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What is the Impact of Communication Structure on a Community's Ability to Successfully Manage a Common Pool Resource? A Research Proposal

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Introduction

Many of the world's environmental resources are common pool resources. Forests, waterways and meadows are often collectively owned, making these resources rivalrous but non-excludable. This does not bode well for their management: Hardin (1968) teaches us that, given the disparate individual and social incentives, common pool resources must either end in collapse or be subject to aggressive government intervention. Although logically consistent, this "tragedy of the commons" is not always observed in practice (Ostrom et al, 1999). Hence, Ostrom et al (ibid) argue that when members of a community have the opportunity to communicate with one another, build trust relationships and thus craft institutions, the common pool resource may be maintained without external force. Empirical and experimental literature supports this claim (Ostrom, 2005).

Several experimental studies have also shown that communication has a profound effect on resource management (Ostrom et al, 1994). These studies have focussed on communication as a binary variable (i.e. there is either full or no communication) and thus disregard the effect the structure of the communication mechanism may have on resource management. However, theories on structural holes suggest that how communication is structured can have a significant impact on group performance (Monge & Contractor, 2003). Likewise, Ostrom (2005) explains that in any given interaction the social role of actors is significant in shaping institutions and group responses. If, as this paper posits, social roles in turn shape the structure of communication, then we need to examine the organization of communication to interpret and study institutions. Thus, taking a more nuanced look at how communication shapes group responses to management is imperative in optimizing policies and overcoming the tragedy of the commons.

This paper seeks to contribute to the analysis of the impact of communication by outlining an experimental design that manipulates the modes of communication available to participants. The design therefore expands on the binary view of communication and thus permits the analysis of the impact of the *structure* of communication on common pool resource management decisions.

The paper will be structured as follows: The next section will establish the importance of studying communication by examining multiple theories of how communication impacts common pool resource management. Here I will also elaborate on experimental work on communication in common pool. The subsequent section will develop a set of hypotheses. Thereafter, the paper will outline the experimental design used to test hypotheses derived from the communication theories. Finally, the paper will conclude by highlighting possibly limitations of the research proposal and suggesting extensions to the design.

Networks and Common Pool Resources

Networks are important. We have found that personal characteristics alone cannot fully explain observed behaviour. When we add institutional arrangements to the analysis we are still excluding a key component that motivates human behaviour: Social ties. How individuals perceive and react to any given situation will depend on their environment and the opinions held by their aquaitances.[1]

Networks are defined through the ties between nodes. Hence, we can have multiple networks for the same group of actors/nodes (Monge & Contractor, 2003). The paper will focus on one such network, the communication network.

With regard to common pool resources (CPR), the importance of communication networks in their management is twofold: It acts as a means for information dispersion and it allows individuals to interact and in turn build trust relationships (Ostrom et al, 1994). In effect, repeated interaction creates a new network by establishing ties amongst the actors involved. These new ties may in turn lead to a reduction in uncertainty and a change in payoffs by means of interrelated utility curves and a newly practiced idea of reciprocity. With these changes in the structure of the CPR game, behaviour exhibited by participants will change. This observation has been made in the experimental literature. Overall, when communication was introduced in CPR games, groups that interacted with one another tended to receive greater payoffs than groups that did not have the opportunity to communicate.

<u>Communication in CPR Experiments</u>

CPR management has been studied within laboratory experiments to assess whether Hardin's prediction of the tragedy of the commons held. It was found that groups did tend to overexploit a CPR (i.e. individuals extracted more from the resource than what is predicted under the Nash equilibrium and considerably more than the social or Pareto optimal extraction rate). However once face-to-face communication was introduced, extraction rate fell and accrued rents increased from about 30% to near social optimum (Ostrom & Walker, 1991) (see experimental design for a more in depth discussion of rent accrual and efficiency). Changes in frequency of communication (one-shot

[1] For an empirical application of this concept, with respect to political behaviour, see Zuckerman (2005).

communication before a set of several decision rounds versus the opportunity to communicate before each decision round) alter the increase in efficiency but does not change the underlying finding: Communication improves group payoffs (Ostrom et al, 1994). Furthermore, changes in participant endowments (i.e. the amount they can extract from a CPR) also do not negate the positive impact of communication.

