The Ecology of Games as a Theory of Polycentricity: Recent Advances and Future Challenges

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The Ecology of Games approach to examining complex governance systems in democratic societies has been recently refurbished to infuse renewed vitality in the analysis of institutions and collective action in polycentric governance systems. This opening article to the special issue on the Ecology of Games Theory (EGT) will discuss the main component elements of the theory, as well as recently produced empirical advances that test and extend it. The article is structured in three sections. The first section describes the EGT as a theory of polycentricity and explains why it is critical to study both the structure and function of polycentric governance systems, including collaboration among policy stakeholders, learning about problems, and equitably distributing the resources generated by policy interactions. The second section reviews empirical evidence that examine structure and function in polycentric systems, including their coevolution. Finally, the third section will provide insights on future research needs to strengthen this newly developed theory of polycentricity.

生态博弈方法主要研究民主社会中复杂的治理体系，而近来对该方法的革新，为分析多中心治理体系中的制度和集体行动注入了新的活力。作为本期生态博弈理论（EGT）特刊的开篇文章，本文将讨论该理论的主要组成部分，以及近来在检验和拓展该理论时的实证研究进展。本文分为三个部分。第一部分把EGT描述为多中心理论，并解释为什么研究多中心治理体系的结构和功能至关重要，在此之中，我们也探讨了政策利益相关者之间的合作、对政策问题的学习以及政策互动过程中产生的资源公平分配。第二部分回顾了检验多中心体系的结构和功能的实证证据，这其中包括了结构和功能协同进化的实证研究。最后，第三部分将提供我们对未来研究需求的深入见解，进以巩固最新发展的多中心理论。

> "We need to look at political systems as whole entities shaping and being shaped by their environments." (Almond & Powell, 1966)

The ecology of games theory (EGT) conceives policy processes as complex adaptive systems (Folke, 2006; Levin, 1998, 2003), and attempts to function as a theoretical lens to improve the empirical analysis of polycentric governance systems. While the EGT as a theoretical tool for analyzing complex governance was initially presented in Lubell (2013), the name itself builds on the metaphor offered by sociologist Norton Long (1958), who described urban systems as "ecology of games" that consist of

interlinked games (e.g., the banking game, the infrastructure game, the ecclesiastical game, etc.) played simultaneously by actors eager to achieve their individual goals. Long saw this self-organizing process of actors deciding to participate in different games as inherently functional, arguing that the territorial system is "fed and ordered" (p. 254) by the constant updated interactions among actors, making political leadership a non-necessary (though not lacking in value) condition for local governance.

The EGT recognizes that in the real world, policy decisions are made by networks of policy actors interacting in multiple forums at different geographic scales ranging from local to global, addressing a myriad of interconnected issues.[1] Some policy forums are informal and voluntary, others may involve the more formal power of the state exercised through administrative authority, courts, or legislatures. Some policy forums use collaborative strategies, while others are adversarial, with a diversity of other structures possible. Actors strategically choose in which forums to participate to pursue their goals, and decisions in one forum may positively or negatively influence decisions in others. In resilient and enduring political systems, these sets of actors, forums, and collective decisions may aggregate to produce welfare-enhancing policies that solve collective-action problems, as long as enough actors are satisfied with the procedural and distributional fairness of the system.

The EGT aims to remedy two major problems with the concept of polycentricity, which was first introduced in Ostrom, Tiebout, and Warren's (1961) seminal paper on the provision of local public goods in metropolitan regions with multiple local government jurisdictions. First, it aims to strip the concept of the normative prescription that polycentric systems are more effective than presumably nonpolycentric forms of governance such as "command-and-control," "networks," or "markets" (Ostrom, 2010). What this perspective fails to recognize is that *all* policy systems—even the most hierarchical—are polycentric, involving networks of actors and policy forums that vary (sometimes widely) in their structure and function. Therefore, it is incumbent on policy theorists to develop a theoretical perspective that is capable of analyzing that variance. The EGT serves as a theoretical platform for scholars to work toward this goal by exploring how the interconnectedness of policy games and actors affects how much the latter learn about problems, collaborate with each other, and distribute the benefits and costs of their interactions.

Second, even if there was agreement about a theory of polycentric governance (a questionable assumption in itself), there has not been adequate empirical research to systematically test hypotheses and establish core principles about how complex adaptive systems evolve over long periods of time in response to feedbacks between structure and function, and also in response to changing social and ecological parameters. These feedbacks have catalyzed a strong intellectual kinship between polycentricity scholarship and theories of social-ecological systems (Lebel et al., 2006; Olsson, Folke, & Berkes, 2004; Ostrom & Cox, 2010). Furthermore, how polycentric systems evolve and perform over time may also vary across spatial and/ or institutional contexts. Yet very little empirical research takes an explicitly comparative or longitudinal approach, which leaves us with many interesting snapshots and one-off conclusions about the working of polycentric systems, but severely

constrains knowledge accumulation. As a result of these two problems, while actual policymakers easily recognize the complex nature of policy systems, policy researchers cannot provide satisfactory answers about how individual actors should navigate the system and how the system as a whole can be "steered" toward better performance (Klijn, Steijn, & Edelenbos, 2010). The EGT aims to remedy this gap by explicitly considering how the structural linkages among actors, issues, and institutions evolve over space and time, and how the social processes that occur within the complex system produces operation rules governing resource use. In addressing these gaps, the EGT joins other theoretical approaches, such as the Institutional Collective Action Framework (Feiock, 2013) and theories uncovering the operation of public economies and governance systems characterized by the simultaneous actions of myriad actors tackling a variety of policy problems in complex, multiscale governing arrangements (Liesbet & Gary, 2003; Oakerson, 1999).

