Policy Coordination in an Ecology of Water Management Games

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Abstract
Public policy researchers must face the reality that policy outcomes in all but the simplest policy arenas 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 actor and institutions on the context of the ecology of water management games in the San Francisco Bay. Actors participating in multiple institutions are analyzed with exponential random graph models of bipartite networks, comparing observed network structures to those predicted by simple models. We find that the most important coordinators in the SF Bay policy ecology are Federal and State agency actors, along with collaborative policy institutions. In addition, network configurations associated with closure and clustering show the most significant departures from the expected frequencies from null random models.

Prepared for presentation at the 2010 Annual Meeting of the Midwest Political Science Association, Chicago, IL. Research supported by the National Science Foundation and the UC Center for Water Resources.
Drawing on Long's (1958) ecology of games (EG) framework, this article analyzes 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. The EG perspective grapples with the fundamental and non-ignorable reality that all but the simplest policy arenas feature multiple policy games operating simultaneously. The potential lack of coordination among individual games and actors is a recipe for the 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 a core question for both policy and political science theory, and practical effectiveness.

Our analysis blends Long's perspective with Scharpf's (1997) actor-centered institutionalism to focus on two possible coordination mechanisms that might help solve these dilemmas: political actors and political institutions. Long is pessimistic about the possibility of coordination in the ecology of games—"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, Long does see a role for "civic leadership" where widely-recognized political leaders participate in multiple games. Scharpf complements this idea by focusing on the capabilities of specific actors, which is a function of their access to police power, expertise/information, and financial resources. These 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 games, 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 evolve to reduce the transaction costs of economic exchange, which is viewed as a problem of cooperation (North 1990; Williamson 1988).

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1 We treat the terms policy game, policy institution, and policy venues 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.
Solving collective-action problems in these settings requires actors to deal with two simultaneous problems: 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 to recognize is that coordination in an EG involves both efficiency and political power, because actors will use political resources in an attempt 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.

With a few exceptions (Dutton 1995; Lubell, Henry, and McCoy 2010; Conwell, Curry, and Schwirian 2003), the EG model and its variants have received little empirical testing and remained largely in the realm of abstract theory with some descriptive case study support. Network analysis is a promising tool for empirically representing the EG and analyzing the coordination roles of political institutions and actors. We represent actors and games 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 a game. Our most sophisticated analytic approach will use exponential random graph models (ERGM) for bipartite network structures (Wang et al. 2009). ERGM models allow us to compare the observed network structure to different statistical models ranging from "random networks" where actors randomly select among games with a uniform probability, to models where different types of structures are more likely. We can use the ERGM to compare observed data to a null distribution of network structures, and then draw conclusions about network processes when network configurations associated with core theoretical ideas are more prevalent in the data than expected under the null model. These hypothesized patterns will be derived from theorized structural processes within the ecology of games.

The empirical context for the study is water management in the San Francisco Bay of California. The SF Bay encompasses numerous environmental collective action problems including water quality, water supply, climate change, and biodiversity. There is also a wide range of actors including Federal, State, and local government agencies, special districts, environmental groups, economic interest groups, and researchers. There are a variety of ongoing policy games, 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. We then describe our research design and data collection in the context of the Bay Area IRWM. The network analysis section begins with more descriptive analysis of structure of the Bay Area EG, and moves towards exponential random graphs. The conclusion summarizes our findings along and speculates on their meaning for political power, efficiency, and policy effectiveness in complex adaptive systems that are analyzed using the EG framework.

**Actors and Institutions in an Ecology of Games**

Our adaptation of the EG framework relies on six interrelated concepts: policy issues, policy actors, policy institutions, policy games, policy arenas, and time. Although our empirical representation of the EG as a bi-partite network does not capture all of these elements, this section briefly defines them and then turns to the question of the role of political actors and institutions as coordinating mechanisms.

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 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 jointly 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 games. 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 generally refer to policy institutions as "planning processes" 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 exact 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 games with jurisdiction over issues they care about, and also form networks with others in order to gain key political resources like information, credibility, and political influence (Berardo and Scholz 2008).

Policy games are defined by the constellation of actors, collective-choice institutions, and issues that are at hand in a particular decision space (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).

