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Abstract

Policy outcomes in all but the simplest policy systems emerge from a complex of ecology of games featuring multiple actors, policy institutions, and issues, and not just single policies operating in isolation. This paper updates Long's (1958) ecology of games framework with Scharpf's (1997) actor-centered institutionalism to analyze the coordinating roles of actors and institutions on the context of the ecology of water management games in the San Francisco Bay. Actors participating in multiple institutions are analyzed using exponential random graph models for bipartite networks representing different assumptions about policy behavior, including geographic constraints. We find that policy coordination is facilitated mostly by Federal and state agencies, and collaborative institutions that span across geographic boundaries. Network configurations associated with closure show the most significant departures from the predicted model values, consistent with the Berardo and Scholz (2010) "risk hypothesis" that closure is important for solving cooperation problems.

Policy Coordination in an Ecology of Water Management Games

This article draws on Long's (1958) ecology of games (EG) framework to analyze the coordinating roles of institutions and actors in policy settings where outcomes emerge from actors pursuing their self-interests in multiple, interdependent and rule-structured games taking place within a geographically-defined policy arena.[1] The EG perspective grapples with the fundamental and non-ignorable reality that all but the simplest policy arenas feature multiple policy institutions operating simultaneously. The potential lack of coordination among different institutions and actors is a recipe for collective-action problems such as the inability to provide public goods or overexploitation of common-pool resources, which are ubiquitous in the water management setting of this article but also in many other policy issues.

How policy activities are coordinated in such settings is one of the "big questions" in public network management theory (Agranoff and McGuire 2002; Klijn, Kooperman, and Termeer 1995), which ultimately has the goal of understanding how to engineer the EG to achieve practical effectiveness. The EG metaphor is one way to describe what Fredrickson (1999) called the "disarticulated state" involving multiple government and non-governmental actors trying to solve complex and interrelated problems (O'Toole 1997; Vigoda 2002;). The EG framework adds to this discussion by explicitly considering the role of *multiple policy institutions* (what van Bueren, Klijn and Koppenjan 2003 call policy arenas) linked through joint participation by actors, where decisions made in different institutions are interdependent. Analyzing the structure of such networks is a necessary first step for understanding how they are linked to policy outcomes.

[1] We treat the terms policy institution and policy venue as synonyms because they all refer to interactions among actors guided by rules (e.g.; consensus versus voting, which actors can participate) about how collective-decisions are made. The process of interaction that occurs in a given institution could also be referred to as a policy or planning process, which are the terms normally used in the vernacular of real policy actors.

Our analysis blends Long's perspective with Scharpf's (1997) actor-centered institutionalism to focus on two types of mechanisms—political actors and policy institutions—for coordinating governance and policy activities within the ecology of games. Long is pessimistic about the possibility of coordination—"The lack of over-all institutions in the territorial system and the weakness of those that exist insure that co-ordination is largely ecological rather than a matter of conscious rational contriving." (p.255). However, while Long does see a role for "civic leadership" where widely-recognized political leaders participate in multiple games, active public administration of policy activities within the EG is a difficult task.

Scharpf envisions a more important role for public administration by focusing on the administrative capacity of specific actors, which is a function of their access to police power, expertise/information, and financial resources. Actors use their political influence to shape policy decisions and behaviors in ways that reflect their preferences. The *actor hypothesis* suggests that politically powerful actors coordinate policy activities by participating (and possibly creating) in many different types of policy institutions, and becoming "popular" with other actors, who want to participate in the same venues as the politically powerful.

The *institutions hypothesis* focuses on the "observed reality of political interaction that is driven by the interactive strategies of purposive actors operating within institutional settings that at the same time enable and constrain these strategies" (Scharpf 1997, p. 36). Institutions consist of the formal and informal rules that structure human interaction by defining the set of actions that may be chosen and the payoffs for those actions. The neo-institutional economics literature analyzes how institutions affect the overall transaction costs (information seeking, bargaining, monitoring, and enforcement) of economic exchange, which is viewed as a problem of cooperation (North 1990; Williamson 1988).

Solving collective-action problems requires actors to deal with two simultaneous issues: finding and implementing mutually beneficial policies (efficiency), and bargaining over the distribution of mutual benefits (distribution). Scharpf (1997) provides the simple idea of the "negotiator's dilemma" to describe these two key processes. However, other authors have noted the importance of bargaining over the distribution of mutual benefits in prisoner's dilemma and other types of social dilemmas (Bowles 2004; Snidal 1985). The important point is that coordination in an EG involves actors using political resources to capture the greatest share of the gains over cooperation. Political conflict and bargaining over efficiency gains is one source of transaction costs in the EG, and effective coordination mechanisms would minimize the transaction costs of searching for mutually beneficial solutions, bargaining over distribution, and monitoring and enforcing the resulting constellation of decisions and agreements. However, there is no guarantee at any given point in time that a particular EG exhibits the right configuration of actors and institutions to minimize transaction costs, especially when the underlying problems are dynamic and feature multiple sources of uncertainty.

With a few exceptions (Dutton 1995; Lubell, Henry, and McCoy 2010; Conwell, Curry, and Schwirian 2003), the EG framework and its variants have received little empirical testing and remained largely in the realm of abstract theory with some descriptive case study support. In this paper we set out some basic tenets of an EG theory, but it is not our empirical goal to examine all the propositions in this argument. Rather, we use network analysis to focus on the structure of relationships among actors and institutions. We represent actors and institutions as comprising the nodes of a *bipartite* or *affiliation* network. A bipartite network has two distinct types of nodes, with connections between nodes of different types. In our case, a connection

represents an actor participating in an institution; connecting an actor to an institution constitutes a policy game being played.

Our most sophisticated analytic approach will use exponential random graph models (ERGM) for bipartite network structures (Wang et al. 2009). We estimate a nested series of increasingly sophisticated ERGM models, each representing different assumptions about strategic behavior in the EG. We make inferences by examining both the parameter estimates of the models, and the residual structural effects not completely explained by a particular model.

These hypothesized patterns will be derived from theorized structural processes within the EG. For example, our analysis provides insights into the *risk hypothesis* recently forwarded by Berardo and Scholz (2010). The risk hypothesis argues that actors' preferences for network structures depend on the payoffs from the underlying games being played. When the policy ecology consists of mainly coordination games, actors prefer to connect to "popular" institutions that increase the efficiency of information seeking. When the policy ecology consists of risky cooperation games with free-riding incentives, actors prefer "closed" network structures with redundant information but the ability to conditionally cooperate and sanction other actors on the basis of reputation and history of interaction. The models we use extend this argument to the case of bipartite networks.

Water management in the San Francisco Bay of California provides the empirical context. The SF Bay encompasses numerous environmental collective action problems including water quality, water supply, climate change, and biodiversity. There is also a range of actors including Federal, State, and local government agencies, special districts, environmental groups, economic interest groups, and researchers. There are a variety of policy institutions, including collaborative partnerships, regulatory processes like Total Maximum Daily Load planning under

the Clean Water Act, advisory commissions to government organizations, and associations of interest groups. Of specific interest are the more recent attempts at collaborative institutions in this area, including Integrated Regional Water Management, the CALFED Bay-Delta Program, and others. Such collaborative institutions are appearing in nearly every policy subsystem domestically and internationally, and thus are receiving serious research attention in terms of their ability to encourage cooperation and solve environmental conflicts (Sabatier et al. 2005; O'Leary et al. 2006; Koontz and Thomas 2006; Ansell and Gash 2008).

The next section provides an overview of our adaptation of the EG framework, with a focus on the coordination roles of actors and institutions. Because in this article we are principally interested in understanding EG structures, we translate relevant propositions from the theory into network-related hypotheses, and describe our research design and data collection procedure. The analysis section begins by describing the observed network structure of the Bay Area EG, and moves towards ERGM estimates. The conclusion summarizes our findings and speculates on their meaning for political power, public administration, and policy effectiveness in complex adaptive systems analyzed using the EG framework.

Actors and Institutions in an Ecology of Games

Our version of the EG framework relies on six interrelated concepts: policy issues, policy actors, policy institutions, policy games, policy subsystems, and time. Although our empirical representation of the EG as a bipartite network does not capture all of these elements, this section briefly defines them and describes the coordinating roles of political actors and institutions.

Policy issues involve some type of substantive collective-action problem such as water pollution, air pollution, traffic congestion, or loss of biodiversity. The strategic structure of these

collective-action problems are the same as in traditional game theory—payoffs from using resources are interdependent, actors often ignore the social costs of their decisions, and equilibrium outcomes (if they exist) are often inefficient. The EG framework adds the complication that issues may be interconnected through biophysical, economic or social processes, so decisions made in the context of one issue may directly affect payoffs in other issues. Policy outcomes depend on how individuals make decisions regarding the resources involved with each issue, for example, the amount of non-point source pollution that flows into San Francisco Bay or the integrity of the levee system.

Policy institutions are "collective-choice" settings where actors collectively make decisions about the “operational” rules governing individual issues (Ostrom 1990). Each institution derives its authority from some type of legislative, administrative, or judicial decision made at higher levels of the political system. Policy institutions typically have jurisdiction over multiple issues at a given time, and hence conversely policy issues are linked to multiple institutions. For instance, the Bay Area IRWM might address land-use and biodiversity, and biodiversity is also affected by habitat conservation planning under the Endangered Species Act. These interconnections increase the likelihood of decisions in one institution affecting decisions in other institutions. Real-world policy actors often refer to policy institutions as "planning processes" or “policy venues” that shape implementation of specific resource management activities.

