Research Article

Internet Fragmentation, Political Structuring, and Organizational Concentration in Transnational Engineering Networks

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Abstract

Is the internet at risk of fragmentation? Whereas the literature has examined this question with a focus on domestic policies, communication standards, and internet governance institutions, we analyze fragmentation and alternative outcomes in transnational engineering networks. These networks constitute the social foundations of the unified or 'global' internet. Our contributions include: (1) broadening the debate beyond fragmentation-related network outcomes to include political structuring and organizational concentration; and (2) new evidence from an important engineering network around the Internet Engineering Task Force comprising thousands of participants and over four decades. Our analyses reveal fast and continuous network growth as well as clear signs of growing concentration of the network around a few major companies. A key implication is that, at the level of engineering networks, concerns about internet fragmentation might be unfounded and might distract from more salient developments such as organizational concentration.

Policy Implications

- Political leaders and other stakeholders engaged in debates about internet fragmentation – at the Internet Governance Forum as well as in parliaments, civil society and the media – should broaden the terms of debate to pay more attention to alternative outcomes such as political structuring and organizational concentration in and beyond transnational engineering networks.
- Leaders of internet governance organizations – and internet governance practitioners more broadly – should assess whether, and to what effect, deliberation and decision-making processes in their organizations afford highly central positions to a few major actors.
- Standards development organizations such as the IETF should debate whether highly central actors should face enhanced responsibility for the openness and inclusiveness of the standards development process and whether procedural changes to enact this responsibility are required.

Two contributions to the internet fragmentation debate

Concerns about the unity of the internet or 'internet fragmentation' have become widespread in policy circles. For example, at the 2019 Internet Governance Forum (IGF), the UN Secretary-General warned: 'It is clear for me that we live in one world, but it is not entirely clear that we will live only with one net' (Internet Governance Forum, 2019). In the 2013 Montevideo Statement on the Future of Internet Cooperation, the leaders of ten major internet governance organizations warned against internet fragmentation and stressed 'the importance of globally coherent Internet operations' (Akplogan et al., 2013). Among others, organizations such as the Council on Foreign Relations (Patrick, 2014; Zylberberg, 2016), The Global Commission on Internet Governance (de Nardis, 2016), the World Economic Forum (Drake et al., 2016) as well as general and specialized media (*Financial Times*, 2014, 2020; Wired, 2019) have featured the issue.

Yet, is the internet at risk of fragmentation? Policy and academic literature has approached this question by focusing on divergent policies at the national level (Drake et al., 2016; Freedom House, 2018), the spread of the Internet Protocol (Mueller, 2017), and the consolidation of internet governance institutions (Harcourt et al., 2020; de Nardis, 2014). We adopt a complementary, yet distinct approach. We examine fragmentation as well the alternative outcomes of political structuring and organizational concentration in transnational internet engineering networks.

What can transnational engineering networks tell us about internet fragmentation? The unified or 'global' internet, in which each participant can reach all others, is a public good (e.g., Drake et al., 2016). As for other public goods such as clean air or sustainable climate, provision depends on various factors. For the internet, the main factors are communication standards, permissive domestic policy, and internet governance institutions. It is less widely appreciated, however, that engineering networks provide the social foundations of these inputs. Recent studies show that engineering collaboration is crucial for communication standards and internet governance institutions. It also is a counterweight to centrifugal pressures from divergent domestic policies (Harcourt et al., 2020; Mueller, 2010, 2017; de Nardis, 2014). Despite this, little evidence on collaboration, fragmentation, or other outcomes in internet engineering networks exists.

This study focuses on the patterns of transnational engineering collaboration. In addition to underlining the significance of engineering networks, our first contribution is to specify fragmentation-related outcomes at the network level as well as to broaden the discussion to further outcomes. In particular, Mueller (2010) has stressed the need to examine internet engineering networks more systematically, and general literature has highlighted the diversity of conceivable network outcomes (Kim, 2019). Broadening the debate is also important since related literature shows that, besides fragmentation, the internet as well as large networks in general can foster outcomes such as *concentration* around selected actors (Barabási and Albert, 1999; *Journal of Cyber Policy*, 2020; Radu and Hausding, 2020). Similar dynamics might be at work in engineering networks. For example, the 2019 Global Internet Report of the Internet Society (2019, p. 8) states:

> [T]he open, collaborative, and interoperable Internet is influenced by a small number of large companies, and organizational scale and market share play a significant role in the development and deployment of the open technical standards on which the Internet depends.

A further concern in recent studies is that participants of transnational engineering networks could face government pressure to act in certain ways (Claessen, 2020; Harcourt et al., 2020; Mueller, 2017; Musiani et al., 2016). As a result, networks could become *politically structured*. Underlining these additional outcomes – organizational concentration and political structuring – scholars such as Benkler (2016, p. 19) emphasize that 'whether the Internet will evolve toward a system that amplifies power in the hands of the state and a concentrated class of private actors, is the central design challenge of the coming decade'. While we do not examine this claim in its entirety, we analyze whether there actually are signs of fragmentation, concentration, or political structuring in the engineering networks at the heart of the global internet.

Our second contribution is to offer new evidence on the characteristics and development of a prominent transnational standard-setting network formed by the Internet Engineering Task Force (IETF). Our data cover all actors contributing to the IETF's *Request for Comments* (RFC) series of communication standards and technical commentary, comprising thousands of individuals and over four decades. Deriving the IETF network from co-authorship of RFC publications, we can examine network outcomes including trends in size, collaboration, political structuring and organizational concentration. Our analysis reveals little evidence for fragmentation-related outcomes or for political structuring of engineering collaboration. However, the evidence shows clearly that the drastic growth of the IETF network since the commercialization of the internet in the early 1990s has coincided with increasing concentration of the network around a few major companies from the United States, Europe, and China. As of 2018, six companies supplied over 35 per cent of the thousands of authors of the IETF's RFCs.

We develop our arguments as follows. First, we explain the relationship between internet fragmentation and transnational engineering networks. Second, we specify relevant network outcomes. Finally, we introduce our data and results, before concluding with implications.

Engineering networks and the global internet

The unified or global internet – the opposite of internet fragmentation – is one in which all participants, regardless of location or method of access, can in principle interconnect (e.g., Drake et al., 2016). Practically, this means for example that the same information (e.g., newspapers) or services (e.g., search or social sites) are available to end users wherever they are physically. The characteristics of users (e.g., computer literacy) affect opportunities to connect yet do not indicate greater or weaker unity of the internet. The unified internet is not about the 'digital divide' – that is, location, generation or wealth gaps in internet use. The fragmentation debate also has to be distinguished from literature on political or other restrictions on internet access for certain populations (Freyburg and Garbe, 2018; Milner, 2006; Weidmann et al., 2016).

We discern three perspectives on fragmentation that respectively focus on domestic policy, technology standards, and global institutions. The most discussed theme is domestic policy. At the level of key technical standards and resources, which we discuss below, the internet is independent of specific jurisdictions, but governments have instruments to shape the internet that is effectively available to citizens. Whereas the unified internet requires permissive policies, governments can prohibit or sanction certain uses, services and contents, filter traffic at their borders, censor information, or foster self-censorship through surveillance. While China is the best-known example (King et al., 2014), these techniques are common, especially among authoritarian states (Hellmeier, 2016). Freedom House's (2018) 'Freedom on the Net' data suggest a rise of internet restrictions in many countries. The UN Secretary-General, cited above, highlighted 'efforts of some states to construct ever harder borders in cyberspace' (Internet Governance Forum, 2019). If government policies diverge, so do citizens' experiences. The internet could then be called fragmented.

Another building block of the internet consists of communication standards. The internet consists of numerous 'autonomous systems' (AS) whose interoperability – and hence ability to combine into the unified internet – depends on shared standards. The most essential standard is the Internet Protocol, which specifies how information is addressed (de Nardis, 2009), but there are others, such as the Border Gateway Protocol that defines how information is routed across the internet (Drake et al., 2016; Mathew, 2016). It is theoretically possible for an AS (e.g., a company) or set of systems (e.g., all AS in a country) to stop using fundamental standards. Historically, companies such as AOL ran closed networks. In reality, however, this strand of literature is far less worried about fragmentation than studies of domestic policies. As Mueller (2017) argues, the attractiveness of being connected to the internet at a technical level is high and growing. The Internet Protocol is so entrenched that overuse, not fragmentation, has become a key infrastructural concern.

