Policy Coordination in an Ecology of Water Management Games

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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, governance institutions, and issues, and not just single institutions 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.

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A fundamental and non-ignorable reality is 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 and resources distributed in such settings is one of the “big questions” in political science, policy sciences, and public administration (Agranoff and McGuire 2002; Klijn, Kooperman, and Termeer 1995). The question is also central in the emerging literature on social-ecological systems, which investigates how networks contribute to the resilience of governance (Bodin and Crona 2009). As V. Ostrom, Tiebout, and Warren (1961) note in their discussion of the closely-related concept of polycentricity, analyzing the *structure* of such complex policy systems is a necessary first step to understanding how they evolve and *function* to solve or not solve policy problems.

This article addresses these issues by drawing 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] With a few exceptions (Dutton 1995; Lubell, Henry, and McCoy 2010; Cornwell, Curry, and Schwirian 2003; van Bueren, Klijn and Koppenjan 2003), the EG framework and its variants have received little empirical testing. In this paper, we empirically operationalize the EG as a *bi-partite* policy network, where actors and institutions are two distinct types of nodes, and a *policy game* occurs

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[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.

when actors are linked to an institution. We then use statistical models of networks to test hypotheses about how different types of institutions and actors are related to the structural characteristics of the network.

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 EG. The *actor hypothesis* suggests that actors with access to political resources like police power, expertise/information, and finances have a greater capacity to coordinate policies and influence outcomes in the EG. 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, collect data and scientific research to support their decision-making, hire employees with specialized expertise, and shape incentives with financial resources like grant programs.

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. Different types of institutions will be embedded in network structures that reflect their overall role with respect to coordination and cooperation in the EG. Here we are particularly interested in collaborative institutions, which 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 water management.

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. Berardo and Scholz's (2010) *risk hypothesis* argues that network evolution is shaped by the type of underlying collective action problems. When the policy ecology consists of mainly coordination games, actors prefer to connect to "popular" institutions that increase the efficiency of information seeking. This is a brokerage-type strategy, whereby network actors seek gains from those who broker information efficiently across the network. 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.

Taken together, these hypotheses predict that government agencies and collaborative institutions will be embedded in network structures that reflect their capacity to coordinate policy. They will have higher levels of network activity and occupy more central locations in the network. To the extent that water management involves cooperation problems, these types of actors and institutions will embedded in more closed network structures. We do not hypothesize that institutions and actors are competing mechanisms for coordination in the EG. Rather, we believe they are complementary (Breiger 1974) and focus on which types of actors and institutions appear to be most important.

We statistically analyze the structure of the EG using exponential random graph models (ERGM) for bipartite networks (Wang et al. 2009). ERGM is a *statistical* model that estimates the probability of network tie formation as a function of different structural characteristics of the network and individual attributes. The ERGM approach analyzes whether different types of institutions and actors are associated with different types of network structures. For example, we find that collaborative institutions are associated with a higher than expected level of network closure relative to the amount predicted by our most complex statistical model. This suggests that collaborative institutions are one of the key mechanisms for solving cooperation problems in our study system.

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 scientists. There is 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 (IRWM), the CALFED Bay-Delta Program, and others. Such collaborative institutions 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 develops propositions from the EG theory into network-related hypotheses. The empirical section describes the data collection protocol, 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 policy effectiveness and the function of complex adaptive systems analyzed using the EG framework.

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 dynamic creation and destruction of institutions is possible. The bipartite representation is admittedly a simplification that does not capture all of the theoretical building blocks of the EG framework (see Lubell et. al. 2010 for extended theoretical discussion). In particular, we do not consider how games and patterns of participation change over time. However, bipartite networks do capture a level of complexity and interdependence that is not typically considered in analyses of single policy actors single institutions in isolation.

We investigate three network processes that are likely to structure the EG: network activity, network centralization (which is linked to degree dispersion or variance), and network closure. The extent to which such processes characterize the global structure of the network, and how they are associated with particular types of actors or institutions, provides clues about how cooperation and coordination emerges within the EG. These three network processes have 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 and reputation building.

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). 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 expected by chance once other possibly relevant processes are controlled. The term *chance* 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. We will later explain how we use ERGM as a statistical framework; this section focuses on the role of different network configurations in the EG framework.