Policy actors have some “stake” (hence the policy vernacular term “stakeholder”) in the outcomes of collective-choice and the resulting rules governing specific issues. Policy actors could be individual resource users like farmers or fishermen, or political actors like agency officials, interest groups, or elected officials. The nature and magnitude of the stakes may vary

across different policy actors—fishermen care about the fish populations and catch limits, bureaucrats care about budgets, politicians care about votes, and interest groups care about members and funding. Actors participate in policy institutions with jurisdiction over issues they care about, and also form networks with others actors in order to gain key political resources like information, credibility, and political influence (Berardo and Scholz 2010). We assume policy actors make boundedly rational decisions in a complex and uncertain environment, with a limited cognitive representation (e.g; how many institutions exist, what the payoffs are across different institutions, and what are the strategies of other actors) of the EG at any given time that makes it difficult optimize on the basis of expected future payoffs as envisioned in classical game theory.

Policy games are defined by the constellation of actors, collective-choice institutions, and issues that are at hand in a particular policy subsystem (Scharpf 1997). Dutton (1995: 381) describes policy games as "arenas of competition and cooperation structured by a set of rules and assumptions about how to act in order to achieve a particular set of objectives." Actors are generally self-interested when playing policy games; they seek to achieve their policy preferences through participation in the games. Policy games are not the same as institutions, because the linkages between behaviors and outcomes described by a game is a function of institutional rules, the preferences and perceptions of policy actors, and the structure of the policy issue (e.g. common-pool resources versus public goods). In the bipartite network, a policy game is an observed affiliation tie from an actor to an institution.

Policy subsystems are geographically defined territories that encompass multiple issues (e.g., flooding, water supply and biodiversity), multiple institutions (e.g., integrated regional water management, Total Maximum Daily Load programs, and recovery planning for endangered species), and multiple actors (e.g.; local, state, and federal government agencies and

interest groups) interacting in multiple games. Our empirical study asks a population of Bay Area policy actors to identify the most important water management institutions in which they participate. These actors participating in these institutions constitute the ecology of games at hand in the context of Bay Area water management, and each game provides different opportunities for involved actors to acquire resources and achieve their policy goals.

The EG that exists in a particular subsystem represents a complex adaptive system that changes over time. Change can be endogenously driven by the actors as they participate in different games, try out different strategies, engage in policy learning, and even create and destroy institutions. Change can also be imposed exogenously according to the dynamics of the underlying resources, which may change incrementally or with tipping points. Exogenous change may also come from higher level institutions, because the EG that occupies a spatially-defined subsystem like a watershed is usually nested in higher level institutions at the State and Federal levels.

The key question is whether cooperation evolves and helps solve the environmental issues in the EG, and the robustness of any cooperative interactions to incremental or sudden exogenous change. For example, if one is interested in the overall level of biodiversity (a common-pool resource) or access to clean drinking water (a public good) in a region, then all of these games should be considered. Long's original EG framework assumes coordination is a rare and unintentional by-product of individual actors pursuing a narrow range of goals in a limited subset of policy games. Long does recognize that political leaders, driven by broader public opinion as expressed through media, may help coordination by exerting leadership across a range of games. Our framework integrates Scharpf's perspective by arguing that the political power of

policy actors or the behavioral constraints of institutional rules can coordinate activities in the EG.

Actors as Coordinators

Scharpf characterizes actors by their capabilities, preferences, and perceptions. Capabilities are a function of the resources an actor commands that allow it to influence outcomes in ways that are consistent with preferences. Our version of the EG framework pays particular attention to political authority, expertise, and financial resources. Actors with the political authority to use the police power of the state have the option to appeal to the legal system to use coercion to shape behavior. Expertise and information allows actors to better understand the consequences of their different strategies. Financial resources allow actors to directly implement policy actions like a wetland restoration, or provide money to other actors.

Within the United States, these resources tend to be concentrated in the hands of government agencies, particularly at the state and Federal level. Government agencies are delegated political authority by higher level political decisions in the legislative, executive, and judicial branches. Government agencies collect data and scientific research to support their decision-making, and hire employees with specialized expertise. Agencies often distribute financial resources through grant programs where applicants must engage in certain types of behaviors to receive the awards. All of these resources give government agencies the capacity to influence the outcomes of policy games in ways that favor their preferences, or even to create new games for addressing unresolved issues. Of course how government agencies shape policy interactions is an enduring and central topic of public administration research.

Institutions as Coordinators

Institutions consist of formal rules and informal norms that constrain the strategies of actors, and define the link between strategies and payoffs. Different institutional arrangements have more or less capacity to solve different types of collective-action problems. Institutional economics focuses on how institutions influence the transaction costs of searching for mutually beneficial solutions, bargaining, and monitoring and enforcing agreements. Transaction costs are reduced when institutional arrangements have a good fit with the structure of the collective-action problem. The capacity of institutions to constrain the behavior of multiple actors over time complements the coordination activities of actors.

The mix of institutional types (species) changes over time, and we are particularly interested in the role of collaborative partnerships as a new type of institution that is spreading throughout all policy arenas. Collaborative institutions emphasize specific types of institutional rules: inclusive participation of multiple stakeholders, consensus decision-making, integration of scientific information, voluntary implementation, and place-based activities (Lubell 2004). Proponents argue collaborative institutions reduce the transaction costs of cooperation in the context of complex and diffuse environmental problems like non-point source pollution or ecosystem management. In contrast, more centralized regulatory institutions have lower transaction costs for concentrated, point-source pollution and have had considerable success in solving these problems (at least in Western Democracies).

We expect collaborative institutions to play a central role within the EG because they continue to expand in number with the promise of a more cooperative solutions to intransigent policy conflicts. However, there is still considerable debate as to the effectiveness of collaborative institutions and we do not claim that the EG observed in Bay Area is minimizing

transaction costs. Furthermore, we do not currently have any objective criteria by which to evaluate the efficiency of any particular configuration of the EG although the number of environmental problems that continue to plague the Bay Area suggest that transaction costs remain substantial. Understanding how particular configurations of the EG relate to measures of policy effectiveness is a rich topic for future research, as evidenced by the continuing debate about what policy network structures are linked to environmental effectiveness and adaptive capacity of social-ecological systems (Bodin and Crona 2009). This article takes a necessary first step by investigating the types of relational structures that exist in a particular EG.

In addition, we do not hypothesize that institutions and actors are competing mechanisms for coordination in the EG. Rather, we believe they are complementary and focus on which types of actors and institutions appear to be most important. Furthermore, we are interested in how the types of network structures that emerge around these important nodes may be related to the types of underlying collective-action problems faced by the actors; we turn to this issue in the next section.

Network Representation and Hypotheses

The EG can be represented as a bipartite network where each policy actor (mode 1) in the San Francisco Bay water management arena plays multiple games through their participation (links) in one or more policy institutions (mode 2). The assumption is that actors are choosing in which institutions to participate given the current set of available institutions, although the creation and destruction of institutions is possible in the dynamics of the system. The bipartite representation is admittedly a simplification that does not capture all of the theoretical building blocks identified in the previous section. In particular, in this paper we do not attempt to consider a dynamic representation, with changing games across time. However, bipartite networks do

capture a level of complexity and interdependence that is not typically considered in analyses of individual policy actors, or single institutions in isolation. An individual-level analysis focusing only on attitudes and behaviors necessarily misses out on the systemic elements of the structure implicit in the term *ecology*. Individual-level variables remain important and are incorporated as attributes in network analysis, but they do not capture how actors participate jointly or separately in multiple policy institutions.

We closely investigate three network processes that are likely to structure the EG: network activity, degree dispersion (which can be linked with network centralization), and network closure. The extent to which such processes are associated with particular types of actors or institutions provides clues about how coordination emerges within the EG. These three network processes been discussed extensively in the analysis of unipartite (e.g., actor-to-actor) networks (Snijders et al. 2006), but less so for bipartite networks. Translated into the context of bipartite networks, Berardo and Scholz's (2010) risk hypothesis suggests that bipartite networks with high levels of activity and degree dispersion, which tend to be centralized around a small number of nodes, provide for efficient information transmission in coordination games. Bipartite networks with high levels of closure provide more redundant links, which can help solve risky cooperation problems by providing opportunities for conditional cooperation.

Each process can be associated with observable *network configurations*. Network configurations are small patterns of ties within the graph (subgraphs), which are sometimes referred to as *network motifs* (Milo et al, 2002)[2]. If a particular configuration is a likely outcome of a social process occurring within the network, that configuration will occur at a higher frequency in the observed network than in a network where links are generated at “random".

[2] We prefer the term *configuration* as it has a much longer tradition in social network theory and methodology (Moreno & Jennings, 1938).

The term "random" in this context refers to the expected frequency of network configurations under different "null" statistical models of the network representing different assumptions about the strategic behavior of policy actors.

Network Activity

The number of ties a node has can be interpreted broadly as a measure of *network activity* or *popularity*[3]; network analysis typically refers to this as the *degree* of a node. We are interested in whether the different types of actor and institutions observed in our data have greater or lesser network activity. For instance, we hypothesize that Federal and State government actors will have more network activity due to greater capacity, and collaborative institutions will have more network activity due to institutional rules encouraging broad participation. Figure 1 shows the two relevant configurations associated with network activity in a bipartite graph, where a square represents an actor and a circle an institution, and a filled (black) shape represents a particular type of institution or actor and an unfilled (white) shape any type of actor or institution.