Finally, the internet depends on institutions for limited but important central management and meeting places. Institutions need to ensure that there is a unique link between domain names and addresses. Central management is currently provided by the Internet Corporation for Assigned Names and Numbers (ICANN). Central meeting places are needed to facilitate the negotiation of communication standards. Key arenas include the IETF, World Wide Web Consortium (W3C), and Institute of Electrical and Electronics Engineers (IEEE) (for an overview, see Harcourt et al., 2020). Studies of these institutions have been concerned about fragmentation. ICANN in particular has suffered legitimacy challenges from its establishment in 1998, faced venue-shifting efforts by governments such as China or Russia, and skepticism from the European Union on account of formal US government ties and dominance of US-based actors (de Nardis, 2014; Glen, 2014). Meeting places such as the IETF have faced similar criticism. Some of the underlying grievances have been addressed in recent years as ICANN has become independent from the US government (Becker, 2019) and Chinese actors increasingly included in standard-setting (Contreras, 2014). However, dissatisfaction with the prominence of US organizations and actors remains in China, Europe and many other countries. At the 2018 IGF, the French President Macron, for example, criticized the current institutions as the 'Californian form of Internet … an Internet driven by strong, dominant, global private players, which at the end of the day are not democratically elected' (Internet Governance Forum, 2018). From an institutional perspective, the internet is thus currently not fragmented but faces tensions.

Engineering networks are essential in all three perspectives. This is most evident for institutions and communication standards. Institutions such as ICANN and the IETF are mere arenas with minimal own resources, leadership structures, and bureaucracies. Even ICANN, which is a more hierarchical organization than other internet governance arenas, is managed by engineers with private sector backgrounds and supported by expert and stakeholder networks in advisory committees. Beyond ICANN, standard-setting arenas, not to mention other institutions such as coordination mechanisms between internet exchange points and service providers, depend on voluntary participation and collaboration of transnational actors (Harcourt et al., 2020; Mathew, 2016; van Eeten and Mueller, 2013). Indeed, when today's internet governance arenas emerged, the networks that run them already existed, managed internet addresses, and produced standards (e.g., Braman, 2010; Naughton, 2016). For example, the RFC series, which publishes the IETF's technical output, started in 1969 – over 15 years before the IETF.

Yet, what exactly do engineering networks do for the internet's governance institutions and standards? To illustrate this, consider the example of the IETF. First, IETF standard-setting takes place in hundreds of working groups, three annual meetings, and mailing lists. These processes are structured by working group chairs, but otherwise rely entirely on voluntary contributions by individual engineers. Second, the IETF, similar to other standard-setting arenas such as the American National Standards Institute (Simcoe, 2012) or the International Organization for Standardization (Heires, 2008) requires: (1) large agreement of all interested actors; and (2) comprehensive treatment of all technical considerations and comments before a new standard can be agreed (ten Oever and Moriarty, 2018). These two formal conditions mean that the IETF's operation does not only depend on the willingness of engineers to contribute but also to collaborate closely so as to muster the large majorities and broad expertise required. In other words, standard-setting depends on engineers' participation and formation of collaborative ties or, in short, transnational networks.

Engineering networks are not only important for the internet's institutions and standards but also constitute a counterweight to the centrifugal pressures arising from divergent domestic policies. It needs to be kept in mind that the existence of internet governance institutions and the adoption of standards does not rest on international treaties or other public authority, but fundamentally depends on output legitimacy. As Drezner (2004) argues, the current regime of central internet management and private communication standards can persist as long as it is effective and consensual enough to convince enough governments to block regime-shifting or unilateral action. This cannot be taken for granted, even if internet governance is widely judged to serve its essential purposes by technical experts, as evident in criticism and challenges by governments from China, Russia, but also other countries such as Brazil, European Union member states, or India (Glen, 2014). These pressures would grow further if engineering networks declined or became visibly structured not by engineering needs but governmental interests, and thus less able to claim output legitimacy on the grounds of effectiveness, expertise, and political neutrality.

In sum, the literature on internet fragmentation has paid careful attention to core dimensions of the global internet, but less to the social foundations of successful governance institutions, communication standards, and the containing effect of these foundations on divergent domestic policies. The social foundations of the global internet consist of the voluntary participation and collaboration of individuals – typically engineers from major companies and organizations – in and around internet governance institutions or, in other words, of transnational engineering networks. To be sure, we are not the first to recognize that 'because of the way the Internet has dispersed control over operations and resources, those with a stake in Internet governance rely heavily on network forms of organization' (Mueller, 2010, p. 7). Yet, few studies analyze the patterns of engineering collaboration theoretically and empirically over extended periods of time.

Fragmentation-related network outcomes

We begin by discussing two fragmentation-related and two alternative network outcomes. In general, as all networks, engineering networks vary along many dimensions. Adding to this complexity, a review by Kim (2019) demonstrates that the global governance literature has used numerous terms to describe network dynamics and outcomes. Kim advocates more explicit specification of the parameters of interest, shows that outcomes such as fragmentation can thus be defined clearly, and distills attributes that existing network analyses have commonly studied. We delineate four network characteristics and relate them to relevant outcomes in transnational engineering networks.

- *Network size*: size refers to the number of actors that partake in transnational engineering networks. Transnational networks in the domain of internet governance do not have a pre-defined size and could thus shrink or grow over time.
- *Ties and density*: network ties denote the number of connections between actors. Ties relative to the size of the network or other benchmarks furthermore indicate the density of a network.
- *Centrality and concentration*: in a network, actors can occupy central positions, as measured for example by the number of their ties or their position between actors. At the aggregate level, networks can vary in the distribution of centrality. For example, there can be many equally central actors or only a few. We refer to the aggregate distribution of centrality as concentration.
- *Structuring*: in some networks, individual collaboration choices depend on factors such as political or country background. In contrast, collaboration could depend on less political and measurable factors such as expertise. At the aggregate level, individual choices can give rise to more or less structured networks.

These characteristics enable us to define two fragmentation-related outcomes in transnational engineering networks. Fragmentation-related refers to network developments that weaken the ability to operate and the appearance of de-politicization of engineering networks – the two properties that enable them to sustain standards development, internet governance institutions and act as counterweight to divergent domestic policies. The first such outcome, *network decline*, occurs if engineers withdraw their voluntary contribution to standards development and, thus, network size declines. We do not suggest that declining size would quickly undermine the work of engineering networks, but it would indicate a gradual drain of contributors. In this sense, network decline is a fragmentation-related outcome.

A second fragmentation-related outcome is *collaboration decline*. Even with stable numbers of network participants, the willingness of these participants to collaborate with each other might decline. In some areas, such as security or routing, collaboration is a requirement for the effectiveness of engineering networks (e.g., Mathew, 2016; van Eeten and Mueller, 2013). In standards development such as in the IETF, collaboration indicates whether engineers are able to combine expertise, which increases the quality of their output, and build larger coalitions, which helps meet consensus requirements for new standards. Of course, collaboration and network size are not independent. If networks grow, the relative level of collaboration necessarily declines because the number of collaboration opportunities increases dramatically (Barabási and Albert, 1999). Yet, even then we can ask whether collaboration is declining in absolute terms and how quick the relative decline is.

While network and collaboration decline are conceivable developments, they have been regarded with skepticism in the literature. In general, sizeable networks such as the ones existing in internet governance are expected to tend towards further growth rather than decline (Barabási and Albert, 1999). Moreover, Mueller (2017) points out that many engineering networks and goods produce benefits for participants, negative externalities on outsiders, and switching costs for actors considering exit. Whereas Mueller examines ICANN and the Internet Protocol in these terms, similar arguments have been made for standards development networks. Standards development networks give private actors an opportunity to gather support for their preferred standards in a large community, ensure widespread visibility of these standards, and potentially obtain formal approval from a reputable network. These benefits would not be as strong if the gains to be obtained were non-excludable. Crucially, however, standard-setting has long been seen as a battle-of-sexes game in which the actors that successfully externalize their preference benefit more than other actors, who have to adopt a standard other than their preferred version (Mattli and Büthe, 2003). 'Once a particular technology is adopted . . . incompatible alternative may become uninteresting and their supporters lose their previous investment' (Heires, 2008, p. 360). In this game, endorsement by a reputable engineering network enhances the likelihood that a standard will become widely used. The larger and more reputable a network becomes, moreover, the stronger this effect.

Political structuring and organizational concentration

We examine two more outcomes: *political structuring* and *organizational concentration*. Starting with the former, scholars have drawn attention to the possibility that engineers in internet governance networks might come under governmental pressure to act in certain ways (Carr, 2015; Glen, 2014; Mueller, 2017). Mueller (2017) provides the example of engineers from China-based academic and private organizations proposing a nationally controlled domain name system in the IETF. This proposal illustrates governmental efforts to 'recreate the power structures of national governments in cyberspace' by influencing engineering networks (Mueller, 2017, p. 41). Recently concerns have also been raised that Huawei might be advocating for a new internet protocol in various arenas (mainly the International Telecommunications Union but also the IETF) in part at the behest of the government (*Financial Times*, 2020). Scholars such as Mueller (2017) have focused on the alignment of national jurisdictions and control of internet infrastructure. It is possible that we might also see an alignment of collaboration patterns in engineering networks along political lines due to governmental pressure on network participants. Political structuring would indicate that these networks might not counteract divergent domestic policy by forging transnational collaboration – rather engineering networks would reflect domestic factors.

