.

To isolate the effect of how changes in the payoff structure affect equilibrium selection, we propose a new experiment with 1 baseline and 4 treatment games. We place subjects in groups of six. Each subject plays a coordination game with her left and right neighbors. In each game with a neighbor, she can choose either a “high” or a “low” action, but her left and right action is constrained to be the same. Simultaneously, her two neighbors also play the coordination game with their neighbors. We choose this set-up because the constrained action, as well as having subjects play in a group of six who are connected, increases the riskiness of the coordination game and heightens awareness of this for subjects. The set-up also mimics real world situations. Social and administrative hierarchies create natural subgroups in which agents interact with only a subset of the larger communities - their local administrative neighbors - yet outcomes are determined both by interactions with the neighbors and the behavior of all actors connected within the organization.<sup>3</sup> In an integrated work environment (such as assembly lines or supply chains), subgroups need to coordinate due to supply, demand, knowledge or other interdependencies (Lambert et al., 1998; Dyer and Singh, 1998; Lee, 2000). Often in these situations, one can only make one decision and this single decision affects all the coordinating partners.<sup>4</sup>

Our treatments change the incentive structure of the baseline coordination game in order to help groups achieve coordination success on the “high” action. We first use a baseline game based on Keser et al. (1998) and establish a baseline level of inefficient coordination in our groups. Using a 2 (on-/off-equilibrium) X 2 (increase/decrease payoffs) design, we change the incentive structure. In each case our changes make the efficient coordination more attractive but for different reasons. Compared to the baseline, our carrot-on treatment creates incentives for both players to achieve coordination success by increasing the efficient equilibrium payoffs. The carrot-off treatment increases the payoffs of choosing the “high” action in miscoordination. The stick-on treatment decreases the

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<sup>3</sup>Ellison (1993) calls this “local interactions”, describing situations where actors interact with a few close friends or colleagues. “For example, such a rule might describe the interactions at a college reunion where each participant knows in advance who he or she wishes to see. The contacts among a group of firms or economists might also be of this type.” (Ellison, 1993, p.1051)

<sup>4</sup>On an assembly line, workers coordinate the rate at which they hand over the work to each other. The rate at which one takes over from a precedent and the rate at which one hands over to a successor are constrained to be the same by workplace practices.

risk dominant equilibrium payoffs. The stick-off treatment adjusts payoffs by decreasing the payoffs for a person who chooses the “low” action. By changing the payoffs in the treatments, we expect to reduce the riskiness of the efficient equilibrium, while keeping the basin of attraction of always choosing the efficient equilibrium strategy mostly unchanged between the games.<sup>5</sup>

We analyze the effect of incentives on equilibrium selection at three levels: the group, the neighborhood (consisting of three players) and the individual level. First, we see unraveling of efficient coordination in the baseline game. All baseline groups converge to the inefficient equilibrium. Such unraveling is not so frequently observed in the treatments. Second, at the neighborhood level, changing the payoffs does not increase the overall coordination success rate significantly but it does decrease the fraction of subjects coordinating with the neighbors on the inefficient equilibrium. Such an effect is stronger when we change the on-equilibrium payoffs than when we change the off-equilibrium payoffs. However the on-equilibrium incentives also create more miscoordination and increase efficiency loss. In other words, the two “on” treatments deter inefficient coordination at the costs of efficiency loss. Third, building on self-reported strategy descriptions collected at the end of the experiment, we use a maximum likelihood estimation method to understand whether strategy adoption varies across the treatments. We estimate the relevant frequency of strategies played at the individual level following Bó and Fréchette (2011). We conclude from the estimation results that the tendency to use certain strategies depends on the incentive structure. In the two “on” treatments, subjects use more tit for tat strategies. These results suggest that the on- versus off-equilibrium payoff adjustments generate different behavior dynamics.

We depart from the previous literature by changing payoffs, in order to specifically contrast the effect of increasing versus decreasing the on- versus off-equilibrium payoffs. Our results fill a gap in the literature and characterize how different changes to the payoff structure affect play controlling for the size of the basin of attraction of always choosing the efficient equilibrium strategy. Our results highlight the trade-off between deterring inefficient coordination outcomes and efficiency loss, and that changing payoff structures does not necessarily enhance efficiencies.<sup>6</sup> Though we do not find that decreasing payoffs when players choose the “low” action has a different effect from increasing payoffs when players choose the “high” action, we do find that individual strategy choices are significantly different across the “on” and “off” treatments. These strategy choices generate different behavior dynamics that contribute to a growing literature on strategic thinking

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<sup>5</sup>One may argue that increasing the payoffs in the Pareto-dominant equilibrium makes it more focal because of higher payoff dominance. The same argument applies to the stick-on treatment as well. As we will show, choices from the first period of play in our experiment do not differ significantly across treatments, suggesting that the argument of incentives making a certain equilibrium focal is not well supported.

<sup>6</sup>The trade-off between coordination success and efficiency loss has also been found in Cason et al. (2012). They show that communication can be a coordination improving mechanism but it also decreases the play efficiency depending on the type of communication. Also see Duffy and Feltovich (2002).

and the theoretical learning models. Our results demonstrate that behavior in games is also shaped by the game payoff structure such that more or less cooperative strategies are adopted depending on how payoffs are changed.