This special issue on the EGT is designed to provide a milestone for nearly a decade of research from scholars developing the approach, and to assess what we have learned to date and think about future research goals. The article has three main sections. The first one is a (re)introduction to some of the central arguments of the EGT as a valuable tool to study complex polycentric governance systems that are pervasive across the world—regardless of the type of formal institutional rules that shape those systems (i.e., both democratic and nondemocratic systems). The second section links the EGT to the broader structural–functional perspective that informs research in complex and networked systems, but is also essential to theories of political systems and social behavior. The third section reviews the main hypotheses that have been supported by existing research, including the research presented in this special issue. We then discuss some of the unanswered questions on polycentricity that deserve future attention, many of which are also highlighted by other articles in this special issue.

Polycentricity: A Concept in Search of a Theory?

This section elaborates on our argument that the EGT provides a useful theoretical approach to the analysis of polycentricity. From Polanyi's (1951) original conceptualization of the term to more modern definitions, the term polycentricity continues to encompass the three core attributes identified by Ostrom et al. (1961, p. 831): "(i) many autonomous units formally independent of one another, (ii) choosing to act in ways that take account of others, (iii) through processes of cooperation, competition, conflict, and conflict resolution" (Ostrom 1991; cf. Carlisle & Gruby, 2017).

In our opinion, the body of polycentricity research that has evolved over the last half-century has revealed a fundamental problem with polycentrism as a theoretical concept—i.e., scholars have embraced a normative assumption that polycentric systems are better at solving collective action problems than some other type of system. Indeed, the central argument of Ostrom et al. (1961) was that polycentric systems were better suited than monocentric systems for providing local public goods. Carlisle and Gruby (2017) provide an excellent summary of additional touted benefits (and associated enabling conditions) of polycentric systems: adaptive capacity,

institutional fit, and mitigation of risk through redundancy. The resulting normative prescription appears in papers like Ostrom (2010, p. 552), where in references to global climate change she states, "No governance system is perfect, but polycentric systems have considerable advantages given their mechanisms for mutual monitoring, learning, and adaptation of better strategies over time."

The problem becomes most apparent when considering what types of institutional systems are compared to polycentric ones. The usual comparison is between polycentric and monocentric systems, what Ostrom et al. (1961) called "Gargantua" in the context of metropolitan governance, or what other policy scholars might refer to simply as "command-and-control" systems. But in the real world, is there really such a thing as a monocentric system where one actor or even a small set of actors has enough authority or information to make binding decisions for all others in a community? We believe that monocentrism is no more than an ideal type, with no real empirical correlate. Instead, real-world governance systems are virtually always polycentric in nature (even in strongly hierarchical systems), with multiple policy forums functioning as arenas where issues can be discussed by actors interested in achieving individual goals and agendas. Polycentricity is a defining characteristic of even highly hierarchical organizations like the U.S. military, or of political systems defined by nondemocratic features.

Accepting this argument creates a troubling dilemma for positive theory and empirical research, because if everything is polycentric, then it follows that there is no institutional variance to serve as a basis for comparative analysis. To escape the horns of this dilemma, we argue that policy scientists must adopt a theoretical framework that analyzes the variance in the structure and function of polycentric governance across different systems and over time. Then based on the key variables that differentiate structure and function, test hypotheses about how polycentric systems affect individual behavior and system performance. In our view, this is the epistemological mission of the EGT, which qualifies it as a theory of polycentrism—a concept in search of a theory.

The EGT provides the basis for the development of more specific testable hypotheses that collectively improve our understanding of how polycentric systems are shaped and function. Empirical research furthers this mission by operationalizing key EGT structural concepts, such as networks and functional ideas such as learning and cooperation, and then developing comparative research designs to investigate how the systems change over space and time, including the causal relationships among different aspects of polycentric systems.

To be clear, the lack of clearly testable hypotheses about the shape and performance of polycentric governance systems is not a fault we find in all of the work on polycentricity. In fact, Ostrom et al. (1961) did present clear hypotheses about the behavior of actors and some structural properties of the systems. Drawing on Tiebout's work on public goods markets, for instance, they proposed that polycentric systems would be better at providing public goods than consolidated systems because citizen-consumers could vote with their feet and choose to reside in local jurisdictions that offer their preferred bundle of public goods and taxes. They also offered a second testable hypothesis that might hint at the institutional structure of

polycentric systems when they asserted that any conflict among local units can be resolved via a "variety of formal and informal arrangements that may exist for set-tling area-wide problems" (Ostrom et al., 1961, p. 842). It is important to recognize that Ostrom et al. were concerned about horizontal competition and cooperation among local governments in the provision of public goods, rather than the structure and function of multilevel systems, something that the contemporary literature on polycentric governance emphasizes much more explicitly.