Policy arenas are territorially defined subsystems 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). Our empirical study asks a population of Bay Area policy actors to identify the most important water management games in which they participate. These games 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 policy arena represents a complex adaptive system that changes over time. These changes can be endogenously driven by the actors as they participate in different games, try out different strategies, engage in policy learning, and even create new 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 levels institutions, because the EG that occupies a spatially-defined arena 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 the policy power of the state, expertise, and financial resources. Actors that are authorized to use the police power of the state can ultimately 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 EG, these resources tend to be concentrated in the hands of government agencies, particularly at the state and Federal level. Government agencies are delegated police powers 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 capability to influence the outcomes of policy games in ways that favor their preferences, or even to create new games for addressing unresolved issues. The normative hope of a democratic political system is that government agencies will use these capabilities to solve collective-action problems and secure mutual benefits, rather than provide benefits to one group at the expense of others.

**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. The institutional economics literature focuses on how institutions influence the transaction costs of searching for mutually beneficial solutions, bargaining, and monitoring and enforcing agreements. Once created, institutions take on a life of their own—they are social entities that are separate from actors, although their rules are often enforced by actors. The capacity of institutions to constrain the behavior of multiple actors over time is an alternative coordination mechanism to 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). Although there is still considerable debate as to the actual environmental effectiveness of collaborative institutions, we expect them to be central institutions within the EG because they continue to expand in number with the promise of a more cooperative solutions to policy conflicts.

We have no *a priori* expectation about whether actors or institutions are the primary coordinators within the EG. Both types of entities could contribute to a coordinating role, although it will be theoretically interesting if one type of entity turns out to be a stronger influence on policy dynamics. Even though actors ultimately create institutions and have some discretion over which institutions they join, institutions do assume a life of their own and constrain actor decisions. Our strong hypotheses center on the types of actors and institutions that will be most influential in the EG,
given the superior political resources of state and Federal agencies, and the emerging and inclusive nature of collaborative institutions. We now turn to a discussion of how these hypotheses will be tested in the context of network analysis.

**Network Representation and Hypotheses**

This paper represents the EG as a bi-partite network where each policy actor (mode 1) in the San Francisco Bay water management arena participates in one or more policy games (mode 2). The assumption is that actors are choosing in which games to participate given the current set of available games, although the creation of new games is possible in the dynamics of the system.\(^2\) The bi-partite representation is admittedly a simplification that does not capture all of the theoretical building blocks identified in the previous section. However, bi-partite 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 are remain important and are incorporated as attributes in network analysis, but they do not capture how actors participate jointly or separately in multiple policy games.

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 as to the how the EG is self-organized. The three network processes that we examine have been discussed extensively in the analysis of unipartite (e.g., actor-to-actor) networks (Snijders et al. 2006), but not so commonly for bipartite networks.

Each process can be associated with observable network configurations. Network configurations are small patterns of ties within the graph (subgraphs); sometimes they are referred to as network motifs (Milo et al, 2002)\(^3\). 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 by "chance". As will be described in more detail later, the term "chance" in this context refers to the expected frequency of network configurations under different "null" statistical models of the network.

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\(^2\) At this point we have no information on the constraints shaping the participation decision. Some actors are required to participate in certain games, while others will be forbidden. Empirically measuring such constraints is a key item for future research, since the network methods are capable of integrating them into the analysis.

\(^3\) We prefer the term configuration as it has a much longer tradition in social network theory and methodology (Moreno & Jennings, 1938).
Network Activity

The number of ties a node has can be interpreted broadly as a measure of network activity or popularity⁴; network analysis typically refers to this as the degree of a node. We are interested in whether any of seven types of actors or six types of institutions observed in our data has greater or lesser network activity. For instance, we expect that Federal and State government actors, and collaborative institutions, are likely to exhibit higher degree and hence more network activity. Figure 1 shows the two relevant configurations associated with network activity in a bipartite graph. In the figure, a square represents an actor and a circle an institution. A filled square or circle represents a particular 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 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, we are interested in observations of a set of these configurations, one for each actor and each institution type.

Centralization and Degree Dispersion

However, network activity may be distributed in different ways. Each node in a particular sector could have a relatively similar number of degrees, or some nodes could have very high degrees with many nodes with relatively low degrees. In the latter case, we see relatively higher levels of network centralization, where the activity operates around a small number of highly central actors. This plays out as higher variance for the distribution of degrees across the nodes, or in other words in higher degree dispersion. Many scholars have noted that many networks have “fat tail” degree distributions, with a large number of low-degree nodes and a small number of very high-degree nodes that may have a disproportionate influence on network structure (Barabási and Albert 1999; Barabási and Crandall 2003). These types of networks emerge when the probability of a new connection is proportional to the number of existing connections (i.e.; preferential attachment).

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⁴ The term “popularity” is best reserved for network ties in which there are directions. In this article with nondirected bipartite graphs, we simply use the term “activity”.