## 2 Experimental Design and Hypotheses

Our experiment has one baseline and four treatments (carrot-on, carrot-off, stick-on and stick-off) where we change the payoff structure of the baseline game. In each condition, six subjects are linked into a group as shown in Figure 1. Every subject plays a coordination game with the left neighbor and an identical game with the right neighbor.<sup>7</sup> The coordination game is a 2x2 normal form game with two actions:  $H$  or  $L$ . A subject's action to the left and to the right neighbor is constrained to be the same. At the same time, a subject's neighbors are playing the same coordination game with their neighbors (who must also choose an action that is played to the right and left). A subject's payoff in each round is the minimum payoff realized from the games with the left and right neighbors. This game has two pure Nash equilibria - everyone choosing  $H$  (all- $H$ ) or everyone choosing  $L$  (all- $L$ ).

Each subject plays the same game with the same neighbors for 20 periods. After each period, we report to subjects their earnings for the round, accumulated earnings and the distribution of their neighbors' actions. That is, we report "0% $H$ 100% $L$ ", "50% $H$ 50% $L$ " or "100% $H$ 0% $L$ ", but not the specific individual action of each neighbor. Subjects know that everyone in their group is playing the same game with the same payoff matrix and that they will play in fixed groups of six with the same neighbors for 20 periods. The individual total payoff is the sum of the payoffs earned in the 20 periods. The show up fee is \$5. The experiment is programmed using zTree (Fischbacher, 2007).

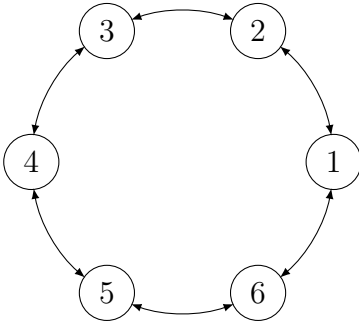


Figure 1: A group of six players

The left panel of Table 1 presents the payoff matrix of the coordination game that a subject plays with each of the two neighbors. The right panel shows the corresponding

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<sup>7</sup>For example, player 2 is playing with one neighbor, player 1, and also with the other neighbor, player 6.

payoff matrix given a subject’s choice and their neighbors’ choices. Subjects earn Experiment Credits (EC) which are converted to dollars at the following rate: 200 Experiment Credits = \$1. In the baseline, a subject can get 90EC by choosing  $H$  if both of her neighbors choose  $H$  as well. Otherwise, she only gets 10EC. A subject choosing  $L$  can get 80EC if both neighbors choose  $L$ . Otherwise, she gets 60EC.

In the four treatment conditions, we change the incentive structure of the baseline game by increasing or decreasing either the on- or off-equilibrium payoffs. All- $H$  and all- $L$  are still the two pure Nash equilibria. We change the payoffs so that the relative payoff gain (loss) of  $H$ , compared to choosing  $L$ , is larger (smaller). For example, in carrot-on, we increase the on-equilibrium payoffs. Subjects get 20EC more than in the baseline if they coordinate with the neighbors on the efficient equilibrium. In this case, we increase the payoff gain of choosing  $H$  by 20EC. In carrot-off, a subject who chooses  $H$ , while a neighbor chooses  $L$ , gets 20EC more than in the baseline. In other words, the payoff loss of choosing  $H$  in miscoordination shrinks by 20EC. In stick-on, if a subject coordinates with neighbors on  $L$ , she gets 40EC less compared to the baseline. In stick-off, a subject choosing  $L$  when at least one of her neighbors chooses  $H$  earns 10EC less.

Changing the incentive structure in any of our treatments leads to a bigger basin of attraction of always choosing  $H$  ( $BAH$ ) than in the baseline because it expands the set of beliefs that make always choosing  $H$  optimal. The  $BAH$  characterizes the set of beliefs under which one prefers to always choose  $H$ . In particular, the larger the size of the  $BAH$ , the lower the belief threshold needs to be for one to always choose  $H$ , which may make coordination success more likely. Although previous experimental studies on two-person coordination games such as Straub (1995) and Schmidt et al. (2003) use different metrics to characterize the payoff structure, we find that the decision to coordinate on  $H$  seems to be well predicted by the size of the  $BAH$ .<sup>8</sup> The size of the  $BAH$  is also predictive of coordination success in minimum effort games, a class of coordination games with a larger action space with multiple players. Assume that there are only two strategies: always exerting the highest effort or always exerting the lowest effort. The  $BAH$  characterizes the set of beliefs under which one will always exert the highest effort. Brandts and Cooper (2006) increase the  $BAH$  by increasing the return of the minimum effort which leads to improved coordination on the high effort. Goeree and Holt (2005) decrease the cost of effort to increase the  $BAH$  and obtain similar findings.<sup>9</sup> Hamman et al. (2007) further contrast the effect of different incentive changes (e.g. positive versus negative rewards) when increasing the  $BAH$  and find that the effectiveness of the incentives differs with respect to achieving coordination success. Van Huyck et al. (2007) increase the size

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<sup>8</sup>Take Straub (1995) as an example. If we assume that each player is choosing one of the two extreme strategies: always choosing  $H$  and always choosing  $L$ , then we calculate the  $BAH$  to be smallest in their Game 8 which is consistent with the experimental results that Game 8 has the smallest fraction of subjects playing  $H$ . In Schmidt et al. (2003), the game with a smaller  $BAH$  also leads to less  $H$  play in the last two rounds.

<sup>9</sup>Goeree and Holt model the effort choice based on maximizing a stochastic potential function.

