Connected Coordination: Network Structure and Group Coordination

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Abstract: Networks can affect a group's ability to solve a coordination problem. We utilize laboratory experiments to study the conditions under which groups of subjects can solve coordination games. We investigate a variety of different network structures, and we also investigate coordination games with symmetric and asymmetric payoffs. Our results show that network connections facilitate coordination in both symmetric and asymmetric games. Most significantly, we find that increases in the number of network connections encourage coordination even when payoffs are highly asymmetric. These results shed light on the conditions that may facilitate coordination in real-world networks.

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Introduction

Social scientists have devoted enormous attention to understanding how real-world political actors can coordinate to solve collective problems. Much of this research focuses on situations in which actors must resolve a coordination problem that occurs within a network. Two areas in which coordination within a network are common in American politics are elections and policy implementation. In the electoral arena the ability of disaggregated individuals to coordinate on campaign strategy and fundraising affects the ability of a candidate to win elected office. Networks affect the adoption of coordinated policy solutions as well as the ability of disaggregated actors to coordinate on implementing policy solutions.

To study how network structure affects coordination we embed game theoretic models of coordination into various network structures. The experimental setting allows us to vary network structure without changing anything else, thereby providing a causal test of how networks affect coordination games. The empirical literature on the effects of networks is largely unable to make causal claims because the network does not vary independently of other aspects that may affect behavior. Our experiments resolve this problem and allow us to make causal claims about how network structure affects group behavior.

We find that when subjects have common, symmetric incentives to coordinate they can successfully achieve coordination regardless of network structure. However, with asymmetric incentives network structure significantly affects the ability of a group to coordinate – networks with more connections facilitate coordination better than networks with fewer connections.

The paper proceeds as follows. In the next section we briefly review the literature on coordination and networks. In section 2 we elaborate our model of coordination within a

network. We present the specifics of our experimental design in section 3. In section 4 we analyze the results of our experiments and in section 5 we discuss and conclude.

1. Literature Review

Scholars of American politics have studied many situations in which coordination is affected by the interaction between decision makers. The underlying coordination games can be either symmetric or asymmetric. In symmetric games payoffs are equivalent across outcomes as long as coordination occurs. In asymmetric or impure coordination games payoffs are still contingent on successful coordination, but the payoff to each person differs as in the Battle of Sexes game. We now discuss two common types of coordination problems in American politics.

Coordination problems frequently occur in electoral politics and policy making. Two examples from the electoral arena are decentralized scheduling of campaign functions and fundraising decisions. The need to coordinate campaign activity occurs because the scarcity of time creates an allocation problem. This fits the general condition Calvert (1992) identifies, "A common variety of impure coordination problem arises whenever a group must agree on how to allocate some fixed stock of value among themselves." For example, consider a situation in which multiple political activists agree on the candidate they want to support, and they each desire to organize some type of campaign activity (fundraiser, voter registration/mobilization, canvassing, etc). The candidate's supporters will want to coordinate the timing of the multiple events so that they are not all scheduled on the same day. If all the events are scheduled for the same day then attendees can only attend one event, even if they would be willing to attend multiple events. As a result, campaign activities may not be as effective as if they were spread

out among multiple days.[1] Even though these activists all want the events to take place, they may disagree on whose event will occur first, second, third and so on. Therefore the organizers have an incentive to coordinate timing and the situation resembles an asymmetric coordination game. The process of communication reflects the existence of a network that determines how information spreads among the multiple actors.

Another example from electoral politics is explained in Cox (1997) who considers how campaign donors decide to allocate their financial resources. Donors to the same party will likely have different preferences about which candidate they prefer, but they will also prefer that their party's nominee win the general election. As it becomes clear who the front-runners are in a party's primary, donors will have incentives to coordinate their activity to ensure that the candidate most likely to win in the general election emerges from the primary election. Coordination is facilitated by information about candidate characteristics, the activities of other donors, and how much time remains before the primary election. The information to facilitate coordination moves between different actors based on the connections, that is the network, between individuals.

The relationship between network structure and coordination has been studied extensively by scholars interested in policy making (Heclo 1978; O'Toole 1997; Laumann and Knoke 1987). Policy makers share information among themselves, which can play a role in the ability to solve coordination problems in a decentralized fashion. Scholz, Berardo, and Kile (2008) find that cooperation among estuary management organizations depends on the network in which the organizations operate. In their view, a network is formed by connections between different organizations and the connections facilitate information flow about others' actions,

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[1] This is clearly a simplified example that includes a great many assumptions about the effectiveness of campaign activities, the behavior of activists and the absence of a central planning agent who can successfully solve the problem. Regardless, the example demonstrates a common form of coordination involving time constraints.

thereby improving collaboration. Policy actors that are highly connected to others are more likely to work together on policy implementation, suggesting that networks influence coordination. Likewise, Carpenter et al. (2004) show that network structure is both affected by and affects information flow between interest groups attempting to influence policy making. In particular, they conclude that when demand for information increases lobbying firms invest more resources in creating strong ties in their network, but that the resulting network actually impedes the distribution of information. Mintrom and Vergari (1998) find that network connections facilitate the spread of policy ideas between states. Policy entrepreneurs learn about policies and then propose similar policies (a form of coordination) based on information from the networks.[2]

This empirical literature suggests that networks will have considerable affect on attempts to coordinate policy implementation. However, it is difficult, if not impossible, to draw causal inferences about the effect of network structure on coordination from empirical research, because the networks are endogenous to the task (or behavior). In an experimental setting we can vary the network structure, while holding constant the coordination task subjects must complete, and therefore have a direct, causal test of the effect of networks on coordination.