Network Activity

The number of ties a node has can be interpreted broadly as a measure of *network activity;* network analysis typically refers to this as the *degree* of a node. 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. The top, left panel of Figure 1 shows the configurations associated with general network activity in a bipartite graph for the overall frequency of ties (i.e. irrespective of actor/institution types), and for specific types of actors (black circle) and institutions (black square).

[Figure 1 about here]

The right, top panel of Figure 1 shows a configuration of an actor of a particular type having a tie to an institution (of any type), where a particular type is treated as a binary variable and is represented by the filled black circle in the figure. If that type of actor is more active than others in the network, we will see more of these configurations than expected controlling for the general level of network activity. 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. Conversely, an institution of a specific type (filled black square) may have ties to actors of any type. Accordingly, the analysis measures the frequency of these configurations for each type of actor and institution.

Centralization and Degree Dispersion

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.

[Figure 2 about here]

Network centralization and degree dispersion are represented by *star* configurations, where a node has connections to multiple other nodes as in Figure 1. The left, middle panel of Figure 1 shows 2-, 3- and 4-star configurations that represent the degree distributions for both actors and institutions. The standard way to treat these configurations in ERGM is to combine them into the one parameter for each degree distribution (Snijders et al, 2006; Wang et al, 2009), the so-called *alternating star* parameter.[2] A positive alternating star parameter indicates a higher dispersion in the degree distribution and hence a more centralized network. A negative parameter indicates that a degree distribution without great variation among nodes.

The right, middle panel column of Figure 1 depicts 2-stars with actors and institutions of a particular type at the center of the star. These configurations represent within-category centralization that occurs over and above tendencies for centralization captured by the general alternating star parameter. For a given level of network activity, the presence of more two-stars indicates a more centralized network structure based around a particular type of actor (e.g., Federal government) or institution (e.g.; collaborative institution).

The middle, central panel displays spatial star configurations centered on institutions that involve actors from the same geographic region. We combine these different stars into an alternating star parameter to represent geographic centralization, which can be interpreted as a form of geospatial homophily where actors from the same region play similar games. This is a novel parameter in bipartite ERGMs and has been specially incorporated in our models to control geospatial effects.

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. We also expect geographic

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[2] In this paper, we do not present the precise mathematical definition of the associated statistic but refer interested readers to Snijders et al (2006) and Wang et al (2009). The parameter is also referred to as the *geometrically weighted degree distribution parameter* (Snijders et al, 2006). The alternating star parameter encompasses higher-order star configurations beyond those depicted in Figure 2.

centralization, because especially local actors and institutions have overlapping jurisdictions tied to political and physical boundaries.

Network Closure and Clustering

Network closure has been discussed extensively for unipartite social networks and is widely observed empirically. 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*. 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 (Berardo and Scholz 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 an extension to the notion of closure beyond the triadic configurations, the simplest of which are the cyclic structures displayed in in the bottom panel of Figure 1. The left, bottom panel shows depicts 2-paths between pairs of actors participating in the same two, three, and four institutions. Analogous to the star parameters, these configurations are combined into one *alternating 2-path* parameter to represent general bipartite network closure for actors. A positive parameter indicates a tendency for actors to share institutions to create denser regions of the network, whereas a negative parameter indicates the opposite, suggesting brokerage activities across the network as at least some actors tend to participate beyond a small number of shared institutions. With the alternating 2-path parameter in the model, closure for specific types of actors and institutions can be represented by simple 4-cycles as depicted on the right, bottom panel of the figure. The specific actor 4-cycle represent actors of a particular type (e.g.; Federal agencies) participating in the same institutions, while specific institution 4-cycles represent institutions of the same type attracting similar sets of 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. A high number of 4-cycles relative to network activity suggest tendencies for closure, while a lower than expected level of closure indicates network brokerage where actors are connected through institutions to other actors who are participating in different institutions. 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 on 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 Bay Area IRWMP is one of the most inclusive policy institutions 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 in the region. The survey was administered in April/May 2008 via a mixed-mode Dillman method (Dillman 2000). 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."

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. 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 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 involved actors without the necessity to survey a respondent from every single actor organization.[3] Hence, the network data includes 387 total

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[3] 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%

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 5 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.

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 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 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.

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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.

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.