How plausible is political structuring? On one hand, skepticism might be warranted as engineering networks consist of nongovernmental actors. Drezner (2004) has argued that, at least throughout the 1990s, governments regarded the work of internet engineering networks as collectively beneficial and a governance niche to be left to the private sector. On the other, recent studies suggest that governmental interest in influencing engineering networks might have increased. Scholars argue that governments understand the political effects of engineering networks, monitor these networks, and seek to influence participants' behavior (Harcourt et al., 2020; Mueller, 2017; Musiani et al., 2016). For example, the IETF has been a key site for negotiations over improved encryption of internet traffic since the 'Snowden affair' (de Nardis, 2015; Harcourt et al., 2020). Furthermore, some anecdotal evidence indicates that governments have the tools to influence actors in engineering networks. The Chinese government has been found to exert pressure on Chinese companies in internet governance networks (Galloway and Baogang, 2014; Harcourt et al., 2020; Shen, 2016). Moreover, government regulation might shape engineering collaboration. For example, consider rules that long existed in the US on banning exports of cryptography technology. As this technology posed legal risks for standards developers, US-based participants in the IETF faced similar challenges and incentives to collaborate (Harcourt et al., 2020).

Finally, *organizational concentration* has received less attention in studies of transnational engineering networks but has played a prominent role in the wider literature on the digital economy, which suggests that the scale and logic of internet-based activity fosters high concentration of market shares and authority in few actors (*Journal of Cyber Policy*, 2020). Recently studies have suggested that concentration dynamics might influence internet governance in general and engineering networks in standard-setting (Gahnberg, 2019; Internet Society, 2019; *Journal of Cyber Policy*, 2020; Radu and Hausding, 2020; Simcoe, 2012). It is uncontested that companies are the main actors in internet standard-setting. Simcoe (2012) shows that, by the late 1990s, standards negotiations in the IETF had become dominated by major companies, whereas civil society organizations remain marginal (Harcourt et al., 2020). Moreover, as engineering networks grow, for reasons discussed above, broad participation becomes difficult for all but resourceful companies. Consider that engineering networks typically work on hundreds of standards in parallel. The IETF operates over 100 working groups at any given moment. In line with the Internet Society's (2019, p. 42) observation that 'scale is . . . an important and growing factor in developing standards', we consider organizational concentration in transnational engineering networks a likely development.

The Internet Engineering Task Force

By focusing on the engineering network that underpins the standards process of the IETF, we gain an opportunity to gather extensive data in order to assess the alternative network developments discussed in the previous sections. How does the IETF operate? We noted earlier that, as other standards development organizations, the IETF is a thin organization without significant resources or bureaucracy. It provides and administers a procedural framework that private actors can use to develop standards and obtain formal IETF endorsement by publishing standards and related experimental and informational documents in the RFC series. The specifics of this process have been described in detail (Harcourt et al., 2020; ten Oever and Moriarty, 2018). Importantly, the IETF depends on the participation and collaboration of private actors, who write RFCs and conduct the underlying research, testing, and negotiations in its hundreds of working groups. By examining who actually is involved in writing RFCs, we can obtain an idea of the contours of the IETF's network of private actors.

The IETF is of course only one engineering network. Other cases exist, for example, in the W3C or IEEE (Harcourt et al., 2020). The IETF is interesting, however, because unlike the IEEE it focuses exclusively on internet-related standards and unlike the W3C, which was founded in 1994, it has existed for a longer period. If we include the informal beginnings and first publications in the RFC series, the IETF and its predecessor networks can be said to have existed since at least the late 1960s (Naughton, 2016).

The IETF as a case has some additional advantages. Unlike, for example, the International Organization for Standardization, IETF membership is by actor rather than country-level industry association. Additionally, the IETF does not charge membership fees such as the W3C and is said to have a comparatively open predisposition towards new actors (Harcourt et al., 2020; Russell, 2006; ten Oever and

Moriarty, 2018). This means that, in contrast to other cases, the IETF network can in principle be expected to be more fluid rather than being stabilized by institutional conditions. This renders it a particularly suitable case to examine the dynamics of the network, which is the focus of our argument.

IETF network data

To obtain network data, we assume that engineering collaboration is visible in co-produced RFC documents including standards as well as research and informational documents or draft standards produced in anticipation to or as background for standard-setting.[1.] It is crucial not to mistake preparatory, background and draft documents as unimportant. These documents are widely noticed and often implemented before a proposal obtains standards status. Practitioners thus point out that 'the Internet runs on Proposed Standards' (Bygrave and Bing, 2009, p. 131).

We benefit from the fact that all IETF output is published in the RFC series. New RFCs list all contributing authors and their organizational affiliations. We use this information to identify the actors involved in the IETF engineering network and the ties formed between them through co-authorship of RFCs. By focusing on co-authorship, we omit actors that have never written RFCs but still participate more passively in the network (e.g., by giving input via mailing lists). However, we cannot evaluate the extent of these informal activities. In contrast, RFC authorship is unambiguous evidence of network participation, and co-authorship clearly shows collaboration.

Information on co-authored RFCs enables us to compose a network and examine network outcomes of interest. These outcomes are: network decline, collaboration decline, political structuring, and organizational concentration. First, to assess network and collaboration decline, we count individuals and their co-authorship ties to other individuals on an annual basis. Specifically, we assess the total number of nodes (individuals) in the network over time and their total ties. The number of ties of network participants relative to the size of the network furthermore enables us to measure density (discussed below).

Second, to measure organizational concentration, we assess over time which companies are the most frequent participants. For this, we rely on the self-reported organizational affiliation of RFC authors, but manually ensured consistency across a wide range of ways in which authors name, spell, or abbreviate their affiliation. We also manually coded the location of the headquarters of all organizations in the data. We further examine the centrality of organizations based on their node degree score. The node degree counts the ties of an actor with other actors at a point in time (Luke, 2015). We also evaluate betweenness centrality. Betweenness indicates how important a node is in connecting other nodes of the network (Luke, 2015). To aggregate these organization-level measures to the network level, we examine the distribution of centrality or *concentration*. For example, we can compare the difference between the 99th percentile and the median in the distribution of degree and betweenness scores and trace change over time.

Finally, to assess political structuring, we employ exponential random graph models (ERGM). ERGMs allows us to test whether structural differences, such as different political systems within which actors operate, affect the likelihood of a tie forming between two actors. We are especially interested in the formation of ties between actors from states with similar political and economic structures and capacities. To determine where actors are from, we rely on our information on the headquarters of their organizational affiliations.

Finally, to operationalize the time dimension of our analysis, we trace network characteristics on a yearly basis. For some analyses, we divide our data into distinct periods: 1969–1991, 1992–2001, 2002–2009, 2010–2018. While there are substantive reasons for this division, discussed below, the choice of periods does not affect our findings. We choose periods instead of modelling our network each year for some analyses because the network otherwise becomes sparse, rendering the yearly analyses uninformative.

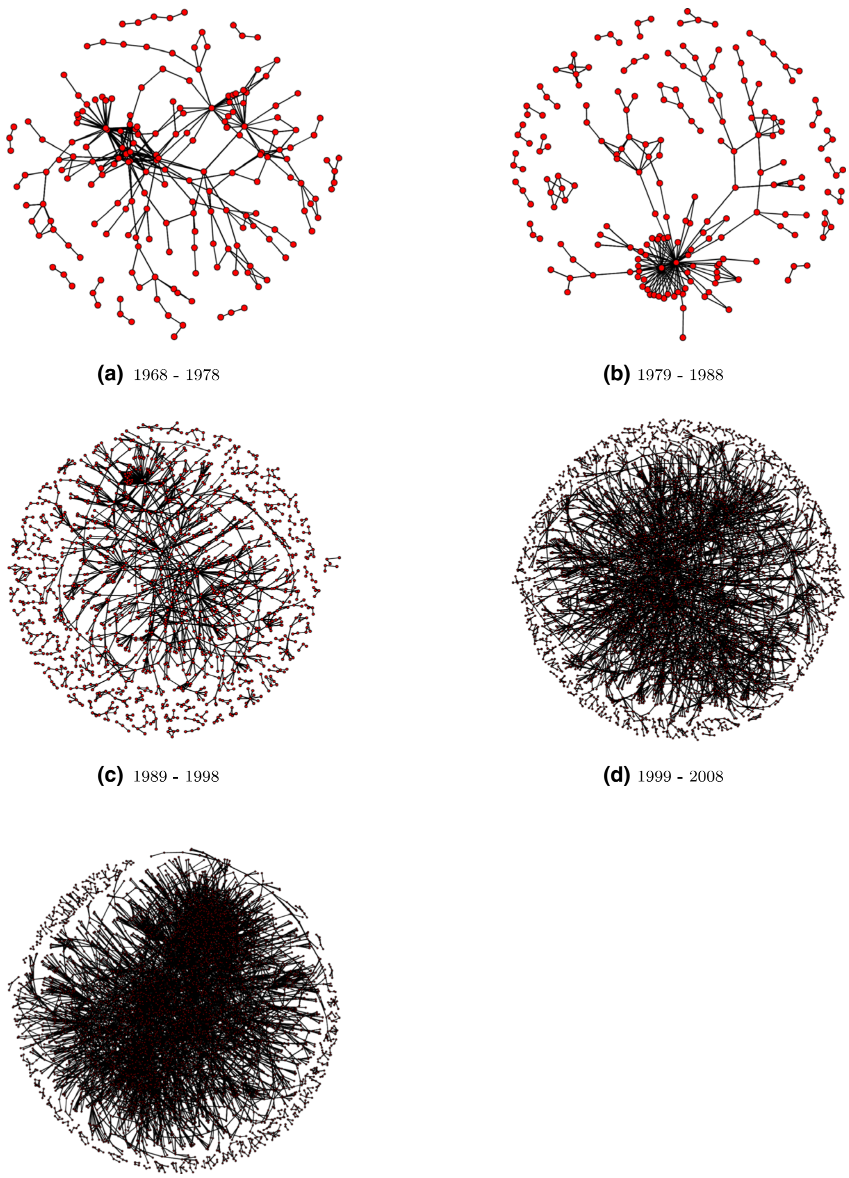
Examining the IETF engineering network empirically: network growth and density

