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ANALYTICAL ESSAY

Is Global Governance Fragmented, Polycentric, or Complex? The State of the Art of the Network Approach

Rakhyun E. Kim
Utrecht University

International institutions such as treaties and organizations shape, and are shaped by, the large web-like architecture of global governance. Yet we know little about what this architecture looks like, why certain structures are observed, and how they are linked to the functioning of international institutions as well as the overall effectiveness of global governance. Over the past decade, network science has emerged as a promising and indispensable approach to unraveling structural nuances and complexities of the system of international institutions. This article presents a state-of-the-art review of this emerging field of research and seeks to stimulate its further development. In this article, I draw connections between various network analyses of global governance that are found in different bodies of literature. In so doing, I integrate three separate but overlapping strands of work on institutional fragmentation, polycentricity, and complexity and bring much-needed conceptual clarity to the debate. Building on previous studies, I propose a framework for operationalizing fragmentation, polycentricity, and complexity in network terms in order to enable systematic and comparative analysis of global governance systems. This article argues that there is much potential in the network approach and makes a case for advancing the "network science of global governance."

Keywords: complexity, fragmentation, global governance, network, polycentricity

Introduction

Over the past few decades, international institutions—broadly referring to treaties and organizations—have proliferated in response to a wide range of global issues such as trade, security, and the environment (Duffield 2007). Tens of thousands of international institutions are in existence today. Most of these institutions enjoy a significant degree of autonomy, but they do not always operate in silos. International institutions interact with each other and form a complex web of interdependent relationships. A de facto system of global governance has emerged (Najam, Christopoulou, and Moomaw 2004) with internal complexities (Orsini, Morin, and Young 2013) and an overarching architecture (Biermann 2014). The structure of this system is important to map and analyze as it may enable or constrain the

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functioning of individual international institutions. A good understanding may also lead to the possibility of optimizing the global governance architecture and improving its overall effectiveness.

Yet we know very little about the structural characteristics of this system of international institutions. No major empirical research has been conducted to unravel what has been dubbed a "maze" (UNEP 2012) or "spaghetti bowl" (Bhagwati 2008). In the absence of a solid empirical basis, scholars have imported three concepts from different disciplines and applied them to global governance research. They are fragmentation (Biermann et al. 2009), polycentricity (Jordan et al. 2018), and complexity (Orsini et al. 2019). Each of these concepts comes with its own assumptions and biases. For example, fragmentation focuses on patterns of cooperation versus competition or connectivity versus disconnectivity. Polycentricity is contrasted against monocentricity, and it refers to a situation where many elements mutually adjust and order relationships with one another in the absence of a central authority. Complexity requires emergence and self-organization among parts, distinguishing complex systems from systems that are just complicated by possessing many parts. All three concepts have merit in describing and explaining the structural intricacies of global governance, but there is still confusion around what the implied structures look like exactly, how to identify and measure them, and how the concepts relate to each other. There is a dire need for conceptual clarity and more empirical analysis to advance our understanding of structural features of global governance.

A key challenge in this regard has been the absence of a common analytical lens or framework. Over the past decade, however, network science has emerged as a promising and indispensable approach through which we study social structures (Lazer et al. 2009), including systems of international institutions. A network is an abstract representation of a system as elements (called "nodes") and their interconnections (called "ties" or "links") (Newman 2010). Modeling a system as a network loses some of the information about the system, but it enables focused analysis of the underlying pattern of relations. In particular, network science provides a methodological toolkit consisting of a set of algorithms for measuring various topological properties. Therefore, network analysis allows for more comparable quantitative characterization of complex structures that are often too complicated to comprehend visually. The network approach has attracted the interest of global governance scholars, whose units of analysis include sizable groups of international regimes (Morin et al. 2017), intergovernmental or nongovernmental organizations (Beckfield 2010; Murdie 2013), and multilateral agreements (Kim 2013).

In addition to an effective analytical method, the growing interdisciplinary science of networks offers theoretical explanations as well. These explanations relate to, first, why certain structures are observed and, second, how they are linked to certain functional outcomes through "network effects" (e.g., Bodin and Crona 2009; Hafner-Burton, Kahler, and Montgomery 2009; Kinne 2013b; O'Neill et al. 2013). Similar questions can be asked about the system of global governance. Until now, scholars have effectively deconstructed this system and developed theories of individual international institutions (e.g., Young 1999; Miles et al. 2002; Mitchell 2003; Barrett 2005) and their dyadic interactions (e.g., Gehring and Oberthür 2009; Johnson and Urpelainen 2012). Building on this knowledge, network scientists are now reassembling the parts to understand the architecture or macrostructure of global governance. There have already been some early successes in this regard, which I introduce later on.

This article makes a case for advancing the *network science of global governance*. Here, by unraveling structural complexities of the global governance system, we would seek to evaluate, explain, and enhance the (overall) effectiveness of the myriad autonomous yet interdependent intergovernmental and transnational institutions. To that end, this article makes connections between various existing network

analyses of global governance that are found in different bodies of literature. It attempts to integrate three separate but overlapping strands of work on institutional fragmentation, polycentricity, and complexity and bring much-needed conceptual clarity to the debate around the architecture of global governance. Furthermore, this article proposes a framework for operationalizing fragmentation, polycentricity, and complexity in network terms in order to enable systematic and comparative analysis of various structures of global governance.

Following this introduction, I begin with an overview of the theoretical debate around whether the global governance architecture is fragmented, polycentric, or complex. Then I introduce the basics of network science by focusing on its theoretical and methodological approaches that are particularly relevant to unraveling structural complexities of global governance. Building on these two sections, I review the literature on global governance where network thinking has played a prominent role and examine how networks of international institutions were modeled, analyzed, and characterized. Here I pay special attention to studies in the field of global environmental governance, with examples from other fields such as global trade, security, and investment. Building on these previous studies, I offer a framework that enables measuring and comparing degrees of fragmentation, polycentricity, and complexity through a network approach. I then discuss some of the key theoretical, empirical, and methodological challenges to advancing the network science of global governance. Before I conclude, I outline two new research frontiers.

Global Governance: Fragmented, Polycentric, or Complex?

What does the architecture of global governance look like? This question has occupied global governance scholars for many years. Three key analytical lenses have emerged around the concepts of fragmentation, polycentricity, and complexity.

Many scholars characterize the architecture of global governance as *fragmented* (e.g., Biermann et al. 2009; Zelli 2011; van Asselt 2014). Originating from international law scholarship, the concept of fragmentation is understood in global governance as "the extent to which the world consists of distinct clusters of [intergovernmental organization]-based cooperation" (Greenhill and Lupu 2017, 193). These clusters are often based on regions or sectors. The rapidly increasing number of treaties (Brown Weiss 1993; Hicks 1999; Anton 2012) and international courts (Stephens 2006) has generally been understood as a key underlying cause. The resulting institutional fragmentation demands cooperation between international institutions. While the possibility of synergistic relations is not ruled out (Biermann et al. 2009), the concept tends to highlight the potential for conflict (Wolfrum and Matz 2003; Fischer-Lescano and Teubner 2004; van Asselt 2014). For example, the relationship between two multilateral environmental agreements can be synergistic or conflictive (Oberthür and Gehring 2006), but the architecture is diagnosed as fragmented if the latter type dominates the interinstitutional dynamics (e.g., Fernández-Blanco, Burns, and Giessen 2019).