Network Visualization

Figure 2 displays the a “spring-embedding” visualization of the entire Bay Area ecology of games network, and Figure 3 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 3) 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.

[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 after important changes in the 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.

Degree Distribution and Centrality

Figure 4 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 5 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 flow 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 explicitly posit a set of interdependent 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 (Figure 1) between actors and institutions can (loosely) be understood as the independent variables in the model. The parameters for these independent variables yields a probability distribution of networks from which our observed network (the dependent variable) is drawn.

ERGM is appropriate for analysis of cross-sectional network data, and has some similarities to traditional regression or logistic regression approaches of regular survey sample data. As with any cross-sectional analysis, ERGM only captures a snapshot of a dynamic social process. However, the network parameters estimated by ERGM can be conceptualized as describing the cumulative results of a process of network formation that has been operating over time. While the EG theory is explicitly dynamic, a cross-sectional analysis provides important initial insight especially when coupled with substantive knowledge about policy change. As with other social research, longitudinal data collected in future studies will provide the opportunity for stronger tests of a broader range of hypotheses.

[Table 1 about here]

Table 1 describes a series of nested models representing different assumptions about political behavior in the EG, and including different sets of parameters from Figures 1-3. 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. It only includes the general network activity parameter in Figure 1, where negative (positive) parameter indicates a rate of tie formation less (greater) than a 50% chance of forming any particular tie.

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 political activity model includes the type-specific network activity parameters, 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 *strategic decision* model introduces the alternating 2-stars for actors and institutions and the alternating 2-path parameter for actors[4], which imply that actors have preferences over more complex network structures and participation decisions are interdependent and strategic. According to the risk hypothesis, a positive star parameter indicates a centralized network that

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[4] We experimented with a model that included institutional closure but were not able to obtain convergent estimates. This is not surprising given that the two closure statistics are very highly correlated. Theoretically, of course, it makes sense to attribute closure to strategic decisions by actors, rather than institutions, so the actor closure parameter is appropriate in the model.

makes coordination and information transmission more efficient, while positive closure parameter suggests that actors are participating in institutions to solve cooperation problems.

The *strategic geography* model adds the geographic centralization parameter (bottom of Figure 2) and implies that opportunities for strategic interaction are constrained by the spatially explicit nature of environmental collective-action problems. 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 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 greater than 2 in absolute indicates the observed data is extreme in comparison to 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. This strategy goes beyond other network studies (Baldassarri and Diani 2007; Bearman et al. 2004) that simply compare the observed network statistic to the "naive actor" model, 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. Fixing hubs was also necessary to obtain model convergence for the strategic decision and strategic geography models.[5]

The parameter estimates in Table 2 provide initial insight into the structure of the EG network. The best fitting model is the *strategic geography* model, which introduces more

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[5] 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.

complex parameters reflecting the interdependency of decision-making within geographic constraints. The strategic geography model shows significant effects for centralization around institutions, even controlling for exogenous hubs and the average activity levels of different types of nodes. The large and positive geographic centralization parameter means that actors from the same specific geographic regions are clustering around central games.

The actor type activity parameters show five types of actors with significantly higher levels of activity than local government: Federal government, state government, water special district, environmental special district, and "other" actor. As hypothesized, these actors have higher levels of political resources and capacity to coordinate activities in the EG. The institutions activity parameters suggest that regulatory processes and "actors as venues" have lower levels of activity than collaborative institutions, reflecting the inclusiveness collaborative institutions relative to traditional regulatory institutions.

Comparing the results of the strategic decision model to the strategic geography model provides additional and surprising insights. Including the geographic centralization parameter means that the other general structural parameters are germane to connections between regions. In particular, the sign of actor centralization is positive in the strategic decision model but negative (and close to significance) in the strategic geography model, suggesting that centralization tends to occur within spatial regions and that actor activity that bridges across regions is somewhat decentralized. The general actor closure model also becomes insignificant, which means that actors that span geographic boundaries are not especially likely to form closed structures.

At the same time, the activity parameters for government agencies and special district become much larger relative to local government once geographic centralization is included.

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: Residual Analyses.

Table 3 presents *t*-statistics for actor and institution centralization and closure based on the final strategic geography 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). For each graph in the sample we count the number of various type-specific 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.