How has the transnational engineering network of the IETF developed over time? Figure 1 displays the network over 10-year periods. The growth of the network in terms of participants is apparent. During 50 years of standard-setting, the IETF has developed from a small, US-based to a global endeavor, encompassing around one thousand individuals collaborating on RFCs per year. It is also obvious that growth has not been continuous, but has taken place after the invention of the World Wide Web – the system of websites and other online resources that runs on the internet and that is often equated with the internet – and the commercialization of the internet in the early 1990s (Brügger, 2016; W3C, 2000). This is compatible with studies that distinguish the early period of internet development and the 1990s and after, in which companies have started to join the network in large numbers (e.g., Naughton, 2016; Simcoe, 2012). Overall, there is little evidence for network or collaboration decline.

Figure 1 also conveys the impression that there might be differences in centrality between network participants. Some seem highly connected and others more remote. Visual inspection further suggests that there might be clusters around some central actors, potentially supporting the idea of organizational concentration, although more careful examination is required.

We further examine the network by year. First, we consider the total number of nodes. Figure 2(a) and (b) displays total RFC authors each year (nodes). The dashed line in the Figure indicates the year 1991, which signifies the start of the World Wide Web and beginning commercialization of the internet. Historically, except for a spike in the 1970s, RFC authorship long remained at low levels. The initial spike was created by actors from universities located on the west coast of the United States. After 1991, we observe a rapid

Figure 1. Network development over time.



(a) 1968 - 1978
(b) 1979 - 1988
(c) 1989 - 1998
(d) 1999 - 2008
(e) 2009 - 2018

increase in authorship. Zooming in on the period after 1991, it becomes obvious that the trend has not slowed down so far.

How many ties do actors forge when working on an RFC? Figure 2(c) and (d) displays the mean and median degree of the participants in the IETF engineering network per year. The degree of an individual is the number of connections (i.e., co-authorships) with others. Both panels indicate an increase in the average number of connections an individual makes in a year from approximately 1–4. The median number of ties is more conservative (it is unaffected by outliers) but follows a similar development. Overall, these data show growing rather than declining collaboration.

We have to relate the number of ties to the entire network. Figure 2(e) and (f) displays the density of the network. Density indicates how many potential ties are realized. If all individuals are connected to one another, density is one. We observe that the network of IETF engineers was tight-knit in some early years, in line with historical accounts (Naughton, 2016), although even then density was far from perfect. Rarely have more than 10 per cent of possible ties been realized. With growing participation, the network has become less dense. Following the year 1995, density has consistently been around 0.01. Collaboration has not kept pace with network growth. This is not surprising considering that adding one actor to the network in a year creates a new collaboration opportunity for *every* existing actor. In fact, the more noteworthy development, if we focus on the years since 1990, is that density has been stable and potentially even increased slightly since 2000. Overall, while network participants have become relatively isolated, collaboration has grown in absolute terms and has even kept pace with the drastic network expansion of the last two decades.

In sum, this assessment suggests little evidence for network or collaboration decline. The findings are in line with the idea that transnational engineering networks grow rather than decline. Nevertheless, declining density suggests that there are challenges associated to growth. Two additional challenges that we suggested might arise are organizational concentration and political structuring.

Political structuring

Political structuring occurs if the collaboration choices of participants in transnational engineering networks become determined by political factors. In principle, a wide range of political and jurisdictional characteristics could conceivably matter. For our assessment, we remain close to major variables, which are prominent in the literature and which, if ineffective, would raise doubt as to the possibility that transnational engineering networks are characterized by political structuring.

First, we focus on the political regime. Scholars have suggested that autocratic governments exert pressure on non-governmental actors in transnational arenas in general and in particular in technology governance (Galloway and Baogang, 2014; Harcourt et al., 2020; Shen, 2016). A possible consequence could be that actors from such countries limit collaboration to actors from similar political contexts and that actors from democracies refrain from collaborating with actors from autocracies. We operationalize shared political regime by examining the similarity of any two actors in terms of the polity index of the country in which their organizational affiliation is based (Marshall et al., 2011). Second, we examine whether actors from the same countries or from countries at similar levels of economic development, measured in GDP per capita based on World Bank data, are likely to collaborate. We regard both as indicators that actors are subject to similar regulatory environments.

As noted earlier, we rely on ERGMs, which estimate the likelihood that two actors in the IETF network form a tie. Table 1 presents the results for three time periods. We excluded the first period (1969–1990) as the IETF network was small and predominantly comprised US-based academics. The first model (1991–2001) covers the initial years after the commercialization of the internet and the burst of the 'internet bubble' in 2001. The second model (2002–2009) covers the years following the burst of the internet bubble up to, roughly, the global financial crisis. It also covers the time frame in which Chinese involvement became prevalent. The third model (2010–2018) covers the years following the global financial crisis up to 2018. In this period, China-based actors were highly active network participants.

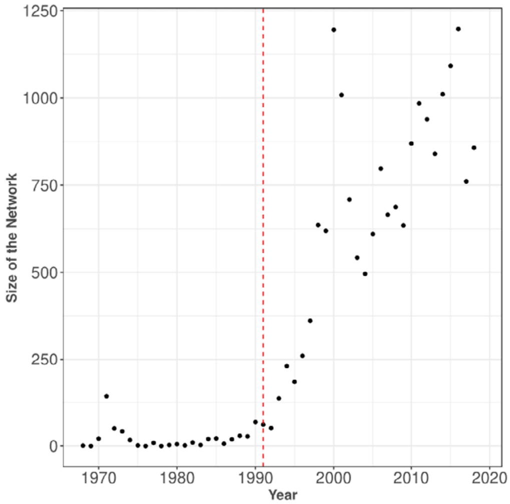
Turning to the results, relevant relationships appear to exist. We find a weak effect of discrepancies in political regime, as measured by the polity index, in all analysis periods. Additionally, similarity in terms of economic development has a small effect, but in the opposite direction than what would be expected in the first and last periods. And actors from the same state are more likely to collaborate in 1991–2001, but not later. However, two problems present themselves for the claim that the IETF network exhibits political structuring. First, there is a valid concern that these effects could be driven by US actors, which are more numerous in our network than actors from other countries. We re-estimated the models without US-based actors (see Table 2). Without these actors, the original findings largely disappear. Dissimilarity in economic development and coming from different states even seems conducive to collaboration in some periods. In general, the relationships are too inconsistent and weak to constitute strong evidence for political structuring. Second, there is no evidence that political structuring, as operationalized here, is growing as could have been concluded had the relationships become stronger in later years.

Organizational concentration

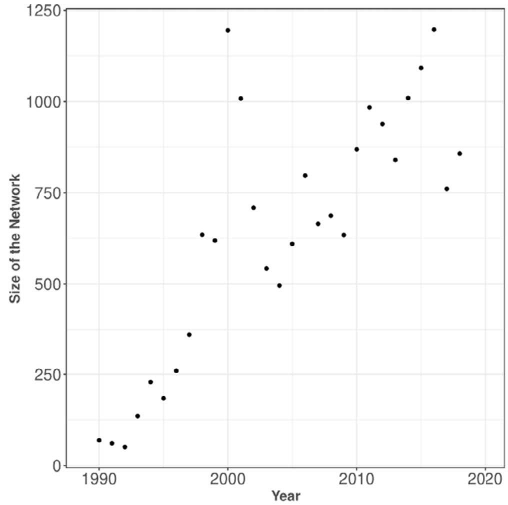
Finally, we examine concentration first by identifying key organizations in the IETF network. The network has undergone a change in who collaborates and authors RFCs. As shown above, after initial growth in the late 1960s and early 1970s, collaboration in the IETF reverted to low levels in the 1980s. Following 1991, in addition to network growth, there has also been a shift in the main authors of RFCs. Figure 3 shows from which organizations most authors come in each year. Early, we observe Bolt, Beranek, and Newman (BBN) whose founders were affiliated with the Massachusetts Institute of Technology (MIT). Other important organizations were the University of Southern California's Information Systems Institute and the University of California, Los Angeles. As historical accounts suggest (Naughton, 2016), this period was dominated by actors from US Universities and a few research-oriented companies. Since then, a shift has taken place to private US telecommunications companies, and in particular Cisco Systems. In 2018, for the first time, a non-US organization, Huawei from China, supplied most RFC authors.