More recently, the system of global governance has been characterized as *polycentric* (e.g., Jordan et al. 2018). The concept of polycentricity is adopted from the literature on managing the commons (Ostrom 2010; Aligica and Tarko 2011), and it brings attention to the possibility that global institutions may mutually adjust and align themselves toward a collective goal (Galaz et al. 2012). In contrast to fragmentation, polycentricity draws our attention to the potential for net positive interactions between independent governing authorities when certain conditions are met. Therefore, whereas fragmentation views a unified and integrated regime as generally desirable, the concept of polycentricity underlines that relatively decentralized systems, as opposed to monocentric systems, may function effectively. That is because the diversity and multiplicity in polycentric systems allow room for

experimentation, out of which successful institutions are selected, diffused, or scaled up. Scholars highlight, however, that more research is warranted to identify and explain specific conditions under which polycentric governance arrangements actually work (Morrison 2017).

Yet others argue that global governance is best described as *complex* (e.g., Orsini et al. 2019). Here, complexity is not merely a metaphor but a quality of many real-world systems as understood in the field of complexity science (Mitchell 2009). The concept of complexity highlights that components of a system may self-organize and give rise to seemingly coordinated and adaptive behavior even in the absence of a central authority. This notion of complexity made its way to the global governance literature through public administration theory (Klijn 2008) and resilience theory (Duit and Galaz 2008; Duit et al. 2010). And now, many scholars recognize the relevance of the lens of complexity to the study of global governance, especially at an aggregate level (Seyle and Spivak 2018; Orsini et al. 2019). In general, they call for a more fundamental analytical shift toward system-level properties such as emergence, nonlinearity, and adaptation (Kim and Mackey 2014; Pauwelyn 2014; Morin, Pauwelyn, and Hollway 2017; Boulet, Lajaunie, and Mazzega 2019).

It can be surmised from the foregoing that the three concepts offer varying descriptions and explanations of the causes and consequences of the structure of global governance, as well as different policy implications. Fragmentation points to flat and nonhierarchical structures, polycentricity points to uneven and rugged structures, while complexity points to modular and hierarchical structures. Importantly, these concepts and the structures they imply are not mutually exclusive. All of the mentioned structural features are often found simultaneously in different systems of international institutions. Most of these systems are sparse, uneven, and modular. Therefore, it will be unfruitful to use only one of the three concepts. Rather we need to integrate these concepts in a general analytical framework in order to offer an adequate explanation for the emergence and evolution of global governance structures and their impact on performance.

The network approach is promising in this regard. According to Maoz (2012a, 251), for example, network analysis is "eminently suited for capturing, analyzing, and modeling complexity." As I will demonstrate in the article, network analysis has in fact already been instrumental in revealing structural nuances and complexities of the global governance system through studies on institutional fragmentation (Beckfield 2010; Kim 2013; Gomez and Parigi 2015; Greenhill and Lupu 2017), polycentricity (Galaz et al. 2012; Ahlström and Cornell 2018), and complexity (Green 2013; Kim 2013). But before I review these studies and extract key insights, I turn next to the basics of network science.

Network Science: Theory and Method

There are currently two key strands of network thinking in global governance research. I call them "institutional network theory" and the "theory of institutional networks."

Generally speaking, network theory is about "the mechanisms and processes that interact with network structures to yield certain outcomes for individuals and groups" (Borgatti and Halgin 2011, 1168). It explains *effects* of observed connectivity patterns on elements in the network. Institutional network theory in particular aims to explain governance outcomes of individual institutions or their complexes as controlled or mediated by network variables (Klijn and Koppenjan 2012, 2014). To that end, analysts focus on relating differences in network topology to outcomes. The default expectation is that every system of institutions is different in shape, with varying degrees of fragmentation, polycentricity, or complexity, and that these structural variations account for differences in outcomes for the individual institutions or the system as a whole (Borgatti et al. 2009; Borgatti and Halgin 2011). Outcomes

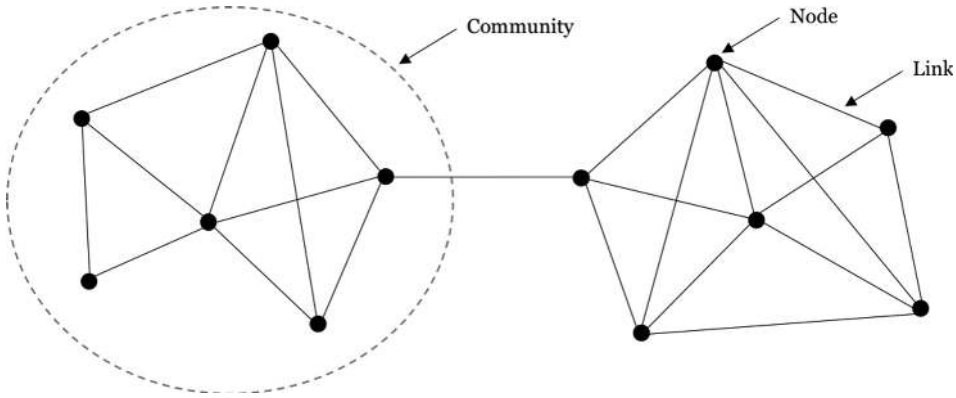

Figure 1. A network is a set of nodes joined by links. This example consists of twelve nodes and twenty-three links, organized in two communities.

of interest may include effectiveness, resilience, and adaptiveness (Underdal 2010; Young 2017). For example, how does the relative position of an international institution affect its power or influence (Lazer 2011; Kinne 2012)? How do differently fragmented regime complexes compare in terms of flexibility across issues or adaptability over time (Keohane and Victor 2011)? What explains the network effect?

In contrast, "the theory of networks" concerns "the processes that determine why networks have the structures they do" (Borgatti and Halgin 2011, 1168). It is about explaining *causes* of observed connectivity patterns. The theory of institutional networks, in particular, aims to explain why, for example, global climate governance is more (or less) fragmented, polycentric, or complex when compared to others such as global biodiversity governance. Here, the formation of institutional network structures is explained through nonnetwork variables. These processes might include, for example, homophily whereby "similarity breeds connection" (McPherson, Smith-Lovin, and Cook 2001) and preferential attachment whereby "the rich get richer" (Barabási and Albert 1999), which are found to be relevant in explaining the structure of international networks (Maoz 2012b; Atouba and Shumate 2014). Furthermore, the structure is also dependent on the nature of ties, that is, whether ties mean something "good," such as alliances, or "not good," in the case of conflict (Cranmer and Desmarais 2011, 2016; see also; Cranmer, Desmarais, and Kirkland 2012; Cranmer, Desmarais, and Menninga 2012).

As such, network science presents a way to combine attributes of nodes and relations in the context of a larger structure (Maoz 2012a). In order to better understand the interaction between node attributes and network properties, either nodes or the network can be treated as dynamic while the other is treated as static. Here, it is analytically useful to distinguish between the dynamics *of* networks (Newman, Barabási, and Watts 2006) and dynamics *on* networks (Barrat, Barthélemy, and Vespignani 2008). While the former is about how the structure of a global governance network evolves over time, the latter pays attention to dynamical processes (e.g., how information spreads) on a given (static) network by taking each international institution as a dynamic system. The two types of network dynamics are of course intertwined. Dynamical processes occurring on a global governance network affect the overall structure of the network, which, in turn, affect the dynamics of individual international institutions. This interplay between the dynamics of and on global governance networks is a promising area of research, to which I will return later in the article.

In terms of method, network analysis starts with modeling a real-world system as a network. A network consists of nodes with a set of links (figure 1). By capturing

only the basics of connection patterns between its components, network representations inevitably lose useful details about a system. However, such systematic abstraction enables effective quantitative analysis of real-world systems. Analysts may still enrich their network models by adding extra information about individual components and relationships. For example, one could assign a numerical figure to each node and link; define relationships as positive, neutral, or negative; and give direction to the flow of influence between two nodes. These data can be visually represented through nodes and links in different sizes, colors, thicknesses, and so on (Pfeffer 2017).