[Figure 1 about here]

The top panel of the figure shows a configuration of an actor of a particular type having a tie to an institution (of any type). If that type of actor is more active than others in the network, we will see more of these configurations than we expect to see by chance in the data. For instance, if the filled square represented Federal government agencies, and if these agencies exhibited more network activity than other types of actors, then we would see relatively more of these Federal government configurations in the data. Accordingly, the analysis measures the frequency of these configurations for each type of actor and institution.

[3] The term "popularity" is best reserved for network ties in which there are directions. In this article with undirected bipartite graphs, we simply use the term "activity".

Centralization and Degree Dispersion

However, network activity may be distributed in different ways. Each node could have a relatively similar number of degrees, or some nodes could have very high degrees with many nodes with relatively low degrees. More centralized networks have high levels of activity around a small number of central actors and institutions. This plays out as higher variance for the distribution of degrees across the nodes, or in other words higher degree dispersion.

Central actors or institutions are likely to have the most potential to exercise leadership and coordination in the rest of the system. Given their access to information, financial resources, and police power, we expect state and federal government agencies to be the most centralized type of actor. Given their role as new institutions specifically designed to integrate across multiple actors and address issues left unresolved by older institutions, we expect collaborative partnerships to be the most centralized type of institution.

Network centralization and degree dispersion is represented by "two-star" configurations, where a node has connections to two other nodes as in Figure 2. The top panel of that figure represents a particular type of actor with connections to two institutions. It is important to recognize that the configuration does not represent connections to only two institutions. A node with degree d is involved in $d(d\text{-}1)/2$ distinct two-stars; so, for a fixed number of ties, high degree nodes are the most efficient way to produce a large number of two-stars. For a given level of network activity, then, the presence of more two-stars indicates a more centralized network structure based around a smaller number of high degree nodes.

[Figure 2 about here]

The conclusion about centralization is conditional on the level of basic network activity. For instance, a network with a high level of activity in general will naturally produce high degree

nodes even if the activity is equally distributed among them. On the other hand, a low activity network can still be highly centralized if most of that (low) activity is centered on one or two nodes. In a more statistical sense, the activity and dispersion configurations can be seen as representing the mean and variance of the degree distribution. The basic activity configuration represents the average level of activity, while the two-star or dispersion configuration represents the variance of activity around that mean.

Network Closure and Clustering

Network closure has been discussed extensively for unipartite social networks and is widely observed empirically (e.g. see Snijders et al., 2006). Network closure occurs in unipartite networks when a network path from actors *i* to *j* to *k* is *closed* into a triangle configuration with an additional tie between *k* and *i*. The ratio of closed triangles to potential triangles is often referred to as the clustering coefficient (Wang et al. 2009). Discussions of network closure extend back to Simmel (1908), and remain a major theme in network theory since the work of Granovetter (1973) and Burt (1992), both of whom consider how closed versus open network structures influence an individual's access to social resources.

Unipartite network closure can arise because individuals introduce acquaintances to each other, because people with similar interests, concerns or pressures come into the same social environment, or because people tend to operate in team-like, collaborative structures. There are various likely outcomes: these closed structures can enhance social support and cooperation, they permit closer scrutiny of actions, and they may lead to stronger group norms or localized cultures. Closed structures provide the security of redundancy (more ties are used than necessary to provide connection between actors), but may inhibit the flow of new information or innovation (Scholz and Berardo 2010). Network closure involves a tradeoff between processes

that benefit from coherence and reputation, versus the efficiency of information that comes from a multiplicity of non-redundant ties.

Bipartite networks require extending the notion of closure beyond the triadic configurations and the simplest configuration is a four-cycle depicted in Figure 3 (Wang et al, 2009). In our case, these represent circumstances when actors of the same type are tied to the same multiple institutions, and when institutions of the same type attract the same actors.

[Figure 3 about here]

Analogous to the unipartite arguments above, bipartite closure represents a more cohesive, collaborative structure, but possibly with costs in terms of overlap and redundancy. Given our discussion of the coordinating role of institutions and actors, we expect the highest levels of closure to be centered on Federal and State government actors, and collaborative institutions that have the goal to organize multiple stakeholders.

Study Design: The Ecology of Water Management Games in the San Francisco Bay, California

The SF Bay is one of the most important coastal regions in the West Coast of North America, and involves numerous environmental issues, actors, and policy institutions. The environmental issues encompass both public goods such as water supply and flood control, and common-pool resources like water quality, biodiversity, and mitigation of climate change. Federal and state agencies have consistently played important roles in the governance of these issues, with the US Environmental Protection Agency, US Fish and Wildlife Service, CA Department of Fish and Game, CA Department of Water Resources, and CA State/Regional Water Resources Control Boards as the central actors. But the cast of actors also includes local

governments, special districts for water management, special districts for environmental management (e.g.; open space), environmental groups, economic interest groups, and scientists.

Like in many other watersheds, the policy ecology of the SF Bay is constantly evolving and has most recently experienced the emergence of a number of collaborative institutions. The most famous collaborative partnership is CALFED, which emerged from a 1984 agreement between California and the USEPA and evolved to encompass both the entire SF Bay-Delta watershed. Especially relevant for this study is the Bay Area Integrated Regional Water Management Plan (IRWMP; http://www.bairwmp.org/), which was first initiated in 2005. The 2005 California Water Plan embraced IRWMP as one of two strategic initiatives for meeting the state's water management objectives, and California has provided funding for IRWM through state bond acts. The Bay Area IRWMP is one of the most inclusive policy games in the region, and also was a primary source for the development of our survey sample.

Bay Area Survey: Eliciting the Bipartite Network

The survey identified actors involved with SF Bay water management by first culling the list of participants from the IRWMP public meetings, outreach workshops, and implementation projects. Contact people were identified for each partner organization through web searches or by emailing or calling the organizations directly. A small number of respondents were added to the list via nominations from previous stakeholder interviews. We also cross-checked the list with a centralized database of water-related environmental impact reports (EIR) in the region. Reflecting the inclusiveness of the IRWMP, most of the organizations were found in both the IRWM documents and the EIR database. The survey was administered in April/May 2008 via a mixed-mode method (Dillman 2000), with an introductory letter delivered by first class mail, an internet survey to study participants, three email reminders, and then a telephone follow-up with

opportunity to answer the survey via telephone. A total of 167 responses were received (157 via Internet, 10 via telephone) for a response rate of 50.8 percent.

To identify the range of policy institutions in which actors were involved, we used a variant of a name-generator network question with the following wording:

> "There are many different forums and processes available for participating in water management and planning in the Bay Area. Planning processes are defined as forums where stakeholders make decisions about water management policies, projects, and funding. In the spaces below, please list the most important planning/management forums and/or processes that you yourself have participated in during the last three years. Please be as specific as possible with the name of the process."[4]

The survey provided space for respondents to nominate up to three policy institutions, and then for each nominated institution, a "hybrid name generator" asked the respondent to write-in their collaboration partners in that institution from the categories of Federal agencies, state government agencies, local/regional agencies, and private/non-profit actors. In other words, respondents not only reported about the activity of their own organization but also about other participants in the same institution. Assuming respondents are reliable informants on that part of the EG in which their organization participates, we include these other actors and institutions in our dataset. Of the 167 respondents who answered the survey, 70 (41.92%) did not answer these questions, 13 (7.78%) nominated one institution, 21 (12.57%) nominated two, and 63 (37.72%) nominated three. Hence, 58% (97/167) of the respondents identified at least one policy

[4] We are assuming that each respondent is an informant for the organization. We did not create a valued link if multiple respondents from the same organization indicated participating in the same policy game. For example, there were four respondents from Santa Clara Valley Water District who indicated participating in the Bay Area IRWM, but Santa Clara Valley Water District only received a score of "1" for linking to IRWM. This is a conservative treatment of the data for organizations that have multiple survey respondents; in particular it avoids the possibility of double counting where multiple respondents from the one organization report separately on a single activity. In cases where we have only one survey respondent per organization, we are forced to assume that individual represents an entire organization, which means it is possible we miss linkages to policy games that are made by non-surveyed members of the organization. This potential undercount of activity is at least somewhat alleviated by the hybrid name generator questions, because those questions capture many organizations that were never even sent a survey. But our measured links in the Bay Area ecology of games is likely to be sparse relative to a "valued" network that measures connections for every potential respondent from all organizations.

institution, and the majority of these identified the requested three institutions. The hybrid name generator mitigates response rate issues because it allows respondents to report on the range of actors involved across the ecology without the necessity to survey a respondent from every single actor organization.[5] Hence, the network data includes 387 total actors including the organizations of the primary respondents and actors nominated via the hybrid name generator.

The data was assembled into a bipartite network where each nominated policy institution was associated with the respondent's organization, plus any actors nominated using the hybrid name generator. The actor and institution types (see Figure 7 below) were coded by the researchers on the basis of Internet searches. Two codes that are not straight-forward are "actor as venue", which refers to a respondent mentioning a particular agency (e.g.; US Environmental Protection Agency) as a venue where important policy decisions are made, and "actor coalition" which refers to a coalition of actors that sometimes overlaps with the planning processes elicited in the policy institutions question.[6]

Using actor websites, we manually coded actors into geospatial regions based mostly on county boundaries. A few actors spanned multiple counties and thus were given sub-regional designations like “East Bay” and “South Bay”, which are nomenclatures commonly used throughout the region. The regional coding is used in the ERGM models to designate a

[5] This procedure does not limit an organization to have a maximum degree of three connections to any particular policy institution. This is because the hybrid name generator allows multiple mentions of organizations; so an organization like the California Department of Water Resources will be nominated as a participant in many different institutions. The hybrid name generator is not as good as “complete” network data that would come from a 100% survey response rate of all possible actors in the EG, but it provides data on a much larger component of the EG than if just respondent organizations were considered.