This approach treats the strategic geography model as a null model, and analyzes whether there are significantly more or less structural configurations in the observed data than predicted by the model. Analysis of the residuals in this manner is a major benefit of ERGM relative to more traditional linear models, where most researchers limit interpretation to the model parameters alone.

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 coordination and information brokerage roles in the EG.

The results for closure provide additional evidence about the coordinating roles of institutions and actors. While there is not significant *general* closure in the final model, the observed data has significantly more closure around certain types of actors and institutions and these closure processes are more extreme than for centralization. According to the risk hypothesis, this suggests that actors and institutions of particular types 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 are consistent with our hypotheses about collaborative partnerships and government agencies in shaping cooperation in the EG, but they also reflect how actors are cooperating to bargain over the distribution of policy resources. Environmental groups and water special districts are two of the key competing interest groups in water management, and the network closure results suggest they are organized into competing coalitions through the institutional vehicle of interest group associations. The more extreme closure effects around water districts is consistent the traditional view of water districts as the more powerful and well-organized interests (Lubell and Lippert 2011).

Conclusion: Actors, Institutions, and Policy Effectiveness

This paper breaks new ground by combining the EG framework with ERGM analysis of bipartite networks to identify the types of institutions, actors, and network structures that play a central role in shaping policy coordination and cooperation. 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 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 institutions play a key institutional function in the Bay Area EG, consistent with their inclusive approach for building multi-stakeholder collaboration. They are the most common type of institution, with the highest degree of network activity, and embedded in more closure than all other institutions other than interest group associations. This finding reflects the recent popularity of collaborative institutions as an alternative to traditional command-and-control regulations. But the continued importance of interest group associations suggests that coalitional bargaining over the distribution of resources is a core political process.

Comparing the different network configurations, network closure configurations show 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 and mutual monitoring are necessary to guard against free-riding.

While this analysis provides important insights into the structure of the EG, it cannot yet fully answer questions about the *function* of the EG for effectively solving policy problems. Some clues are provided by the fact that government actors are central boundary-spanners, and collaborative institutions are involved with high levels of closure. These structural characteristics reflect the purposely designed roles of these actors and institutions within the complex governance system, along with the evolution of the system to manage collective-action problems. But many observers would still argue the EG presented in Figure 2 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 2005).

Evaluating the functional effectiveness and adaptive capacity of this system requires a dynamic analysis, including measuring environmental outcomes. There is no guarantee that collaboration will continue to spread in any particular policy ecology, and cooperation and conflict are likely to cycle over time. Understanding what types of institutions and network structures are related to effectiveness requires longitudinal research along with comparisons across different types of policy arenas. Such research will also be crucial for providing concrete recommendations about network management (Klijn, Koppenjan, and Termeer, 1995) regarding how to link actors to institutions in ways that promote cooperation, adaptation, and resiliency. Understanding the structure of the EG is a necessary first step to these applied policy goals, and the EG framework and network science are promising theoretical and analytical tools for this type of future research.

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Figure 1: Bipartite Network Configurations