Based on such a mapping, researchers can use a range of network measures and metrics that help quantify topological properties at different levels of analysis (e.g., Wasserman and Faust 1994; Boccaletti et al. 2006; Newman, Barabási, and Watts 2006; Jackson 2008; Scott and Carrington 2011). At the *level of nodes and links*, an important and useful class of network measure is that of centrality, which identifies the most important nodes in a network. For example, nodes with more connections or in bottleneck positions are identified as central and, hence, as playing a more important role in the system's functioning (Borgatti 2005). Another key network measure is clustering coefficient (or transitivity in the case of directed links), which measures the degree to which nodes tend to cluster together into triads (Wasserman and Faust 1994; Watts and Strogatz 1998). At the *level of subsystems*, network analysis can identify hierarchical and modular components in the form of communities (Ravasz and Barabási 2003). In network-speak, a community is a group of nodes that are relatively densely connected to each other but sparsely connected to other dense groups in the network (Porter et al. 2009; Fortunato 2010). Regime complexes are one such example of a community of international institutions in global governance. A number of algorithms have been developed to detect community structures, most of which relate to the concept of modularity (Newman 2006). At the *level of system*, basic network metrics include density (the sum of the actual links divided by the number of potential links), centralization (how central the most central node is in relation to how central all the other nodes are), and average path length (the average distance of all shortest paths between two random nodes).

These network measures enable both exploratory and explanatory network analysis. In exploratory network analysis, researchers map a network and summarize its main structural characteristics. Here, novel combinations of network metrics can be used to measure system properties such as robustness, or how tolerable a system is to random failures (Albert, Jeong, and Barabási 2000), and efficiency, or how efficiently a network exchanges information (Latora and Marchiori 2001). For explanatory network analysis, statistical inference models are often used to test how the observed network correlates to or deviates from random or other types of modeled networks (Desmarais and Cranmer 2017). In particular, exponential random graph models (Robins et al. 2007; Cranmer and Desmarais 2011; Desmarais and Cranmer 2012) and stochastic actor-oriented models (Kinne 2013b; Milewicz et al. 2017) are among the most relevant.

Network Approaches to Unraveling Global Institutional Structures

Now I turn to the emerging body of literature that analyzes and theorizes structural complexities of global governance from a network perspective. This section reviews their analytical approaches and extracts some of the key crosscutting findings.

International Institutions and Networks

The system of global governance consists of actors and institutions. In network analysis, this system is often modeled as a bipartite or affiliation network where both

actors and institutions appear as two different types of nodes. A prominent example is a network of states and international organizations joined through state membership (e.g., Hafner-Burton and Montgomery 2006; Wilson, Davis, and Murdie 2016; Lupu and Greenhill 2017). Depending on the analytical focus, this network can be converted into a network consisting of only one type of node, either (1) a *network of actors*, in which institutions serve as links through which actors interact, or (2) a *network of institutions*, where institutions are nodes that are coupled in some way. Examples of the first type include network models of states or cities that are institutionally tied together through bilateral (e.g., Goyal and Joshi 2006; Saban, Bonomo, and Stier-Moses 2010; Oatley et al. 2013; Cranmer, Heinrich, and Desmarais 2014) or multilateral agreements (e.g., Maoz 2011; Kinne 2013b; Milewicz et al. 2017; Sopranzetti 2018; Lee 2019). The second type is exemplified by studies on international agreements and organizations that are linked through references or overlap in membership (e.g., Kim 2013; Greenhill and Lupu 2017; Perez, Cohen, and Schreiber 2018). This article is particularly concerned with this second type—networks of international institutions—which is also referred to as "global governance networks" (Eilstrup-Sangiovanni 2017).

With the rise of research interest in regime complexes and governance architectures over the past decade, the analytical focus has started to shift away from networks of actors to networks of institutions (Burch et al. 2019). These include, for example, networks of intergovernmental agreements, international organizations, transnational initiatives, and private standards, which are interconnected through shared membership, references, partnerships, or other forms of institutional interlinkage. Studies suggest that these institutions enhance interstate cooperation among their members (Kinne 2013a,b, 2018; Lupu and Greenhill 2017), thereby bringing the network of states into an increasingly cohesive and integrated whole. But the proliferation of these international institutions has raised new concerns about institutional fragmentation or complexity (Beckfield 2008). Attention is increasingly paid to structural properties of these "clubs of clubs" that are divided along sectoral or regional lines (Greenhill and Lupu 2017). In other words, just like states had to be brought together with the help of international institutions, the myriad international institutions themselves are in need of coordination for their effectiveness. This is an ultimate policy objective of the emerging field of research on global governance networks.

A significant amount of research has already been conducted on various aspects of global governance at different levels of analysis (table 1). For example, there is a rich body of literature on individual international institutions (Young 1999; Miles et al. 2002), their interlinkages (Young 1996; Chambers 2008) and interactions (Biermann 2008; Gehring and Oberthür 2009; Johnson and Urpelainen 2012), as well as lineages (Mitchell 2003), clusters (von Moltke 2006), complexes (Raustiala and Victor 2004; Keohane and Victor 2011; Abbott 2012), and larger architectures (Biermann et al. 2009). Furthermore, the dynamics or evolution of these units has been of key scholarly interest (Young 2010). Yet, these insights remain unintegrated, waiting to be weaved together for a more holistic understanding of the structure and dynamics of global governance.

Here, network science has begun making a significant contribution. The wealth of scientific knowledge generated so far is guiding network research on global governance systems, which, in turn, could help integrate the separate lines of research on global governance. Such interdisciplinary exchange is particularly valuable in the field of global environmental governance, where multilevel, multiscalar, and multiplex governance structures have emerged over the years in response to complex and dynamic environmental problems. Next, I turn to these network analyses of global governance with an empirical focus on the environment.

Table 1. Key studies of global environmental governance selected and categorized based on their units and levels of analysis. Network analyses are excluded; see table 2

Level of analysis	Unit of analysis	Key studies of global environmental governance
Nodes	Treaties, regimes, international organizations (governmental and nongovernmental), international bureaucracies	Young 1982, 1999, 2010, 2012, 2011; Miles et al. 2002; Mitchell 2003; Underdal and Young 2004; Barrett 2005; Betsill and Corell 2008; Biermann and Siebenhüner 2009; Boyd and Folke 2012; Jinnah 2014
Links	Institutional interlinkages, interaction, interorganizational relations, treaty conflicts, partnerships, information sharing, resource flow	Young 1996, 2002; Wolfrum and Matz 2003; Oberthür and Gehring 2006; Biermann 2008; Chambers 2008; Gehring and Oberthür 2009; Andonova 2010; Jinnah 2011; Borgen 2012; Johnson and Urpelainen 2012; Hall 2015; Biermann and Koops 2017
Clusters	Regime complexes, treaty clusters, lineages	Mitchell 2003; Raustiala and Victor 2004; von Moltke 2006; Colgan, Keohane, and Van de Graaf 2012; Keohane and Victor 2011; Abbott 2012; Orsini et al. 2013; Gehring and Faude 2014
Networks	Structure, architecture	Kanie 2007; Biermann et al. 2009; Backer 2012; Zelli and van Asselt 2013; Zürn and Faude 2013; van Asselt 2014
	Dynamics, evolution, adaptation	Sand 2007; Sanwal 2007; Morin, Pauwelyn, and Hollway 2017
	System (structure and dynamics combined)	Meyer et al. 1997; Najam et al. 2004; Galaz et al. 2012; Morin and Orsini 2013; Kim and Mackey 2014; Pauwelyn 2014; Jordan et al. 2018

Network Analysis of Global Governance

Network analysis of the global governance architecture emerged in the 2000s (table 2). Most of these studies map systems of intergovernmental organizations or multilateral agreements, but more recently scholars have started looking into systems of international nongovernmental organizations and other transnational private regulations. The network approach has been particularly popular in the field of global environmental governance. This is arguably because of the exceptionally high number of international environmental institutions as well as the networked nature of global environmental risks that the myriad institutions are set up to manage (Galaz et al. 2017). Due to the sheer size, no single analysis has revealed the entire architecture of global governance but only parts of it, with each focusing on one type of institution and one type of link.