[6] There is some indeterminacy in the definitions and survey elicitation of games and institutions, because in principle any organization consists of a set of actors making collective decisions within the constraints of formal and informal institutional rules. The indeterminacy occurs because of the multi-scale nature of actors and institutions—individual people are embedded in organizations and then organizations are embedded in policy processes. As much as possible, we tried keep separate the organizations that are typically considered policy stakeholders from the policy institutions where collective decisions are made. The small number of "actor as venue" and "actor coalition" nodes is where there is some minor overlap. Further theoretical development and refinement of the research instruments is needed to analyze the consequences of actors nested in multiple levels of institutions. Given the small numbers here we do not consider this issue is likely to threaten our general results.

geographical clustering parameter. Actors with statewide jurisdiction such as the California Department of Water Resources were excluded from geographical clustering because they cannot logically cluster at the sub-regional level.

The policy institution and hybrid name generator reflect some important theoretical issues. The policy institution question was designed to identify what Ostrom (1999) would call the "collective choice" level of governance institutions in the Bay Area. The question wording attempted to translate the policy theory jargon of "collective-choice rules" into the policy vernacular of "processes", "forums", and "venues". These basic terms were accompanied by a brief description of the type of decision-making and management functions we were looking for. In general, we tried to avoid "constitutional" level institutions like the courts, legislature, and governor's office and none of the respondents mentioned these institutions. We also tried to avoid the "operational" level of institutions, where specific decisions are being made about how to harvest resources and build infrastructure projects. As discussed in Alston (1996), it is important to hold some levels of a nested institutional structure constant to examine the dynamics at other levels.

By asking for collaboration partners, the hybrid name generator assumes a non-zero-sum payoff structure to the interactions where mutual benefits are possible. It is clear that we have not precisely defined the payoffs available within each game or how payoffs are linked among games, and there are many different types of payoffs among the class of non-zero sum games, plus different actors may have different mental representations of the rules. Some of interactions may constitute non-zero-sum games where coalitions of actors compete for limited resources. In that case, the collaboration networks within institutions reflect coalition building among common interests rather building ties across coalitions with different preferences.

The limitations of this research design should be recognized so that future work can replicate and improve on the results here. As with other network studies, defining the appropriate boundaries of the network is a difficult problem. In this case, our entry point into the EG was shaped by the fact that the study funding had the goal of evaluating the IRWMP process. Thus the centrality of the Bay Area IRWMP is partially an artifact of the research design and this is explicitly considered in the statistical analysis. However, the survey sampling frame and resulting nomination of policy institutions does encompass a very large portion of the Bay Area ecology. Future research needs to continue to improve on ways to draw satisfactory boundaries on the policy ecology. The network question asking people to nominate specific policy processes plus participants was also quite burdensome and created some problems with item non-response on those questions. Future data collection should attempt to separate the nomination of the policy institutions from the identification of the actors, possibly using the Internet as a method for gaining more information about what actors are participating.

However, these shortcomings do not eliminate the scientific value of this study. Despite not all respondents answering the policy institutions question, we still identified a large number of institutions and have likely explored near boundaries of the network. In addition, this is the first study to measure the EG in this manner and apply the tools of modern network analysis. The findings here will provide a useful baseline to compare to later studies using improved methodologies. As in other domains of scientific knowledge, the accumulation of research over time will provide more agreement on the key causal processes driving the EG.

Network Visualization

Figure 4 displays the a "spring-embedding" visualization of the entire Bay Area ecology of games network, and Figure 5 zooms into the most central actors and institutions having a

degree of sixteen or greater. The red circles represent actors, while the blue squares represent institutions. The size of the shapes is scaled to the degree of the node. The visualizations show that the most the most central actors tend to be state and federal agencies, which have the broad geographic scope, expertise, information and political authority hypothesized in the earlier section. The only local actor in the most central group (Figure 5) is the East Bay Municipal Utility district, which is one of the largest urban water districts in Northern California. The peripheral actors tend to be local governments and other actors with fewer political resources than the keystone agencies. Some of these peripheral actors are attached to only one institution (e.g.; degree of one), and they only appear in the diagram because they were mentioned by a survey respondent as important participants in that particular institution. These peripheral actors may be more connected to other institutions if we had full responses from every actor, but a slight increase in connectivity in peripheral actors is unlikely to have major effect on the basic results reported below.

[Figures 4 and 5 about here]

The central institutions consist mostly of watershed-scale collaborative groups, either covering the entire Bay-Delta or important sub-watersheds. Given our study design, it is no surprise that IRWMP has the highest centrality of all nodes since our sample list started with that institution. Interestingly, some of the widely known collaborative partnerships have a lower degree, such as CALFED and Delta Vision. Although our data is not longitudinal, the survey was conducted at an interesting moment in the evolution of Bay Area water management. CALFED had been the dominant policy process in the late 1990s and early 2000s, but after mounting political criticism was dismantled in 2010 and replaced by a brand new agency called the Delta Stewardship Council. In other words, our survey was conducted when CALFED was

dying while the Delta Stewardship Council was being born, which is one reason why CALFED and Delta Vision do not appear as central as one might expect. This anecdote hints at the importance of studying the EG over time, in order to witness changing patterns of participation as well as the birth, death, and survival of different types of institutions and actors.

Another suggestive aspect of these visualizations is the role of geographic scale and spatial jurisdiction. Visual examination suggests that institutions and actors with a narrower geographic scope relative to the policy subsystem under examination are likely to be less central nodes. Furthermore, actors appear linked to institutions with similar place names, which suggests geographic clustering. The ERGM analysis specifically includes a parameter to capture the effect of geographic clustering.

Degree Distribution and Centrality

Figure 6 displays the fat-tail distributions characterized by a large number of nodes with small numbers of ties, but with a small number of nodes with high numbers of ties. For actors, the modal observed number of connections is one, with median degree of one and an average of degree of 3.09. For institutions, the modal degree is 5 with a median degree of 7 and an average degree of 10.33 (without the IRWMP institutional node, the average is still 9.66.) The mean degree of institutions is significantly higher than for actors (t-test=11.67; reject null hypothesis of difference =0; $p<.01$), which suggests that the network is more clustered around institutions than actors.

[Figures 6 and 7 about here]

Figure 7 provides further evidence with several standard measures of centrality for bi-partite networks sorted by actor and institution type (Everett and Borgatti 2005): normalized degree, normalized betweeness, and normalized eigenvector centrality. Degree is simply the

number of connections, betweeness is the number of connections that flows through a particular node, and Eigenvector centrality is higher when an actor is connected to institutions that are well-connected themselves (and vice versa). As expected from the earlier theoretical discussion, it appears that Federal and state government agencies are the most central actors, while collaborative partnerships are the most central institutions. The centrality scores of institutions are distributed more evenly across institution types than for actors, suggesting that Federal and State agencies serve a stronger coordinating role relative to other actors than collaborative institutions relative to other types of institutions.

Exponential Random Graph Models

Exponential random graph models (ERGM) are statistical models of networks that account for the interdependent nature of network relationships by explicitly positing a set of network processes that give rise to an observed network structure (Robins *et al.* 2007a; Robins *et al.* 2007b). The observed network structure (in this case, the Bay Area bipartite network) is viewed as one possible outcome of these stochastic network processes. The localized network configurations between actors and institutions can (loosely) be understood as the independent variables in the model. The parameters for these independent variables (i.e., just how attractive or unattractive is a particular network configuration?) yields a probability distribution of networks from which our observed network (the dependent variable) is drawn. ERGM models allow to be drawn from both the estimated model parameters, and analysis of the residuals where certain types of network configurations are more frequent in the observed data than predicted by a particular model. Because the models explicitly assume dependence among observations of network ties, they require simulation methods to obtain maximum likelihood estimates.

[Table 1 about here]

Table 1 describes a series of nested models that we fit to the data, where each model represents a different set of assumptions about political behavior in the EG. The *naïve actor* model suggests that participation decisions are uniformly distributed across actors and institutions without regard to the capacity of different actors or the benefits available in any institution. The *political capacity* model suggests that participation decisions are non-strategic and proportional to the capacity of the actors and the rules shaping participation (i.e.; more narrow versus more inclusive) in each institution. The *strategic decision* model introduces parameters that imply actors have preferences over more complex network structures and participation decisions are interdependent and strategic. In this case, actors may decide whether they face challenges of efficient information access as opposed to risk, so that the model includes generic parameters pertaining to centralization and closure. The *strategic geography* model introduces a parameter for geographic clustering and implies that opportunities for strategic interaction are constrained by the spatially explicit nature of environmental collective-action problems.

Each model includes parameters interpreted in terms of how they influence network structure. The *density* parameter captures the overall number of ties, with a negative parameter indicating a rate of tie formation less than a 50% chance of forming any particular tie. We also specify *activity* parameters specific to each type of actor and institution, which are equivalent to dummy variables that capture the rate of tie formation for the listed node type relative to a baseline excluded category (local government for actors and collaborative partnerships for institutions).