Of particular interest for policy coordination is the types of institutions and actors that exhibit high centralization in the EG. Central actors or institutions of a particular type are likely to have the most influence over the decisions in the rest of the system, or in other words, have the potential to exercise leadership and coordination. Given their access to information, financial resources, and police power, we expect state and federal government agencies to exhibit the most centralized systems within actor-types. Given their role as new institutions specifically designed to integrate across multiple actors and issues, we expect collaborative partnerships to be the most centralized in the ecology. Collaborative partnerships are also the most recent species of institutions to evolve, and thus are attracting a greater share of attention than older institutions that have exhausted their problem-solving capacity. Older institutions have captured some gains from cooperation in the past, but are now mired in conflict, leaving a niche for new institutions to emerge to seek further cooperation in the ecology.

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 $d(d-1)/2$ 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 sector with very high activity in general will have very high degree nodes as a result. Despite the high activity and the prevalence of high degree nodes, it is not necessarily centralized around a few nodes. In that case, we may not need to invoke a centralization argument to explain those high degree nodes. On the other hand, a low activity sector can still be highly centralized if most of that (low) activity is centered on one or two nodes. As a result, inferences about centralization need to be made conditioning on the overall amount of activity. 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

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5 For example, the National Pollution Discharge System under the 1972 Clean Water Act is a regulatory institution that requires point-sources of water pollution to acquire a permit and control emissions. The control of point-sources of water pollution is fairly effective, but there remains a large amount of non-point source pollution from diffuse sources like agricultural and urban runoff. One motivation for collaborative partnerships is an attempt to control non-point source pollution through voluntary cooperation.
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 the 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). Closure has remained a major theme in social network theory since the work of Granovetter (1973), who considered circumstances when network ties might or might not close; and Burt (1992), who focused on the importance of network brokerage where closure does not always occur, permitting some nodes to “broker” between two others.

Unipartite network closure can be interpreted in various ways. It 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, the simplest form of which is a network triangle. 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). Burt’s work on brokerage on the other hand suggests that non-closure may reap benefits for the brokering node in the form of social capital, but there is evidence to suggest that a brokerage position may also be difficult (Krackhardt, 1992). 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.

The discussion of closure in bipartite networks has not been as extensive. Firstly, triangles are not possible in bipartite networks, because ties only occur between nodes of different types, not between nodes of the same type. The simplest closed configuration, then, is a four-cycle as depicted in Figure 3. 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 organizational field, 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.

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

Water management in the SF Bay provides the empirical setting for testing these initial hypotheses about the EG. 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 processes. 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. Some of the most important environmental issues include water supply, water quality, flooding, biodiversity, and 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. Among 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/](http://www.bairwmp.org/)), which was first initiated in 2005. The 2005 California Water Plan update 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 Affiliation Network**

The survey attempted to identify all of the main actors involved with SF Bay water management. We began by 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 an examination of water-related environmental impact reports (EIR) in the region; California maintains a centralized database of EIR submissions. 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 games 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." \(^6\)

The survey provided space for respondents to nominate up to three policy games, and then for each nominated policy game, the respondent was asked to identify in an open-ended format the Federal agencies, state government agencies, local/regional agencies, and private/non-profit actors involved. In other words, a "hybrid name" name generator was embedded within each nominated policy network. Of the 167 respondents who answered the survey, 70 (41.92%) did not answer these questions, 13 (7.78%) provided one answer, 21 (12.57%) provided two answers, and 63 (37.72%) provided three answers. Hence, 58% of the respondents identified at least one policy institution, and the majority of these identified the requested three institutions. \(^7\) The resulting data was then used to create an

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\(^6\) 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 in for organizations that have multiple survey respondents. 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.

\(^7\) This procedure does not limit an organization to have a maximum degree of three connections to any particular policy game. This is because the hybrid name generator allows multiple mentions of organizations; so an
affiliation network where each nominated policy game was associated with the respondent's organization, plus any actors nominated in the embedded name generator.

The policy-game elicitation question was designed to identify what Ostrom (1999) would call the "collective choice" level of governance institutions at play 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 policy games, although they have had an important influence on the Bay Area. 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. But the boundaries between these levels are in reality quite fuzzy and fluid over time, and while our study gathered mostly collective-choice level institutions, we also have some spillover to the operational level.