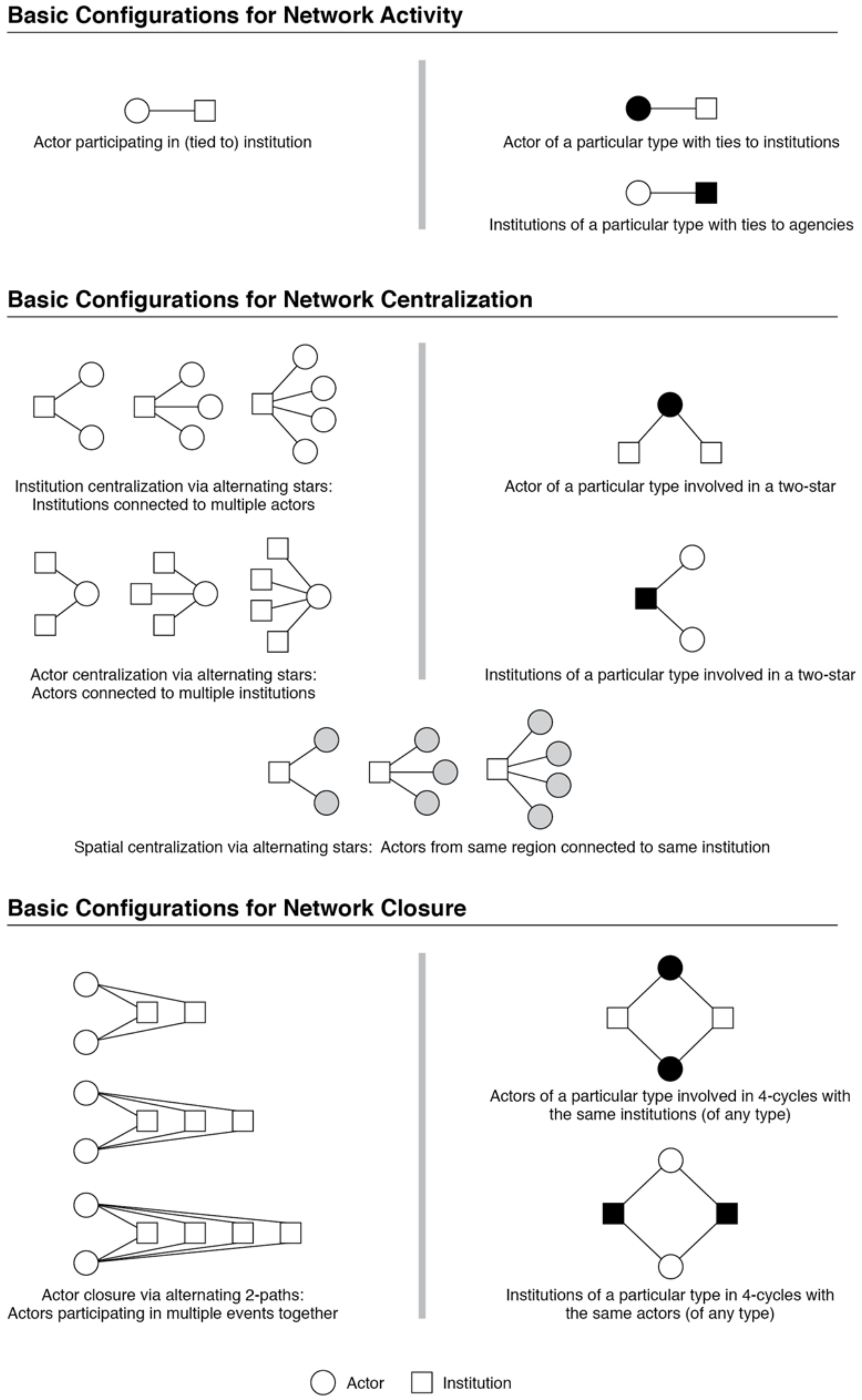

Figure 2: Affiliation Network for the Bay Area Ecology of Games

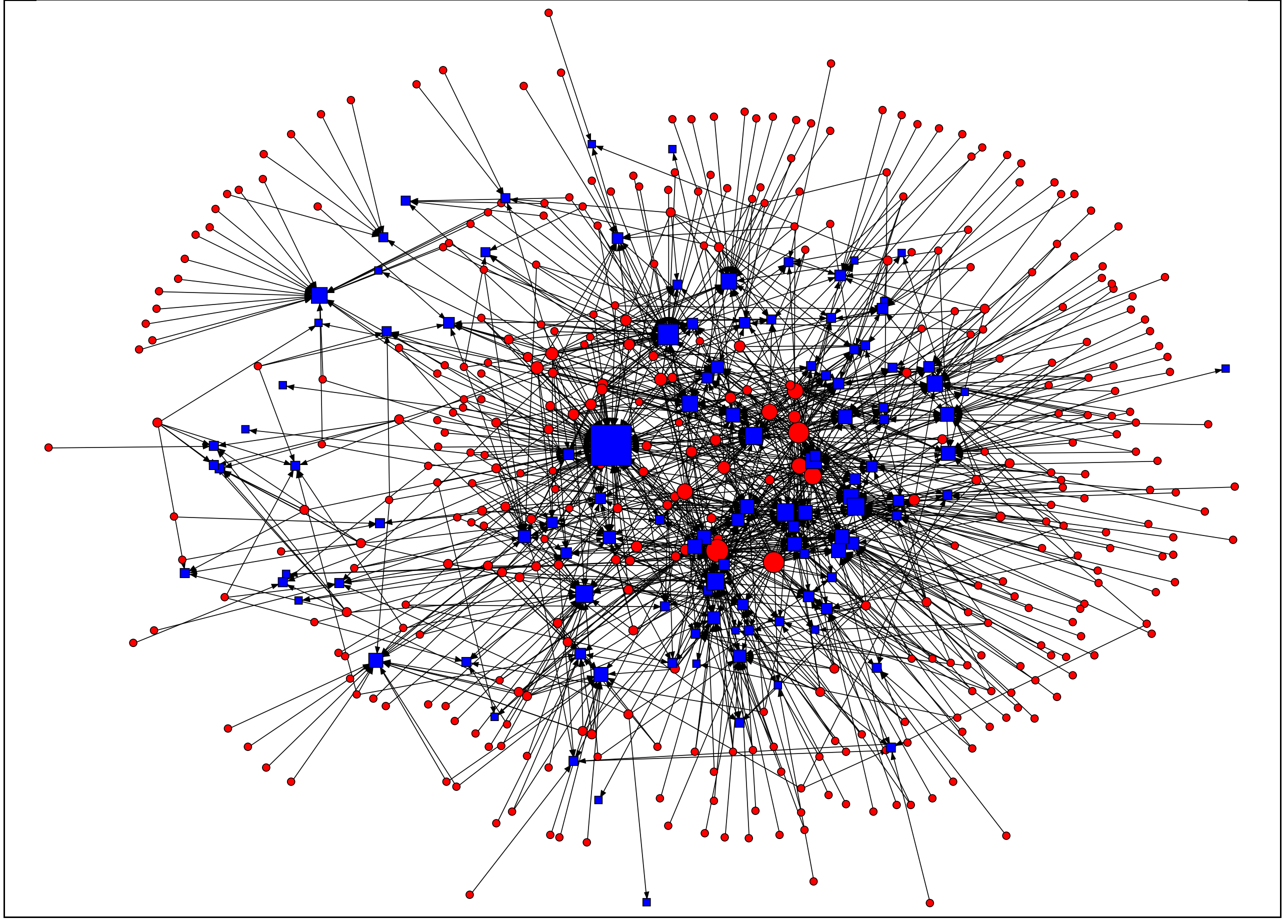

Figure 3: Most Central Actors and Institutions in the Bay Area Ecology of Games

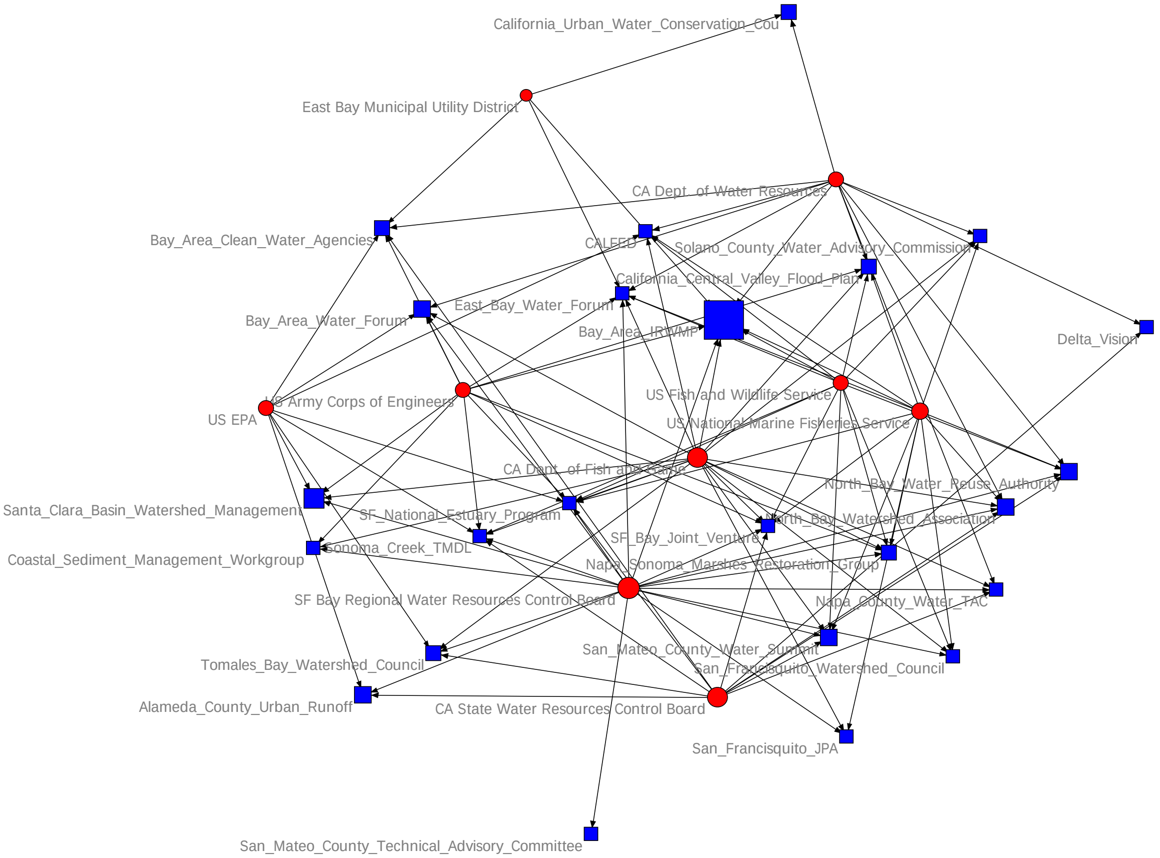