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[2] Coordination problems occur across a broad range of social phenomena ranging from solving common pool resource problem (Ostrom 1990; Ostrom and Keohane 1994; Ahn, Ostrom and Walker 2003); to electoral coordination (Cox 1997); to evolution of behavioral strategies (Axelrod 1984, 1997), to economic development and rule of law (Greif et al. 1994); to the development of social leadership (Calvert 1992); to political participation (McClurg 2003); to which side of the road we should drive on (Lewis 1969); to ending footbinding (Mackie 1996). At least as common as coordination problems in social settings are the presence of network effects in which the decisions of one actor affect the behavior or environment of other actors (Grannovetter 1973, 1974; Heclo 1978; Huckfedlt and Sprague 1987, 2006; Coleman 1988; Ostrom 1990; Wasserman and Faust 1994; Putnam 2000; Scholz, Berardo, and Kile 2008; Fowler 2006; Christakis and Fowler 2008 Watts 2003; see the various chapters in Kahler 2009). Again we simply provide a snippet of the literature that uses networks to understand behavior across a wide range of topics.

The most direct antecedent of our work is Kearns et al. (2006) who study the ability of a large group of human subjects to solve a symmetric coordination problem called the graph coloring problem.[3] The basic task in the experiment we both utilize is to color the nodes of a network such that every node is a different color than its immediate neighbors.[4] In the experiment subjects know the color choices of all their neighbors as well as the amount of time remaining in the experiment and how close the entire network is to completion. Subjects can freely change colors as often as they wish. Therefore, this set up is quite similar to a coordination game with communication. The authors find that groups of 38 subjects can quickly solve the coordination problem, and that an increase the number of connections leads to faster solution times. This result is consistent with the idea that communication can facilitate coordination. In this paper we build on Kearns et al.'s results and study how network structure affects the ability of subjects to solve both symmetric and asymmetric coordination games.

2. Modeling Coordination in a Network

In this paper we embed two standard game theoretic models of coordination into a multi-person, networked environment. To date there is little experimental research that combines game theory and networks.[5] Our experiments and model build on Kearns et al.'s (2006) study of the

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[3] Because coordination is a global phenomenon in the experiments we utilize it is at least partially analogous to some form of public goods games. See Bramoulle and Kranton (2007) for a discussion of public goods provision in a network setting.

[4] The general problem they are studying is the graph coloring problem, which is a form of coordination problem. In this problem, there is a minimum number of colors needed to color successfully any given network referred to as that graph's chromatic number. For instance, some graphs can be colored successfully with two colors and others with three colors and so no. The reported experiments utilized the minimum chromatic color for a given graph.

[5] A good theoretical discussion about networks and game theory appears in Jackson (2008). For recent papers that study experimentally game theory and networks see Corbae and Duffy (2007), Charness and Jackson (2007) and Callander and Plott (2005). Most of these studies involve only a few number of actors (fewer than 6) and still involve one-shot decision making rather than the dynamic games we study in this experiment. In addition, much of the research in experimental economics has focused on network formation rather than on the effect of different network structures, which is our focus.

graph coloring problem. Although the problem is conceptually simple it contains a number of interesting nuances that make it an appealing problem to study.[6]

First, the graph coloring problem is an example of coordination in a network making it analogous to the empirical examples that motive our interest in the paper. The problem has been widely studied by computer scientists, both theoretically and via simulation (see Jensen and Toft 1994 for a review of much of the graph coloring research). Second, for the two-colorable graphs we focus on there are good centralized algorithms for solving the problem, but the properties of distributed algorithms are not well understood. Our experiments utilize distributed problem solving because each human subject controls the color of only a single node in the network, so there is no centralized decision maker. The upshot of this is that we may be able to learn about good mechanisms to solve the graph coloring problem in a distributed fashion through human experiments. Third, the graph coloring problem is a dynamic problem in which subjects can change their choices as they learn about the choices of other actors in the game, which mirrors many real-world problems in which we change our actions as we observe the actions of others. We first outline the basic, static form of each game and then move to a discussion of the dynamic model.

The basic, non-dynamic two person form of the symmetric coordination game is displayed in Figure 1 below. The payoff for individuals is identical whether they coordinate on action Red or Green in Figure 1. There are two Nash equilibria to this game either (Red, Green) or (Green, Red).

Insert Figure 1 here

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[6] The simplicity of the problem makes it ideal for human subject experiments because we can be confident that the subjects actually understand the task facing them during the experiment.