These experiments have been central in helping us understand how CPRs are managed and how repeated communication may help avoid the tragedy of the commons; however, they have so far tested communication only as a binomial variable. A more nuanced look at communication may be useful in several ways.

Why Should We Care about Structure?

Distinguishing Between Trust and Information Flow

As discussed above, communication leads to improved information dispersion and builds trust relationships amongst actors. There is value in being able to distinguish between the impacts on rent accrual of these two effects. Although we may never be able to fully disentangle trust from informational flow, we can design networks where one may be favoured more than the other. For example, highly centralised networks are not conducive to trust building, as trust flourishes most when nodes share several ties. By having overlapping ties, there is greater monitoring capability and more accountability, and reputational effects are more far reaching[2] (Berardo & Scholz, 2010). On the other hand, centralised networks have been found to be relatively efficient in dispersing information (Bavelas, 1950). Hence, if we find that centralised communication structures lead to results similar to those of full communication, then we can infer that informational flow may be more important than trust to efficient CPR outcomes. Of course, there are several caveats with this approach but it is an initial step to disentangling the sources of improved CPR management performance.

External Imposition of Structure

Identifying which network structures are conducive to efficient CPR management is of direct practical relevance. Communities manage CPR within an environment of national and local legislation and organization. These policies impose structures on the individual communities. Although informal communication networks will arise organically between individuals in the community and between communities, there are still outside structural constraints.[3] To improve policy design, it would be useful to examine whether centralised structures, where management groups communicate with a central authority figure that formulates and implements regulation, result in as efficient a CPR outcomes as decentralised systems do.

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[2] Consider when an actor *i* abuses another actor *j*'s trust. If they have overlapping ties, by spreading the word about the betrayal *j* can punish *i*'s much more significantly than if they share no common ties. *j* reaches a much larger portion of *i*'s network and the consequences are thus more severe. This acts as a deterrent to defection of part of *i*.

[3] The external imposition of formal communication networks warrants the proposed approach of imposing communication constraints to test for structural impacts.

The Cost of Communication Ties
Finally, consider that the maintenance of communication ties is costly. Individuals can only maintain a limited number of meaningful ties,[4] such that every tie comes with an opportunity cost. Thus, it would be of interest to determine the minimum number of ties necessary to attain the same resource management outcomes as compared to a fully connected network.[5] Hence, the experimental design will outline several treatments with differing number of ties and assess how these compare. Clearly, number of ties alone may not be a good predictor of CPR performance; however, the number of ties will not be assessed distinct from structure.

<u>A Nuanced Look at Communication</u>
There have been experimental treatments where the structure of communication was tested. For example, Bavelas (1950) analyses how different communication structures impact the speed and ability of a group to arrive at and implement a collective solution to a problem. He finds that highly centralised networks are faster at arriving at a solution, as there are fewer ties that need to be bridged in order for one or a group of actors to have all the information necessary to understand, interpret and solve a problem. These networks also seem to make fewer mistakes when implementing the solution. However, he also observes that there is greater potential for innovation in decentralised networks (especially ring shaped networks). Many ties need to be bridged to distribute information to the whole group. This makes individuals feel involved, gives them time to think about the process, and subsequently makes them more likely to get involved and suggest innovations. This may be of particular significance in highly complex management situations (e.g. for managing CPR).

As intriguing as these results are, they are not directly applicable to CPR management. Bavelas (1950) studies how communication structures impact coordination problems rather than collective action problems such as CPR games (commonly studied as prisoner's dilemmas). By doing a content analysis of discussions amongst participants, Janssen (2010) takes a more nuanced view of the role of communication in CPR management. In addition, Schmitt et al (2000) analyse the impact of communication in CPR games when the community is confronted with external appropriators that do not partake in the discussions. Neither study is an explicit analysis of how the structure of communication affects CPR payoffs.

Hypotheses
<u>Proposed Network Structures</u>
This research proposal aims to study the impact of externally imposed formal communication network structure on CPR outcomes. It aims to test the following structures (see Appendix 1 for diagrammatic representations):

A. *Empty network*
   This is used as a control network to determine whether the proposed experiment results in similar outcomes as previous experiments. It also serves as a baseline to

[4] Meaningful refers to personal interaction rather than being linked up on social networking sites.
[5] This motivation still holds true if communication ties have intrinsic value.

determine whether and how communication affects CPR outcomes in the first place.