Table 1: Payoff tables in five games

baseline

		A Neighbor's Choice		Two Neighbors' Choices		
		H	L	HH	LH	LL
H	(90,90)	(10,60)	H	90	10	10
L	(60,10)	(80,80)	L	60	60	80

carrot-on

		A Neighbor's Choice		Two Neighbors' Choices		
		H	L	HH	LH	LL
H	(90+20,90+20)	(10,60)	H	110	10	10
L	(60,10)	(80,80)	L	60	60	80

carrot-off

		A Neighbor's Choice		Two Neighbors' Choices		
		H	L	HH	LH	LL
H	(90,90)	(10+20,60)	H	90	30	30
L	(60,10+20)	(80,80)	L	60	60	80

stick-on

		A Neighbor's Choice		Two Neighbors' Choices		
		H	L	HH	LH	LL
H	(90,90)	(10,60)	H	90	10	10
L	(60,10)	(80-40,80-40)	L	60	40	40

stick-off

		A Neighbor's Choice		Two Neighbors' Choices		
		H	L	HH	LH	LL
H	(90,90)	(10,60-10)	H	90	10	10
L	(60-10,10)	(80,80)	L	50	50	80

of the *BAH* by increasing the order statistic in an order statistic coordination game.

The larger *BAH* mitigates the negative group size effect on coordination. Battalio et al. (2001) and Dubois et al. (2012) hold the *BAH* constant and find that convergence to an equilibrium is affected by other payoff structure parameters.<sup>10</sup> Our study differs from these two papers in that we change either the on- or off-equilibrium payoffs, as well as increasing or decreasing payoffs relative to a baseline to isolate their effect on coordination.

The curves in Figure 2 represent the beliefs under which one is indifferent between always playing *H* or always playing *L* in our games. The X(Y)-axis is the belief about the right(left) neighbor always playing *H*. The area to the upper right of the curves characterizes the size of the *BAH*. As one can see, all four treatments have a similar *BAH* that is also larger than the baseline.

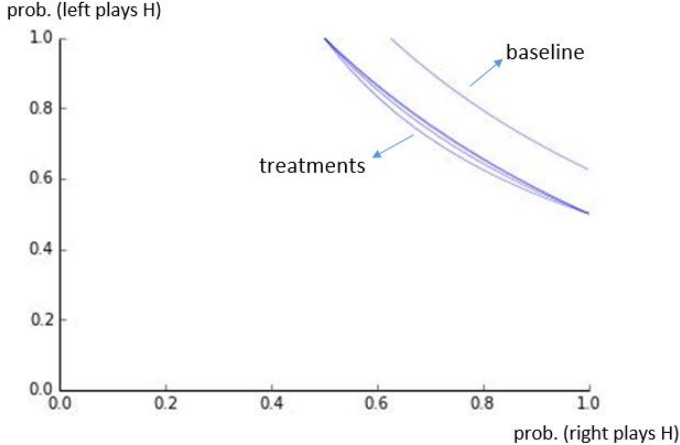


Figure 2: Characterizing the *BAH* across five games

Thus we hypothesize that in treatments with a larger *BAH*, a subject is more likely to coordinate on the payoff dominant equilibrium with her neighbors.

**Hypothesis 1** *There will be more coordination on H and less coordination on L in the four treatments than in the baseline.*

In the four treatments, we match the sizes of the basin of attraction as closely as possible to test the effect of different ways to change the payoff structure. Results from Berninghaus et al. (2002) suggest small differences in the *BAH* between our treatments will not lead to significant behavioral changes.<sup>11</sup>

<sup>10</sup>Battalio et al. (2001) vary the “optimization premium” - the expected payoff difference between choosing the “high” and “low” action. They find a convergence to the inefficient equilibrium with a larger optimization premium. Dubois et al. (2012) vary the riskiness ratio while keeping the optimization premium constant. The riskiness ratio is the ratio of the expected payoff range of the two actions. They find that a lower riskiness ratio decreases the frequency of *H* choice.

<sup>11</sup>Subjects in Berninghaus et al. (2002) play a coordination game in a similar fashion to our experiment.



Since most empirical work changes both the basin of attraction when on- or off-equilibrium payoffs are changed, we do not have a strong prior on the effect of on- versus off-equilibrium payoff changes nor on the use of decreasing payoffs when players choose  $L$  or increasing payoffs when players choose  $H$ , conditional on the size of the  $BAH$ . Thus, our second hypothesis is that:

**Hypothesis 2** *There will be an equal amount of coordination on  $H$  or  $L$  in the four treatments.*

### 3 Results

A total of 168 University of Michigan students participated in the experiment. Table 2 summarizes the treatment and session statistics.

Table 2: Number of sessions, groups and subjects

	Sessions	Groups	Subjects	Obs. (SubjectXChoice)
baseline	3	6	36	720
carrot-on	2	5	30	600
carrot-off	2	5	30	600
stick-on	3	6	36	720
stick-off	3	6	36	720

We first provide a general description of observed aggregate group and neighborhood behaviors in each treatment. Then we look at individual strategies to understand what strategy choices drive the aggregate patterns.

#### 3.1 Aggregate Group Behaviors

The most central outcome of interest is whether the incentives in our treatments help groups achieve coordination success. Table 3 Panel A reports the number of groups starting either with all choosing  $L$ , all choosing  $H$  or not everyone coordinating on the same action (an off-equilibrium). Panel B reports the same statistics for the last period of play. Just focusing on Panel A, we see that many groups start without everyone coordinating on the same action regardless of which treatment they are in. For example, none of the groups start with coordinating on the inefficient equilibrium of all playing  $L$ , and only one group in stick-on reaches the payoff dominant equilibrium of all choosing  $H$  in the first period.