The structural and geographic parameters include bipartite structural parameters representing generic centralization and closure effects proposed by Wang et al (2009). The

alternating k-star parameter represents network centralization by combining all star-like configurations with a geometric weighting so that very high stars do not come to dominate the statistic (this assists with model convergence). A strongly positive parameter estimate indicates a structure centralized around a few high degree nodes, while a negative value is a decentralized structure with the degree distribution spread more evenly across nodes. The *alternating 2-path* parameter represents closure by combining 4-cycles and higher order 2-path connections between nodes so that configurations with many 2-paths between nodes do not come to dominate the statistic. A positive parameter suggests tendencies for network closure, whereas a negative parameter indicates the presence of network brokerage. By brokerage, we mean that actors can be connected through institutions to other actors who play different games. The strategic versions of our models apply the centralization and closure parameters to actors, and the centralization parameter to institutions.[7]

The *spatial centralization* parameter is identical to the generic centralization parameter (alternating k-star) except that it only applies when actors come from the same geospatial region. The geographic centralization parameter controls for spatial clustering of actors: a positive parameter suggests that actors within the same region tend to play the same popular games.

After fitting each model and interpreting parameter estimates, we examine residual structural effects. Each model can be conceptualized as a "null hypothesis" that generates a distribution of network statistics that can be compared to the observed network. From a sample of graphs from the distribution, we then count the number of ties, two-stars and four-cycles of different types (e.g., Federal government agency four-cycles) and compare them to the observed counts in the data and draw further inferences. For example, if the count of a particular type of four-cycle in the data (for example, those involving Federal agencies) is "extreme" compared to

[7] We experimented with a model that included institutional closure but were not able to obtain convergent estimates.

the distribution of four-cycles arising from our simulation of graphs under the null model, we can infer a particular process of network structure (in this case, closure among Federal agencies) not captured by the parameters of the model. If it is not extreme, then the number of four-cycles is explained by the parameters of the model.

Following standard null hypothesis criteria, an "extreme" value in the residual analysis occurs if the observed data has more or less of a particular configuration than 95% of graphs from the simulation. The means and standard deviations for each type of configuration provide the basis for calculating a *t*-statistic for the observed data; a *t*-statistic is greater than 2 in absolute indicates the observed data is extreme in comparison the null distribution.

Interpreting model parameters in conjunction with residual analysis is necessary when a more complex, well-fitting model has difficulties producing converged maximum likelihood estimates (Wang et al 2009). A full model would contain over 50 parameters including structural effects as proposed by Wang et al (2009), as well as three parameters (activity, dispersion, closure) for each of ten types of actors and six institution types, and spatial parameters for sixteen types of actors/institutions. The novelty of our approach is to apply the Pattison et al (2000) strategy of a hierarchy of null models to sharpen inference for bipartite networks. As a result we go further than other network studies (Baldassarri and Diani 2007; Bearman et al. 2004) that simply compare the observed network statistic to the "naive actor" model (a long tradition in network analysis; see Katz and Powell 1957), because we attempt to build more complexity and different assumptions about policy decisions into each stage of model building.

Results: ERGM Model Estimates and Interpretation

Table 2 presents parameter estimates for each of the four model types, where very high-degree nodes (hubs) were treated as exogenous and fixed to be consistent with the data. There

was one institution with a degree over 80 (IRWM), and eight Federal and state agencies with degrees greater than 20. When these connections are fixed, the resulting variation in the graph distributions is due to network activity away from the hubs. This is one way to control for high-degree nodes that are possible artifacts of data collection procedures, such as developing survey sample lists from previously known institutions. It also concedes that some actor and institutions are central "by design", and focuses inference on network processes in other parts of the system. Fixing hubs was also necessary to obtain model convergence for the strategic decision and strategic geography models; including hubs as free parameters caused the models to not converge.[8]

The parameter estimates in Table 2 provide initial insight into the structure of the EG network. The *naïve actor* model suggests that overall probability of tie formation is less than .50, but this simple model is a poor fit to the data.[9] The *political capacity* model takes into account the types of actors and institutions involved in the EG, where the activity parameter for each type can be viewed as dummy variable that adjusts the overall density parameter to represent greater (positive) or lesser (negative) activity relative to a reference type. We chose local government and collaborative partnerships as reference categories because they expressed the largest number of ties in total across respective categories (but not necessarily the greatest average number of ties per node within category). A positive parameter indicates that nodes within the category tend to exhibit more activity than local government or collaborative partnership nodes.

[8] We were able to obtain converged parameter estimates for the naïve actor and political capacity models without fixed high degree nodes. These models show higher positive parameter estimates for Federal and State agency activity, and smaller negative activity parameters for interest group associations and advisory committees.
[9] Results are not presented here in the interests of space, but a residual analysis shows that the naïve model cannot identify the different activity levels of different types of actors and institutions, or the general configurations associated with centralization, closure and spatial effects.

The results for actor types indicate that Federal agencies have the highest levels of activity and that industry groups and education/consulting groups have the lowest in comparison to local governments. Although not shown in Table 2, Federal and state agencies have even higher activity in the political capacity model without fixed hubs because the activity parameters are capturing their high levels of connectivity. The negative parameters for all institution types indicate that the highest level of network activity is observed within the reference category of collaborative partnerships. These results are consistent with the centralization measures reported in Figure 7, and also support our hypotheses about the coordinating roles of collaborative institutions and government agencies.

The *strategic decisions* model introduces more complex parameters that reflect the interdependency of decision-making in the EG. The strategic decisions model shows significant effects for centralization around both actors and institutions, even controlling for exogenous hubs and the average activity levels of different types of nodes. There is a negative effect for closure, suggesting some brokerage as actors share games in some institutions but not in others. The actor activity parameter estimates are broadly consistent with the previous model.

The *strategic geography* model suggests overall patterns of activity, centralization, and closure are conditional on spatial opportunities. To begin with, the large and positive geographic centralization parameter means that actors are clustering around central games within specific geographic regions—geography is constraining strategic decisions. Several of the activity parameters become larger and more significant in the strategic geography model: Federal government, state government, water special district, environmental special district, and "other" actor. This suggests that local government activity is more confined within spatial regions and the actors with higher activity are more likely to bridge across geographic boundaries.

At the same time, the general actor centralization and closure parameters become insignificant once we control for geography; the general structural parameters are now germane to network connections between geographic regions. In particular, the sign of actor centralization has changed from positive to negative (and the estimate is close to significance), which indicates that centralization tends to occur within spatial regions and actor activity that bridges across regions is somewhat decentralized.

The spatial geography model is the overall best fit to the data, and portrays an interesting story of spatially constrained, strategic coordination within the EG. Local government actors in particular are participating in institutions within local sub-regions. State and Federal agency actors, along with collaborative partnerships, are more involved in networks that span geographic boundaries, which is consistent with their broader jurisdiction and goals of policy coordination. Environmental and water special districts play boundary-spanning roles that may reflect some of the unique policy dynamics of the Bay Area. While many water districts are nested within counties, one of the most central actors in network is the East Bay Municipal Utility District, which has a service area spanning two counties, acquires water from the Sierra Nevada Foothills and tributaries of the California Delta, and water delivery systems that span the entire width of the state. One of the most central environmental special districts is the SF Bay Conservation and Development Commission, which regulates land development on the shoreline and riparian areas, and also conducts Bay-wide land-use planning. Actors with this type of broad jurisdiction achieve their policy goals through participation in multiple venues in many locations, and thus coordinate and influence actors with a more local focus.

Results: Inferences from Residual Analyses.

Table 3 presents *t*-statistics for actor and institution centralization and closure based on the final strategic geography model, which is the most complex and best fitting ERGM. We simulated 10 million graphs and took as our sample every 10,000th graph, giving a sample size of 1,000 (see Wang et al, 2009 for more technical details). For each graph in the sample we count the number of various centralization and closure configurations (as in Figures 2 and 3) to create distributions of graph statistics. We use the mean and standard deviation from the simulated distribution to calculate a *t*-statistic for the relevant observed graph statistic. Table 3 reports only extreme results with *t*-statistics greater than two.

In terms of centralization, the geographic centralization model explains most of the type-specific centralization effects, except that there is greater centralization observed for state agencies and water special districts. The Berardo and Scholz (2010) risk hypothesis would suggest that these agencies have particularly important information roles in the EG.

The results for closure provide additional evidence about the coordinating roles of institutions and actors. In general, observed closure processes are more extreme than for centralization. According to the risk hypothesis, this suggests that actors and institutions are involved in solving high-risk cooperation games with strong free-riding incentives. Closure processes are especially pronounced for government agencies (at each of federal, state and local levels), water districts, and environmental groups. For institutions, the strongest results are for interest group associations and collaborative partnerships. These results hold even controlling for geography and fixing central hubs, and again are consistent with our hypotheses about the coordinating roles of government agencies and collaborative institutions. There is also evidence of coalition building by environmental groups and water special districts, which are two of the

key stakeholders who bargain over the distribution of policy resources in the water management EG. As discussed in the introduction, the EG requires solving both cooperation and bargaining problems, and the more extreme closure effects around water districts is consistent the traditional view of water districts as powerful and well-organized interests (Lubell and Lippert 2011).