B. *Fully connected network*
This is the structure tested in prior experiments. It will also function as a yardstick for measuring the success of the remaining communication structures.

C. *Centralised network*
This hierarchical structure, commonly studied in organizational theory, allows n-1 members to communicate with only one central node. This design will give us some insight into how trust versus information flow affects accrued rents. By virtue of its frequent use in institutional design, establishing the effect of this structure on CPR outcomes is essential for developing more effective policies.

D. *Circle network*
This network combines decentralisation and small number of ties. This will be key in testing whether structures rather than number of ties (i.e. in comparison with the fully connected network) are instrumental in managing CPR at Pareto optimal levels.

E. *Unconnected dyads*
This is, in effect, an extension of the Schmitt et al (2000) research design where an insider group is posited against an outsider group. Both groups have access to the CPR. In this design, we have four insider groups that, at the same time, act as outsider groups because they cannot communicate amongst each other. These structures are observed frequently in cross-boundary CPR problems (e.g. watershed management). Although there is communication within one community, these groups will not be in touch amongst each other. However, for effective CPR management, cooperation at a higher level is necessary.

Means of Analysis

To reflect the motivations for the study of communication outlined above, the CPR outcomes will be analysed in terms of:

1. Rent dissipation
2. Time taken to arrive at a collective strategy
3. Individual performance

1. Rent dissipation
Rent dissipation is the main method of testing whether informational flow versus trust building will lead to greater efficiency in terms of rent accrual. This makes outcome predictions difficult. However to generate testable hypotheses, I will make predictions on the basis of the closure interpretation of social capital (Putnam, 1993 in Burt, 2001). Network density[6] (i.e. number of ties divided by

[6] Alternatively I could have formulated a hypothesis in terms of reachability, which would have favoured network structures where nodes are separated by fewer links (e.g. the centralised network).

number of total possible ties) is an indicator of social capital. Greater social capital will lead to more efficient outcomes.

Furthermore, once a strategy has been agreed on, I expect less defection in networks with a flatter hierarchical structure. This is a reflection of inclusive strategy development. Institutions that have been developed collectively will have a higher agreement rate. Even if strategy developed is identical to strategy developed in centralised structure, having an institution imposed will lead to some resistance. In addition, if the central node is not accepted as a figure of authority, then individuals are more likely to deviate as time progresses. Hence:

- **Hypothesis 1: B > D > C > E > A outcomes**
- **Hypothesis 2: C ~ D similar**[7]

2. *Finding a collective strategy*
   Bavelas (1950) finds that hierarchical structures are quicker to develop and implement, as information has to travel through fewer nodes to reach everyone. In network C, the central node comes up with a strategy and then informs all remaining nodes. In network D, information needs to pass around the whole circle for full information to take place. In network E, a strategy can only be discussed amongst couples. Thus, to have a network wide strategy, trial and error will be required. Comparing this with full communication: Network B will take less time to develop a strategy than D and E due to fewer communication paths, but there may be an overload of communication and agreement may be hard to come by (it is easier to agree where n is small). Therefore:
   - **Hypothesis 3: C < B < D < E < A time to agree on a strategy**

3. *Individual performance*
   This section is primarily concerned with the central node in network C. All other nodes are otherwise structurally equivalent.

   The bridging concept of social capital (Burt, 2001) suggests that individuals that span structural holes will perform better than individuals that do not. In network C, the central node connects all other actors. She can coordinate between the actors and suggest a collective strategy. She is then in a prime position to defect from the suggested strategy and maximize her own profits. Given this position, however, I expect other actors to immediately suspect that the central node defected. This, if it does not reduce the central node's relative payoffs, will most likely weaken the acceptability of a centrally implemented strategy and will thus affect rent dissipation.