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They contrast two payoff schemes: the minimum payoff structure (what we use in the experiment) versus the average payoff structure (a player receives the average payoffs realized from playing with the two neighbors). The two payoff schemes have a similar  $BAH$  and similar play.

Table 3: Groups' starting and ending play

Panel A		Number of Groups Starting with			
Period 1	All playing $L$	5 playing $L$	Other	5 playing $H$	All playing $H$
baseline	0	0	4	2	0
carrot-on	0	0	3	2	0
carrot-off	0	0	4	1	0
stick-on	0	2	1	2	1
stick-off	0	1	5	0	0

Panel B		Number of Groups Ending with			
Period 20	All playing $L$	5 playing $L$	Other	5 playing $H$	All playing $H$
baseline	6	0	0	0	0
carrot-on	1	1	3	0	1
carrot-off	4	0	0	0	1
stick-on	1	2	2	0	1
stick-off	3	2	0	0	1

Notes: All playing  $L$  and all playing  $H$  are the two pure Nash equilibria. The shaded three columns show how many groups start or end with not everyone coordinating on the same action. The column “Other” refers to either 2 play  $H$ , 3 play  $H$  or 4 play  $H$  in a group.

Focusing on Panel B, we make three key observations about how groups end up playing. In the baseline, all six groups converge to the inefficient equilibrium. Baseline results are in line with findings from Keser et al. (1998) who also observe the unraveling of efficient coordination. In the two “off” treatments, a majority of the groups also converge to the inefficient equilibrium in the last period. For example, column “all playing  $L$ ” in Table 3 Panel B tells us that 100% of the groups end on the all- $L$  equilibrium. However, in the two “on” treatments, one group coordinates on  $L$  and one coordinates on  $H$  but a majority of the groups do not converge to any pure Nash equilibrium. For example, as we can see from Table 3 Panel B, 4 out of 6 groups in the stick-on treatment end with not everyone coordinating on the same action. This pattern also holds in the carrot-on treatment. Thus it appears that increases or decreases in incentives while holding “on” or “off” constant, do not affect group coordination differently. However, we see some differences between the “on” and “off” treatments.

### 3.2 Aggregate Neighborhood Behaviors

Having established that the groups end up with different outcomes after 20 periods of play, we now look at how the play of a neighborhood of three subjects evolves. The

neighborhood analysis allows us to test whether the incentives have some effects on the local interaction. We say a subject coordinates on the (in)efficient equilibrium if she and both of her neighbors choose  $H(L)$ .

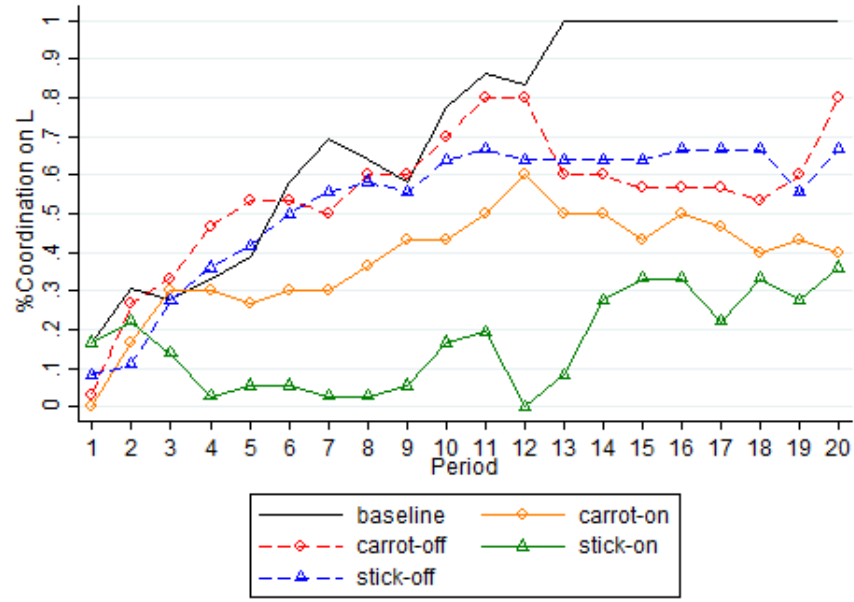
Figure 3 shows the fraction of subjects coordinating on the two equilibria across treatments and periods. Visually all the treatments end with a lower fraction of neighborhoods coordinating on  $L$  relative to the baseline. As we can see from Figure 3(a), the two “on” treatments decrease the fraction of coordination on  $L$  the most (from 100% in the baseline to about 40% in the two “on” treatments). In stick-on, the fraction of neighborhoods coordinating on  $L$  is the lowest (39%). Figure 3(b) shows the fraction of subjects coordinating with neighbors on  $H$ . We see that all the four treatments increase successful coordination on  $H$  to an average of about 20% compared to the baseline in the last period.