So far, three types of links have been used for modeling networks of international institutions. First, *shared membership* across international institutions has been a common proxy for interinstitutional relationships. Scholars have employed it in studies on, for example, networks of intergovernmental organizations (Beckfield 2010; Gomez and Parigi 2015; Greenhill and Lupu 2017), multilateral agreements (Böhmelt and Spilker 2016; Hollway and Koskinen 2016), and public international and transnational institutions (Widerberg 2016; Perez et al. 2018). Second,

Table 2. Key studies of various networks of international institutions that characterize the overall network topology

Study	Node (N)	Link	Time (Years)	Network measures	Observed features
Kim and Barnett (2000)	Intergovernmental telecommunications organizations (69)	Self-reported relationships, shared membership	Static (1995)	Centrality, modularity	"center-periphery," "multi-centric"
Beckfield (2008)	Intergovernmental organizations (11, 50)	Shared membership	Dynamic (1950, 2000)	Centralization, density	"centralized," "complex," "fragmented," "sparse," "uneven"
Atouba and Shumate (2010)	Intergovernmental organizations (50) and international nongovernmental organizations (58)	Self-reported relationships	Static (2001)	Centralization, density, reciprocity, transitivity	"centralized"
Beckfield (2010)	Intergovernmental organizations (495)	Shared membership	Dynamic (1820–2000)	Centralization, clustering, density, path length	"centralized," "disintegrated," "fragmented," "sparse," "uneven"
Green (2013)	Carbon management standards (41)	Recognition	Static (2009)	Centrality	"hierarchical," "order"
Kim (2013)	Multilateral environmental agreements (747)	Citations	Dynamic (1857–2012)	Centrality, clustering, density, giant component, modularity, path length	"complex," "defragmented," "hierarchical," "modular," "polycentric"
Murdie (2013)	Human rights international nongovernmental organizations (681)	Self-reported relationships	Static (2002)	Centrality	"not very cohesive," "sparse"

Table 2. Continued

Study	Node (N)	Link	Time (Years)	Network measures	Observed features
Gomez and Parigi (2015)	Intergovernmental organizations (unspecified)	Shared membership	Dynamic (1971–2005)	Modularity	"contracted," "fractured"
Hollway and Koskinen (2016)	Multilateral fisheries agreements (200)	Shared membership	Static (2013)	Transitivity	"clustered"
Widerberg (2016)	Climate institutions (31)	Shared membership	Static (2014)	Centrality, density	"dense"
Greenhill and Lupu (2017)	Intergovernmental organizations (unspecified)	Shared membership	Dynamic (1945–2005)	Modularity	"clustered," "consolidated"
Ahlström and Cornell (2018)	International legal instruments (99)	Citations	Static (2014)	Centrality	"loose," "multiscalar," "polycentric"
Lajaunie, Mazzega, and Boulet (2018)	Conferences of the Parties to multilateral biodiversity agreements (27)	Shared terminology	Dynamic (1973–2014)	Centrality, modularity	"modular"
Perez et al. (2018)	Transnational corporate social responsibility schemes (49) Transnational corporate social responsibility schemes (61)	Shared membership Direct institutional links	Static (2014)	Centrality, centralization, clustering, density, path length	"cohesive," "multiplexed"
Perez and Stegmann (2018)	Transnational corporate social responsibility schemes (57)	Citations	Static (2018)	Centrality, giant component, modularity, path length	"well-connected"

textual references or *citations* have also been instrumental in mapping global governance networks. These citations are found in documents such as treaties (Kim 2013; Ahlström and Cornell 2018) or other official documents published by public or private international organizations (Perez and Stegmann 2018). Some used variations of citation such as "recognition" of one institution by another (Green 2013; Green 2017) or "shared terminology" found across different texts (Lajaunie, Mazzega, and Boulet 2018). Third, *direct institutional links* are another type, such as partnerships between international organizations (Perez et al. 2018). A prominent example is interorganizational relationships identified and reported by organizations themselves (Shumate, Fulk, and Monge 2005; Atouba and Shumate 2010; Murdie 2013). All three types of links have pros and cons, which I will discuss in a later section.

As summarized in table 2, scholars have mapped and analyzed a range of global governance systems using various network measures. Notably, these studies observe comparable underlying patterns of relations across a wide range of systems. The structures are found to be generally uneven, modular, and centralized.

In the absence of a common analytical framework, however, the structures are sometimes inconsistently described. Despite structural similarities, some characterize a governance system as primarily unintegrated or fragmentated while others conclude it is cohesive, consolidated, or contracted. The inconsistencies are due to both conceptual and methodological reasons. Different operationalizations of fragmentation, polycentricity, and complexity are partly to blame (e.g., Beckfield 2010; Gomez and Parigi 2015). But more importantly, defining a network of institutions as either, for example, dense or sparse in absolute terms has proven difficult. Therefore, network analysis of what a single network looks like at a particular moment in time has not led to conclusive findings about topological properties of the system in question. When characterizing the structure of a global governance system, a more sensible approach would be to make a cross-system or longitudinal comparison for a relative assessment (Beckfield 2010; Kim 2013; Gomez and Parigi 2015; Greenhill and Lupu 2017).

Initial Insights on Global Governance from a Network Perspective

The first generation of network analyses has generated some initial insights into the structural complexities of global governance. Here I discuss three.

First, the process structuring the global governance architecture is nonlinear. So far, the process has been believed to be dominated by, for example, either fragmentation or consolidation, through which the number of clusters is either increasing or decreasing in a somewhat linear fashion. Most of the analyzed cases, however, suggest oscillations in the number of clusters. The degree of fragmentation has been wavering between opposing forces acting simultaneously on the architecture. Whether a new institution contributes to fragmentation or defragmentation of global governance largely depends on the connections it makes (Kim 2013). For example, global or cross-cutting institutions generally exert "centripetal" forces and defragment global governance, whereas regional or issue-specific institutions exert "centrifugal" forces that tend to fragment the structure (Gomez and Parigi 2015; see also De Lombaerde et al. 2019).

Despite the nonlinear oscillation, the general trend over a long span of time has been, contrary to the general wisdom, governance defragmentation. In other words, the continuing proliferation of international institutions has resulted not in fragmentation but rather in a surprisingly cohesive structure with multiple centers of decision-making that are, to varying extents, interconnected. For example, the studies of multilateral environmental agreements (Kim 2013) and intergovernmental organizations (Greenhill and Lupu 2017) show that both of these networks have become less fragmented over the past decades. Overall, global institutional networks are not simply fracturing but also contracting or defragmenting, making

the system topology increasingly uneven. This nonlinear network-forming process is critical in explaining how the system of global governance has maintained structural coherence despite the ever-increasing number of international institutions with relatively few dying away (Eilstrup-Sangiovanni 2018).