   On the other hand, the central actor may be able to foresee her immediate implication in defection. This in turn may be enough to keep her from defecting,

[7] However D may outperform C, as network structures with flat hierarchies tend to be more innovative than hierarchical structures (Bavelas, 1950). This suggests that if some strategies for sustainable resource management fail, network D may be more resilient (i.e. better able to develop a new, more effective strategy).

and she will thus not receive higher payoffs than her group members. It is thus not clear what rational choice theory would predict. However, given the anonymity of the game, she remains in the prime position to exploit the network structure, suggesting the following hypothesis:

- **Hypothesis 4: Central actor > Other actor payoffs**

Experimental Design

This section will outline the experimental design used to test the aforementioned hypotheses.

<u>Structural Form</u>

The experimental design outlined in this section borrows heavily from the experimental setup in Walker et al (1990), Ostrom et al (1994) and Schmitt et al (2000). It will thus rely on a quadratic formulation of the declining marginal per capita returns (MPCR) to investment observed in CPR markets. Concern has been raised that appropriation over and beyond the Nash equilibrium may be a reflection of the complexity of the experimental set up (Delaney, 2009). In other words, either the potential payoffs do not warrant the effort required to understand and determine payoff maximizing investment strategies or participants are overwhelmed by the complexity of the experiment. Nevertheless, quadratic modelling of CPR MPCR are commonly used (see for example Schmitt et al, 2000). Furthermore, cognitive limits may be avoided to some extent by informing participants of Pareto and Nash equilibrium investments. This may also act as a means of ensuring common knowledge, a basic assumption for efficient outcomes. In addition, this experimental design has players receive tables or a calculator (as in Delaney, 2009) so that they are able to determine individual payoffs given group investments into the CPR. A final comment to justify the use of the quadratic CPR MPCR form: this allows comparison between results obtained in this experiment with those previously obtained by Ostrom et al (1994).

General Setup

The proposed experiment is a computer-based CPR game built on single-play CPR games[8] and thus has a fixed number of individuals (N=8 in this experiment). They are given 25 tokens each to invest either in Market 1 or Market 2 (the CPR). Market 1 has a linear payoff function:

$$\mathbf{F_1(x_i)=\$0.05(e-x_i)}$$

where e is the individual token endowment (in this case e=25) and x_i is individual investments in Market2).[9] Market 1 hence yields constant marginal returns (MPCR), $MPCR_1$=$0.05. Market 2 however has a quadratic payoff function:

$$\mathbf{F_2(\Sigma x_i)=\$0.01[23\Sigma x_i-0.25(\Sigma x_i)^2]}$$

It thus exhibits decreasing MPCR. Subject i's earnings will therefore be the income from investments in Market 1 and a fraction of the payoffs from Market 2 proportional to her investment into Market 2 (i.e. $\$0.05(25-x_i)+(x_i/\Sigma x_i)(\$0.01)[23\Sigma x_i-0.25(\Sigma x_i)^2]$). Individual earnings are hence dependent on group investments.

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[8] There are multiple rounds, but subjects do not know how many rounds will be played.

[9] I will explain the CPR game using the values imposed by SSW. For general results of CPR games please see SSW.

Pareto & Nash Equilibria
Maximising group payoffs we arrive at the Pareto investment level for Market 2. At 36 tokens, $MPCR_1=MPCR_2=\$0.05$ (see figure 1). As $MPCR_2$ is decreasing, it is now more profitable to invest all further tokens in Market 1.

The Nash equilibrium is arrived at by maximising individual payoffs, $\pi_i=F_1(x_i)+F_2(x_i)$. If the CPR is a symmetric game, the Nash equilibrium is at $\Sigma x_i=64$ with $x_i=8$ (i.e. no individual has any incentive to invest more or fewer tokens in Market 2[10]).

Measuring Efficiency in Terms of Rent Accrual
Efficiency of the investment decisions will be measured in terms of rents dissipation. Rents refer to the earnings from a CPR over and beyond opportunity cost—that is, the earnings from the most profitable investment alternative (in this case, earnings if tokens had been invested in Market 1). Rents are fully dissipated (i.e. rents accrued are zero) when the earnings accrued are equal to opportunity cost.