For instance, Elinor Ostrom (2010, p. 552) argues that "polycentric systems are characterized by multiple governing authorities at differing scales rather than a monocentric unit." This type of governing arrangement might facilitate adaptive governance in the presence of complex global problems that operate at different geo-graphic and institutional scales, such as adaptation to climate change or protection of water quality in watersheds that cut across multiple subnational or national juris-dictional limits. While Ostrom innovates in describing in certain detail some of the benefits of polycentrism (e.g., enhancing learning, cooperation, and adaptiveness), and some of its challenges (e.g., inconsistent policies across governmental levels), perhaps her most important contribution is in the double acknowledgment that (i) polycentric systems are not a panacea, and (ii) a theory of polycentricity does not yet exist to explain "how much" or "what type" of polycentricity might be useful to address problems in different social-ecological contexts. The EGT recommends pay-ing explicit attention to measuring the structural aspects of polycentric systems, for example, how different "centers" of decision making are embedded in the overall system, and examining how those structural features relate to core social processes and ecological outcomes over time.

The next section reviews the building blocks of the EGT from the perspective of structure and function, modern perspectives on complex systems and classic work in sociology and political science.

The Structure and Function of an Ecology of Games

The main insight of the EGT as a theory of polycentricity is that complex gov-ernance systems are characterized by the existence of multiple "policy games" operating simultaneously within a geographically defined policy arena. Each of these games can be thought of as a rule-governed collective decision-making pro-cess, dealing with one or more policy problems (e.g., water quality, transportation, education, public health, etc.), usually taking place inside well-defined forums or venues (e.g., a planning process, a city council, a legislative committee, etc.) with multiple "players," or policy actors who are endowed with a unique combination of resources and policy preferences. Importantly, these games may operate inde-pendently, though it is typical for them to be interconnected (Lubell, Mewhirter, Berardo, & Scholz, 2017; Lubell, Robins, & Wang, 2014; Mewhirter & Berardo, 2019). For example, multiple games may deal with similar topics, as when policy actors discuss local adaptation to climate change in different forums. But different games may also affect linked policy issues, as when one policy forum deals with ground-water management and another focuses on surface water. When decisions made in

policy forums are interdependent, the decisions made by an actor in a game may positively or negatively affect its own outcomes (or that of other actors) in other games. The existence of such externalities in polycentric systems may require actors to learn, coordinate, and cooperate across games.

In addition, the polycentric systems that the EGT is interested in examining have interdependent components, including different types of network relationships within and between different types of social, political, and biophysical nodes. These complex, networked systems are usefully analyzed in terms of structure and function (Turnbull et al., 2018). Structure refers to the architecture of the system, while function refers to the dynamic processes that operate within the system and affect its change and performance. Usually within a short time scale, structure has a direct causal effect on dynamic processes as when institutions shape behavioral incentives. But in the long run, structure and function coevolve (e.g., political behavior may also lead to changes in institutional rules).

The interplay of structure and function in the EGT is anchored in a long tradition of theoretical work in sociology, political science, and economics. In sociology, the focus on structure and function dates back to classic Parsonian structural–functionalist theory, which initially conceived social life as inherently complex and regulated by institutions and structures that are in turn reshaped by the social functions they have. A common early criticism of structural–functionalism was that it viewed social life almost as devoid of social conflict, a perception that changed after Robert K. Merton (1957) showed that certain structures may facilitate "social disfunction." This idea resonates strongly with the EGT, as we conceive polycentric governance systems as loci where functional behaviors and/or attitudes can be pursued, but also as arenas where conflict can be openly expressed and channeled.[2]

In political science the structural–functionalist approach was initially championed by Almond and Powell (1966), who argued for a comprehensive understanding of how institutions operate in political systems according to their functions, and who also claimed that a careful examination of institutions and their effect on behavior needs to be placed in historical and political context, a view we have espoused elsewhere (Berardo & Lubell, 2016). Almond and Powell described a few functions of the American polity, which collectively gave form to what they called the "conversion processes" of a political system, which turn input into political systems into outputs such as regulation and distribution of benefits for political actors, to name a few. Some of the functions they identified are similar to the functions that we mentioned above. For instance, they argued that key systemic functions are those of *interest articulation*, *interest aggregation*, and *communication*, which we see as analogous to the functions of cooperation (in the case of articulation), and learning (in the case of aggregation and communication). Almond and Powell also criticized the exceedingly optimistic assumptions of structural–functionalism and explicitly advocated for studying political systems as complex webs of sociopolitical interactions where harmony and stasis are the exception rather than the norm.

In economics, structure and function are key aspects of neo-institutional economics and game theory, two fields that had a profound influence on Elinor Ostrom's work. With a lineage that traces from Coase (1937) to Williamson (1985) to North

(1990), neo-institutional economics focuses on how the structure of formal and informal institutions affects the transaction costs of cooperation. Neo-institutional economics argues that market exchanges are fundamentally cooperation problems that require searching for mutually beneficial solutions, bargaining over distributional benefits, and monitoring and enforcing the resulting agreements. Depending on the attributes of the transaction, the costs associated with it might be lower in the market or organized in the context of a hierarchical firm (Williamson, 1985). The evolution of institutions that enable a wide range of economic transactions is the key to economic development and growth over time (North, 1990). From a game theoretical perspective, the structure of the game determines the best response strategies and the existence and efficiency characteristics of different possible equilibrium outcomes.