This first overview does not tell us how concentrated the engineering network is around these major players. To assess organizational concentration, we first examine the six companies in the IETF which have been most involved in RFCs overall. Figure 4(a) displays the share of RFC authors of the six most frequently involved companies after 1990. The underlying assumption is that organizational concentration would be reflected in authors from these companies making up a large and increasing share of all authors. This is what we observe. Initially, one quarter of the participants in the network was from these organizations. This share has strongly increased to over 35 per cent. To appreciate the magnitude of this change, keep in mind that the overall

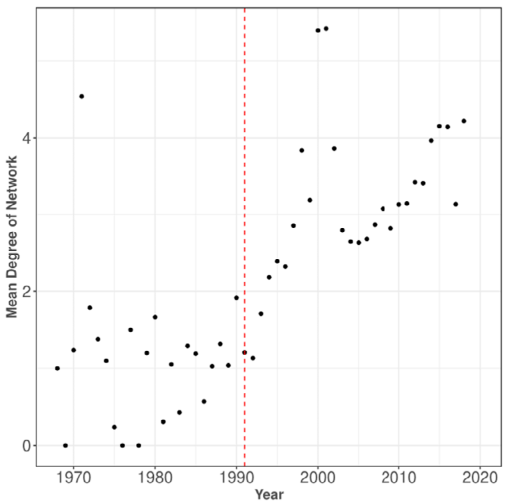
Figure 2. Network characteristics over time.



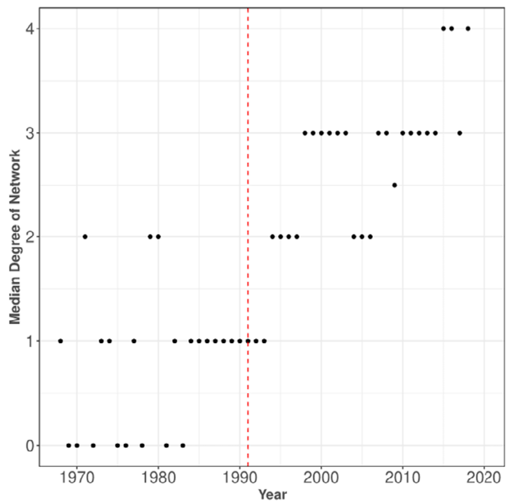
(a) Network Size



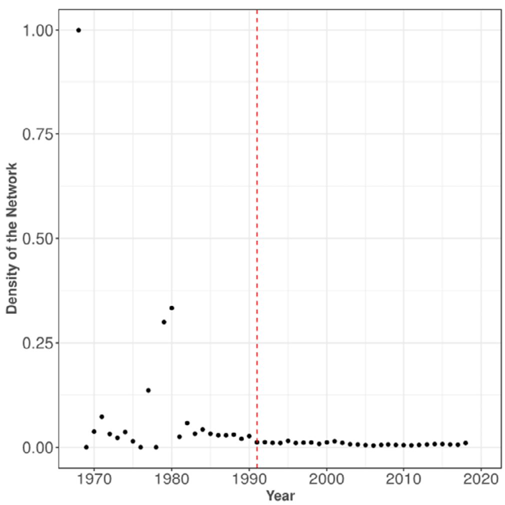
(b) Network Size after 1990



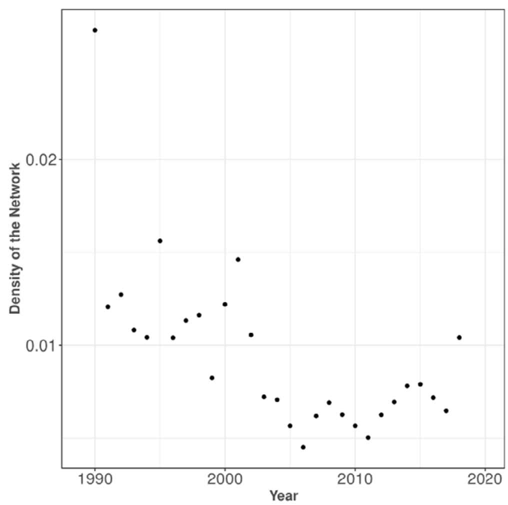
(c) Network Mean Degree



(d) Network Median Degree



(e) Network Density



(f) Network Density after 1990

Table 1. ERG models of the likelihood of IETF collaboration

Variables	1991–2001	2002–2009	2010–2018
Edges	−7.82**	−7.96***	−7.28***
	(0.04)	(0.03)	(0.02)
Difference: polity	−0.04***	−0.14**	−0.01*
	(0.01)	(0.05)	(0.00)
Difference: GDP/capita	0.33***	−0.17***	0.04***
	(0.04)	(0.03)	(0.01)
Same state	0.16***	0.01	0.01
	(0.04)	(0.03)	(0.02)
AIC	57,060.71	81,999.09	110,467.24
BIC	57,115.41	82,056.37	110,523.45
Log Likelihood	−28526.35	−40995.55	−55229.62

*Notes: ***p < 0.001; **p < 0.01; *p < 0.05. Standard errors in parentheses.*

Table 2. ERG models excluding US-based actors

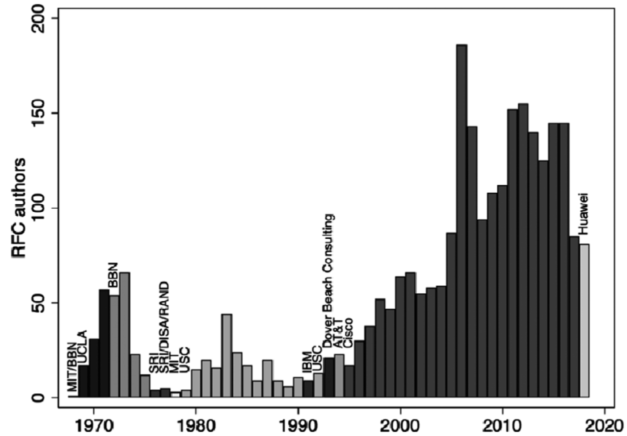
Variables	1991–2001	2002–2009	2010–2018
Edges	−5.95***	−7.70***	−6.64***
	(0.09)	(0.04)	(0.04)
Difference: polity	−0.03	−0.06***	0.01
	(0.02)	(0.02)	(0.00)
Difference: GDP/capita	0.00	0.14***	0.03*
	(0.08)	(0.03)	(0.02)
Same state	−0.27**	−0.09*	−0.04
	(0.10)	(0.04)	(0.04)
AIC	5587.79	35,146.96	40,924.33
BIC	5628.14	35,200.06	40,974.43
Log Likelihood	−2789.90	−17569.48	−20458.17

*Notes: ***p < 0.001; **p < 0.01; *p < 0.05. Standard errors in parentheses.*

number of RFC authors has grown rapidly during this period – yet, the share of authors from the six main companies has grown faster still. In 2018, Huawei and Cisco were the most prolific RFC authors (see Figure 4(b)). It is not the case, however, that all companies other than Huawei are US-based. With Nokia and Ericsson, European companies feature prominently. These findings support the view that organizational concentration is growing in the IETF engineering network.

To examine organizational concentration more systematically, we compare the centrality of the actor at the 99th percentile of the centrality distribution to the median. We do this for betweenness centrality, which captures whether an actor occupies the path between two other actors, and degree centrality, which reflects how many collaborative ties an actor has. In the case of both measures, we clearly find that the gap between the most central actors and the median in the network has grown continuously, starting with the growth of the network in 1991. This suggests not only that organizational concentration is on the rise but also that the growing size of the network might be an important driving factor.

Figure 3. Companies from which most RFC authors come per year.



Note: MIT, Massachusetts Institute of Technology; BBN, BBN Technologies; UCLA, University of California, Los Angeles; SRI, SRI International; DISA, Defense Information Systems Agency; RAND, RAND Corporation; USC, University of Southern California.