Second, the network approach has revealed some degree of order or hierarchy in the underlying structure of various global governance systems. In the system of multilateral environmental agreements, for example, order was identified to have emerged around 1992 as a result of structural transformation into a small world through a set of new critical "short cuts" between a few key agreements (Kim 2013). Similarly, Green (2013) also observed that a district order emerged out of the seemingly chaotic and complex institutional landscape of global carbon standards. The observation of emergent hierarchy across many global governance systems is contrary to the conventional wisdom that institutional complexes of nested, partially overlapping, and parallel international regimes are nonhierarchically ordered (Alter and Meunier 2009).

Network analysis has provided empirical evidence confirming earlier theoretical propositions that institutional complexity does not necessarily imply chaos, anarchy, or disorder (e.g., Kanie 2007; Galaz et al. 2012). Institutional complexity, emerging from self-organization of the myriad institutions involved, is often organized. This finding stands in contrast to the literature on international regime complexity that tends to emphasize the negative effects of complexity (Drezner 2009), but it supports the more recent literature on polycentric governance (Jordan et al. 2018; see also Meyer et al. 1997; Keohane and Victor 2011; Zürn and Faude 2013). Importantly, such insights from network analysis shed light on conceptual similarities and differences between fragmentation, polycentricity, and complexity.

Third, network analysis has revealed nuanced ways in which the underlying pattern of connections in a governance system shapes its outcomes and vice versa. As predicted by network theory, the performance of an individual international institution depends in part on its position in the network because its network position affects the opportunities and constraints that the institutions encounter (Murdie 2013; Perez et al. 2018). For example, rules, norms, and principles of the institutions in most central positions have a higher chance of diffusing across the network and have system-wide effects. The United Nations Convention on the Law of the Sea, which is the most central institution in the system of multilateral environmental agreements, is a case in point (Kim 2013). These central institutions that are rich in connections attract even more connections from other international institutions. Global governance networks serve as a public good for institutions embedded therein, and this perspective points to the possibility of improving and exploiting this social capital (Ingold 2017; Young 2017).

What is interesting to note is that "the network effect" is often parabolic. For example, the small-world structure increases the performance of a system up to a threshold, after which point the positive effects reverse (Uzzi and Spiro 2005). This is because, for example, if institutions are too loosely coupled, then they remain as disjointed parts, and if they are too tightly coupled, then there is little room for specialization or innovation. It is in the middle section, where a global institutional network is neither too fragmented nor unified, that the performance of the network and its institutions reaches a peak.

Such an understanding of network effects vis-à-vis network structure implies that we may be able to determine which structural configuration is optimal for specific global governance systems. Building on this knowledge, appropriate network interventions could be designed and executed (Valente 2012), which would include forging new strategic institutional links (e.g., Jinnah 2011; Abbott 2014; van Asselt and Zelli 2014; Betsill et al. 2015) and rewiring existing counterproductive ties. We may call this a complexity-informed approach to networked global governance. The idea of embracing rather than reducing global institutional complexity is at

its crux (Ruhl, Katz, and Bommarito 2017; see also Oberthür and Stokke 2011). Some scholars argue that this governance approach is imperative for responding to globally networked risks (Duit et al. 2010; Teisman and Gerrits 2014; Le Prestre 2017). That is because, in the end, "it takes a network to fight a network" (Borgatti et al. 2009, 893).

Operationalizing Structural Complexities in Network Terms

The network approach to unraveling structural complexities of global governance shows much potential. To advance further, however, we need more systematic and comparative analysis. By building on previous studies, this section presents a framework for operationalizing fragmentation, polycentricity, and complexity in network terms.

Current Approaches to Measuring Fragmentation, Polycentricity, and Complexity

Many studies presented in table 2 have put forward different but comparable ways to operationalize institutional fragmentation. For example, Kim (2013) used a relatively simple way of measuring the degree of fragmentation through the fraction of the largest component of a network. Orsini et al. (2013) operationalized fragmentation in terms of low network density and centralization. Pattberg et al. (2014) similarly used average degree and centralization as key variables. Beckfield (2010) proposed a combination of low density and relatively high average path length in comparison to network diameter. Yet other studies conceptualized fragmentation primarily in terms of modularity. For example, Greenhill and Lupu (2017) used a combination of metrics including modularity, and Gomez and Parigi (2015) used a special class of modularity measure called hierarchical link clustering to measure the degree of fragmentation.

More recently, a number of scholars adopted polycentricity as a key concept in their studies of global institutional networks (Kim 2013; Ahlström and Cornell 2018). In the field of global governance, however, no major network analysis has made an attempt to quantify the degree of polycentricity. Some initial thinking has been done on the question of what polycentric systems might look like in network form. For example, Galaz et al. (2012) offer schematics of weak and strong polycentric order with network visualizations, ranging from a distributed structure on the "weak" end of the spectrum to a modular and hierarchical structure on the "strong" end. Similarly, Gallemore and Munroe (2013) place polycentricity on a continuum defined by the degree of network centralization. These typologies form a useful basis for operationalizing polycentricity in global governance systems.

The issue of measuring global institutional complexity is an area where there is little consensus. This is understandable, as there are no agreed ways of measuring complexity in the broader science of complex systems (Mitchell 2009). However, operationalization remains a significant challenge in global governance research, where there is no agreed understanding of which attributes make global governance complex. Institutional complexity has been vaguely understood as a quality of an institutional complex (e.g., Widerberg 2016), which is generally understood in the literature as a loosely coupled set of institutions (Keohane and Victor 2011). But such a circular definition has led to the development of divergent views on how to measure institutional complexity.

So far, global governance scholars have operationalized global institutional complexity with two key nonnetwork variables: diversity and multiplicity. For example, Zelli, Möller, and van Asselt (2017, 670) define institutional complexity as "a diversity of international institutions that legally or functionally overlap in addressing a given issue area of global governance." Similarly, Zelli and van Asselt (2013) consider the number of institutions as a proxy for institutional complexity.

The underlying logic is that a global governance system with more diverse and numerous international institutions is likely to be more complex. In general, these analysts observe an increasing level of institutional complexity at the global level and attribute it to the proliferation of public international institutions and the more recent rise of private or hybrid authority in global governance.

Yet there is a limit to what these nonnetwork variables can tell us about complexity. For instance, diversity and multiplicity may point to compositional complexity, but they do not capture structural complexity. This also implies the failure of the existing studies to account for the *emergence* of complexity because the analysts make an ex-ante assumption that the system in question is already complex before measuring the level of complexity. However, if we were to take the concept of complexity seriously, as characterized by emergence, self-organization, and adaptation (Orsini et al. 2019), one should not dismiss the possibility that the system in question (e.g., regime complex) could well be merely complicated and not complex. By definition, a system is complex if the collective or emergent behavior of the parts together is more than the sum of their individual behaviors. Otherwise, that is, if the whole can be explained by studying the parts, the system is merely complicated (Mitchell 2009; Newman 2011). Diversity and multiplicity often lead to complex dynamics and, hence, emergence but not necessarily. A typical example is an airplane that consists of many diverse parts yet forms a predictable, complicated system. Therefore, we should be careful not to conflate complicatedness with complexity and first detect complexity in any attempt at measuring it (Allen et al. 2018).