Conclusion: Actors, Institutions, and the Effectiveness of Collaboration

This paper breaks new ground by combining the EG framework with exponential random graph models of bipartite networks to identify the types of institutions and actors that play a central role in coordinating policy activities in the face of risky cooperation problems. Consistent with our hypotheses, Federal and state government agencies show the highest levels of activity, centralization, and closure, reflecting their control of the important public administration resources of expertise, information, police authority, and finances. Water districts, environmental special districts, and environmental groups are also coordinating around similar policy institutions, reflecting how different interests form coalitions to bargain over water management outcomes. Geography plays a crucial role in constraining this strategic behavior, with more local actors clustered around central institutions with their immediate neighbors, while actors with a broader geographic scope are involved with more cross-boundary interactions.

Collaborative partnerships are by far the most important type of institution in the current Bay Area water management system. They are the most common type of institution, with the highest degree of network activity, and the most closure. This finding reflects the recent popularity of collaborative institutions as an alternative to traditional command-and-control regulations.

Comparing the different network configurations, network closure as captured by 4-cycle configurations produces the strongest departures from the final model. While there are several

potential social processes that explain this finding, all of them have some link to the reputation of different types of actors and institutions for solving problems. Berardo and Scholz's (2010) risk hypothesis argues that this is evidence that the EG involves many high-risk cooperation problems where reputation is necessary to guard against free-riding. While this hypothesis cannot be completely confirmed without directly measuring the underlying payoffs in these various policy games, the findings here strengthen the validity of the Berardo and Scholz argument.

The EG framework brings into sharp focus two critical questions not answered by this analysis. First, while this study measures collaborative ties between actors and institutions, it is not clear whether the actors are participating in institutions to solve collective-action problems or exert political power to achieve policy preferences. As noted in the introduction, these are not necessarily incompatible goals—actors may be seeking to bargain over the shares of gains from cooperation. But some water management issues may be zero-sum games, where actors are participating in institutions in order to shift policies in their favor at the expense of other actors. Indeed, Scharpf (1997) highlights the importance of analyzing different types of games, and future research will need to develop methods to understand the structure of the different games occurring within the institutional ecology.

Second, this analysis does not answer the question of policy effectiveness. We take a necessary first step by analyzing the structure of Bay Area water management policy networks, but the idea of network management requires investigating how different structures are related to policy and public administration outputs and outcomes over time. The standard argument is that the picture of the EG presented in Figure 4 is a highly fragmented and ineffective system. Indeed, we are not arguing that the current set of institutions in this system has minimized

transaction costs; many collective action problems still exist. However, the Bay Area policy ecology is a complex adaptive system that may become more effective as collaboration evolves across multiple, diverse institutions. The current level of institutional diversity provides many opportunities for collaboration, as well as policy learning and innovation in the face of complexity and uncertainty (Ostrom 2009). Evaluating effectiveness and adaptive capacity of this system requires a dynamic analysis, including measuring environmental outcomes. While any policy ecology will also experience periods of conflict, our results suggest collaborative institutions and government actors will play a crucial role in securing gains from cooperation over time. However, there is no guarantee that collaboration will continue to spread in any particular policy ecology, and understanding what types of institutions and network structures are related to effectiveness requires longitudinal research along with comparisons across different types of policy arenas. The EG framework and network science are promising theoretical and analytical tools for this type of future research.

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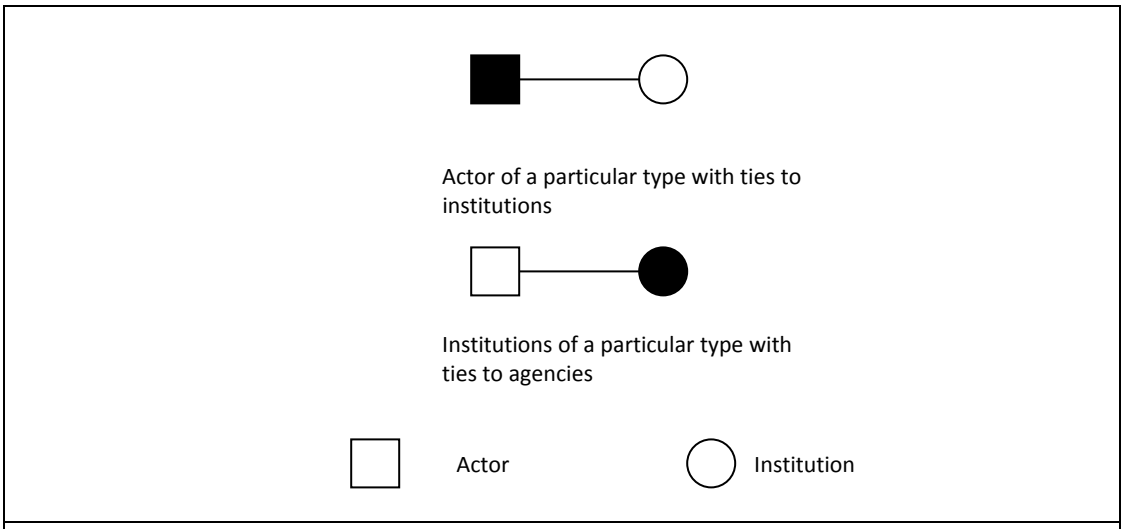


Figure 1: Basic Configurations for Network Activity

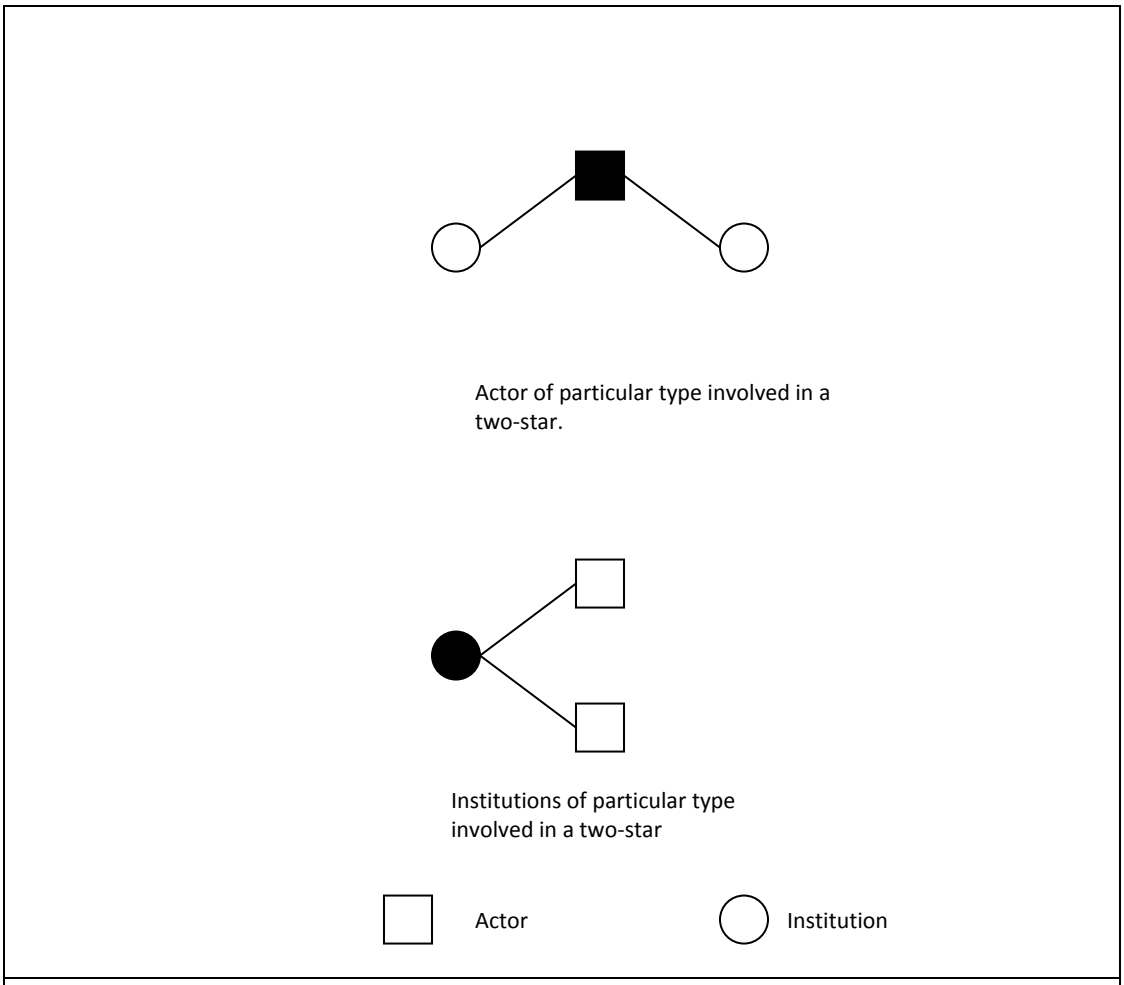
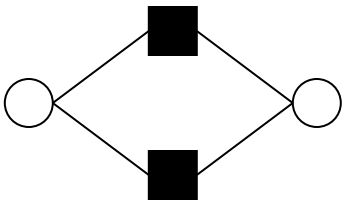
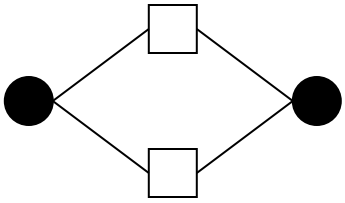


Figure 2: Basic Configurations for Network Centralization



Actors of a particular type involved in 4-cycles with the same institutions (of any type)



Institutions of particular type in 4-cycles with the same actors (of any type)