Key Structural Features in the EGT

In a context of complex governance where multiple games are simultaneously played, it is critical to understand both the structure of the system and its functions. The structure of an ecology of games refers to three characteristics of a complex governance system. The first defining characteristic of the structure is the informal and formal rules governing collective decision making within different individual forums. At a minimum, these rules determine the issue scope of a forum (i.e., the jurisdiction of the forum), who can participate in it, the process by which individual preferences are aggregated to collective decisions, and the way in which information is made available to participants.

The second defining characteristic of structure in a complex governance system refers to the patterns of interactions among policy actors, which can take place through formalized channels, such as when policy actors participate in well-established policy forums (Berardo & Lubell, 2016; Fischer & Leifeld, 2015), but also informally when actors interact in dyadic relationships that are not necessarily open (nor transparent) to third parties (Berardo, 2009; Lee, Lee, & Feiock, 2012; Weare, Lichterman, & Esparza, 2014).[3] The EGT analyzes how the mix of formal and informal interactions works within the system. For example, the EGT hypothesizes that institutional change is precipitated by informal discussions in response to new issues or perceived problems. These informal discussions occur with a fairly high frequency in polycentric systems, and only rarely translate into more formal institutional changes. These formal institutional changes then constrain and enable the types of informal discussions that will occur in the future—that is, the dynamic feedbacks between formal and informal interactions are crucial components of institutional change.

The third defining characteristic of structure in a complex governance system is the level of interconnections among policy-relevant issues. In the context of environmental policy, these connections are rooted in the biophysical interconnections inherent in ecological systems, and from this standpoint the EGT can be thought of as a theory of social-ecological systems (Folke, Hahn, Olsson, & Norberg, 2005; Olsson et al., 2006). Harmful algal blooms (HABs), for instance, can be triggered

by excess application of fertilizers in farms that are not necessarily located near the places where their negative effects on public health are felt. The issues of farming best management practices in the application of fertilizer and responses to public health crises triggered by algal invasion of drinking water sources are therefore connected. Because games and topics are interconnected, understanding the structure of interactions among actors, and issues is critical in order to devise effective strategies to deal with system-wide problems. Some recent EGT research offers some insights about how the structure of a governance system may explain effectiveness in dealing with a certain policy problem (Berardo, Olivier, & Lavers, 2015). However, far more empirical research is needed in order to precisely illuminate the set of core empirical regularities that link structure, function, and effectiveness in different social-ecological contexts, and different points of time in the policy process.

Key Functions in the EGT

The EGT also emphasizes the need to study the functions of polycentric governance systems, which are the dynamic processes that occur conditional on structure. The EGT considers three of these functions as critical to understand system performance, cooperation, learning, and fair distribution of gains resulting from actors participating in the system (see Lubell, 2013, for more details). Cooperation involves shaping the behavior of multiple actors in ways that increase the likelihood that they will jointly contribute to achieving outcomes that are both collectively and individually desirable.

Learning takes place when actors can effectively process new information about problems they care about, and about how other actors think about those problems. Because learning requires improving knowledge of how other actors operate in a complex governance system, it "typically requires the actors to draw from a range of knowledge domains and expertise" (Bodin, 2017) that are available in the system.

Finally, resource distribution refers to the way in which collective benefits and costs are distributed across the myriad stakeholders that partake in the governance system. In a polycentric system where actors may engage others in different games, the distribution of efficiency gains (Pareto improvements) that result from solving problems are by no means guaranteed to be equitable or fair (Lubell, 2013, p. 543). In fact, it is common for policy actors to engage in a series of tactics to increase their individual share of gains from a cooperative process. Actors can, for instance, form coalitions of like-minded others (Fidelman et al., 2014) with the goal of strengthening their relative positions in the system, or simply take advantage of power imbalances that result from an unequal availability of individual or organizational resources to accomplish the same goal. Governance systems where distribution is fair (or at least perceived as so by the main actors participating in the decision-making centers) should be more likely to produce decisions that are, on average, less controversial, and thus more likely to be supported by a larger cast of actors (Berardo, 2013). A system that is perceived by enough political actors to fairly distribute the gains from cooperation is more likely to be considered legitimate and politically stable over time.

As with the work of Ostrom, these three processes reveal an important link between the EGT and neo-institutional economics. In particular, the transaction costs searching for potential agreements, bargaining over the distribution of benefits, and monitoring and enforcing agreements (North, 1990; Williamson, 1985) are analogous to the costs that affect the functions of learning, distribution of resources, and cooperation, respectively. However, the analysis of these transaction costs and processes must encompass the entire polycentric system (actors, forums, and issues) not just one policy forum in isolation.

Empirical Research on the EGT

Lubell (2013, p. 543) argued that the EG could evolve into a "fertile" theory of polycentric governance provided that "more intellectual development and empirical investigations" were produced from the growing community of researchers interested in this approach. In the time that has passed since the publication of that agenda-setting article, a growing number of scholars have found value in the EGT as a tool to examine the characteristics of complex polycentric systems. This research has mainly focused on environmental policy, because of the obvious link to Ostrom's work and previous research on polycentric governance in that area (Anderies & Janssen, 2013; Ostrom, 2009).