As Kearns et al. (2006) showed, and as previous experimental results on coordination games with communication suggest, subjects can often solve this game. In the experimental set up subjects have a tremendous amount of information available to them as they play the coordination game. This experiment involves dynamic decision-making rather than one-shot decisions, which is the typical way coordination has been studied experimentally. The dynamic nature of the game essentially turns the game we are studying from a one-shot coordination game without information into a coordination game with information. In the actual experiment subjects can change their color repeatedly until coordination is achieved, and they get tremendous information about their neighbors and feedback about how their actions affected the networks overall level of coordination. Therefore, we expect that human subjects can solve this symmetric, dynamic coordination game.

The second type of coordination game we utilized in these experiments is an asymmetric coordination game (such as a battle of the sexes). Again, subjects are only paid if coordination is achieved, but the payoff to a subject depends on the outcome. Figure 2 displays a general form of this game in which the bonus amount is a parameter that can be modified.

Insert Figure 2 here

The key difference in the asymmetric coordination game is that although there are still two Nash Equilibiria (Red, Green) and (Green, Red) the actors now have a preference for which color they choose. In games of this type there is conflict over how coordination will occur. We view this as a more realistic and interesting form of coordination. In particular, in this type of game we expect network structure to have significant effects on whether or not global coordination is achieved. We turn now to a brief discussion of the dynamic nature of these games.

2.1 Dynamic Coordination

In the previous section we outlined a one-shot version of coordination games, but the actual model and the one we test experimentally is a highly dynamic game. In the dynamic model subjects can change their chose color repeatedly until the time limit is reached or coordination is achieved. The one-shot models in Figures 1 and 2 display the payoffs subjects receive if coordination is achieved before the time limit is reached. In the experiment actors can move asynchronously, and they learn about the choices of the nodes to which they are connected instantly. This turns the one-shot game into a dynamic game with communication. Myerson (1991) demonstrates that in a coordination game with information (an analogous setting to the one we model here) there are an infinite number of equilibria. One implication of this is that we do not analyze whether or not subjects pursue equilibrium strategies because there are no bounds on what constitutes an equilibrium strategy. [7,8] Instead, our predictions and analysis are about a group's ability to solve the coordination problem, but not about individual strategies.

2.2 Combining coordination with network structure

The key aspect of our experimental design is the ability to test how different network structures affect coordination. In particular, we want to explore the relationship between the number of connections in a network and how long it takes for subjects to complete the coordination game under symmetric and asymmetric incentives. The core assumption in the following predictions is that networks facilitate information flow between actors and greater information flow (via network connections) will lead to faster solutions to the coordination

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[7] We do not discuss the equilibrium properties of the dynamic game, because as Callander and Plott (2005) note "Strategic incentives within dynamic networks are little understood and a characterization of equilibrium is not available."

[8] Jackson and Watts (2008) demonstrate that here are equilibrium strategies in bipartite games where subjects both pick a partner and one action. However, our set up is fundamentally different because 1) subjects do not pick their partners, and 2) subjects can change their actions after the experiment begins.

problem. Our predictions are related to the interaction between network structure and incentive structure.

Prediction 1: In the symmetric coordination games subjects will be able to solve all of the games, regardless of network structure.

Prediction 2: In symmetric coordination games, more connections will lead to faster times for the subjects to achieve coordination.

Prediction 3: Asymmetric coordination games will reduce the probability of a network being solved and increase the time for a solution compare to symmetric coordination games, holding the network constant.

Prediction 4: In asymmetric coordination games, a greater number of connections will increase the probability that a network is solved and decrease the time it takes to coordinate.

3. Experimental Design

In all of the experiments reported in this paper we utilized the following experimental design. The networks consisted of 16 nodes (one per subject) and were able to be successfully colored using two colors. After subjects reported to the experiment they were placed at a computer behind partitions so that they could not see the other participants. Before the experiment began we read aloud the directions to all the subjects in the room to ensure that the procedures, rules, and incentives are all common knowledge. In addition, all subjects take a short quiz (with payment for correct answers) to make sure they understand the experiment.[9]

To ensure that subjects did not repeatedly choose the same color over and over again (thereby possibly facilitating coordination), we used a palate of 10 colors and for each coordination game a subject was randomly given two of the ten possible colors. In addition, subjects in a given game chose from different colors to ensure that if they were able to see

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[9] We utilize common instructions and quizzes in our experiment to ensure adherence or compliance with the protocol. This allows us to be confident that changes in our treatment (network structure and/or bonus amount) are understood by the subjects who receive the treatment.

another's monitor the subject could not learn anything about how that subject was acting. The central server presented each subject's terminal with two different colors that a subject could choose for his or her node in each round. The information displayed on each computer was controlled by our central server that utilized a software program developed and shared by Michael Kearns and Stephen Judd and the University of Pennsylvania.

Each experimental group took part in approximately 30 attempts to solve various coordination games. The baseline payment for coordination was $1 per subject and groups had three minutes to achieve coordination. Each experimental trial ends either when the time limit is reached or the group achieves coordination successfully, and this is known to all subjects in the experiment.

In the experiment each subject controls the color of one node in the network so coordination is the result of distributed actions. However, subjects do have more information than just the color of their own node. The screen that subjects saw during the experiment contained the following information.