This experimental design will mirror the operationalization of rents used by Schmitt et al (2000). The authors measure extracted rents as a percentage of maximum possible rents and calculate these in terms of group earnings:

R=[(Earnings from Market 2 from investing x tokens)–(Earnings if x tokens had been invested in Market 1)] (100) / [(Earnings from Market 2 from investing x* tokens)–(Earnings if x* tokens had been invested in Market 1)]
where R is rent and x* is Pareto investment level

As explained above, maximum group earnings in Market 2 occur when aggregate investment is 36 tokens. Thus, all group rents are measured with reference to the Pareto investment level. To illustrate, when investing 64 tokens in total (Nash equilibrium when N=8), we receive:

$$R=100[\$0.01(23(64)–0.25(64^2))–\$0.05(64)] / [\$0.01(23(36)–0.25(36^2))–\$0.05(36)]$$
$$= 39.5\% \text{ of maximum.}$$[11]

This then gives us a measure of efficiency. The Nash equilibrium is hence 39% efficient. In comparison, when investments are Pareto efficient (i.e. 36 tokens in total) then the market is 100% and no rents were dissipated. When rents are fully dissipated, the makret is completely inefficient.

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[10] In contrast, in Pareto efficient investment each individual can increase their personal payoffs by investing more in Market 2 (because individuals receive ($x_i/\Sigma x_i$) of payoffs) but thereby reduce aggregate payoffs.
[11] From Figure 1 we can infer that although Market 2 will yield positive payoffs up to 92 invested tokens (i.e. y=0 when x=0 or 92), rents will only be positive up to 72 invested tokens (this is where the opportunity costs i.e. returns from Market 1 are greater). Greatest possible rents are at 36 invested tokens, where $MPCR_1=MPCR_2$ (as can be seen by the dotted line (i.e. shifted $F_1(\Sigma x_i)$) tangential to $F_2(\Sigma x_i)$ when $\Sigma x_i=36$).

Baseline Experiment

Having elaborated the payoff structures of Market 1 and 2, let us now consider the experimental procedure.

Participants will be randomly assigned to groups of eight. They will each receive 25 tokens per round and have the opportunity to invest in Market 1 and/or 2 as outlined above. They will play 20 decision rounds.[12] Following every round, players will receive information on their investments, group investments and their individual payoffs. Although they will be aware of group investment decisions, they will not know the individual investments made by their group members. Thus, all investment decisions are anonymous.[13] Players are not able to communicate amongst each other to coordinate strategies.

Treatments

There will be four treatments and one control. (Henceforth, for descriptive ease, the control group will be considered a treatment group. For lack of a better phrase, the control will be a non-treatment treatment group.) The treatments are implemented after ten rounds of the no-communication baseline. Participants are not informed ahead of time that there will be a change in procedures so as to avoid strategic investment decisions with respect to the expected treatment.

Ideally, there would be five groups of eight people per treatment and thus a total of 200 participants. Individuals would be randomly assigned to groups and treatments. The treatments will be implemented as follows:

A. *Control group, (i.e. non-treatment treatment group)*

   This group will continue to play no-communication rounds as outlined under the baseline. This group acts as a control so as to identify investment decisions that would have occurred without treatment.

B. *Full communication*

   This treatment mirrors the communication treatment as utilized in Ostrom et al (1994). Prior to every one of the last ten decision rounds, subjects will have the opportunity to communicate with *all* members of the group via their computer screens. A chat will open up for five minutes where group members can communicate. There are no limitations to the content of the discussion except that individuals may not reveal their identity—hence, anonymity is maintained. Furthermore, individuals have the opportunity to leave the chat when they feel that there is no further need to communicate.

[12] Participants will not be informed about the number of rounds played so as to arrive at an infinite repetition equilibrium.

[13] In fact, the experimenter will also not know which participant made which investment, thus guaranteeing a double-blind experiment.

After the chat is terminated, participants make their individual investment decisions for the round. Thereafter, they receive their payoff information and the next round commences with a five-minute chat.

C. *Centralised communication*
This treatment is similar to treatment B in terms of procedure; however, communication will be restricted. Seven participants will only be able to communicate with a central player. This player in turn is able to communicate with all group members. Hence the central player will have seven different chats to operate. Participants are randomly assigned to positions in the communication network (central node or "normal" group member), so as to avoid selection bias.

D. *Circle*
Treatment D will follow the same procedure as B and C. After ten rounds of no communication, the groups will play ten rounds with the opportunity to communicate for five minutes prior to investment decisions.