This research design has some shortcomings that 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 that is often without a clear answer. In this case, our entry point into the ecology of games was shaped by the fact that the study funding had the goal of evaluating the IRWMP process. But as will be seen later, not all actors in the Bay Area ecology were covered by the survey sampling frame and the centrality of the Bay Area IRWMP is partially an artifact of the research design. However, the survey sampling frame and resulting nomination of policy games 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 policy organization like the California Department of Water Resources will be nominated as a participant in many different games.
games 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**

Figures 4 and 5 display the visualization of the entire Bay Area ecology of games network, and then the network that contains the most central actors and institutions, which have a degree of sixteen or greater. The red circles represent actors, while the blue squares represent institutions. The layout of the network is determined by a "spring embedding" algorithm that tries to minimize the "tension" in the distances between all nodes of the network. The size of the shapes is scaled to the degree of the node. The whole network diagram clearly shows the fat-tailed degree distributions because a small subset of the actors and institutions is in the center of the diagram.

[Figures 4 and 5 about here]

The central node diagram shows that the most central actors tend to be state and federal agencies, which have the broad geographic scope, expertise, information and police power resources hypothesized in the earlier section. All of these government agencies have been delegated responsibility to implement the primary environmental laws governing water supply, water quality, and biodiversity. The only local government that shows up in this most central group is the East Bay Municipal Utility district, which is one of the biggest utility districts in Northern California. The peripheral actors tend to be local governments and other actors with fewer political resources than the big 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 across the entire system and across actor- and institution-types that we will report below.

The central institutions in the diagram 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—our sample list started with the IRWMP. Interesting, there are some other very famous collaborative partnerships that have a lower degree, such as CALFED and Delta Vision. Although we do not have over time data here, this survey was conducted at
an interesting time in the evolution of Bay Area water management. CALFED had been the dominant policy process in the late 1990s and early 2000s, but then came under increasing criticism from higher level political authorities, eventually leading to the dismantling of the program in 2010. At the same time, California Governor Arnold Schwarzenegger had convened the "Delta Vision" process as high-level task force to form recommendations about the future of CALFED and California Bay-Delta planning. In other words, our survey was conducted when CALFED was dying while Delta Vision was being born, which is one reason these institutions do not appear as central as one might expect. This anecdote also hints at the importance of monitoring the ecology of games over time, in order to witness 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. Although this data does not include spatially explicit quantification of the jurisdiction of each actor or institution, 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. Future research will be needed to develop reasonable classification schemes for the geographic scope of actors and institutions. The question of scale is also one of the most central questions in ecological sciences, and but remains seriously understudied in political science and policy studies (Heikkala and Gerlak 2005).

**Degree Distribution and Centrality**

Figure 6 directly displays the fat-tail distributions that are seen in networks that governed by some type of preferential attachment process. The defining characteristics of a fat-tailed distribution are a very large number of nodes with small numbers of ties, but with a small number of nodes with very high numbers of ties. For actors, the most frequently observed number of connections is one, with median degree of one and an average of degree of 3.09. For institutions, the most frequent degree is 5 with a median degree of 7 and an average degree of with an average of 10.33 (without the single high degree 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 is the first piece of evidence to suggest that more of the network is clustered around institutions than actors.

[Figures 6 and 7 about here]

Figure 7 provides further evidence with several standard measures of centrality for affiliation networks sorted by actor and institution type (Everett and Borgatti 2005): normalized degree, normalized betweenness, and normalized eigenvector centrality. All of these measures are normalized
relative to the maximum possible score that could be achieved in an affiliation network with this number of actors and institutions. Degree is simply the number of connections, betweenness 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 take into account 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; Robins and Morris 2007). The observed network structure (in this case, the Bay Area ecology of games affiliation network) is viewed as one possible outcome of these stochastic network processes. The localized network configurations that individual actors seek to create or avoid as they form collaborative relationships 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 (which again may be thought of as the dependent variable) is drawn. Because the models can explicitly assume dependence among observations of network ties, they require simulation methods to obtain maximum likelihood estimates.

We fit exponential random graph models to the data based on simple parameterizations (described below), then simulate the models to produce various “null” distributions of graphs, each with same number of actor and institution nodes as in the data, in addition to the properties implied by the model specification. From a sample of graphs from the distribution, we then count the number of ties, two-stars and four-cycles of different types (eg. Federal government agency four-cycles) and compare them to the observed counts in the data. For example in the case of four-cycles, we can check whether the count of a particular four-cycle in the data is extreme or not, compared to the distribution of four-cycles arising from our simulation of graphs under the null model. If it is not extreme, then the number of four-cycles can be explained by the properties of the null distribution, and a special process of closure
does not need to be invoked. If, however, the count is extreme in the distribution, we can reject the null hypothesis that the closure observed in the data is explained by the properties of the null distribution.