- Local View: Subjects are able to see their node and the neighboring nodes to which they are connected. Each node in their local neighborhood contains a number in its center that tells the subject how many total edges a neighboring node has. This allows them to see the color they have chosen for their node as well as the colors chosen by their neighbors

- Color choices: subjects can see the two colors from which they can choose

- Elapsed Time Bar: This bar kept track of the amount of time since the session began, and allows subjects to determine how much time is remaining before the time limit.

- Completion Percentage Bar: This bar provides information about how close the entire network is to completion. The percent completed represents the number of edges without a coloring conflict divided by the total number of edges in the graph.

Insert Figure 3 about here

During the actual experiment the bars for elapsed time and completion percentage are updated in real time. Figure 3 displays a typical screen shot that a subject sees before the experiment begins. By looking at the screen a subject with this picture can determine that he is connected to three nodes and that one of those nodes has eight total connections (and the other two nodes each have three total connections. The subject can also see that he can choose between pink and violet during this session and he will receive a normal payoff of $1 if the network is colored successfully and he ends up as pink, and he will receive $4 if the network is colored successfully and he ends up as violet when the session ends. During the experiment subjects continue to see this screen shot, but the progress bar and elapsed time bars change to reflect the global condition of the network.

The screen shot shows that although subjects have a tremendous amount of information available to them during the experiment, they do not know the structure of the entire network nor do they know who their geographic neighbors are in the experiment. In addition, subjects are assigned to their node randomly at the beginning of each session within a given experiment. Therefore, even if they discover to whom they are connected in a given session that will only last for one session. This procedure ensures subjects do not always occupy the same position in a network when we repeat network structures with different bonus parameters. Because subjects do not know the entire structure of the network they are not able to learn anything about how their choices relate to the group's success or failure for a given network type.

3.1 What Networks Do We Study?

The goal of our experiment is to understand how network structure affects group coordination, and therefore we had to determine the networks to study. We report the results of our research on five different network structures. For the sake of understanding we called the networks: zero-chord cycle, 6-chord cycle, barbell, cylinder and leader. In Figure 4 below we present a visual representation of each of the different networks.

We chose these networks because each of them is a representation of some real-world type of network that we want to study. For instance, the zero chord (or simple cycle) network might represent a situation in which connections are purely geographic and people do not interact with anyone other than their local neighbors. The 6 chord cycle adds a few connections across the cycle, but retains the basic cycle structure. The Leader network is built from the simple cycle, but includes two nodes that are highly connected to other members of the network. To retain two colorability, one leader is connected to each odd member and the other leader to each even member. The barbell network consists of two simple cycles with eight nodes joined by a single link between the cycles. This might be similar to networks with only a few ties between groups such as political parties or racial groups. The Cylinder network is similar to the barbell in that there are 2 cycles, but in the cylinder every person in the two cycles is connected to a member of the other eight-person cycle.

3.2 Information Flow in a Network

The network's primary role in this model is to transfer information throughout the network about the actions/decisions of other nodes. To order the networks based on their connections we use the average nodal degree of a network, which is defined as the sum of each

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node's degree divided by the total number of nodes (Knoke and Yang 2008). The average nodal degree of each network is presented in Table 1.

3.3 Incentive Structures Utilized During Experiment

We utilized the two general (symmetric and asymmetric) payoff structures as we described in Figures 1 and 2. In both types of payoff structure subjects were only paid if global coordination was achieved. The baseline payment was $1 for successful coordination, which we augments with bonus amounts of $1, $2, $3, and $4 to create asymmetric incentives. Before each time that we changed the bonus amount we read subjects a brief description of the new bonus amount and how it would be implemented. Additionally, the first time the subjects were exposed to the bonus rounds they took a quiz to ensure they understood how bonuses operated. Our Prediction 4 (above) is that networks will respond differently to the imposition and level of asymmetry.

4. Data Analysis and Results

Our experiment employs both within and between subject designs. In all of our experiments subjects take part in trials that involve symmetric and asymmetric games and that involve multiple network structures. However, we cannot rely solely on within group analysis because we cannot conduct enough trials with one group of subjects to explore all the relevant combinations of networks and levels of asymmetry. Furthermore, we want different groups to attempt the same networks and bonus structures so we can ensure that our results are not due to one group of idiosyncratic subjects.

A first cut at the data is shown in Table 2 where we present the relationship between bonus ratio and successful network coordination across all of the network structures we utilize. These results strongly support Prediction 1 that under symmetric incentives (asymmetry level

equals 0) subjects will be able to solve the networks. There is only one instance out of 19 trials with symmetric incentives where subjects fail to complete successfully the coordination problem. We also include in this table the average time spent on all of the networks across the five different levels of asymmetry. These averages include instances in which the network is not solved, which are counted as lasting for 180 seconds, which clearly biases the average time downwards for networks in which many of the graphs are not solved. Increases in the bonus ratio are associated with less coordination and longer times for successful coordination.