While we mainly seek to assess organizational concentration, historical evidence and further examination of our data also sheds some light on the underlying processes. The role of BBN, which was founded at and remained closely linked to MIT, in the early history of the internet has been documented in detail (Beranek, 2005; Naughton, 2016; Partridge and Blumenthal, 2006). BBN won the first public contract to run Arpanet, the internet's predecessor, in 1968 and would thus be central in early standards development (Beranek, 2005). Its mandate required connecting, among others, the University of California, Los Angeles, and SRI International to the network, both of which feature prominently in our data (Partridge and Blumenthal, 2006). More broadly, the early internet remained dominated by academic researchers, and by research-oriented companies with public contracts to maintain the network and close ties to universities. The significance of academic institutions in our data is consistent with this.

To understand the subsequent rise of organizational concentration, we need to ask what drove the growth of the network and the engagement of companies. Historians identify the period from approximately 1989–1995 as the turning point (Brügger, 2016; Naughton, 2016). In this period, the internet became a commercially attractive technology for two reasons. First, the World Wide Web was invented in 1989 and publicized in 1991. Second, the internet's infrastructure was privatized. With this, a restriction on commercial use imposed by the National Science Foundation ended. An implications of these changes was that internet standards became salient for companies building, operating, and relying on the internet (see also Simcoe, 2012). While we cannot test this argument conclusively here, Figure 5(a) shows that the period around 1989–1995 is when companies started to contribute significantly to RFC authorship compared to academics and other actors such as civil society and the technical community.

Regarding the motivations of particular actors – notably Cisco and Huawei – some evidence suggests that Cisco benefited from an early mover advantage. Figure 5b indicates its engagement in the IETF early on after its foundation in 1984. Kraemer and Dedrick (2002), for example, argue that Cisco successfully build an integrated set of services around its preferred standards and network operating system. Anecdotal evidence of intra-industry tensions indicates that Cisco engages in the IETF to promote standards favorable to and compatible with its products and services (e.g., Cnet, 1997; The Register, 2020). In contrasts, the emergence of Huawei as an important actor in the IETF has been attributed not only to commercial incentives and the rapid growth of the Chinese information technology sector but also to political changes (Contreras, 2014; Shen, 2016). Our data support this view to the extent that Huawei's growing RFC authorship begins in the mid-2000s (Figure 5(b)), which is often seen as the period in which the Chinese government developed policies to influence global technology governance in intergovernmental arenas but also through influence on private participants in the IETF and other standard-setting organizations (Shen, 2016). Huawei's growing IETF involvement is thus likely to reflect a mix of commercial interests, given its global business interests and capacity, as well as governmental permission and even pressure to set standards. This mix of incentives is also reflected in the reactions of other governments to Huawei in various areas of internet governance (Harcourt et al., 2020).

Overall, the evidence indicates that the IETF engineering network has become more concentrated around major companies. The centrality of these companies relative to the average network participant has increased at the same time that the density of the network has declined. Three interrelated trends – growing network size, declining density, and growing activity of these companies – thus contribute to organizational concentration. Changes in the incentive structure around 1990, the market strategies and early mover advantages of Cisco, and the political environment of Huawei and other Chinese actors appear to be important drivers although more systematic analyses than could be offered here is needed. The dominant companies in 2018, in terms of centrality, were headquartered in four distinct countries (three in the US, and one in China, Finland, and Sweden respectively). Organizational concentration thus does not simply reflect the US-origins of the IETF.

The broader context: IETF participants and leaders

We have found signs of organizational concentration in the IETF. What is the broader context of this development? If we examine other indicators such as participation in the IETF's meetings or occupation of leadership positions, do we find organizational concentration in RFC authorship reinforced or rather embedded in a more diffuse environment?

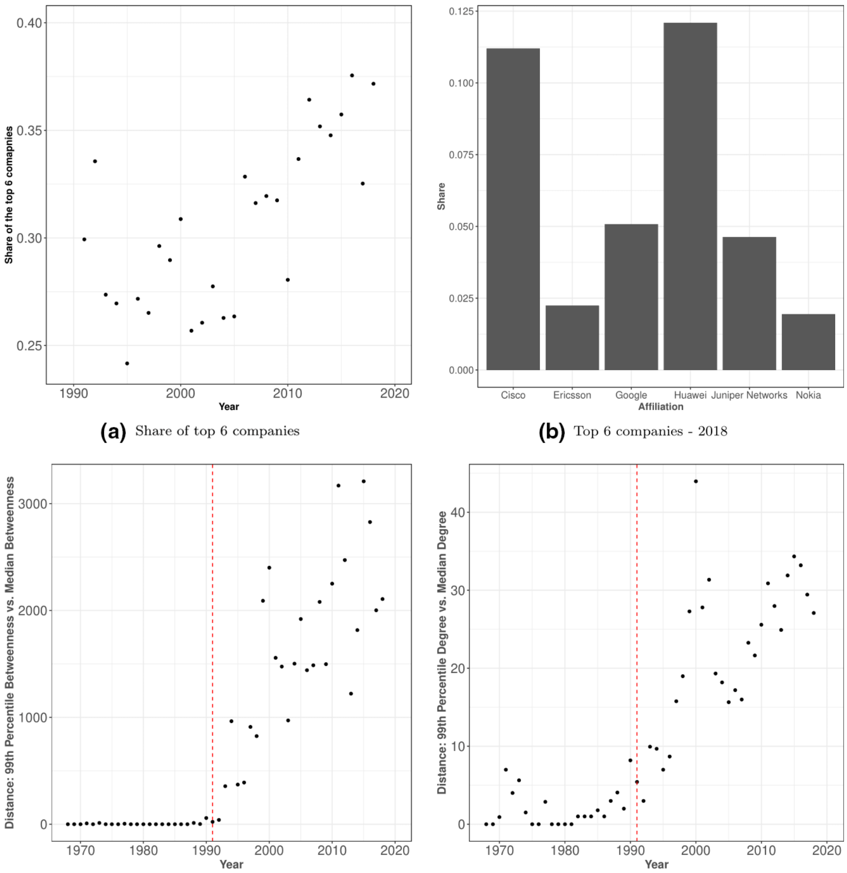
Figure 6(a)–(c) charts meeting participation across countries and organizations. Meeting participation is an easy form of involvement. It does not necessarily coincide with influence or authority but is an indicator of the contours of the wider IETF community. We collected a decade of data (27 meetings from 2008 to 2017). As in the case of RFC authorship, we standardized organizational affiliations and coded the headquarter location of these organizations.[2.] We classified organizations as academic, civil society, companies, public, and technical organizations. We have information on 31,899 participants from 145 countries and 2,799 organizations.[3.]

The results suggest that most participants come from a few organizations (Figure 6(c)) in a few countries Figure 6(a)). Moreover, participation remains strongly US-centric. On average, 501 meeting participants come from US-based compared to 125 from China-based organizations. While one might suspect that these averages hide longitudinal change, Figure 6(b) indicates that this is not the case for some major origins. In fact, the US presence appears to have grown. Nevertheless, if we focus on the organizational level in Figure 6(c), we find broader geographic representation as well as some non-profit actors such as the Internet Society, ICANN, and the Internet Systems Consortium (ISC). There is also more change (not shown here). For example, Huawei and Google increased their presence and Alcatel formally disappeared after being absorbed by Nokia. Overall, we find the patterns of organizational concentration that we saw in RFC authorship reinforced rather than ameliorated. We observe similar long-tailed distributions with a leading position for a few major organizations. We also observe strong US-centrism but, as in the case of RFC authorship, less clearly for the most prominent organizations.

Figure 6(d) suggests similar conclusions if we examine actors in IETF leadership positions. We focus on the current (spring 2019) distribution of working group chairs. The role of chairs has been described in detail elsewhere (ten Oever and Moriarty, 2018). Crucially, their support is required for the adoption of Internet Standards. Working group chairs predominantly come from a few major organizations. The same organizations that supply most RFC authors also provide many chairs, notably Cisco and Huawei. In the case of these leadership positions, US organizations are again highly prominent. Of the 242 working group chairs in 2019, 60 per cent came from US organizations. Unlike in RFC authorship and meeting participation, this holds true even for the organizations that supply most chairs. Of the top 15 organizations, 10 are US-based. These patterns also remain if we turn our attention to area directors, who constitute the next leadership level in the IETF and together vote on the adoption of Internet Standards. Of the 15 area directors in office in spring 2019, 10 were affiliated to US organizations.

Overall, the broader context, as visible in meeting participation and leadership positions, reinforces our assessment that the IETF is characterized by significant organizational concentration. We also find strong US-centrism not only in general but also among the most important organizations, particularly in terms of who occupies leadership positions.

Figure 4. Organizational concentration.