Table 1 describes four general models of increasing complexity that act as a hierarchical sequence of null distributions. A hierarchical sequence of null models allows one to make inferences about the meaning of extreme observed frequencies of graph configurations relative to the null models (Pattison et al. 2000 describes this approach for unipartite networks). An effect may be extreme in a simpler distribution, so we infer that it cannot be explained by the properties of that distribution. For example, suppose that counts of Federal agency four-cycles are extreme in a model that only takes into account the overall level of activity in the network (i.e. model 2 in Table 1). We infer that closure involving Federal agencies cannot be explained simply by the amount of network activity. If we stopped at this point, we may decide that there are important closure processes at work here. Yet, suppose the same count is not extreme in the next null distribution up the hierarchy. In that case, the count of Federal agency four-cycles is not extreme in a model that takes into account the general level of activity, as well as activity within agency and institutional types (the attribute activity model 3 from Table X). Then we infer that the presence of four-cycles involving Federal agencies can be explained by the basic activity of those agencies, and there is no need to infer additional closure processes to explain the data.

[Table 1 about here]

It is worth stressing that these models produce null distributions of graphs against which we can examine the observed counts of ties, two-stars and four-cycles. We are not attempting to provide good fit to the data by including a model with every possible effect. A full model would contain important structural effects as proposed by Wang et al (2009), as well as three parameters (activity, dispersion, closure) for each of seven types of actors and six institution types, of the order of 45 parameters or more. For this data, a statistical model with all these parameters faces difficulties in producing converged maximum likelihood estimates\(^8\). So, in the case of this study, it is simply not practicable to fit models with all effects and then to interpret parameter estimates. Accordingly, the approach of hypothesis testing against null distributions is a feasible method to draw inferences, when a complex, well-fitting model is not available for technical reasons. Wang et al (2009) provided an example in drawing inferences about bipartite graphs from extreme graph statistics in comparison to a partially fitting null model.

Our approach is in line with a long tradition in network analysis of comparing observed data with bootstrapped null distributions, extending back to Katz and Powell (1957) who discussed a number

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\(^8\) As noted below, we have not been able to obtain full convergence for some models simpler than this.
of conditional uniform graph distributions for unipartite networks. Such an approach has recently been applied in the study of networks of civic organizations (Baldassari and Diani, 2007); and in the study of bipartite networks of corporations and directors (Robins and Alexander, 2004). 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.) that simply compare the observed network statistic to the "fixed activity" model, because we attempt to build more complexity into the model at each hierarchical level.

To provide an insight into this process of comparison of observed data with null distributions, we present an example in Figure 8 of Federal government activity (left hand column of the figure) and two-star statistics (right hand column). From the top row of the figure to the bottom row, we move up the hierarchy of models from the fixed activity model to the probabilistic activity model to the attribute activity model. In Figure 4 the histograms are the relevant statistics for 1000 graphs simulated from the model (see below). The vertical line represents the observed data. For the left hand column, we see that Federal government activity is much higher than expected from the first two null distributions, so that we infer that Federal government agencies are substantially more active than the average. However, against the third null distribution, which has a parameter expressly for Federal government activity, we see that Federal government activity is no longer extreme (as indeed we want, given that it is now explicitly parameterized in the null model.) In the second column, however, we see that the number of two-stars is consistently more than expected against all three distributions; in the results below, this appears as a significant t-statistic. We infer that there is a relatively higher level of centralization that cannot be explained simply by the level of higher activity of Federal government agencies.

[Figure 8 about here]

For each of the four model types we fitted two versions: one where all nodes participated freely in the model fit and simulation, and one where connections involving high degree nodes were included in the fit and simulation but were treated as exogenous and fixed to be consistent with the data. The difference in results between the two is an indication of the effect of high degree nodes. It could be, for instance, that a closure effect is principally the outcome of lots of shared activity centered on one or two high degree nodes: that is, the result of graph centralization. When these connections are fixed, however, the resulting variation in the null graph distributions is due to network activity away from those regions. If the effect is solely due to the central nodes, then we will see an extreme effect in the first model but not in the second. This is one way to control for high-degree nodes that are possible artifacts of data collection procedures, such as gathering sample lists from previously known
institutions. If the network configurations of interest are still frequent even when fixing the degree of some nodes, we can feel more comfortable about making inferences. We call the first version of our models, general models, and the second version exogenous hubs models.

There was one institution with a degree over 80 (IRWM), and eight agencies with degrees greater than 20. For all exogenous hubs models, connections to these nodes were fixed. We were unable to obtain a converged general model for the higher order structural model, so only an exogenous hub model is reported here. Accordingly we report results for seven types of actors and six types of institutions across seven different null distributions.

The results are presented as t-statistics (full parameter estimates are in an Appendix). For the sample of graphs simulated from the model we count the number of various network configurations 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. If the t-statistic is greater than two in absolute value, we treat the observed data as extreme in the null distribution. Only extreme results are reported below. For each model 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).