We combine number of connections, bonus structure and time spent solving a network in Figure 5 that presents the average amount of time to solve a given combination of network and bonus amount.[10] The figure allows us to explore predictions 2, 3 and 4 by examining comparisons along the x-, y- and z-axes in the figure. We start by focusing on the observations where the bonus ratio is zero, which allows us to examine Prediction 2. As we predicted, networks with fewer connections (on the left of the x-axis) take longer to solve than networks with more connections under the symmetric incentive condition.

To examine Prediction 3 about the effect of asymmetric coordination games on time to achieve coordination we can move along the z-axis from a bonus amount of zero to a bonus amount of four dollars, within a given network in the figure. Doing so reveals that there is a general increase in the average time to coordinate as we move from symmetric to asymmetric games. Prediction 4 is that networks with higher connectivity will take less time than networks with lower connectivity, when compared at similar bonus structures. We can see this result by comparing the amount of time it takes for coordination within a given bonus ratio, but across

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[10] We include networks that were not successfully solved, which receive a value of 180000 milliseconds although in fact it would have taken longer than 180000 milliseconds for these networks to be solved. Therefore, some combinations of networks and bonus structures that were often not solved will have artificially low average solution times.

network structures. For example, if we focus on the networks with a bonus ratio of four we see that the amount of time it takes for a group to coordinate increases as we progress from the highest connected leader network to the least connected zero-chord network. The same general pattern is true across the different bonus structures.

We build on the simple descriptive results presented in the previous tables and figure by utilizing a logit model and a Cox proportional hazard model to test the effect of the bonus and network structure on successful coordination and time until coordination.

We focus first on the logit model. To test the effect of network structure on coordination we include a counter for the session number within each experimental group, a dummy variable for each network, a dummy variable for whether the given session was an asymmetric game, a variable for the level of asymmetry, and a variable for the interaction between the level of asymmetry and the network structure.[11] This is analogous to a dosage-response study in which we want to understand both the effect of the treatment (asymmetry) and the dosage of the treatment (the magnitude of the asymmetry). In addition to the treatment variables we include a fixed effect for each group that participated in the experiment to account for any group-level characteristics that affect successful coordination. Our Prediction 4 is that networks with higher connectivity will be solved more often in the asymmetric condition than networks with lower connectivity. We also estimate a parameter to account for learning effects by counting the first trial in an experiment as 0 and counting upwards until we reach the end of that day's trials.[12]

We expect to find that the interaction between bonus ratio and network structure depends on the number of connections in the network. Referring back to Table 1 where we listed the

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[11] To further test for learning we looked for serial correlation within each experimental group by regressing the time it took for each session against a counter variable for the session, and then tested for 1st, 2nd, and 3rd order serial correlation using Durbin-Watson's alternative test. We could never reject the null hypothesis of no serial correlation.
[12] We typically ran about 30 sessions with a given group of subjects. This is an admittedly crude way to account for learning within the experiment, but it will account for general learning.

average degree of network we would generally classify the zero chord and barbell network as low connectivity and the other three networks as relatively high connectivity.

Insert Table 3 about here

In Table 3 we present the results of our logit analysis. The excluded network in the analysis is the leader network, and therefore the dummy variables for each network and the interaction between the dummy variables and the asymmetry level should be interpreted relative to the leader network. The level of asymmetry variable that is not interacted with a network variable is the effect of changes in asymmetry in the leader network. We turn now to the result of the analysis. There is not a main effect of asymmetry on the probability of coordination as indicated by the insignificance of the asymmetry variable. The zero-chord and barbell networks are both solved less often as asymmetry increases relative to the leader network. The six chord network is statistically indistinguishable from the leader network, but the cylinder network is solved successfully less often than the leader network as asymmetry increases. These results demonstrate that networks with more connections facilitate the ability of groups to solve asymmetric coordination games.

Another way to study successful network completion is to utilize a Cox proportional hazard model, which allows us to study the time until the network is solved. (Box-Steffensmeister and Jones 2004). We use the same variables as in the logit analysis. We again exclude the leader network as this has the highest level of connectivity of the networks.

Insert Table 4 about here

Table 4 presents the estimated hazard ratios from the Cox regression. A hazard ratio less than one implies that a given variable makes coordination less likely to happen given that it has not already occurred, whereas a hazard ratio greater than one means the variable makes

coordination more likely to happen. Based on Predictions 3 and 4 we expect to see that the effect of asymmetry depends on network structure. To improve interpretation we generate predicted hazard ratios for each combination of network and asymmetry.

In Figure 6 we present each network's predicted hazard ratio along the y-axis and the level of asymmetry on the x-axis. We do not present the hazard ratio for the symmetric coordination games because there is such a significant difference between the hazard ratios for symmetric and asymmetric games that they do not make sense to place on the same figure. This means that there is a main effect of asymmetry on the time to solve the coordination game. Under asymmetric incentives, the two networks with the lowest nodal degree (cycle and barbell) have a much lower hazard ratio, indicating longer times to achieve coordination, than networks with more connections. Among the other three networks (Six Chord, Cylinder and Leader) increases in asymmetry do cause a decline in the hazard ratio; however, the hazard ratio is remains higher than it is among the Cycle and Barbell networks. The Cylinder network maintains a much higher hazard ratio (faster coordination) until the bonus reaches $4. These results are consistent with our predictions that links between nodes can attenuate the effect of asymmetric coordination.