(a) Share of top 6 companies

(b) Top 6 companies - 2018

(c) Distance - Median and 99th percentile (Betweenness)

(d) Distance - Median and 99th percentile (Degree)

Conclusions

There have been growing concerns in recent years about the fragmentation of the internet. The literature has engaged with these concerns by studying the key dimensions of the unified or global internet: domestic policies, communication standards, and internet governance institutions. We contribute an analysis of transnational engineering networks, which provide essential social foundations for communication standard-setting and internet governance institutions as well as a counterweight to heterogeneity in domestic policies. Our contributions comprise: (1) broadening the debate to encompass not only fragmentation-related outcomes such as network and collaboration decline, but also the alternative outcomes of political structuring and organizational concentration; and (2) new evidence for a key engineering network that has formed around the IETF. We find robust network growth as well as a strong tendency of the network to concentrate ever more around a limited number of central and mainly (but not only) US-based companies. There is little evidence for fragmentation-related network outcomes or political structuring. While we noted some evidence that the growing role of Huawei in the IETF might be driven in part by Chinese government policy, we did not find this reflected in political structuring of collaboration patterns more broadly.

An important implication is that debates about internet fragmentation, at least at the level of engineering networks, might distract from other important developments. While there is little doubt that domestic policies are diverging and that this fragments the internet as available to citizens in different jurisdictions (Freedom House, 2018), and that internet governance institutions remain under strain, the internet's fundamental communication standards have become increasingly consolidated. We similarly find that the engineering networks underpinning these dimensions of the global internet are growing steadily in size and collaborative ties. Actors from the country best known for restrictive internet policies, China, are central and prolific contributors to these networks. We thus share the objection by Mueller (2017) that fragmentation might not be the key issue. Our conclusions rather accord with concerns raised by the Internet Society (2019) that the internet fosters the concentration of authority, market shares, and other characteristics such as centrality in standards development in a few major companies. We find that a key transnational engineering network has become concentrated around a few highly central actors.

Figure 5. RFC authorship of different groups and actors.

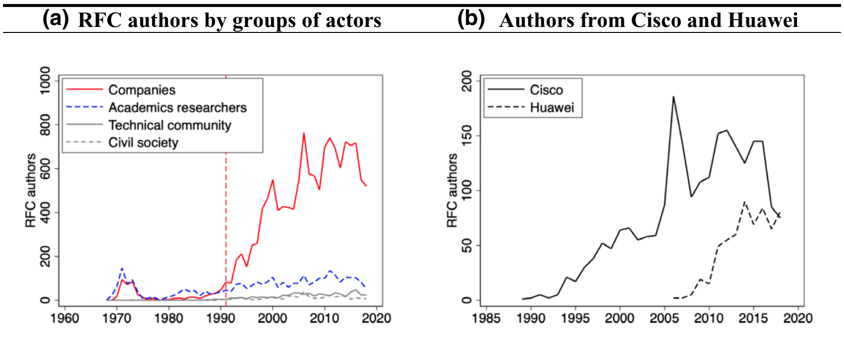
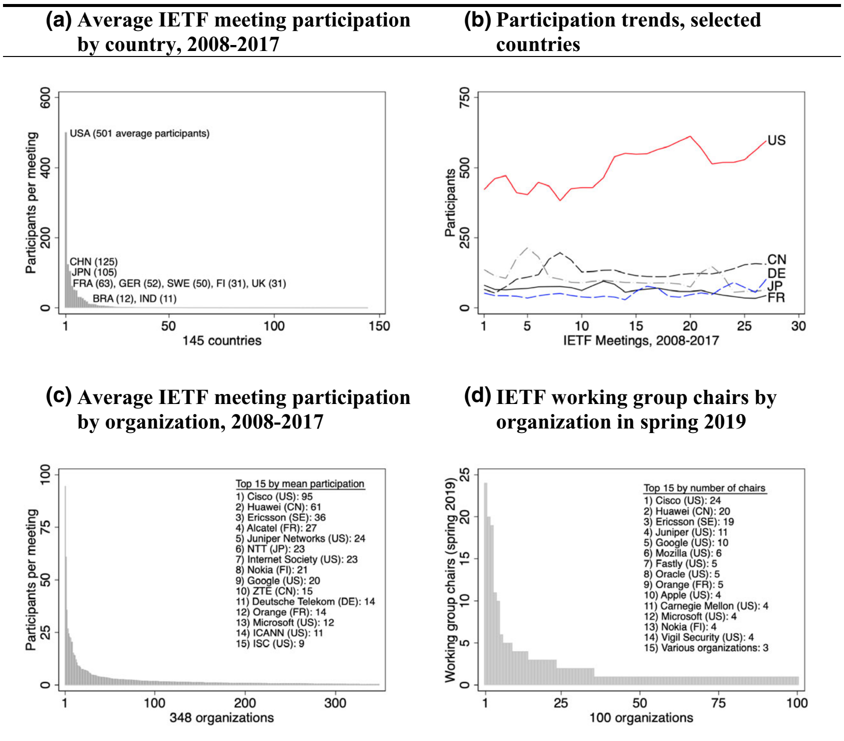


Figure 6. IETF participants and leaders by country and organizational affiliation.



Note: Panels (a)–(c) rely on data for all 27 IETF meetings from 2008 to 2017. Panels (a) and (c) show averages over this period, panel (b) shows trends over time. Panel (c) only includes organizations that sent participants to at least 10 of the 27 IETF meetings in our data. Panel (d) covers organizations with at least one current working group chair. An IETF working group tends to have about two chairs.

Finally, we have focused on *assessing* fragmentation, political structuring, and organizational concentration in engineering networks and found noteworthy evidence of concentration. While we have not examined the *consequences*, some possibilities can be raised. At a minimum, organizations centrally involved in standards development can be assumed to use their position to advance, at least to some extent, their commercial goals and accommodate their constraints. For example, critics recently alleged that Cisco employs its prominence in RFC authorship and working group leadership to block innovations by other actors (The Register, 2020). Huawei's promotion of a new internet protocol in the International Telecommunications Union and, if less directly, in the IETF has been seen by some as reflecting government interests (*Financial Times*, 2020). Regardless of whether these specific concerns hold true, it seems likely that organizational concentration in the IETF and other internet governance contexts affords some actors significant opportunities to exert technological and policy influence. It is less likely that these actors will reliably use their opportunities to shape technology and policy in the interest of a wider community, irrespective of how we define it exactly, of actors with stakes in the operation of the internet. As recent controversies around the aforementioned examples indicate, even the perception that this might be the case can give rise to debates about the legitimacy of standards development in the IETF and other engineering networks.

Notes

The authors are grateful to the Mannheim Centre for European Social Research for financial support and to the editors of *Global Policy* as well as two anonymous reviewers for insightful comments.[2]

1. Data and replication files for this study are available from the authors on request.[3]
2. Where participants indicated an affiliation to a subsidiary (e.g. Google Japan), we recorded this but rely on the parent company's headquarter location in our analysis. We excluded countries below 1 million inhabitants.[4]
3. In total, the IETF recorded 38,009 participants. We found information for 84 per cent (31,899). The other participants had not reported any organizational affiliation. It is uncertain what explains the missing information. However, even if we distribute them evenly over the countries and meetings in the data, they would add only 1.6 participants per country and meeting. The changes would be too small to matter for our conclusions.

References

Akplogan, A. A., Curran, J., Wilson, P., Housley, R., Chehadé, F., Arkko, J. et al. (2013) Montevideo Statement on the Future of Internet Cooperation [online]. Available from: https://www.icann.org/news/announcement-2013-10-07-en [Accessed 17 August 2020].

Barabási, A.-L. and Albert, R. (1999) 'Emergence of Scaling in Random Networks', *Science*, 286 (5439), pp. 509–512.

Becker, M. (2019) 'When Public Principals Give up Control Over Private Agents: The New Independence of ICANN in Internet Governance', *Regulation & Governance*, 13 (4), pp. 561–576.

Benkler, Y. (2016) 'Degrees of Freedom, Dimensions of Power', *Daedalus*, 145 (1), 18–32.

Beranek, L. L. (2005) 'BBN's Earliest Days: Founding a Culture of Engineering Creativity', *IEEE Annals of the History of Computing*, 27 (2), 6–14.

Braman, S. (2010) 'The Interpenetration of Technical and Legal Decision-making for the Internet', *Information, Communication & Society*, 13 (3), 309–324.

Brügger, N. (2016) 'Introduction: The Web's first 25 years', *New Media & Society*, 18(7), 1059–1065.

Bygrave, L. A. and Bing, J. (2009) *Internet Governance: Infrastructure and Institutions*. Oxford: Oxford University Press.

Carr, M. (2015) 'Power Plays in Global Internet Governance', *Millennium*, 43 (2), 640–659.

Claessen, E. (2020) 'Reshaping the Internet – the Impact of the Securitisation of Internet Infrastructure on Approaches to Internet Governance: the Case of Russia and the EU', *Journal of Cyber Policy*, 5 (1), 140–157.

Cnet (1997) Cisco's IP Switching Foes Consolidate [online]. Available from: https://www.cnet.com/news/ciscos-ip-switching-foes-consolidate/ [Accessed 17 August 2020].