Results: Network Activity

[Table 2 about here]

Table 2 reports the results for the network activity configurations. The first point to note is that there are not any extreme effects for models 3 and 4, because by including attributes those models explicitly parameterize these effects. Maximum likelihood estimation by definition centers the distributions on the observed data, so converged estimation for a model necessarily implies that the observed statistics are not extreme. Accordingly, for basic network activity, we restrict ourselves to inference based on models 1 and 2.

The second point to note is that models 1 and 2 are technically very similar to each other, so the similar pattern of results is not surprising. The statistical models basically reflect the descriptive statistics about degree distributions presented earlier. Consistent with our hypotheses, Federal and State government agencies have higher than expected levels of activity, while local governments and interest groups have fewer connections. Collaborative partnerships also have the highest level of activity, where as interest group associations and regulatory processes have fewer than expected connections. These results also hold for the exogenous hubs model, except that state and local
governments no longer have extreme values. This suggests that high-activity institutions are attracting more state government agencies than local government agencies.

**Results: Degree Dispersion and Centralization**

**[Table 3 about here]**

Table 3 provides the results for dispersion and centralization. Models 1 and 2 take into account average levels of network activity, and show more two-stars than expected for Federal and state government agencies, water districts, collaborative partnerships and joint power authorities; and fewer than expected for educational/consultative groups, and regulatory processes. Model 3 explicitly takes into account the baseline activity for each actor and institution type. In some cases, the sign on the statistic changes from models 1 and 2 (environmental group, regulatory process). We know from Table 1 that environmental groups and regulatory processes had lower than average levels of activity. Models 1 and 2 in Table 2 suggest lower counts of two-stars overall; but model 3 adds the refinement that, given the lower level of activity, the number of two-stars are in fact greater than expected. In other words, while environmental groups and regulatory processes have lower than expected numbers of connections, those connections tend to be relatively centralized.

The overall results from models 3 and 4 suggest that Federal agencies, state agencies, and water districts are the most centralized actors, with the Federal and state agencies centered most on the large hubs. This is important given the role of water agencies as the dominant economic actor in water management (Lubell and Lippert 2010). Collaborative partnerships are the most centralized institutions, with interest group associations a distant second. While these results are consistent with the descriptive measures of centralization, they also suggest some nuanced effects of large centralized hubs like the IRWP program. Water districts are centralized independent of IRWMP, reflecting their powerful position in water management. Regulatory institutions are also centralized outside of the major hub of the IRWMP; this is a result of their early emergence but continued functional role within the EG.

**Results: Closure**

**[Table 4 about here]**

Table 4 provides the results for network closure as represented by four-cycles. While the results for network activity and centralization show clear departures from random models, the results for closure provide the most compelling evidence about the coordinating roles of institutions and actors.
Closure processes as 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 collaborative partnerships, with regulatory processes and interest group associations also important sources of clustering. When the hubs are treated as exogenous, almost all extreme effects remain extreme, although less so. This suggests that while highly central nodes are affecting the structure in major ways, similar – although less intense - closure processes are still occurring among less central nodes. The exception is that of regulatory process which ceases to be extreme in the exogenous hub density models. This result suggests that regulatory process clustering is centered on high degree nodes, which again reflects the historical role of regulatory processes associated with state and federal agencies providing a backdrop for the emergence of new collaborative institutions.

When we include nodal attributes (model 3), we see that the effects largely remain although the t-values generally are smaller. This suggests that attributes go some way to explaining the closure effects but are not sufficient to do so completely. In other words, it is not enough to invoke differing activity by agency or institutional type to explain the number of four-cycles in the data; there are endogenous closure processes that go beyond agency or institutional type. These closure processes suggest the importance of shared participation in institutions. Actors of the same type may invite each other to co-participate in institutions; similarities in activities or interest may encourage same-type actors agencies to co-participate; or same-type actors may wish to participate in the same institutions in order to scrutinize the activities of their rivals.

Profiles of Actor and Institution Types

Table 5 about here

In order to understand the profile of each actor and institution type across all three network dimensions of activity, centralization and closure, it is helpful to regroup the previous results in a summary table that compares the strength and direction of effects. Table 5 summarizes the results for each actor and institution type across the three network dimensions for both the general and exogenous hub models. For the purposes of simple qualitative comparison, we have used a ‘high’ descriptor to represent a positive extreme t-statistic and a ‘low’ descriptor to represent a negative extreme t-statistic from the previous tables.