5. Discussion and Conclusion

In this paper we present experimental results from embedding standard game theoretic models of coordination into a network environment. Our results in this paper shed light on the conditions under which network structure affects coordination. Prior empirical suggests that there will be a connection between network structure and coordination, but the empirical literature cannot determine the causal effect of network structure on coordination. In this paper we take the first steps towards understanding how networks affect coordination.

Our results demonstrate that with symmetric incentives, many different types of networks are quickly and easily solved by subjects. These results mirror those of Kearns et al. (2006), despite the fact that we utilized even shorter amounts of time and different networks. In particular our results under the symmetric incentive condition suggest that an increase in the connectivity of the network leads to faster solutions. One possible way to extend these results is to study how human subjects can solve coordination problems when the task becomes more complex. Second, our results demonstrate that when we move to asymmetric coordination games that better mirror many real-world situations there is a considerable difference between network structure and the ability of groups to solve coordination problems. Our experiments reveal that more connection in a network can help to overcome asymmetry in a coordination game. This is an important result because many real-world coordination situations involve asymmetric payoffs and these results may help us to better design networks that can lead to successful coordination.

Returning to the examples of coordination discussed earlier – electoral politics and policy implementation – our results suggest that increasing the density of the network, *ceteris paribus*, can improve coordination. In particular, when coordination is difficult because of asymmetric incentives these results suggest that building connections between actors can facilitate coordination. For instance, if settings where policy coordination is desirable the results indicate that it may be useful to develop institutions that create more connections between various actors. As long as these connections do not cause other changes, then they may improve the possibility of successful coordination. In addition, our results provide a true causal test of many of the claims in the empirical literature about the effect of network connections.

These results can help us to build better theory about the effect of networks on a wide variety of tasks. For example, our results show that the number of connections matter for

coordination, but there is also some evidence that the pattern of connections might matter. The cylinder network has slightly fewer connections than the leader network, but in the cylinder network each node has the exact number of connections. Therefore, coordination may depend not just on the number but the distribution of connections. These experiments do not provide a full test of this possibility, but the results are interesting and suggestive.

The results in this paper provide support for the empirical claims that network structure affects group coordination. We have only started to understand the conditions when, how and why network structure influences group and individual actions. Ultimately, we must improve our understanding of dynamic games and networks to help us understand the complex interaction between information, networks and individuals' decisions in experimental and empirical settings.

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Figure 1: Symmetric Incentive Coordination Game

		Player 2	
		Red	Green
Player 1	Red	(0,0)	(1, 1)
	Green	(1,1)	(0,0)

Figure 2: Asymmetric Incentive Coordination Game with Red as Bonus Color

		Player 2	
		Red	Green
Player 1	Red	(0, 0)	(1 + B, 1)
	Green	(1, 1 + B)	(0, 0)