Table 4 uses a linear probability model to test for treatment effects on deterring the inefficient coordination during the first (columns 1, 3 and 5) and last two periods (columns 2, 4 and 6). The dependent variable in each regression is a dummy for whether a subject has coordinated with both neighbors on  $L$  (columns 1 and 2), on  $H$  (columns 3 and 4) or on either  $L$  or  $H$  (columns 5 and 6). Comparing the baseline and the four treatments, we see no differences in the fraction of subjects coordinating with neighbors on  $L$  in the first two periods ( $\beta_{carrot-on} = -0.153$ ,  $\beta_{carrot-off} = -0.086$ ,  $\beta_{stick-on} = -0.042$ ,  $\beta_{stick-off} = -0.139$ , all with  $p < 0.01$ ). This tells us that changing the size of basin of attraction does not change behaviors immediately. However, in the final periods, the two “on” treatments reduce the rate at which subjects choose the inefficient equilibrium from 100% in the baseline by 52 percentage points and 68 percentage points respectively ( $\beta_{carrot-on} = -0.523$ ,  $p < 0.01$ ;  $\beta_{stick-on} = -0.681$ ,  $p < 0.01$ ). The reduction is sizable and statistically significant. The two “off” treatments reduce coordinating on  $L$  by about 30 percentage points. However the estimates are not strongly statistically significant at conventional levels ( $\beta_{carrot-off} = -0.300$ ,  $p \geq 0.10$ ;  $\beta_{stick-off} = -0.389$ ,  $p < 0.1$ ).

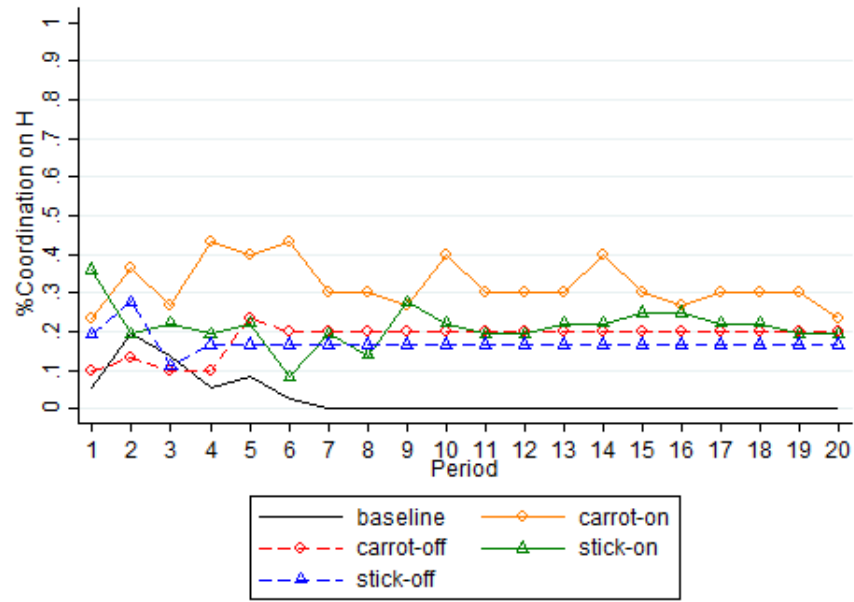
In the last two rounds, both “on” treatments increase successful coordination on  $H$  from 0% in the baseline to about 25% but the differences are not statistically significant ( $p \geq 0.10$ ). Thus, we conclude from these results that changing the on equilibrium payoffs does not increase coordination success but it deters inefficient coordination, especially when incentives for coordinating on the inefficient equilibrium are small.

**Result 1** *Increasing the BAH does not increase coordination success overall. Increasing the BAH through changing the on-equilibrium payoffs decreases local inefficient coordination on  $L$  in a neighborhood.*

Figure 4 plots out the fraction of subjects coordinating with neighbors on either the  $H$  or  $L$  equilibrium. Notice that stick-on starts with, and continues to achieve, the lowest level of neighborhood coordination compared to other treatments as well as the baseline. In Table 4 columns 5 and 6 we test such differences in the tendency to coordinate. We see that the differences between the “on” treatments and the baseline are both economically and statistically significant. Subjects in stick-on are almost 50 percentage points less likely



(a) Coordination on  $L$



(b) Coordination on  $H$

Figure 3: Neighborhood coordination across 20 periods

Table 4: OLS estimated treatment effects on coordination

	Coordinate on L		Coordinate on H		Coordinate on either	
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment/Period	P=1&2	P=19&20	P=1&2	P=19&20	P=1&2	P=19&20
carrot-on	-0.153 (0.129)	-0.523** (0.184)	0.175 (0.132)	0.267 (0.178)	0.022 (0.117)	-0.317* (0.137)
carrot-off	-0.086 (0.130)	-0.300 (0.168)	-0.008 (0.111)	0.200 (0.183)	-0.094 (0.112)	-0.100 (0.056)
stick-on	-0.042 (0.145)	-0.681*** (0.148)	0.153 (0.134)	0.194 (0.153)	0.111 (0.113)	-0.486** (0.154)
stick-off	-0.139 (0.129)	-0.389* (0.147)	0.111 (0.128)	0.167 (0.156)	-0.028 (0.131)	-0.222* (0.102)
$R^2$	0.03	0.25	0.03	0.06	0.02	0.17
N	336	336	336	336	336	336

Notes: \*\*\*, \*\*, \* Denote statistical significance at the 1, 5 or 10 % level, respectively. The numbers are the estimated coefficients of the treatment dummies in a linear probability model. All the standard errors in the parentheses are clustered at the group level.

than in the baseline to coordinate with their two neighbors on any pure equilibrium after 20 periods of play ( $\beta = -0.486$ ,  $p < 0.01$ ). Changing the on-equilibrium payoffs regardless of using carrot or stick, generates more miscoordination and results in less coordination on  $L$ .