But the EGT has also been applied to a diverse set of policy issues, including education (Firestone, 1989; Nisar, 2015), economic development (Cornwell, Curry, & Schwirian, 2003), telecommunications policy (Dutton, 1992), nonprofit management (Mendel, 2003), and even talent development in Nordic sports (Andersen, Bjørndal, & Ronglan, 2015; Bjørndal, Ronglan, & Andersen, 2017). While some of the earlier research is more directly related to Norton Long's original ideas, more recent research incorporates the EGT's perspective to explicitly study the relationship between structure and function of polycentric systems. Thus, the scope of the EGT is not limited to environmental policy; it is applicable to any policy system with multiple issues, actors, and forums (which in our view, is virtually all policy systems). The body of empirical research has not only contributed to furthering our understanding of the structure and function of these systems but also deepened our knowledge of how the component elements of an ecology of games operate under different political and institutional conditions. However, there are still far more unanswered questions about the structure, function, and evolution of polycentric systems than accepted answers.

The remainder of this section reviews what we know about structure and function in polycentric systems based on EGT research of the last decade, including research presented in other articles of this special issue. We organize the review according to the main structural features and functional processes discussed above.

What We Know About Structure

Regarding the structure of ecologies of games, research has shown that institutional rules do in fact affect how actors participate in forums, and how their needs

and demands are aggregated in them (or not). Fischer and Leifeld (2015) observe that policy forums enable political exchange among actors, but that these exchanges are mediated by institutional rules. For example, they show that the composition of a forum (who gets to participate) and the characteristics of the decision-making process (how participants make decisions) affect the way actors learn about problems and cooperate with each other. Berardo et al. (2015) examine the ecology of games to manage natural resources in the Parana River delta in South America and also find that the overall structure of interactions among stakeholders is shaped by institutional constraints that are in turn impacted by external environmental shocks. In particular, they study how the ecology of games to address land and water use in the delta was affected by wildfires initiated by agricultural producers to clear native vegetation in the delta's islands in 2008, and observe that the new forums that were created to address the problem may not be effective enough in the long term due to their inability to incorporate the voices of all affected parties.

Other EGT research has examined in more detail the architecture of relationships that form when actors exchange resources with each other, either directly through one-on-one relationships, or indirectly through their participation in joint forums. Berardo and Scholz's (2010) risk hypothesis, enunciated in the context of collaborative networks operating in environmentally sensitive estuaries in the United States, is one of the first applications of the EGT to the study of collaborative partnerships, and links the behavior of actors in complex ecologies of games to the types of uncertainty they face. According to the risk hypothesis, actors in high uncertainty, risky situations in which defection by counterparts is more likely should be more willing to exchange information and resources with others in tight-knit, highly bonded groups in which defection carries important reputational costs. On the other hand, actors in low uncertainty, less risky situations should be more likely to build bridging ties in their networks, which maximize their capacity to explore distant parts of it, improving their access to non-redundant information that can be of value to solve coordination, rather than cooperation, problems. Berardo and Scholz found a mix of binding and bonding structures in the networks they studied, which they saw as evidence of the co-occurrence of cooperation and coordination problems that reveal the complexity of governance systems where myriad actors have sometimes aligning, sometimes clashing policy views and preferences.

Their results have been replicated elsewhere, including in studies of regional governance in China (Yi et al., 2018), policy networks dealing with autism in Virginia (Parsons, 2018), management of small-scale fishers in Jamaica (Alexander, Bodin, & Barnes, 2018), joint-venture partnerships for suburban residential planning in Australia (McAllister, Taylor, & Harman, 2015), and water supply for human consumption in New York City and Boston (Olivier, 2018), to name a few.

While the risk hypothesis as originally stated concentrated on the analysis of one-mode networks (i.e., direct actor-to-actor relationships), other work has focused on the indirect ties that are established when actors participate in games together. Lubell et al. (2014) and Berardo (2014a) extended the risk hypothesis to the analysis of two-mode networks. Lubell et al. examined the ecology of games in San Francisco Bay (California) formed by joint attendance of stakeholders to forums and found

that structural features of the system, which included an abundance of configurations associated with network closure, were more conducive to the solution of cooperation problems of a system-wide scale. Berardo, on the other hand, found that bridging structures can dominate in networks where different organizations partner to design and implement water management projects in southwest Florida. More recent work has explored in detail the drivers of activity in ecologies of games in the United States and Argentina, showing that the structure of interactions among actors that takes place through their joint participation in policy forums is likely affected by macro-level variables (e.g., supra-local institutions) that condition the ability of policy stakeholders to engage each other repeatedly (Berardo & Lubell, 2016).

New studies shed some light on the drivers of activity in the two-mode structures that form when actors engage each other in common forums. Nohrstedt (2018), for instance, analyzes the exchange of information among 51 organizations participating in 50 collaborative forums that respond to weather warnings in Sweden and shows that actors avoid exchanging information in closed subgroups, which he sees as evidence that actors seek to achieve the long term goal of sustaining collaboration in the forums. Hileman and Bodin (2019) add a temporal dimension to the study of ecologies of games and suggest that the structure of collaborative governance networks in two case studies in Sweden may change substantially when collaborative processes are sustained in time, as actors are able to increase their capacity to engage with multiple policy forums and other actors. An interesting corollary from this work is that extensive participation in an ecology of games does not necessarily translate to an improvement of functions (e.g., cooperation). For that to happen, the authors argue, new organizational capacity to process the myriad resources that can be accessed in the ecology has to be developed concurrently with participation in the system.