Figure 3: A Subject's Screenshot Before Experiment Begins

Figure 4: Different Networks Utilized During Experiment

Zero-chord Cycle

Barbell

Cycle 6

Cylinder

Leader
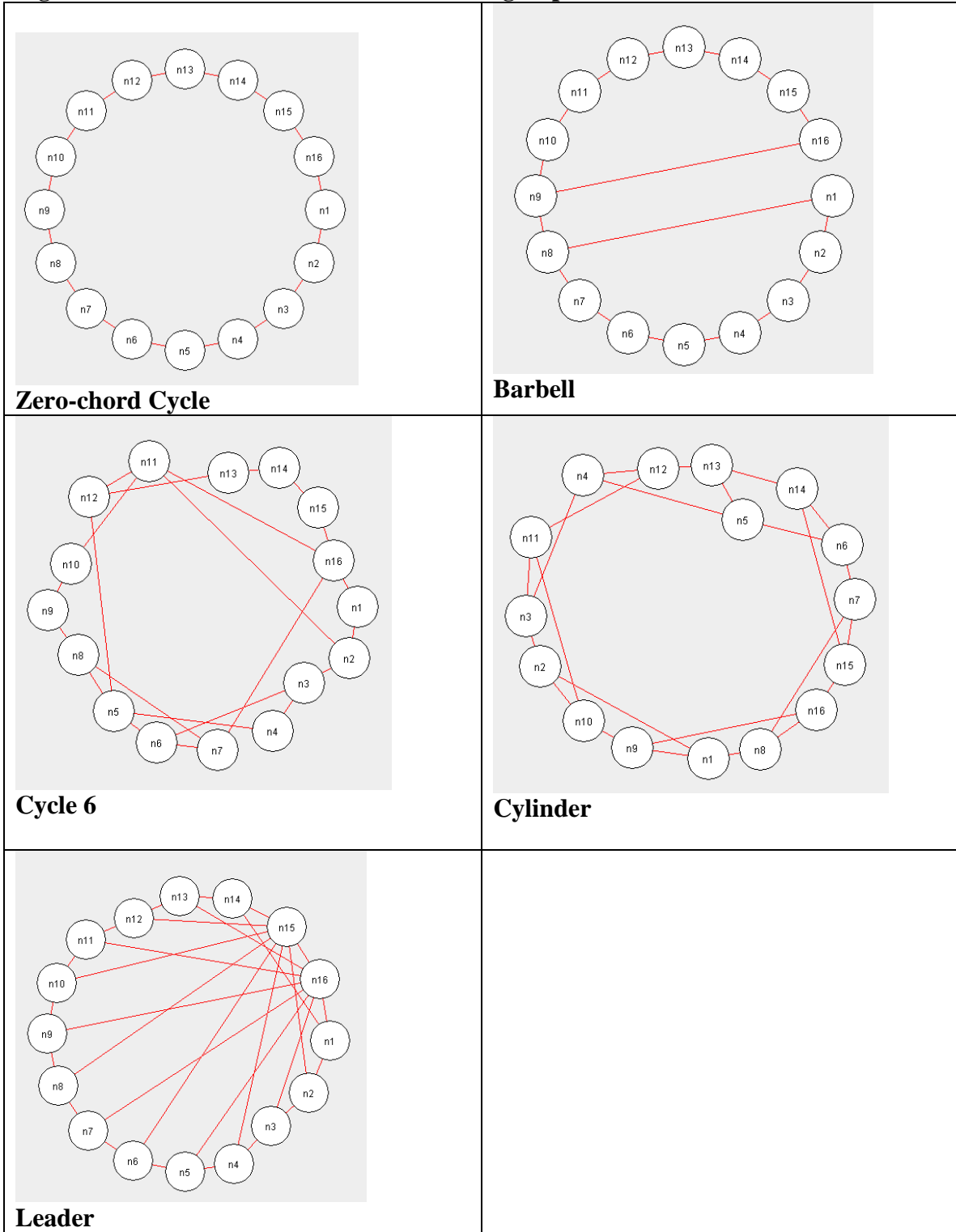
Figure 5: Average Time for Coordination Based on Bonus Amount and Connectivity
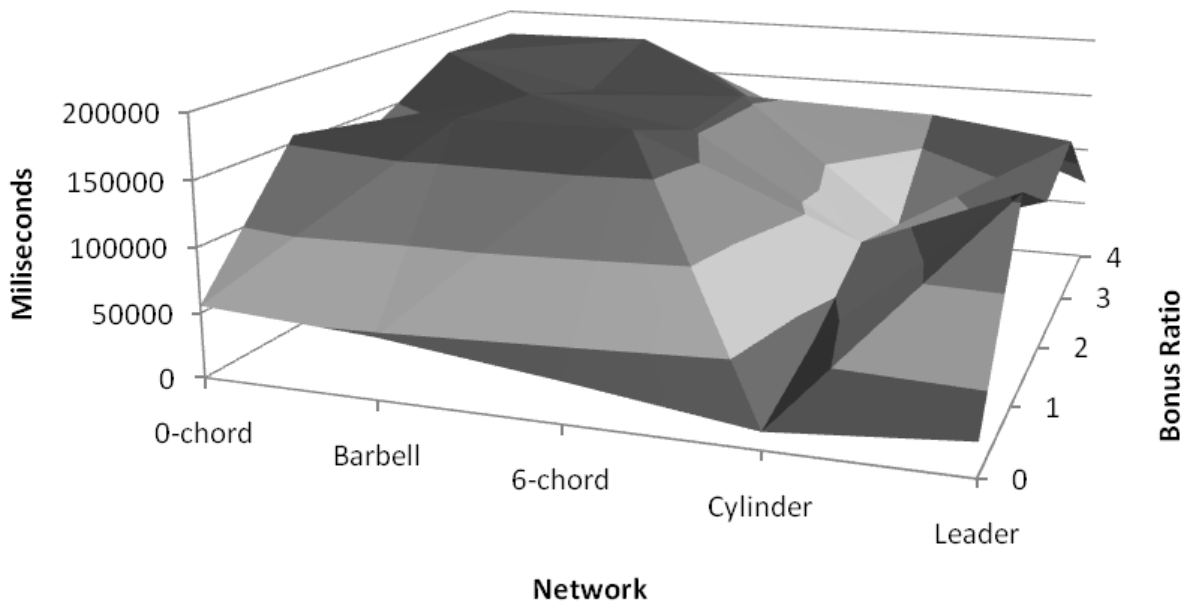
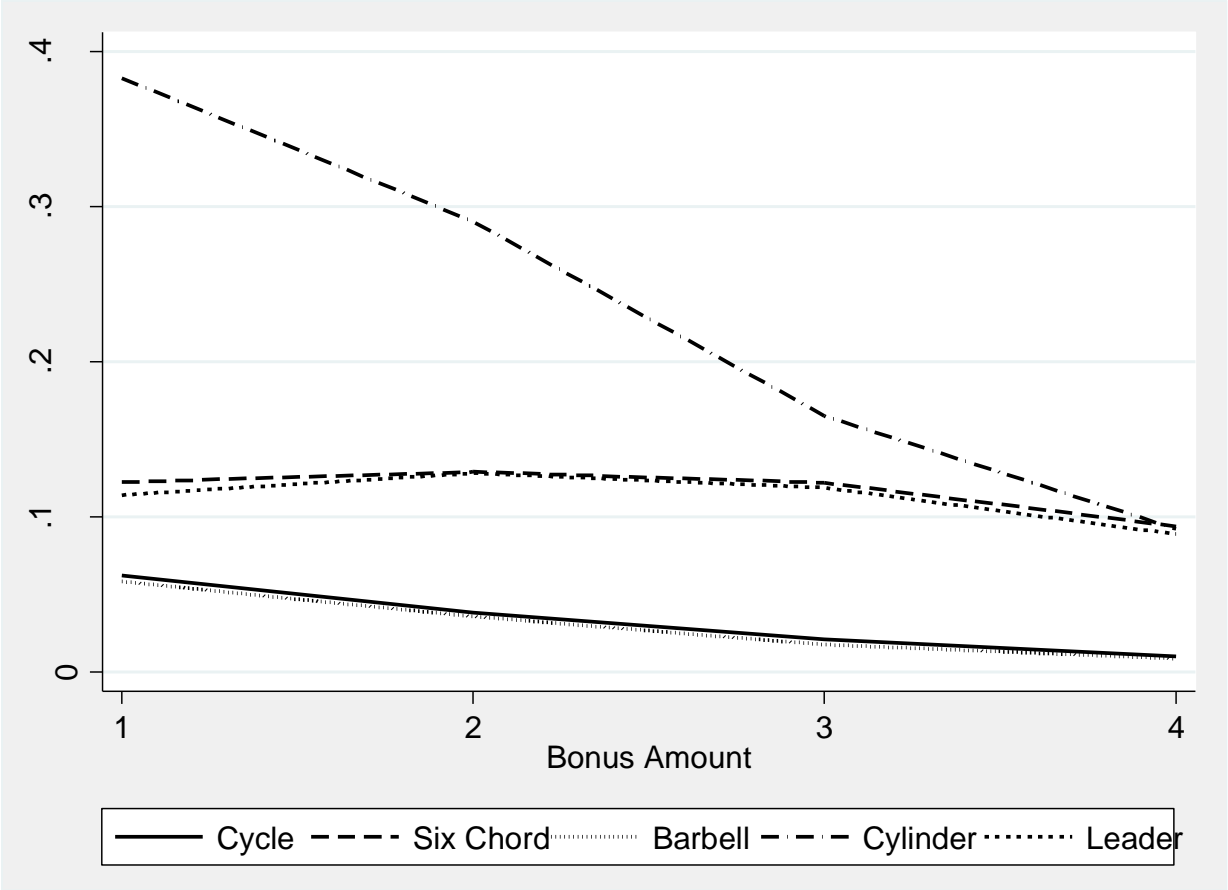**Figure 6: Network Connections Reduce the Impact of Asymmetric Coordination**