Note that miscoordination is costly. Stick-on achieves a much lower efficiency compared to the baseline (Figure 5).<sup>12</sup> In the final two periods, the “on” treatments decrease the baseline game efficiency by about a third. The baseline game achieves a 90% efficiency whereas the two “on” treatments on average reach only a 60% efficiency. This is because in our games, coordination on  $L$  yields a higher efficiency than miscoordination. Hence although play in the baseline converges to the inefficient equilibrium, the baseline game achieves the highest efficiency in the ending periods. Our hypotheses are silent about efficiency but the results indicate that deterring coordination on  $L$  is coupled with efficiency loss.

**Result 2** *Changing the on-equilibrium payoffs increases miscoordination and efficiency loss.*

Since subjects in the treatments start similarly but end with different play, how sub-

<sup>12</sup>The difference is statistically significant at the 1% level. The regression result is not presented here but available from the authors.

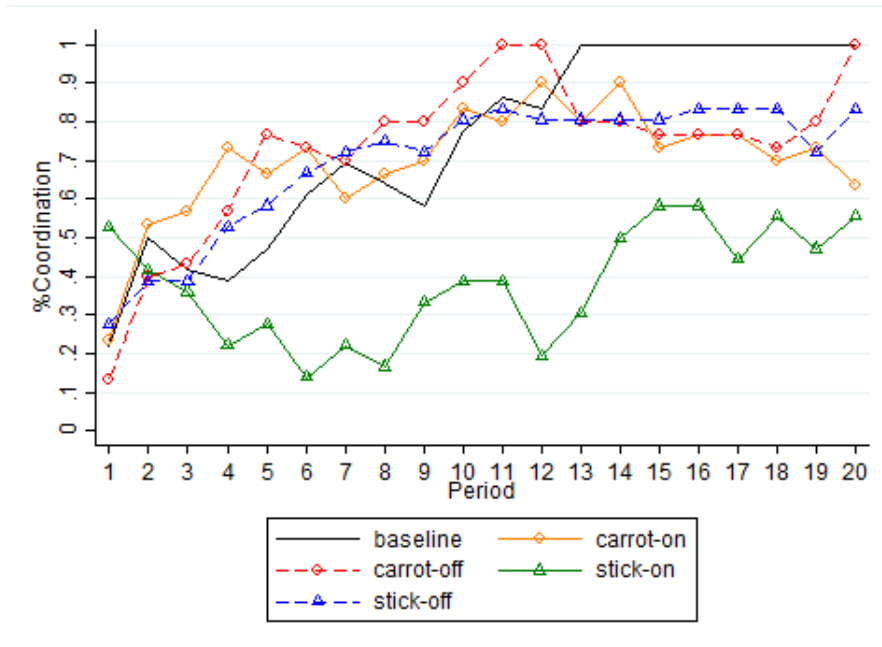


Figure 4: Fraction of coordination on either  $H$  or  $L$  across 20 periods

jects play in repeated games matters. The next section focuses on individual level behaviors to understand how individual play varies across the treatments.

### 3.3 Individual Strategies

In order to better understand the evolution of coordination over the 20 periods, we now consider how changing the payoff parameters changes individual choices. Figure 6 plots out the aggregate percentage of subjects choosing  $H$  for each treatment. We observe clear and distinct patterns of choice dynamics depending on whether the “on” or the “off” incentives are present. This may be caused by individuals adopting different strategies in the two “on” versus the two “off” treatments. This motivates us to estimate the relative frequencies of strategies used by the subjects in each treatment following the estimation procedure in Bó and Fréchette (2011).<sup>13</sup>

Although there are an infinite number of strategies that we can estimate, we choose to focus on strategies that subjects report playing the most in the first five periods in the survey conducted at the end of each session.<sup>14</sup> Some subjects report that they always choose  $L$  because it is safer and they report not being concerned with the efficiency loss. We consider this as the “always choosing  $L$  strategy” (Bó and Fréchette, 2011). Many

<sup>13</sup>We thank Guillaume Fréchette for his helpful comments on this section.

<sup>14</sup>In our survey, we ask subjects “Think back to when you were in the first 5 periods of this experiment. Describe how you made your decision to play  $X(L)$  or  $Y(H)$ .” Survey data is available upon request.