Topological Signatures of Complexity in Networks

Then, how can we detect institutional complexity through network analysis? Does it appear in certain shapes? For many decades, the underlying architecture of complex systems has been thought to be random with no apparent organizing principles (Erdős and Rényi 1960). But through the availability of data in the late 1990s on the structure of large networks such as the web, network scientists discovered that the topology of real-world networks deviates from that of a random network (Albert and Barabási 2002; Newman 2003). They found that complex networks have a structural configuration somewhere between regular and random networks (Newman, Barabási, and Watts 2006). That is to say, complexity takes the form of a nonrandom structure that emerges from neither extreme order nor disorder (sometimes denoted as the "edge of chaos"). Such "organized complexity" (Weaver 1948; see also Hidalgo 2016) is observable, as it is encoded as signatures in the topology of a network (Barabási 2005).

Two key structural forms in which complexity is organized are small-world and scale-free. *Small-world* networks interpolate between highly clustered regular networks and random networks (Watts and Strogatz 1998). In a small world, the degree of local clustering is high but the average path length is low, allowing any two nodes in the network to be only a few steps apart (Watts 2004). For example, despite the gigantic size of the web, two randomly chosen documents are on average only nineteen clicks away from each other (Albert, Jeong, and Barabási 1999). *Scale-free* networks are those with a highly skewed degree distribution called power law, which is far from random (Barabási and Albert 1999). In scale-free networks, hubs can be identified that have many more connections than most other nodes (Barabási 2009). The small-world and scale-free network structures have implications for collective dynamics in terms of adaptiveness, robustness, and vulnerability (Albert et al. 2000), the relevance of which has also been acknowledged by global governance scholars interested in the effectiveness of international regimes and institutions (Young et al. 2006).

A network approach to detecting the emergence of institutional complexity (hence some degree of order) would then involve identifying these structural

features commonly found in many complex networks. Although small-world and scale-free topologies are not perfect proxies for complexity (Albert and Barabási 2002), if a network displays both of these properties in conjunction, then one could reasonably conclude that the system is structurally complex. This approach to detecting complexity was first used in global governance research by Kim (2013), where, by tracking the changes in the topological patterns over time, it was found that the system of multilateral environmental agreements became both a scale-free and small-world network in 1992. In addition, the presence of a giant component, or the largest connected component that contains a significant portion of the nodes, was also seen as suggestive of emergent order and complexity (Janson et al. 1993). These network-based indicators may tell us whether a system of institutions is complex or merely complicated.

A Framework for Analyzing the Architecture of Global Governance

Building on previously uncoordinated attempts at operationalizing structural fragmentation, polycentricity, and complexity of global governance, I outline a general analytical framework below (figure 2; table 3). This framework will provide conceptual clarity and allow for characterization and comparison of various networks of international institutions.

From a network perspective, a global governance system is structurally fragmented when it is highly modular at the community level but sparsely connected at the network level. The degree of clustering at the node level is not a crucial factor because clusters may well be disconnected from one another. Following such a conceptualization, the degree of fragmentation can be measured as a function of density, modularity, centralization, average path length, and the fraction of the giant component. A system is fragmented when it displays "high modularity," "low centralization," "low density," and "high average path length." In addition, a relatively small giant component indicates the possibility of fragmentation. The opposite would signal a defragmented governance structure, which is also described as cohesive, contracted, integrated, or consolidated in the literature (see table 2).

The structure of a global governance system is polycentric when it is highly clustered at the node level, modular at the community level, and decentralized at the network level. The density may range widely from low to high, and the average path length would not be a defining factor as a polycentric system does not need to be a small world. The degree of polycentricity is then a function of clustering, modularity, and centralization. A system is polycentric when it displays "high clustering coefficient," "high modularity," and "low centralization." The opposite would indicate a monocentric structure or star-like topology, where a single governing authority is clearly identifiable in the core.

The structural complexity of a global governance system can be approximated by the presence of a small-world and scale-free topology. The emergence of complexity can be detected as a function of clustering, average path length, and degree distribution. A network of international institutions is structurally complex when it displays "high clustering coefficient," "low average path length," and a "highly skewed degree distribution" that follows the power law. Also a giant component containing more than half of all nodes is indicative of emergence. Once complexity is detected, we may then measure the degree of complexity. In general, the architecture of global governance is structurally more complex if it is denser, more modular, or more hierarchical. The degree of complexity however decreases when the network reaches a certain density.

It needs to be noted that the required levels of modularity, centralization, and so on (i.e., what is meant by "high" or "low") are not absolute but always relative. For example, how modular a system must be to qualify as polycentric cannot be determined a priori. The threshold values will vary across systems as well as over

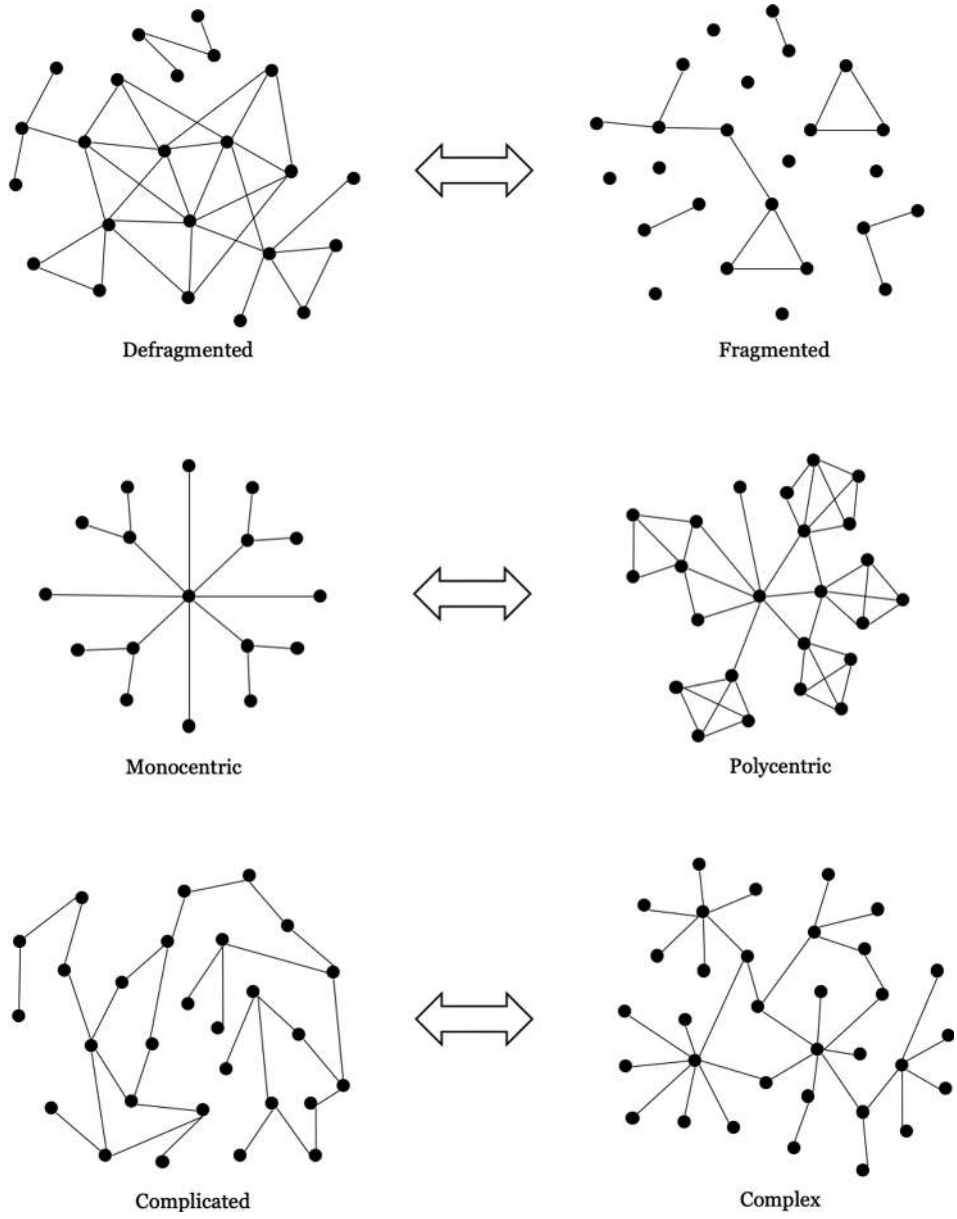

Figure 2. Three models of the global governance architecture: (1) defragmented and fragmented; (2) monocentric and polycentric; and (3) complicated and complex.

time. One can only define a system structure in comparison to another or to itself at a different point in time. This is to say, we may only reasonably suggest that a global governance network is *relatively* more fragmented, polycentric, or complex than another but not in absolute terms. Therefore, comparative or longitudinal analysis is imperative to put observed structural features into perspective.