Figure 3: Basic Configurations for Network Closure

Figure 4: Affiliation Network for the Bay Area Ecology of Games

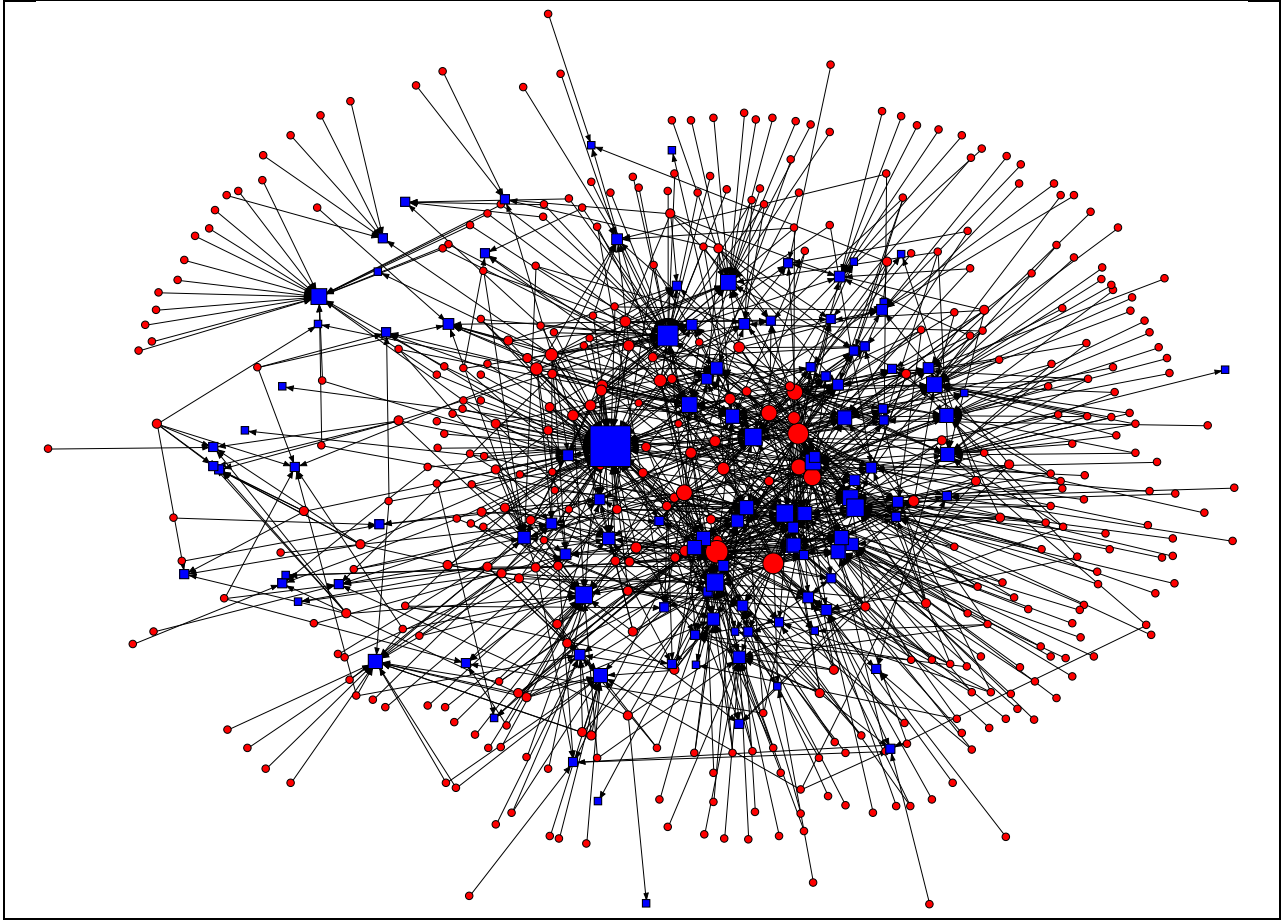


Figure 5: Most Central Actors and Institutions in the Bay Area Ecology of Games

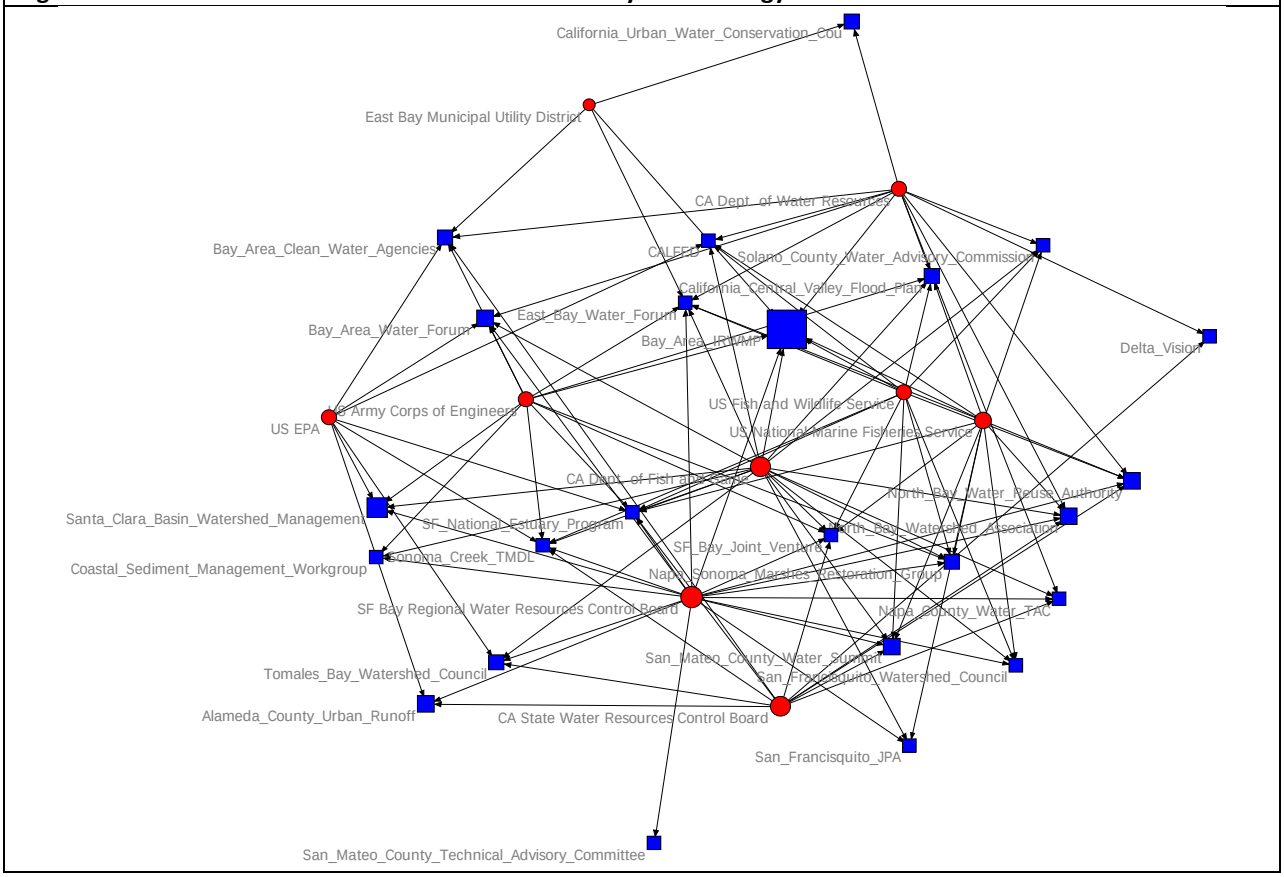


Figure 6: Degree Distributions for Actors and Institutions

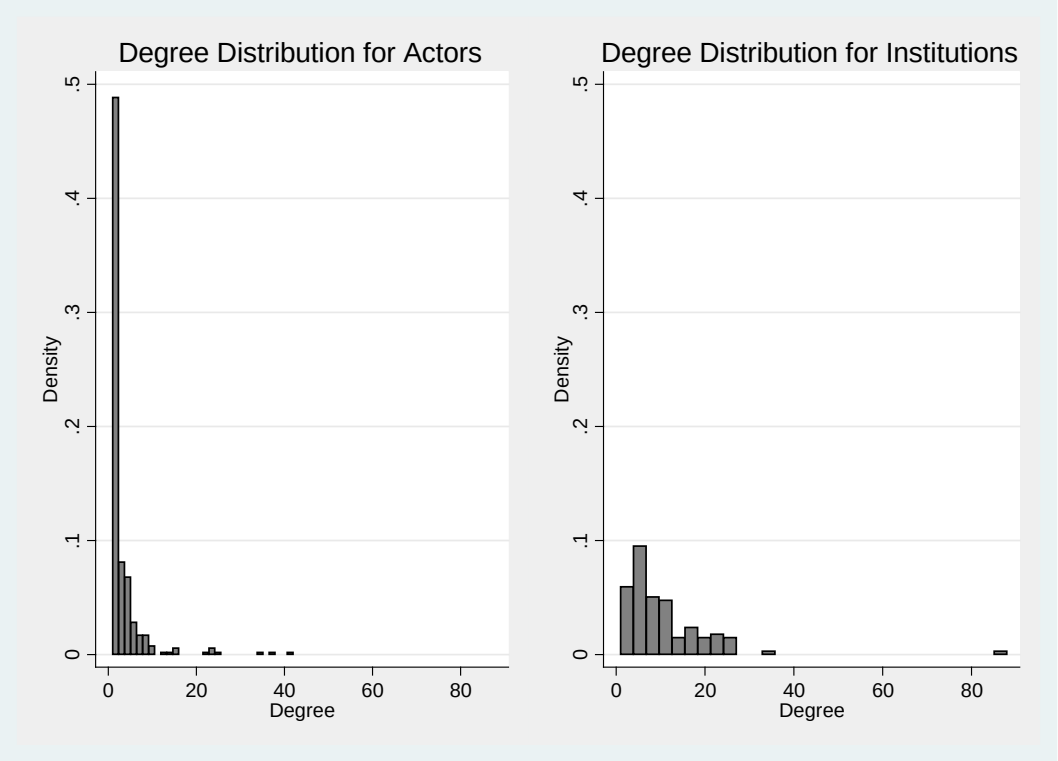
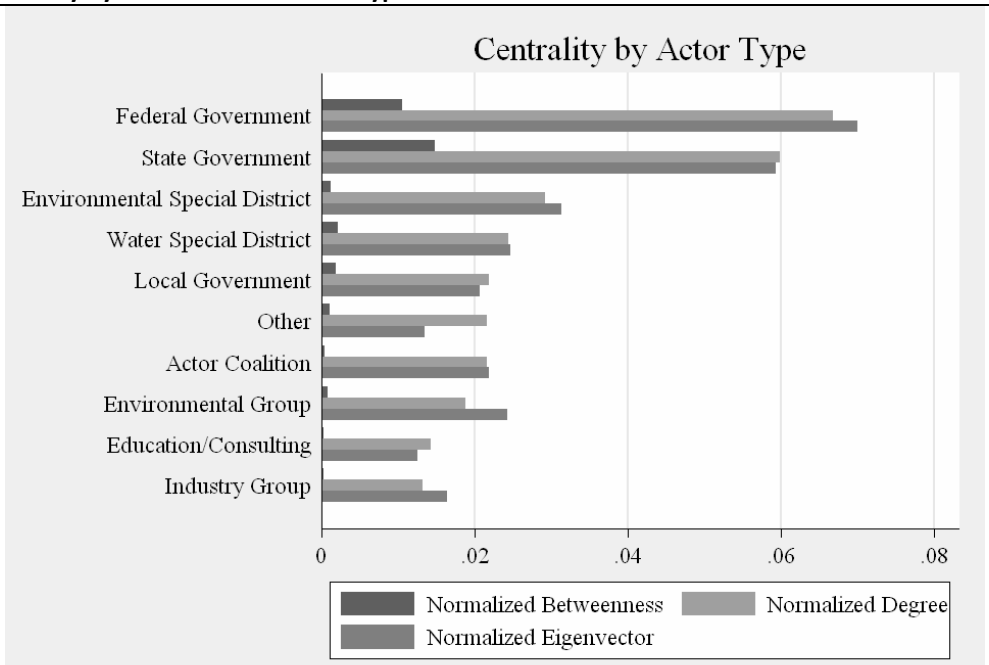


Figure 7: Centrality by Actor and Institution Type



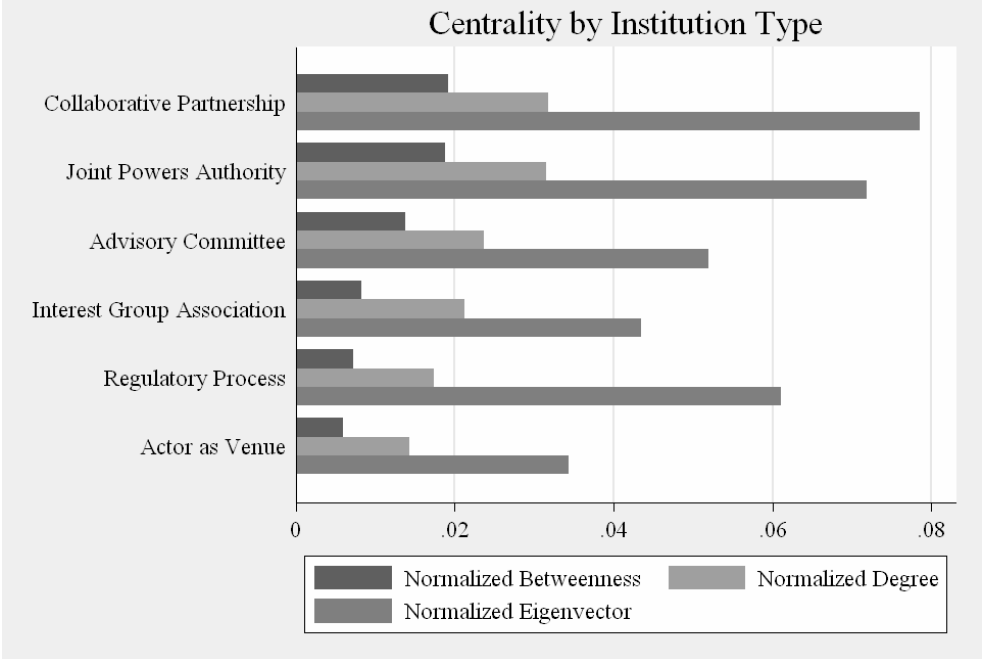


Table 1: Hierarchy of Exponential Random Graph Models
Naive actor model (Bernoulli model): The observed *probability* of tie is fixed and connections are then probabilistically distributed across each graph in the distribution. This is similar to a fixed activity distribution except that now the mean number of connections across all graphs in the distribution will be the same as the data. This model is equivalent to an Erdos-Renyi model, or Bernoulli random graph distribution, in unipartite network analysis. It is analogous to a one-parameter log-linear or logistic regression model, predicting the presence or absence of an agency-institution connection. The single ERGM parameter is called the density parameter.
Political capacity model (Bernoulli with node attributes): This is the naïve actor model with the addition of parameters that control for the activity of different types of actors and institutions. This model is analogous to a logistic regression model, predicting the presence of absence of an actor-institution connection, with actor and institutional type as dummy variables representing difference in average degree relative to a baseline.
Strategic decisions model (Structural model with attributes): The political capacity model with the addition of parameters that control for centralization of both actors and institutions, and for closure attributable to actor type. The additional parameters are the agency and institution alternating *k-stars* and actor alternating *k-2paths* described by Wang et al (2009).
Strategic geography model (Structural model with attributes and geographic centralization): The strategic decisions model with the addition of a spatial centralization parameter, an alternating geography k-star parameter that indicates actors from a similar geospatial region participate in the same popular institutions.