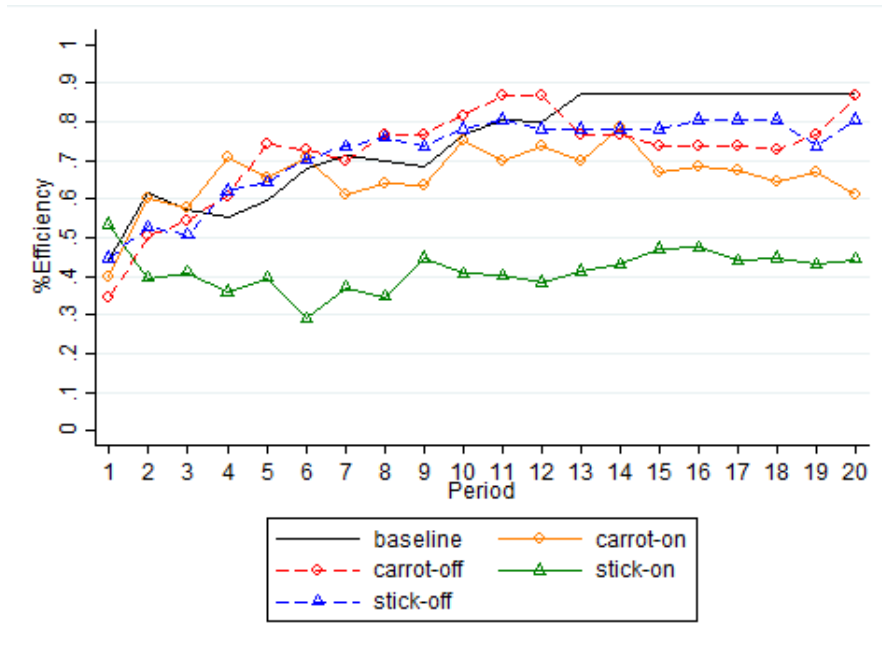


Figure 5: Efficiency of play across 20 periods

other subjects report that they start with choosing  $H$  and switch to  $L$  if the neighbors are not coordinating on  $H$ . We refer to these strategies as the “cooperative grim trigger strategy”. We then add in other important strategies observed in the literature such as the “tit for tat strategy”. Grim trigger and tit for tat are cooperative strategies. Subjects using these strategies start with choosing  $H$ . We further specify two types of grim trigger strategies and two types of tit for tat strategies. A subject using the grim trigger type 1(2) strategy chooses  $L$  forever once both neighbors choose  $L$  (at least one neighbor chooses  $L$ ) in the previous period. A subject using the tit for tat type 1(2) strategy mimics neighbors’ choices and chooses  $H$  if both neighbors choose  $H$  (at least one neighbor chooses  $H$ ) in the previous period. The tit for tat strategies feature forgiveness as it is possible that a subject switches back from  $L$  to play  $H$ . In contrast, a subject using a grim trigger strategy always chooses  $L$  once she switches to  $L$ .<sup>15</sup> Hence we consider the following six strategies: always playing  $L$  (AL), always playing  $H$  (AH), grim trigger strategies (G1 and G2) and tit for tat strategies (TFT1 and TFT2). The importance of each strategy is estimated by the maximum likelihood estimation method. We assume that subjects have a given probability of choosing one of the 6 strategies and that they do not change strategies between periods. The estimated proportion for the last strategy, G2, is implied by the fact that all the frequencies need to sum up to 1.  $\gamma$  is a positive number and

<sup>15</sup>We do not consider strategies where subjects start with  $L$  and switch to  $H$  until neighbors have chosen  $H$  for enough periods. We do not include these strategies because only a handful of subjects indicate such strategies and we observe few patterns that correspond to such strategies in the data.

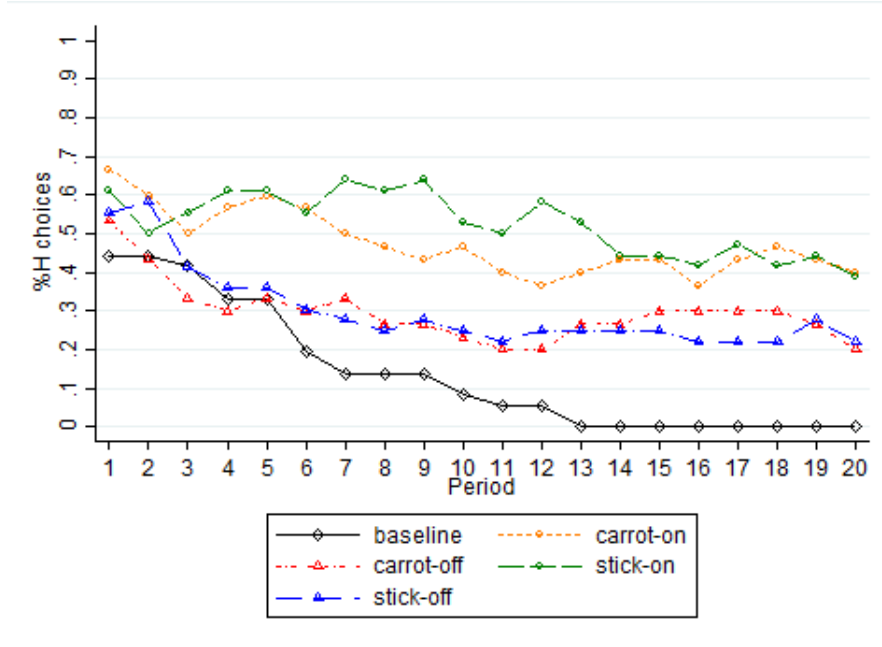


Figure 6: Fractions of  $H$  choice across 20 periods

captures the noise in decisions. This noise allows the choice to be different from the predicted choice:

$$y_{it} = 1\{\hat{y}_{it}(s^k) + \gamma\varepsilon \geq 0\} \quad (1)$$

$\hat{y}_{it}(s^k)$  is the predicted action by strategy  $k$ ,  $s^k$ , and  $y_{it}$  is the actual choice (1 for choosing  $H$  and 0 for choosing  $L$ ) for subject  $i$  in period  $t$ . The error term,  $\varepsilon$ , has a logistic distribution with a mean of 0 and a standard deviation of 1. As  $\gamma$  goes to infinity (infinitely small), responses become purely random (exactly as predicted). We then derive the likelihood function for a given subject and a strategy. Finally we estimate the probabilities of the six strategies to maximize the sum of the loglikelihood for all subjects and all strategies.