Contreras, J. L. (2014) 'Divergent Patterns of Engagement in Internet Standardization: Japan, Korea and China', *Telecommunications Policy*, 38 (10), 914–932.

de Nardis, L. (2009) *Protocol Politics: The Globalization of Internet Governance*. Cambridge, MA: MIT Press.

de Nardis, L. (2014) *The Global War on Internet Governance*. New Haven, CT: Yale University Press.

de Nardis, L. (2015) 'The Internet Design Tension between Surveillance and Security', *IEEE Annals of the History of Computing*, 37 (2), pp. 72–83.

de Nardis, L. (2016) One Internet: An Evidentiary Basis for Policy Making on Internet Universality and Fragmentation [online]. Global Commission on Internet Governance. Paper Series No. 38. Available from: https://www.cigionline.org/sites/default/files/gcig_no.38_web.pdf [Accessed 17 August 2020].

Drake, W. J., Cerf, V. G. and Kleinwächter, W. (2016) *Internet Fragmentation: An Overview*. Davos: World Economic Forum.

Drezner, D. W. (2004) 'The Global Governance of the Internet: Bringing the State Back In', *Political Science Quarterly*, 119 (3), 477–498.

Financial Times (2014) Tying up the Internet [online]. Available from: https://www.ft.com/content/2f2f7274-3a5e-11e4-bd08-00144feabdc0 [Accessed 17 August 2020].

Financial Times (2020) Inside China's Controversial Mission to Reinvent the Internet [online]. Available from: https://www.ft.com/content/ba94c2bc-6e27-11ea-9bca-bf503995cd6f [Accessed 17 August 2020].

Freedom House (2018) *Freedom on the Net 2018: The Rise of Digital Authoritarianism*. Washington, DC: Freedom House.

Freyburg, T. and Garbe, L. (2018) 'Authoritarian Practices in the Digital Age, Blocking the Bottleneck: Internet Shutdowns and Ownership at Election Times in Sub-Saharan Africa', *International Journal of Communication*, 12, pp. 3896–3916. https://ijoc.org/index.php/ijoc/article/view/8546

Gahnberg, C. (2019) Internet Consolidation: What lies Beneath the Application Layer? [online]. *Media@LSE*. Available from: https://blogs.lse.ac.uk/medialse/2019/12/10/internet-consolidation-what-lies-beneath-the-application-layer/ [Accessed 17 August 2020].

Galloway, T. and Baogang, H. (2014) 'China and Technical Global Internet Governance: Beijing's Approach to Multi-Stakeholder Governance within ICANN, WSIS and the IGF', *China: An International Journal*, 12 (3), pp. 72–93.

Glen, C. M. (2014) 'Internet Governance: Territorializing Cyberspace?', *Politics & Policy*, 42 (5), pp. 635–657.

Harcourt, A., Christou, G. and Simpson, S. (2020) *Global Standard Setting in Internet Governance*. New York: Oxford University Press.

Heires, M. (2008) 'The International Organization for Standardization (ISO)', *New Political Economy*, 13 (3), pp. 357–367.

Hellmeier, S. (2016) 'The Dictator's Digital Toolkit: Explaining Variation in Internet Filtering in Authoritarian Regimes', *Politics & Policy*, 44 (6), pp. 1158–1191.

Internet Governance Forum (2018) IGF 2018 Speech by French President Emmanuel Macron [online]. Available from: https://www.intgovforum.org/multilingual/content/igf-2018-speech-by-french-president-emmanuel-macron [Accessed 17 August 2020].

Internet Governance Forum (2019) UN Secretary-General Remarks to the IGF 2019 [online]. Available from: https://www.intgovforum.org/multilingual/content/un-secretary-general-remarks-to-the-igf-2019 [Accessed 17 August 2020].

Internet Society (2019) 2019 Internet Society Global Internet Report: Consolidation in the Internet Economy [online]. Internet Society. Available from: https://future.internetsociety.org/2019/wp-content/uploads/sites/2/2019/04/InternetSociety-GlobalInternetReport-ConsolidationintheInternetEconomy.pdf [Accessed 17 August 2020].

Journal of Cyber Policy (2020) 'Editorial Introduction', *Journal of Cyber Policy*, 5 (1), pp. 1–4.

Kim, R. E. (2019) 'Is Global Governance Fragmented, Polycentric, or Complex? The State of the Art of the Network Approach', *International Studies Review* (in press), https://doi.org/10.1093/isr/viz052

King, G., Pan, J. and Roberts, M. E. (2014) 'Reverse-engineering Censorship in China: Randomized Experimentation and Participant Observation', *Science*, 345 (6199), pp. 1–10.

Kraemer, K. L. and Dedrick, J. (2002) 'Strategic Use of the Internet and E-Commerce: Cisco Systems', *The Journal of Strategic Information Systems*, 11 (1), pp. 5–29.

Luke, D. (2015) *A User's Guide to Network Analysis in R*. Cham: Springer International.

Marshall, M. G., Jaggers, K. and Gurr, T. R. (2011) *The Polity IV Project – Political Regime Characteristics and Transitions, 1800–2010*. Vienna, VA: Center for Systemic Peace.

Mathew, A. J. (2016) 'The Myth of the Decentralised Internet', *Internet Policy Review*, 5 (3). Available from: https://policyreview.info/node/425 [Accessed 17 August 2020].

Mattli, W. and Büthe, T. (2003) 'Setting International Standards: Technological Rationality or Primacy of Power?', *World Politics*, 56 (1), pp. 1–42.

Milner, H. V. (2006) 'The Digital Divide', *Comparative Political Studies*, 39 (2), pp. 176–199.

Mueller, M. (2010) *Networks and States: The Global Politics of Internet Governance*. Cambridge, MA: The MIT Press.

Mueller, M. (2017) *Will the Internet fragment? Sovereignty, Globalization, and Cyberspace*. Cambridge: Polity Press.

Musiani, F., Cogburn, D. L., DeNardis, L. and Levinson, N. S. (2016) *The Turn to Infrastructure in Internet Governance*. Basingstoke: Palgrave Macmillan.

Naughton, J. (2016) 'The Evolution of the Internet: From Military Experiment to General Purpose Technology', *Journal of Cyber Policy*, 1 (1), 5–28.

Partridge, C. and Blumenthal, S. (2006) 'Data Networking at BBN', *IEEE Annals of the History of Computing*, 28 (1), pp. 56–71.

Patrick, S. M. (2014) The Obama Administration Must Act Fast to Prevent the Internet's Fragmentation [online]. Council on Foreign Relations. Available from: https://www.cfr.org/blog/obama-administration-must-act-fast-prevent-internets-fragmentation [Accessed 17 August 2020].

Radu, R. and Hausding, M. (2020) 'Consolidation in the DNS Resolver Market – How Much, How Fast, How Dangerous?', *Journal of Cyber Policy*, 5 (1), pp. 46–64.

Russell, A. L. (2006) '"Rough Consensus and Running Code" and the Internet-OSI Standards War', *IEEE Annals of the History of Computing*, 28 (3), pp. 48–61.

Shen, H. (2016) 'China and Global Internet Governance: Toward an Alternative Analytical Framework', *Chinese Journal of Communication*, 9 (3), pp. 304–324.

Simcoe, T. (2012) 'Standard Setting Committees: Consensus Governance for Shared Technology Platforms', *The American Economic Review*, 102 (1), pp. 305–336.

ten Oever, N. and Moriarty, K. (2018) The Tao of IETF: A Novice's Guide to the Internet Engineering Task Force (Version 2018-11-08) [online]. Available from: https://www.ietf.org/about/participate/tao [Accessed 17 August 2020].

The Register (2020) Open Letter to Internet Engineering Task Force: Back off Cisco, Not all Members Want to "Play to Your Tune" [online]. Available from: https://www.theregister.com/2020/04/17/open_letter_to_internet_engineering/ [Accessed 17 August 2020].

van Eeten, M. J. G. and Mueller, M. (2013) 'Where is The Governance in Internet Governance?', *New Media & Society*, 15(5), 720–736.

W3C (2000) A Little History of the World Wide Web [online]. Available from: https://www.w3.org/History.html [Accessed 17 August 2020].

Weidmann, N. B., Benitez-Baleato, S., Hunziker, P., Glatz, E. and Dimitropoulos, X. (2016) 'Digital Discrimination: Political Bias in Internet Service Provision Across Ethnic Groups', *Science*, 353 (6304), pp. 1151–1155.

Wired (2019) The Dream of a Global Internet is Edging Towards Destruction [online]. Available from: https://www.wired.co.uk/article/internet-fragmentation [Accessed 17 August 2020].

Zylberberg, H. (2016) We Should Not Fear a Fragmented Internet [online]. Council on Foreign Relations. Available from: https://www.cfr.org/blog/we-should-not-fear-fragmented-internet [Accessed 17 August 2020].

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