Figure 4: Degree Distributions for Actors and Institutions

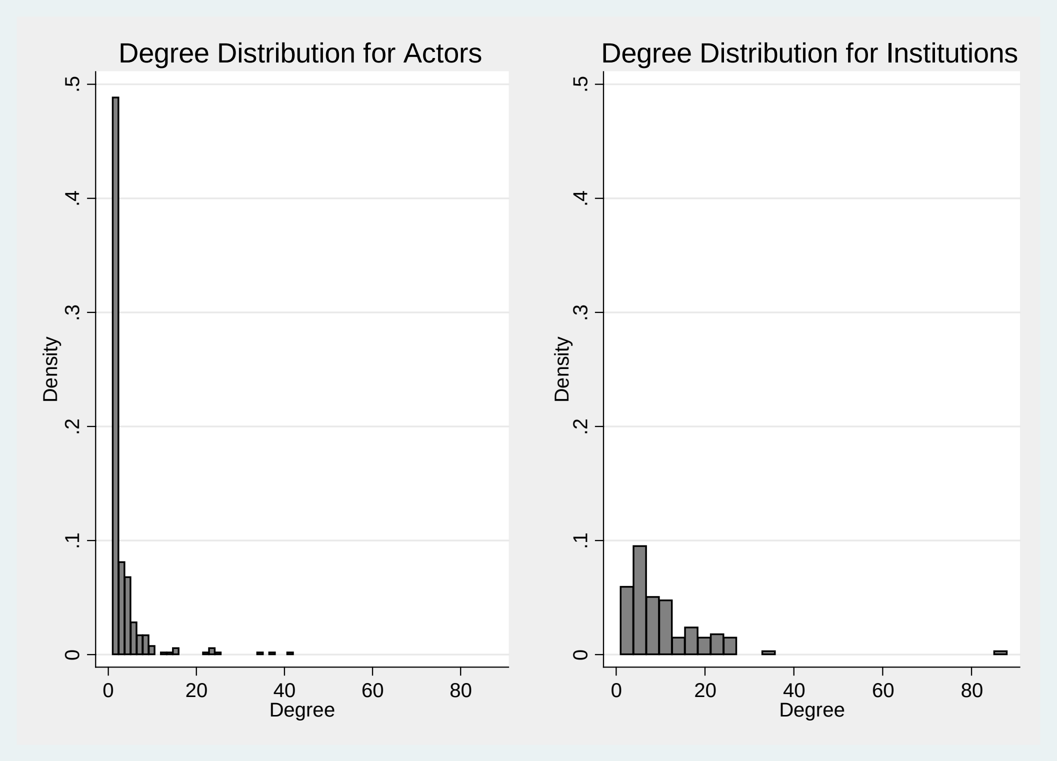

Figure 5: Centrality by Actor and Institution Type

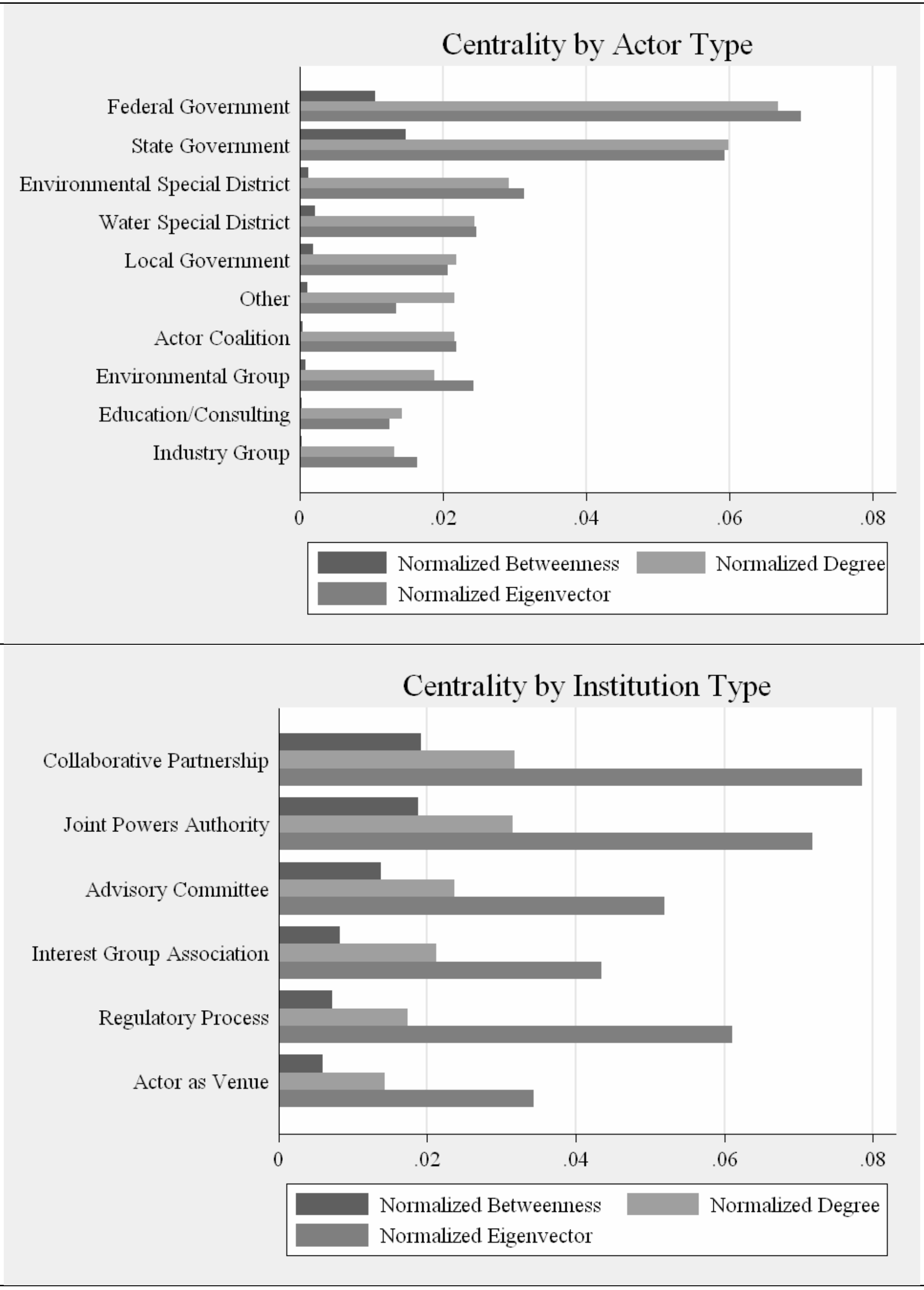

Table 1: Hierarchy of Exponential Random Graph Models
Naive actor model (Bernoulli model): The observed *probability* of tie is fixed and connections are then probabilistically distributed across each graph in the distribution. This model is equivalent to an Erdos-Renyi model, or Bernoulli random graph 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) – see figures 2 and 3 and associated text for further details.
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. See figure 2.

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		17.5
Collaborative Partnership		8.9
Advisory Committee		
Regulatory Process		
Actor as Venue		
Joint Powers Authority		