The estimates of the relative frequency of each strategy are presented in Table 5 with standard bootstrapped errors reported in the parentheses.<sup>16</sup> We make the following observations. First, across all the games, a non-trivial portion of subjects always play  $L$ . This portion is particularly high in the baseline (49.2%, s.e.= 0.118) and always lower in the treatments. The largest decreases happen when we change the on-equilibrium payoffs. For example, in the stick-on treatment, 18% subjects are estimated to always play  $L$  ( $p < 0.10$ ) and this fraction is the lowest of all the treatments. However, our treatments do not seem to induce subjects to always play  $H$ . The fraction of subjects playing  $AH$

<sup>16</sup>Note that stick-on has a higher  $\gamma$  which means that the noise in play in stick-on is larger than the other treatments.



Table 5: Estimation of strategies used

	$\gamma$	AH	AL	G1	TFT1	TFT2	G2
baseline	0.389*** (0.038)	0.000 (0.000)	0.492*** (0.118)	0.261** (0.127)	0.062 (0.073)	0.185** (0.094)	0.000
carrot-on	0.445*** (0.091)	0.070 (0.176)	0.235** (0.118)	0.162 (0.186)	0.238* (0.152)	0.152 (0.106)	0.144
carrot-off	0.396*** (0.061)	0.000 (0.000)	0.390*** (0.117)	0.251* (0.137)	0.117 (0.076)	0.191* (0.099)	0.051
stick-on	0.790*** (0.134)	0.161 (0.112)	0.181* (0.097)	0.027 (0.068)	0.212** (0.107)	0.397*** (0.109)	0.022
stick-off	0.385*** (0.040)	0.043 (0.062)	0.376*** (0.110)	0.319*** (0.130)	0.000 (0.018)	0.263*** (0.096)	0.000

Notes: \*\*\*, \*\*, \* Denote statistical significance at the 1, 5 or 10 % level, respectively. The bootstrapped standard errors of the estimates are shown in the parentheses. We perform 100 bootstrap repetitions.

increases from 0% in the baseline to 16% in the stick-on treatment, although the standard error is large (s.e.=0.112).

Instead, there is evidence that our treatments impact the relative of frequency of the other cooperative strategies. The baseline and the two “off” treatments share similar strategy portfolios; the two most popular strategies played are AL and G1. The estimates show that 49.2% ( $p < 0.01$ ) of subjects in the baseline and almost 40% ( $p < 0.01$ ) of subjects in the “on” treatments are estimated to always choose  $L$ . This fraction decreases to 23.5% ( $p < 0.05$ ) in carrot-on and further decreases to 18.1% ( $p < 0.1$ ) in stick-on. The two “on” treatments differ from the “off” treatments in that fewer subjects use a grim trigger strategy and more use a tit for tat strategy. In carrot-on, a significant portion of subjects (23.8%,  $p < 0.1$ ) use T1 and this is the most frequently used strategy. In stick-off, 21.2% ( $p < 0.05$ ) and 39.7% ( $p < 0.01$ ) of subjects adopt T1 and T2. In other words, almost half of the subjects in stick-on are playing the tit for tat strategies.

**Result 3** *The “on” incentives encourage more tit for tat strategies.*

Recall that it is more difficult for a subject using a tit for tat strategy to coordinate with neighbors than using a grim trigger strategy. Such a high proportion of subjects playing tit for tat in stick-on may explain why so many groups do not converge in the stick-on treatment.

## 4 Conclusion

Group play in coordination games often converges to the payoff inefficient equilibrium. We study whether one can increase the attractiveness of the efficient equilibrium, through increasing or decreasing the on- or off- equilibrium payoffs, to overcome the challenges of group coordination. We test whether the difference in how we change the payoffs affects behavior. We implement a 2X2 design and tweak the incentive structure: we change the on- versus off-equilibrium payoffs and we either increase or decrease the payoffs.

We find that inefficient coordination is prevalent in the baseline game. The frequency of such inefficient coordination decreases in the treatments with a larger basin of attraction of always choosing the efficient equilibrium strategy. However a reduction in the inefficient coordination can increase the efficiency loss. These results are stronger when we change the on-equilibrium payoffs than changing the off-equilibrium payoffs. Estimating individual strategy choices, we find that a popular strategy used in the baseline game is always choosing the risk dominant equilibrium strategy. The tendencies to use particular strategies depends on how we change the incentive structure. Compared to the baseline, the “on” incentives encourage more tit for tat strategies which can lead to more miscoordination. The stick-on treatment also significantly decreases the proportion of subjects always choosing the risk dominant equilibrium strategy.

Among the burgeoning experimental literature on changing the incentive structure to facilitate coordination success, few compare the effectiveness of different incentives in facilitating group coordination success. Our results fill this gap in the literature and characterize how different changes to the payoff structure affect play even when the basin of attraction of always choosing the efficient equilibrium strategy is largely unchanged. We unpack how individual strategy choices shift with changes in the incentive structure, which may guide future theories on modeling how individuals learn to play a certain strategy and select an equilibrium. For managerial policies, our study shows that deterring inefficient coordination can be achieved with changing incentives in a scalable manner, but it comes with an efficiency cost.

One interesting question for future research is to ask how play changes when only some of the group is treated with an alteration in the payoff structure. Although incentives are frequently used in real firms, managers often face constraints. For example, due to budget constraints, not everyone who chooses the “high” action can be rewarded. Under these circumstances, managers need to engineer the incentive structure so as to maximize effectiveness. How many of the group should receive the incentives and how big the incentives should be are relevant questions to be answered.

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