Treatment D differs from the other treatments with respect to the constraints on communication. Participants will have the opportunity to speak to two members of the group only. Each participant subject *i* communicates with will have one link to a group member to which *i* is not directly linked. This means that the group is fully connected, but for *i* to reach all group members she must go through her direct communication partners and their communication partners. In other words, the communication pattern resembles a circle where information is dispersed by means of "Chinese whispers."

E. *Unconnected dyads*
Subjects will be able to communicate with one other group member. These communication couples are unconnected to one another, meaning that communication will take place in four independent chat forums. This treatment is a variation of the communication treatment utilized by Schmitt et al (2000).

<u>Analysing Results</u>
As mentioned above, I will interpret the results in terms of efficiency of group outcomes, individual payoffs with respect to (n-1) average payoffs and speed with which collaborative strategies are found. The first two interpretations will rely on statistical analysis whilst the latter relies on content analysis of the discussions.

Statistical Analysis
Whenever attempting to statistically analyse small samples, we must be wary of drawing strong conclusions from the analysis. Although randomization present in experimental design will take care of selection bias and hence add more statistical power to estimates, I will have a maximum of 25 observations for the interpretation of efficiency of group outcomes. This is because we must distinguish between group rents accrued in the individual rounds. We cannot simply find an average efficiency value for each treatment, as outcomes will not be independent within groups across rounds. Thus we must compare

outcomes per round. This limits observations to 25 in the first ten rounds and then 5 per treatment for each of the final ten rounds. Therefore, although results will be informative, they cannot be used to make strong causal statements.

The analysis of individual payoffs is subject to the same limitations as the interpretation of group level outcomes, perhaps even more so. As each group consists of eight individuals, it will be nearly impossible to determine (with reasonable doubt) whether individual payoffs are different from group average payoffs. However, the comparison should be informative its own right. We do not require statistical "certainty" to be able to identify trends. These trends could then be studied in larger scale experiments to determine statistical significance.

Content Analysis

Participant discussions will be recorded and analysed to determine how many rounds are required for the group in question to agree on a common strategy. Although analytical methodology must be refined during the process of analysis, a preliminary definition of common strategy would be when all active discussion members (not all group members may choose to participate in discussions) openly agree on a strategy. Using this definition, I could assess and compare the speed of agreement across different treatments.

Conclusion and Discussion

As discussed above, communication is significant in the management of CPRs. When communication is permitted within CPR games, rent accrual improves. However, given that communication ties are costly, we would like to know what type/structure of communication is as efficient (in terms of rents accrued) as full communication. In CPR experiments, communication has previously been studied as a binomial variable and has thus not shed much light on the effect of communication structure. This is the gap that this proposal aims to fill. By manipulating communication mechanisms within a CPR game, we can observe whether and how investment (i.e. CPR appropriation) decisions change. This information may be significant in the design of policy and participation structures for collective action.

As with most experiments, we must consider external validity. Participants recruited are likely to be systematically different from individuals faced with CPR management problems. Regardless, there is a large number of very diverse common pool resources. If recruited participants are undergraduate students at IU. they are likely to have been confronted with a CPR problem, be it a dirty kitchen in a shared apartment or the IU bus system. Furthermore, is it not plausible, as well, that groups managing a community forest are systematically different from those managing a fishery? In sum, these experiments may identify common trends in the CPR management but may not be useful for case-by-case prediction.

Restricting communication as proposed may not be an accurate reflection of reality, as social ties and communication networks require time to develop and in turn yield results. We must, however, keep in mind that experiments must simplify in order to be tractable and to single out effects. Again, if not a truthful representation of reality, experiments are useful in disproving theories, shedding light on hypotheses and identifying tendencies and underlying trends (Smith, 1994). Nevertheless, we must consider that the experimental design is attempting to ascertain the impact of formal network structure on rent accrual. These structures are often imposed onto communities through external actors in the forms of governmental policies. This suggests that the experimental design is a plausible recreation of reality and that the results are likely to have external validity.

As with any research design, this experimental setup can be expanded upon by adding participant heterogeneity, changing group sizes and altering payoff structures. However, this experiment is simple, allowing us to focus on the matter at hand: the effect of communication structure on rents. This is the first step in identifying the types of structures that should be promoted when designing common pool resource policy and those that are best avoided.