Table 2: ERGM Model Parameter Estimates				
	Naïve Actor Model	*Political Capacity Model*	*Strategic Decision Model*	*Strategic Geography Model*
General Parameters				
Density	-3.88 (0.03)*	-3.75 (0.07)*	-7.01 (0.35)*	-5.77(0.36)*
Centralization (actors)	---	---	0.61 (0.11)*	-0.21(0.11)
Centralization (institutions)	---	---	1.36 (0.18)*	0.56(0.18)*
Closure (actors)	---	---	-0.19(0.05)*	-0.06(0.04)
Geographic Centralization	---	---	---	1.57(0.05)*
Actor Type Activity Parameters (Local Government is Excluded Category)				
Federal Government	---	0.45 (0.15)*	0.43 (0.16)*	1.82(0.18)*
State Government	---	0.19 (0.14)	0.16 (0.13)	1.35(0.16)*
Water Special District	---	0.13 (0.09)	0.12 (0.09)	0.42(0.10)*
Environmental Special District	---	0.29 (0.17)	0.26 (0.17)	0.46(0.19)*
Environmental Group	---	-0.18 (0.10)	-0.16 (0.09)	-0.01(0.10)
Industry Group	---	-0.59 (0.26)*	-0.50 (0.23)*	0.05(0.29)
Education/Consulting	---	-0.40 (0.18)*	-0.32 (0.17)	-0.06(0.19)
Actor Coalition	---	-0.03 (0.34)	-0.03 (0.33)	0.44(0.38)
Other Activity	---	0.07 (0.48)	0.11 (0.43)	1.33(0.54)*
Institution Type Activity Parameters(Collaborative Partnership is Excluded Category)				
Interest Group Association Activity	---	-0.22 (0.10)*	-0.09 (0.09)	-0.04(0.06)
Advisory Committee Activity	---	-0.16 (0.12)	-0.10 (0.11)	-0.03(0.06)
Regulatory Process Activity	---	-0.78 (0.16)*	-0.61(0.15)*	-0.36(0.12)*
Actor as Venue Activity	---	-0.70 (0.19)*	-0.47 (0.16)*	-0.26(0.13)*
Joint Powers Authority Activity	---	0.16 (0.16)	0.15 (0.15)	0.06(0.10)

Note: Cell entries are ERGM parameter estimates with standard errors in parentheses. All models are estimated with "exogenous hubs", with fixed degree distributions for nodes with greater than 20 edges. *Reject null hypothesis of parameter=0, $p<.05$.

Table 3: Residual Analysis Showing T-Statistics Greater Than Two		
	Centralization	*Closure*
Actor Types		
Federal Government		4.7
State Government	2.0	4.2
Local Government		14.0
Water Special District	4.8	25.9
Environmental Special District		
Environmental Group		6.9
Industry Group		
Education/Consulting		
Actor Coalition		
Other Activity		
Institution Types		
Interest Group Association Activity		17.5
Collaborative Partnership		8.9
Advisory Committee Activity		
Regulatory Process Activity		
Actor as Venue Activity		
Joint Powers Authority Activity		