Table 1: Average Degree for each Network

Network	0-chord cycle	Barbell	6-chord cycle	Cylinder	Leader
Average Nodal Degree	2	2.125	2.75	3	3.625

Table 2: Overall Completion and Time Spent on Each Graph Coloring Problem

Bonus Ratio	0	1	2	3	4
Proportion of Networks Solved and Average Time Spent on a Trial	.95 (18/19) 31 seconds	0.50 (3/6) 144 seconds	0.56 14/25 128 seconds	0.43 13/30 149 seconds	0.25 6/24 153 seconds

Table 3: Logit Analysis of Successful Coordination

	Coefficient (s.e.)
Session count	0.003 (0.08)
Cycle 0	5.50 (3.15)*
Barbell	2.19 (1.95)
Cycle 6	3.06 (2.17)
Cylinder	7.93 (3.66)**
Asymmetric Incentives	-0.28 (0.61)
Level of Asymmetry	0.38 (0.79)
Asymmetry level for Zero Chord	-2.51 (1.24)**
Asymmetry level for Barbell	-1.38 (0.78)*
Asymmetry level for Cycle 6	-0.62 (0.73)
Asymmetry level for Cylinder	-2.19 (1.11)**
Total Number of Sessions	104
Number of Groups	4

*=significant at 0.10 level, ** significant at 0.05 level

Excluded category for the networks is the leader Network.

Regression includes group-level fixed effects

Table 4: Duration Analysis of Time Until Successful Coordination

	Hazard Ratio |z statistic|
Session counter	0.96 (0.78)
Cycle 0	0.83 (0.46)
Barbell	0.86 (0.33)
Cycle 6	1.15 (0.32)
Cylinder	5.01 (2.21)*
Bonus	-.14 (3.78)*
Bonus Ratio	1.15 (0.38)
Bonus Ratio for Cycle 0	0.60 (3.52)*
Bonus Ratio for Barbell	0.58 (3.29)*
Bonus Ratio for Cycle 6	0.96 (0.27)
Bonus Ratio for Cylinder	0.67 (2.18)*
Number of Observations	104

Excluded category is the leader network.
Analysis is stratified by day to account for any day to day variance in ability to solve coordination problem. Standard errors are clustered based on the network.