Finally, some research delves more deeply on the topic of issue interdependency, which is also one of the structural characteristics of the EGT. Mewhirter and Berardo (2019) show that actors in ecologies of games performed better in forums when their interactions with others indicated high levels of bonding capital, but only when that participation took place in interdependent forums. When the level of interdependence dropped, the relationship between individual-level bonding capital and performance actually declined. This is the first test of the interaction between the interdependence of forums and the role of actors' own networks to explain individual-level performance in the EGT. Bodin and Nohrstedt (2016) also explored the topic of issue interdependency and individual-level action in complex governance systems. They did so by examining the response to a major wildfire in Sweden, and found that interdependency among fire management tasks was correlated with collaborative relationships between them.

It is important to note that while most of the work on structure of ecologies of games has focused on how the shape of the governance system is affected when actors meet in forums, new research is expanding the EGT by accounting for different types of networking structures that form among actors beyond their participation in forums. For instance, Scott and Greer (2019) analyze how personnel in more

than 500 special purpose entities responsible for delivering drinking water to local neighborhoods in Texas connect those otherwise independent organizations, and find that districts are more likely to share technical and managerial personnel when they contract with each other or are regulated by a common groundwater management agency. This work contributes to broadening our understanding of how institutional variables can have an exogenous effect (as opposed to the more endogenous effects described by Lubell in his 2013 foundational paper) on the structural characteristics of complex governance systems.

What We Know About Function

While a sizeable portion of the research on the EGT has focused on the study of the structural characteristics of complex governance system, it would be inaccurate to say that the focus has been only on structure. In fact, most of the EGT work explores the coevolving relationships between structure and function. Regarding the relationship between structure and learning, for instance, Berardo and Scholz (2010) showed that systems where the distribution of information depended on nodes with the capacity to bridge distant parts of the network allowed actors to learn quickly about problems and the positions that other actors may have regarding them. Others have shown that collaborative networks in which the structures of interactions are characterized by high levels of heterophily (i.e., ties are built connecting diverse actors) also facilitate learning in the presence of complex problems (Berardo, 2014b; Bodin, Sandström, & Crona, 2017). Fischer and Maag (2019) focus on how structure can affect learning as well. They study the structure of actor participation in a particular subset of policy forums that include a broad mix of different types of actors and are likely to deal with a wide range of issues (what they call cross-sectoral forums), and show that actors value these forums particularly when searching for political knowledge and resource distribution, but less so when searching for cooperation.

The function of cooperation and the relationship to the relational structure of ecologies of games has also been explored in detail. Herzog and Ingold (2019), for instance, find that actors' joint participation in one or more forums that deal with excess micro-pollutants in the Basel catchment area of the Rhine River watershed positively correlates with levels of cooperation, controlling for homophily effects that are ubiquitous in collaborative network studies. Interestingly, they also find that when actors perceive the threat of micro-pollutants similarly, they also have the tendency to collaborate with each other, which suggests that learning (i.e., another one the main functions in the EGT) in turn affects the structure of the governance system. But the relationship between participation in an ecology of games and cooperation does not seem to be simple. Lubell, Henry, and McCoy (2010) studied the relationship between the structure of the ecology of games and the collaboration function in land use and transportation planning policy in California, and found that participation in collaborative forums can actually *reduce* cooperation in more traditional local planning forums. This result hints that there may be an upper threshold of participation for individual actors in polycentric systems that is determined by the

availability of individual or organizational resources needed to participate in policy games.

A more nuanced explanation of the relationships between participation in an ecology of games and cooperation is offered by Hamilton and Lubell (2018) in their examination of the ecology of games on the issue of climate change adaptation in the Lake Victoria region in East Africa. In this study, they find that actors are more likely to collaborate if they jointly participate in policy forums, but also that this effect weakens at progressively higher spatial levels at which forums operate. While policy forums may catalyze cooperation, Hamilton and Lubell's findings suggest that their capacity to do so may diminish as the transaction costs of political contracting grow at higher scales. Smaldino and Lubell (2011, 2014) also explored the relationship between structure and cooperation in an ecology of games through agent-based modeling. Their models show that different types of actor strategies for entering and leaving games, as well as institutional rules governing game entry, can lead to the evolution of cooperation via "positive assortment," which occurs when cooperators are more likely to meet each other. Positive assortment—whether inducted by networks, institutions, geography, or any other mechanism—is a fundamental principle for the evolution of cooperation (Axelrod, 1984; Nowak, 2006).

Finally, EGT research has also provided evidence on how the function of resource distribution takes place in polycentric governance systems, and how it affects the behavior of actors. Lubell et al. (2017), for example, showed that factors that increase the transaction costs among participants in an ecology of games (such as the level of scientific and political knowledge that actors accrue when they participate in a governance system) can imperil their capacity to maximize the gains from interacting with each other. The negative effects of transaction costs on this capacity to appropriate the resources generated by collaborative behavior can weaken governance systems if actors withdraw from them. Mewhirter, Lubell, and Berardo (2018) extend this analysis to explore how "institutional externalities," that is, the effects that decisions in one forum in an ecology of games may have on other forums, affect individual performance in the former. They find that institutional externalities are associated with higher individual performance (a proxy for resource accrual) in the externality-receiving forum when the actors perform well in the externality-generating forum. This finding points at the fact that power imbalances may not be smothered in polycentric governance systems, but rather the opposite. This implication mirrors findings of other recent research. For instance, Scott and Thomas (2017) study 400 actors within a regional environmental governance network in Puget Sound (Washington State) that contains 57 collaborative governance regimes (CGRs). Using exponential random graph models (ERGMs) designed to account for network dependencies, they explore how various attributes of network structure affect actors' ability to access resources through their participation in CGRs. They find that actors who benefit from participation in one CGR are more likely to benefit from participation in other CGRs, which they see as an indication that participation can actually deepen existing imbalances rather than distribute benefits more equitably. These findings go in line with those reported by Mancilla García and Bodin (2019). In their study of the management of the Paraíba do Sul river, in Brazil, they