Furthermore, from a network perspective, fragmentation, polycentricity, and complexity are not mutually exclusive structural characteristics. They are distinct qualities, but they can also coexist in a system. For example, it is conceivable that global climate governance is fragmented (van Asselt 2014), polycentric

Table 3. Network-based framework for measuring fragmentation, polycentricity, or complexity.

Network measures	Fragmented	Polycentric	Complex
Clustering coefficient (or transitivity)	—	High	High
Modularity	High	High	—
Centralization	Low	Low	—
Density	Low	—	—
Average path length	High	—	Low
Skewness in degree distribution	—	—	High
Fraction of the giant component	Low	—	High

(Jordan et al. 2018), and complex (Zelli et al. 2017), all at the same time. Rather than debating which concept best describes the architecture of global governance, it will be more productive to characterize the structure by measuring all three qualities and relating what is observed to attributes such as effectiveness and legitimacy. Nonetheless, as the above framework suggests, certain combinations of these structural qualities (e.g., polycentric fragmentation) are likely to be more common than others (e.g., fragmented complexity).

Toward a Network Science of Global Governance

The framework for analysis presented in the previous section promises potential for generating insights on institutional complexity and advancing the network science of global governance. Yet, a few theoretical, methodological, and empirical challenges remain.

Theoretical Challenges

While the knowledge about the underlying structure of a system is essential to understand its complexity, it should be noted that "network theory is not a proxy for a theory of complexity" (Barabási 2005, 70). In other words, a network approach will not reveal everything we need to know about institutional complexity. This is in large part because network theory is a structural theory. Network science only accounts for the structural backbone of a complex system. However, the overall performance of a group of international institutions, which is ultimately what we seek to understand, is as much rooted in its structure as it is in the dynamic processes taking place within these networks (Barabási 2007). In other words, the *structure* of relationships is important as it puts constraints on who interacts with whom, but it says little about the *content* of relationships in terms of how individual agents behave and interact (Barrat et al. 2008). For example, the degree of structural fragmentation or polycentricity does not mean much without information about the nature of institutional interactions or context (Morrison 2017).

What is important to note, however, is that certain *structural* characteristics such as modularity have been found to be a necessary condition for certain behavioral characteristics to emerge in a system, such as resistance to change or critical transitions (Scheffer et al. 2012). This implies that, independent of the precise content of relationships, an optimal structural configuration for the global governance architecture might exist in terms of modularity. Similar hypotheses can be developed about density, diversity, hierarchy, small-worldliness, and so on, by drawing from the general field of network science. The quest for a combination of desirable structural characteristics and ways to transform the existing architecture will form the core research agenda of the network science of global governance.

Theorizing governance structure in relation to some functional traits, of course, is not an easy challenge. A practical next step may involve defining what "too little"

or "too much" fragmentation, polycentricity, or complexity means (bearing in mind that the answer to this question would depend on who you ask). For example, some legal scholars define "too much complexity" as the point when legal complexity starts to "undermine the system's capacity to achieve its purposes" (Ruhl and Katz 2015, 238). Governance scholars could follow this approach and direct research efforts at identifying and explaining which structures of international institutions are excessively fragmented, polycentric, or complex.

Methodological and Empirical Challenges

Network models often have boundaries that are drawn under theoretical and empirical assumptions. This is the problem of boundary specification (Laumann, Marsden, and Prensky 1983). For example, in mapping global climate governance, the question arises as to which climate-related institutions to include in the analysis and which proxies to use to connect them. This is an important consideration, as it defines the boundaries around the governance system that the network model will represent. However, unlike groups, networks do not have "natural" boundaries, and they do not have to be connected (Borgatti and Halgin 2011). While there is no clear-cut answer to this problem, one's selection of nodes could potentially have significant implications for results of analyses. That is because even one single misplaced or missing node or link could, in theory, distort the overall structure and dynamics of a network model considerably, if that node happens to be in a central position (Nagler, Levina, and Timme 2011). Similarly, there is a question of *how* to identify nodes and links (Borgatti et al. 2009). On the one hand, one could argue that direct observation of institutional interaction is preferable (e.g., citations and shared membership), while on the other hand, survey data that take perceptions into account (e.g., self-reported relationships) could be considered a more accurate reflection of a socially constructed system. Building and analyzing multiplex networks by using more than one type of link in one study or comparing different studies will significantly improve our understanding of global institutional complexity.

Network analysts have not yet been able to pay much attention to the node-to-node dynamics of processes taking place in the global governance architecture. For practical reasons, most studies used citations or shared membership as proxies for interinstitutional relations. However, what flows through these apparent links is not made entirely clear; it is rather only assumed. For example, citations are assumed to imply the extension of effects of the law from cited to citing treaties (Kim 2013), but the exact nature and extent of such legal effects has not been scrutinized. Similarly, it is assumed that if two institutions share a member, then knowledge, ideas, information, and norms can more easily travel between the institutions (Böhmelt and Spilker 2016). However, overlap in membership is not a social tie as such (Borgatti and Halgin 2011). Therefore, network representation could be misleading; that is, a complex institution landscape may look structurally integrated, but it may be functionally unintegrated. These shortcomings point to the need to better capture the dynamic processes in networks in future analysis of institutional complexity. This will be particularly essential to empirically studying changes in the degree of polycentricity, which requires one to take into consideration not only patterns of relationships but also whether institutions mutually adjust their actions in line with shared goals (Ostrom 2010).

To move forward, more event-type ties (as opposed to state-type ties) could be used to capture institutional interactions or transactions (Borgatti and Halgin 2011). This implies tracking real flows of material or information between international institutions (e.g., Böhmelt and Vollenweider 2013) in what some call "influence networks" (Campbell et al. 2019; see also Boulet, Barros-Platiau, and Mazzega 2016). Some progress has been made in that direction. For example, "direct institutional links" between organizations, such as partnership and compliance

cooperation (Perez et al. 2018), and web-based data such as hyperlinks (McNutt and Pal 2011; Yi and Scholz 2016) and Twitter tweets (Kolleck et al. 2017) have been proven useful. Other suggestions include mapping how problems shift (Kim and van Asselt 2016), how policies diffuse (Sommerer and Tallberg 2019), or how resources flow between international institutions. Some argue that we need to move beyond abstract institutional ties and start using more concrete interpersonal ties between decision-makers in global governance (Paterson 2019).