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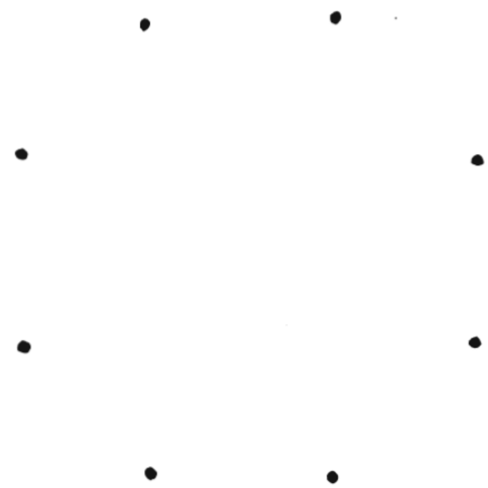
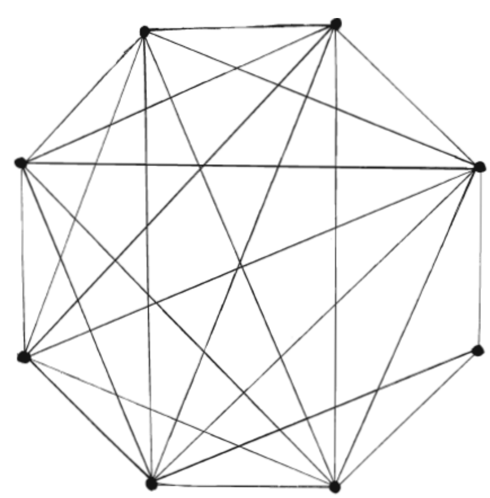
Appendix 1: Network Structures

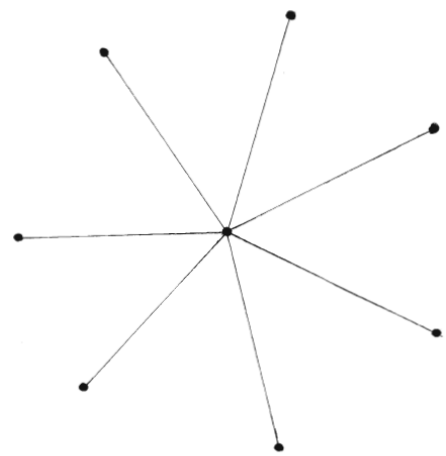
Empty Network



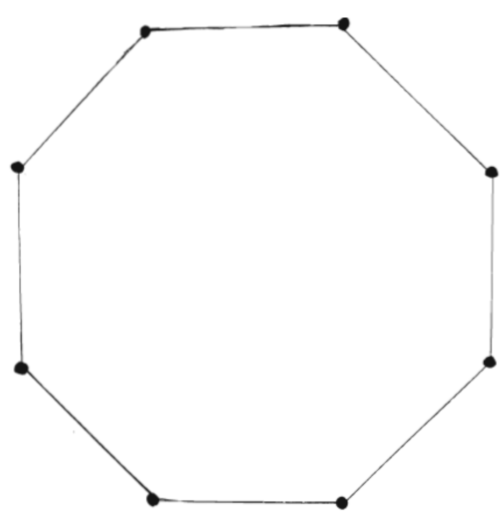
Fully Connected



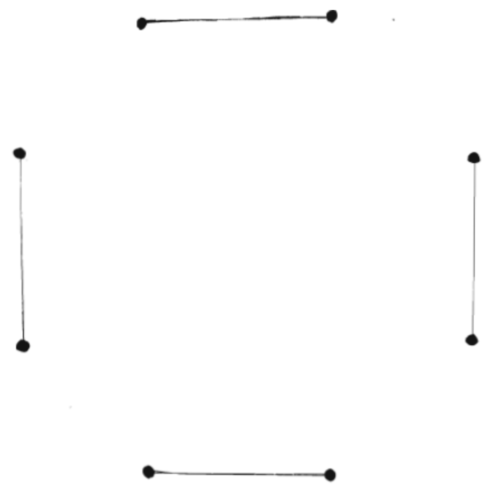
Centralised



Circle



Unconnected Dyads



Appendix 2: Figures

Figure 1: Market 1 & 2 Payoffs