We see that federal and state government actors, and collaborative partnerships, have relatively high activity that is centralized and tends to be closed. This suggests a core-periphery type structure, consistent with figures 6 and 7, with activity structured around some leading actors and institutions, and high levels of cooperation and collaboration within the core. These findings are consistent with our
hypotheses about what types actors and institutions are likely to play the most important coordinating roles in the EG. The picture alters slightly once the hubs are treated as exogenous. Outside of the hubs, the federal actors are not especially centralized and the state actors are not particularly active. The continued centralization of state actors reflects their importance to regional environmental governance in California.

It is interesting to contrast the federal and state government activity with that for local government. Generally, local government tends to have lower activity, but not so outside of hubs. This suggests that local government is not as involved with the hub institutions as other actors. There is no evidence of centralization but there is for closure. This profile suggests a relatively non-hierarchical structure of local government actors, with perhaps smaller regions of collaboration dispersed across the structure.

Of the other actor types, the water groups exhibit consistent centralization and closure, suggestive again of a core-periphery structure but without evidence for high activity. The other four actor types seem to have limited organization in their structures: all exhibit low activity (except for environmental districts), and only environmental groups offer any evidence for closure processes.

Of the other institution types, interest groups seem highly structured, with consistent evidence of centralization and closure, albeit with low activity outside of hubs. Advisory committees and regulatory processes show some structural processes outside of hubs. Actors-as-venues and Joint powers are low activity institutions with no evident structural effects.

**Conclusion: Actors, Institutions, and the Effectiveness of Collaboration**

This paper uses statistical models of affiliation networks to identify the most important types of actors and institutions that serve as hubs of coordination in the Bay Area water management ecology of games. Consistent with our hypotheses, Federal and state government agencies show the highest levels of activity, centralization, and closure, reflecting their control of the important political resources of expertise, information, police authority, and finances. Water districts are also important coordinators, reflecting their typically privileged advantage in water management.

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. However, regulatory institutions still have some important influences on the structure of the network due to their historical role as the backbone of environmental policy and management.
Looking across the different network configurations, network closure as captured by 4-cycle configurations is the dominant network structure. Even after controlling for network activity and centralization configurations, as well as the different types of actors and institutions, there is a high number of observed 4-cycles relative to the model predictions. 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 (2010) argue that this is evidence that the EG involves many high-risk cooperation problems where reputation is necessary to guard against free-riding.

While these findings are definitely new and intriguing, the EG framework brings into sharp focus two critical questions that are not answered by this analysis. First, while this study measures cooperative 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 offers a different perspective on policy effectiveness. The standard response is to say that the picture of the EG presented in Figure 4 is a highly fragmented and ineffective system. In fact, the literature on collaborative institutions highlights the importance of inclusive policies that seek to encompass and coordinate multiple issues and actors. But as seen in the Bay Area, it is possible to have many different collaborative institutions in the same policy subsystem—there is not a single coordinating entity.

An alternative interpretation is that the Bay-Area policy ecology is in fact an adaptive complex-system. Collaboration has spread throughout the EG in the shape of multiple, diverse institutions. This provides a high level of redundancy to cooperation. In addition, like many other ecosystems, Bay Area environmental issues are complex and uncertain, with more uncertainty caused by climate change and policy change at higher levels of state and Federal government. In such complex situations, some amount of redundancy may be beneficial because it allows different actors and institutions to experiment and make mistakes without destroying the entire system. Allowing for trial-and-error
Learning can help the entire system find innovations and adaptations that can potentially track at least incremental environmental changes.

Network theorists have pointed out the adaptive capacity of other systems that have "fat-tail" distributions with a few high-degree nodes and many low-degree nodes. For example, the nervous system is capable of surviving many small errors but is vulnerable to attacks on central, high degree nodes like the brain. We expect similar processes are at play in the ecology of games. But as with standard policy evaluation, the ultimate effectiveness and adaptive capacity of this system depends at least somewhat on evaluating environmental outcomes and the ability of the SF Bay to provide ecosystem services. Unfortunately, Bay Area water management is far from successful on the environmental outcome criteria—it continues to face severe ecological problems that have brought to bear higher level governmental authorities such as the courts on the local EG. Overall adaptive capacity is also hard to judge without a counterfactual; would these problems even be worse if some element of the current EG was missing, such as CALFED or IRWMP? The EG framework adds an important twist to counterfactual thinking, but the issue is not whether a single policy institution exists or does not exist, but whether how any single policy institution operates in the context of the entire ecology.