No doubt data availability is a key bottleneck in this field. There is not enough quality longitudinal, relational data available to significantly advance a network understanding of global institutional complexity. Shared membership data—which is available through a number of datasets including the Correlates of War Project (Pevehouse, Nordstrom, and Warnke 2004)—is probably the only exception. Other datasets on international institutions have been developed and maintained, such as ECOLEX (FAO, IUCN, and UNEP 2019), the International Environmental Agreements Database (Mitchell 2003), the Trade and Environment Database (Morin, Dür, and Lechner 2018), the Design of Trade Agreements Database (Dür, Baccini, and Elsig 2014), and the Yearbook of International Organizations (UIA 2018). However, some of these datasets are not open access and, more importantly, relational data is not always collected or complete. ECOLEX, for example, only lists references between treaties that are legally related, while the Yearbook of International Organizations contains self-reported information on interorganizational relationships, but the data can be expensive for personal research use. In order to advance research on global institutional complexity, it is imperative to build an open-access data repository. Legal scholars are already calling for creating "legal maps" of national legal systems to map the law's complexity (Ruhl and Katz 2015).

New Research Frontiers: Network Adaptation and Interaction

Researchers have made significant progress with regard to understanding structural complexities of global governance. Below I outline two new research frontiers that will be central to the network science of global governance.

First, there is great potential for more research on how the network of international institutions as a whole *adapts* over time through individual institutions acting as adaptive agents. The adaptive network model is well-suited for this type of research (Gross and Blasius 2008; Sayama et al. 2013). This model combines the topological evolution of a network with the dynamics of its nodes to explain how certain complex systems adapt in the absence of an organizational center that could adopt collective decisions. The patterns of institutional interconnections influence its dynamic state, such as the flow of information and the intensity of cooperation. If institutional conflicts are severe in certain parts, new institutions or strategic linkages are created to overcome structural constraints (e.g., Biermann 2008; Jinnah 2011; Schemeil 2013; Hall 2015). In such a way, a feedback loop is formed, which can give rise to a complicated interaction between an evolving network architecture and institutional dynamics. The myriad decisions of international institutions together "adapt" the global governance system, which in turn creates new conditions for both the whole as well as for individual institutions.

Modeling the global governance system as an adaptive network has certain advantages. For example, we can provide room for individual agency, the ability for individual institutions to influence their own success (Dellas, Pattberg, and Betsill 2011), which then no longer rests completely within the structure of their network. This line of research will also contribute to building what Borgatti and Halgin (2011) call the "network theory of networks," where network properties are used to explain other or future network properties of the same network. This could be challenging however because, although what happens on the individual node-level is related to the network-level, it is not to the extent that individual actions are

fully mirrored in the whole (Teisman and Gerrits 2014). Furthermore, international institutions or regimes are themselves networks of elementary heterogeneous actors and institutions (Morin et al. 2017), the behaviors of which unfold over time and manifest themselves on multiple scales (Watts 2007). To make progress on this front, the rich literature on individual treaties and regimes as well as their dyadic relationships (table 1) should be married with network-level studies (table 2).

Second, the global governance research community should consider moving beyond analysis of a single network of institutions to "networks of networks" (Kenett, Perc, and Boccaletti 2015). There are vertical and horizontal dimensions to this challenge. Vertical interaction occurs between networks operating at different levels or scales of analysis. For example, global institutional systems interact with national policy networks. This vertical dimension is central to research on multilevel or polycentric governance (Ostrom 2010) and relates to the analysis of institutional fit (Young 2002; Galaz et al. 2008; Ekstrom and Young 2009; Bodin et al. 2019) or spatial misalignments between governance and environmental systems (Sayles and Baggio 2017). Methodological tools already exist to enable multilevel and evolutionary network analysis (Huisman and Snijders 2003; Snijders 2005; Snijders and Bosker 2012), with some research already conducted with the global fisheries governance complex (Hollway and Koskinen 2016).

Horizontal interaction occurs between networks operating at the same level or scale of analysis. Some attempts have been made to capture the dynamics of horizontal interaction through studies on, for example, nontrade issues in preferential trade agreements (Manger and Pickup 2014; Milewicz et al. 2017), political alliances on bilateral trade networks (Haim 2016), and the coevolution of defense cooperation and bilateral lending (Kinne and Bunte 2018). However, none of these studies are about "cross-network effects" in the true sense (Snijders, Lomi, and Torló 2013). Future research could look at, for example, the coevolution of the systems of international environmental agreements and preferential trade agreements. These networks are distinct yet open systems with porous boundaries; processes taking place in one network affects what is happening in another (Kenett et al. 2015). Therefore, where two systems meet, what is exchanged at this interface, how the interface changes over time, and ultimately how two systems interact are important questions to explore. Such a network approach to analyzing node-level connectivity between two or more systems is a promising area of research.

Conclusions

Significant scholarly attention has been paid to the structural characteristics of global governance systems and what they imply for the performance of international institutions embedded therein. However, empirical and methodological challenges have been severe in this field of research. We have so far drawn most of our insights from qualitative studies of a few prominent international institutions. Global governance scholars have also borrowed concepts from other disciplines and come to characterize the overall system architecture as primarily fragmented, polycentric, or complex. Yet, there is no consensus among the scholars on what exactly these structural descriptors mean or imply. This article is motivated by the need to bring conceptual and analytical clarity to this theoretical debate around the architecture of global governance.

In this article, I put emphasis on the potential of network theory and analysis. The network approach to understanding the structural complexity of global governance has been proven effective as an analytical tool, as well as a theoretical lens. It has allowed us to shed light on key puzzles: how structural complexities emerge and evolve (theory of networks) and how structures yield certain outcomes for individual international institutions or regime complexes (network theory). Furthermore, the network approach has demonstrated its utility in advancing our understanding

of how global governance networks as a whole adapt through adaptive institutions (the network theory of networks) and how these networks interact with one another (networks of networks).

This article has offered a state-of-the-art review of network analyses of global governance found in different bodies of literature. I have outlined various ways of mapping networks of international institutions, ranging from intergovernmental agreements and organizations to private codes or standards. The review shows that, so far, textual references and shared membership are most common proxies for interinstitutional relationships, but there is scope for expansion into using direct links or more event-type ties, which will allow us to capture the dynamics in networks better. Previous studies have generated some initial insights into the structural complexity of global governance. Contrary to widely held assumptions, for example, opposing forces are being exerted on the structure of global governance that make the institutional landscape increasingly uneven. Emergent hierarchy is commonly observed, as well as significant structural variation. Furthermore, the relationship between network properties and the nonnetwork variables such as performance are not linear, but network effects diminish after they reach a peak.

Building on existing studies that attempted to operationalize fragmentation, polycentricity, and complexity in various ways, this article offers an integrated framework for operationalizing these structural characteristics. The new framework will allow systematic and comparative analysis of various global governance systems that go beyond often subjective, therefore incomparable, assessments. This framework could be instrumental in advancing the network science of global governance.

Will network theory and analysis contribute to designing appropriate responses for steering the behavior of complex governance systems? While it is yet premature to make any conclusive statements, a network understanding of institutional or regime complexes or governance architectures has the potential to be useful for forming the basis of policy, organizational, or governance reform measures. In particular, an improved understanding of the networked system will provide valuable insights into how to intervene, where, when, and by whom, helping channel the complexity into desirable change (Klijn and Koppenjan 2014; see also Valente 2012).

It is important to note, however, that the network science of global governance alone will not be able to offer fully satisfactory answers to all our questions. Existing and ongoing research on individual international institutions and their interactions, as well as the complexes they form through organic processes, should be further integrated with the insights that network analysis generates. Furthermore, we may benefit significantly by combining different methods that are available to study complex systems. For example, network analysis could be married with other methods to study the complex dynamics of and on the network over time, such as system dynamics and agent-based modeling (Carley et al. 2007; Morçöl 2014; Morçöl and Wachhaus 2014). Methodological innovation will, in turn, allow us to further theoretical development.

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