show that higher levels of participation in multiple forums partially explains how actors gain influence in the governance system. The imbalance of power that might result from unequal levels of participation in an ecology of games may be an obstacle to the accomplishment of collective collaboration, learning, or fair distribution of benefits across the system, particularly if powerful actors have goals that are detrimental to those of other, less powerful actors.

Future research will need to disentangle the conditions under which power imbalances lead to a fragmentation (or in extreme cases, disintegration) of governance systems that depend on the engagement of myriad actors to find solutions to system-wide problems.

What We Still Don't (But Need to) Know About Structure and Function

Despite new empirical work exploring in increasing detail the operation of complex polycentric governance systems from an ecology of games perspective, we believe that there remain a considerable number of theoretical challenges for scholars working from this perspective. Perhaps the most important among them is the need to carefully document the relationship between structure and function across four dimensions of variation: functional, institutional, spatial, and temporal.

Functional Variation

A large portion of the existing research on polycentric governance and the EGT (e.g., research based on Berardo and Scholz's "risk hypothesis"), assumes that governance systems are designed mostly to achieve cooperation and/or coordination among more or less disparate policy stakeholders. Up to this point, EGT scholarship has paid less attention to the other crucial functions of polycentric governance systems, learning and resource distribution. Cooperation requires learning about the causal processes driving environmental problems and potential consequences of different policy agreements (Gerlak & Heikkila, 2011; Heikkila & Gerlak, 2018). Resource distribution is required to establish the distributional fairness of the system, which is ultimately linked to legitimacy, institutional stability, and collaborative behavior (Berardo, 2013; Leach & Sabatier, 2005; Lubell, 2003). Within polycentric governance systems, different institutional or network structures may enable different governance goals (Hileman & Lubell, 2018; Levy & Lubell, 2018), but the relationships may be far from linear, and dependent on the trade-offs among those goals (Hamilton & Lubell, 2018). For instance, is learning more or less likely when bridging structures in an ecology of games operate in a context where the distribution of benefits that arise from cooperation are largely unequal? Or is cooperation likely to undermine learning in the long term when distributional justice is not achieved, thus pushing certain actors to withdraw from forums that produce scientifically valuable information? Furthermore, over time, polycentric arrangements may feature a higher level of focus on learning (e.g., when an exogenous shock or newly discovered problem occurs), versus cooperation or resource distribution (e.g.,

funding and implementing on-the-ground environmental projects), or vice versa. These evolving changes may also affect the way actors self-organize in forums, and how these forums operate. EGT scholars face the arduous task of theorizing about the nonlinear relationships between structure and function that impact decision-making processes in complex governance systems.

Institutional Variation

The policy sciences and neoinstitutional economics have a long tradition of examining how informal and formal institutions constrain behavior, as well as analyzing the institutional rules that shape regulatory, voluntary, collaborative, and market-based responses to social problems. Yet much of the EGT research has shied away from this focus, and instead focused on the functioning of collaborative policy forums. This is in part because collaborative approaches have been the zeitgeist of policy studies in most Western democratic countries since the 1980s (Schneider, Scholz, Lubell, Mindruta, & Edwardsen, 2003). However, the reality is that policy forums within polycentric governance systems feature a diversity of institutional rules, with a great deal of blending of different approaches (i.e., it is common for forums to embrace a variety of policy responses to problems). Ostrom's work on institutional diversity echoes this point, as well as the emerging work on using the "Grammar of Institutions" to measure this diversity (Basurto, Kingsley, McQueen, Smith, & Weible, 2010; Olivier, 2018; Siddiki, Weible, Basurto, & Calanni, 2011). Polycentric institutions that allow a large amount of experimentation are likely to develop solutions to problems with higher levels of adaptive capacity and resilience. Furthermore, polycentric systems feature a wide mix of formal institutional rules and informal norms, and we hypothesize that policy network interactions constrained by informal norms are crucial preludes to more formal institutional changes and transitions (Olsson et al., 2006). EGT scholars need to pay increasing attention to figuring out how this institutional variation impacts both the functions of polycentric systems and their overall structure, particularly since forum-level institutional variation constrains participation, and thus the influence that actors may exert on the system (Mewhirter, Coleman, & Berardo, 2017).

Spatial Variation

A core hypothesis of studies of social-ecological systems is that governance arrangements perform better when there is a high degree of "institutional fit" between institutional rules and the varying social and ecological contexts at which they operate (Ekstrom & Young, 2009; Young & Gasser, 2002). Institutional fit is also linked to Ostrom's analysis of institutional diversity, because the evolutionary processes governing the emergence of diverse institutions are responsive to different contextual variables, which may affect how well institutions fit the problems they are designed to tackle. The recent literature on social-ecological network analysis also espouses the idea of institutional fit, for example, by searching for network motifs where two actors are more likely to collaborate if they manage interdependent

resources or have interests in interdependent issues (Bodin, Crona, Thyresson, Golz, & Tengö, 2014; Guerrero, Bodin, McAllister, & Wilson, 2015). It is easy to see that the study of the decision-making forums on which the EGT scholarship tends to focus would benefit from applying the concept of fit to analyze how ready the forums may be to tackle problems that usually exceed clear jurisdictional or geographic boundaries. Measuring the structural variation of institutions over space, and what drives such variation, remains an open area of research for EGT scholarship.