This paper breaks new ground by combining the EG framework with exponential random graph models of affiliation networks. It is a modest and early step forward in a promising new avenue of research that will need to solve many new problems, and also puts traditional issues (e.g. counterfactuals) in policy analysis in a new light. Among the most important problems is getting comparative measurements of the EG over space and time and developing the technology of ERGM analysis to get better convergence behavior for this type of data and also expand to three-mode networks.
References


Figure 1: Basic Configurations for Network Activity

- Actor of a particular type with ties to institutions
- Institutions of a particular type with ties to agencies

Actor | Institution
Figure 2: Basic Configurations for Network Centralization

Actor of particular type involved in a two-star.

Institutions of particular type involved in a two-star

☐ Actor ☐ Institution
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

Centrality by Actor Type

Centrality by Institution Type

Legend:
- Normalized Betweenness
- Normalized Degree
- Normalized Eigenvector
Figure 8: Example comparisons with null distributions

(Note: Null distributions in left hand column are for Federal government ties; in right hand distribution are for Federal government two-stars. Top row is for fixed activity model; second row probabilistic activity model; third row, attribute activity model. Vertical line is the observed data.)
### Table 1: Hierarchy of Null Models

<table>
<thead>
<tr>
<th>Model Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed activity:</strong></td>
<td>The observed number of ties is fixed but the connections are distributed at random between agencies and institutions to produce a number of different graphs – a graph distribution. Each graph in the distribution has the property of the same number of connections as in the data. This is equivalent to classic U</td>
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<tr>
<td><strong>Probabilistic activity model (or Bernoulli model):</strong></td>
<td>The observed probability of tie is fixed and connections are then probabilistically distributed across each graph in the distribution. This is similar to the 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.</td>
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<tr>
<td><strong>Attribute activity:</strong></td>
<td>The probabilistic activity model with the addition of parameters that control for the activity of different types of actors and institutions. This model is equivalent to a Bernoulli model with actor attributes in unipartite network analysis. It is analogous to a logistic regression model, predicting the presence of absence of an actor-institution connection, with actor and institutional type as categorical predictors.</td>
</tr>
<tr>
<td><strong>Higher order structural model with attributes:</strong></td>
<td>The attribute activity model with the addition of parameters that control for the degree dispersion of both actors and institutions and for clustering not attributable to agency sector or institution type. The additional parameters are the agency and institution alternating k-stars and institution alternating k2paths described by Wang et al (2009).</td>
</tr>
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Table 1
t-statistics for counts of ties associated with actor and institution types in null distributions.

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Table 2

$t$-statistics for counts of two-stars associated with actor and institution types in null distributions.

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Table 3

*t*-statistics for counts of four-cycles associated with sectors and institution types in null distributions.

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### Table 4
Profiles of actor and institution types across network activity, centralization and closure

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### Appendix: Full Parameter Estimates for Hierarchy of ERGM Models

Parameter estimates (and standard errors) for models in this paper

Note: Fixed activity distribution is modelled by rewiring, not from a fitted model. Significant effects indicated by asterisk.

**Probabilistic activity (Bernoulli) model**

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<th>Exogenous hubs model</th>
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<tr>
<td>Density</td>
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<td>-3.88 (0.03)*</td>
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**Attribute activity model**

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<th>Exogenous hubs model</th>
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<tbody>
<tr>
<td>Density</td>
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<td>-3.90 (0.20)*</td>
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<tr>
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<td>1.50 (0.16)*</td>
<td>0.75 (0.20)*</td>
</tr>
<tr>
<td>State Govt Activity</td>
<td>1.38 (0.15)*</td>
<td>0.50 (0.18)*</td>
</tr>
<tr>
<td>Local Govt Activity</td>
<td>0.33 (0.15)*</td>
<td>0.30 (0.15)*</td>
</tr>
<tr>
<td>Water infrastructure Activity</td>
<td>0.44 (0.15)*</td>
<td>0.44 (0.16)*</td>
</tr>
<tr>
<td>Environmental district Activity</td>
<td>0.63 (0.21)*</td>
<td>0.60 (0.21)*</td>
</tr>
<tr>
<td>Environmental group Activity</td>
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<td>0.13 (0.16)</td>
</tr>
<tr>
<td>Industry group Activity</td>
<td>-0.18 (0.27)</td>
<td>-0.28 (0.28)</td>
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<tr>
<td>Interest group Activity</td>
<td>-0.40 (0.16)*</td>
<td>-0.38 (0.18)*</td>
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<tr>
<td>Collaborative partner Activity</td>
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<td>Advisory committee Activity</td>
<td>-0.29 (0.17)</td>
<td>-0.32 (0.20)</td>
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<tr>
<td>Regulatory process Activity</td>
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**Higher structural model with attributes model**

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<tbody>
<tr>
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<td>Water infrastructure Activity</td>
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