Temporal Variation

While some research on the EGT has explored the temporal changes in relationships among actors that participate in an ecology of games (e.g., Berardo & Scholz, 2010), there is a dearth of studies measuring how polycentric governance systems change over time. As a result, we remain relatively ignorant about how functions and structure of an ecology of games coevolve in time as systemic conditions change. For instance, we know little in regards to how collaboration, learning, and distribution of resources coevolve with forum-level interactions in the presence of external shocks that may force a realignment of political and social relationships as stakeholders scramble to adapt to the new systemic conditions. This is an important topic to examine because polycentric systems require stability (McGinnis, 1999), which can create the conditions under which collaboration, learning, and the establishment of equitable and fair relationships can emerge. Whether external shocks disturb this stability, for example, is an empirical question of importance to assess the real capacity of the system to respond to problems that demand the attention of multiple stakeholders. Additionally, taking time seriously requires understanding how polycentric systems respond to both slow (e.g., climate change, sea-level rise) and fast (e.g., wildfires, floods) exogenous shocks, along with endogenous changes in state variables (e.g., fish populations, groundwater levels, rangeland health). Following the existing policy process literature on focusing events, we believe the EGT responds most quickly to fast, exogenous shocks by producing a large amount of institutional change, some of which becomes a permanent feature of the institutional landscape and some of which is impermanent (see Berardo et al., 2015, for an example). But this expectation is grounded on empirical evidence that is limited in geographic and institutional scope and so more research is needed. It is also important to keep in mind that examining temporal variation explicitly will likely illuminate the differences among polycentric systems governing distinct policy areas, some of which may benefit from dynamic changes more than others. For example, biosecurity and disaster management systems that require a great deal of collaborative planning in the preparation stage, but shift to more hierarchical command-and-control strategies during incident response (McAllister, 2017; McAllister et al., 2017), are inherently different than systems where decentralized responses to crises might be a more desirable feature. As researchers shed light on these differences, a more complete picture of the drivers of polycentric evolution will begin to emerge.

Conclusion

The study of complex governance systems has received increasing attention in policy studies in the last few decades, and the speed at which scholarship in this area is produced continues to accelerate. The EGT is a contribution in this crowded field to generate testable hypotheses to explain how polycentric governance systems are shaped and evolve.

The research highlighted in this opening article, and the contributions of all individual articles in this special issue, provide valuable insights on the performance of governance systems across a range of policy areas and geographic settings, and suggest that polycentricity is not necessarily sufficient to produce negotiated solutions to societal problems. We believe that this goes in parallel with Ostrom and Cox's (2010) warning about the need to not think about institutional responses to policy problems as panaceas. Just as ideal types of institutions can rarely be applied to solve problems without regard to specific local conditions that might apply in some places but not others, polycentric systems should not be considered as good (or for that matter, bad) *per se*. Instead, researchers need to be able to carefully examine the local conditions under which certain structural and functional characteristics of the systems are more likely to be conducive to policy outcomes that maximize public good. Needless to say, this is not an easy task, but we believe that by testing and refining theories, such as the EGT, scholars will be able to get closer to accomplishing this goal.

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Notes

1. Policy forums (or venues) are the physical representation of games. For example, a collaborative partnership of actors gathering to design a watershed management plan is a forum where discussions have an effect on the topic of water quality. In other words, a game is defined—among other things—by a problem or issue area (in our example, water quality), whereas a forum is the physical space where those problems are dealt with. In governance systems with a highly developed formal institutional structure, games are more likely to be dealt with in specialized forums. In systems with a weaker institutional structure, forums might not be as pervasive, and in those cases, games are played (i.e., issues are dealt with) mostly through the informal, one-on-one interactions that take place among actors.

2. In this regard, we adopt a view that departs from the predominant views of polycentricity that many scholars have. Carlisle and Gruby (2017, p. 2), for instance, claim that "a polycentric governance system, may exist if the decision-making centers … are capable of resolving conflicts." We do not think that the capacity of solving conflicts is what defines polycentric systems, but rather their capacity to channel that conflict, regardless of the end result—which in some cases might be the exacerbation of such conflict.

3. A systemic approach similar to the EGT has also been espoused to provide a better, more comprehensive examination of the character of deliberative democracy. Mansbridge and colleagues, for instance, argue that studying the operation of individual venues of deliberation misses the opportunity to fully

understand how the interconnections that exist among multiple venues can lead to more or less beneficial outcomes in terms of the quality of deliberative democracy (Mansbridge et al., 2012). They claim that "parts of a system may have relationships of complementarity or displacement. In a complementary relationship, two venues … with deliberative deficiencies can each make up for the deficiencies of the other … Conversely, and institution that looks deliberatively exemplary … can look less beneficial in a systemic perspective when it displaces other useful deliberative institutions" (p. 3).

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