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Knowledge Commons (2019)

Michael J. Madison
University of Pittsburgh School of Law, madison@pitt.edu

Brett M. Frischmann
University of Villanova School of Law, brett.frischmann@law.villanova.edu

Katherine J. Strandburg
New York University School of Law, strandburg@exchange.law.nyu.edu

Knowledge Commons

Michael J. Madison,[*] Brett M. Frischmann,[**] and Katherine J. Strandburg[***]

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Abstract

This chapter provides an introduction to and overview of the knowledge commons research framework. Knowledge commons refers to an institutional approach (commons) to governing the production, use, management, and/or preservation of a particular type of resource (knowledge). The research framework supplies a template for interrogating the details of knowledge commons institutions on a case study basis, generating qualitative data that may be used to support comparative analysis.

I. Introduction

This chapter provides an introduction to and overview of the knowledge commons research framework. Knowledge commons refers to an institutional approach (commons) to governing the production, use, management, and/or preservation of a particular type of resource (knowledge). The research framework supplies a template for interrogating the details of knowledge commons institutions on a case study basis, generating qualitative data that may be used to support comparative analysis.

The framework was introduced to the literature by Madison, Frischmann, and Strandburg (2010) as a framework for researching 'constructed cultural commons,' a shorthand for shared resources composed primarily of products of the human mind, namely knowledge and information in scientific domains, domains related to arts and culture, and resource domains defined largely by their human-generated character and their intangibility. That shorthand has been refined in later work into the phrase 'knowledge commons' (Frischmann, Madison, and Strandburg 2014; Strandburg, Frischmann, and

[*] Professor of Law and Faculty Director of the Innovation Practice Institute at the University of Pittsburgh School of Law, Pittsburgh, PA, USA. Email: madison@pitt.edu.
[**] Charles Widger Endowed University Professor in Law, Business and Economics at Villanova University, Villanova, PA. Email: brett.frischmann@law.villanova.edu.
[***] Alfred B. Engelberg Professor of Law at New York University School of Law, New York, NY. Email: katherine.strandburg@nyu.edu.

Madison 2017), aligning the focus of the research with an earlier introduction by Ostrom and Hess (2007) to themes raised by 'knowledge commons.' Other research on related topics has characterized such resources as 'information commons' (Bollier & Helfrich 2012), 'intellectual commons' (Boyle 2003), 'cultural commons' (Bertacchini et al. 2012), 'socio-technical' commons (de Moor 2015; Hinkel et al. 2015,; and 'new commons' (Hess 2008). Subdomains of research in these domains include scholarship on 'data' commons (Borgman 2015), 'research' commons (Reichman and Uhlir 2003; Reichman et al. 2016), 'spectrum' commons (Weiser & Hatfield 2005), and 'scientific' commons (Nelson 2004). The word 'commons' has been applied for rhetorical effect to a variety of ideological and institutional forms, such as the 'Creative Commons' licensing enterprise.[1] Those rhetorical applications of 'commons' terminology are not addressed here.

For purposes of this chapter, and to render the research framework inclusive and meaningful in a broad, comparative sense, the term knowledge refers to all of the domains identified in the previous paragraph and therefore to a broad set of intellectual, scientific, technical, and cultural resources. Differences among the domains and among the resources within them may be significant. Knowledge, information, and data may be different from each other in meaningful ways. The research framework described here is sufficiently flexible to permit researchers to capture both their commonalities and their differences in their respective ecological contexts. For similar reasons related to inclusiveness, potentially narrower definitions of relevant goods are avoided. Neither this chapter nor the framework limit its approach to precise distinctions among private goods, public goods, club goods, and/or toll goods.

Commons refers to a form of community management or governance of a shared resource. Governance involves a group or community of people who share access to and/or use of the resource and who manage their behavior via an established set of formal and informal rules and norms. "The basic characteristic that distinguishes commons from noncommons is institutionalized sharing of resources among members of a community" (Madison et al. 2010, 841). Commons does not denote the resource, the community, a place, or a thing. Commons is the institutional arrangement of these elements and their coordination via combinations of law and other formal rules and social norms, customs, and informal discipline. Community or collective self-governance of the resource, by individuals who collaborate or coordinate effectively among themselves effectively, is a key feature of commons as an institution. Self-governance may be and often is linked to other formal and informal governance mechanisms.

[1] Creative Commons, https://creativecommons.org.

Technological and other material constraints may play important roles in the constitution and governance of knowledge commons.

Knowledge commons thus refers to the institutionalized community governance of the creation, sharing, and preservation of a wide range of intellectual and cultural resources. This chapter briefly describes the motivations for creation of the knowledge commons research framework. It reviews the content of the framework, indicating where appropriate how the framework builds on but is distinguishable from its most important antecedent, Ostrom's Institutional Analysis and Development framework. This chapter briefly summarizes tentative conclusions from case study research completed to date and indicates important directions for future research.

II. Motivations

The knowledge commons research framework owes its origins in part to the insight that knowledge, in its broadest and most general form, suggests social dilemmas that can be addressed by commons governance (Hess and Ostrom 2007). In an important early work, Hess (2008) suggested the extension of Ostrom's commons research to specific institutional settings beyond natural resource domains that she denominated so-called 'new' commons. These included knowledge-related domains. However, these early efforts did not advance beyond the suggestion that perspectives on commons, based on Ostrom's work, might be useful in knowledge and information contexts.

From a different beginning but at approximately the same time, legal scholars studying the Internet questioned systems of exclusive intellectual property (IP) rights (patent and copyright in particular) as appropriate comprehensive legal and governance systems for cultural and scientific resources, particularly digital resources circulating in networks. Information and knowledge sharing as a modality of production appeared to be especially salient, exemplified by open source software production and Wikipedia. Because of the apparent absence of firm-style hierarchy in these contexts, this perspective on governance, drawing a contrast between intellectual production by firms in markets, relying on exclusive rights, and intellectual production by actors organized non-hierarchically, not relying on exclusivity, was crystallized by Benkler (2004, 2006) in the phrase 'commons-based peer production.' However, attention to commons-based peer production did not advance beyond the conceptual modeling of a handful of salient institutions.

Madison, Frischmann, and Strandburg initiated the knowledge commons research framework in part by building on the instinct to critique IP

systems that motivated Benkler. The problem of providing empirical justifications for IP law regimes has vexed modern researchers for at least 50 years (Machlup 1958). Intellectual property products such as patentable inventions and copyrighted works are conventionally modeled as or assumed to be public goods, which are neither excludable nor depletable, in contrast to private goods, which are both. That assumption leads to framing production of knowledge and information resources as a classic tragedy of the commons. It is typically assumed by researchers that likely overconsumption of intellectual property goods by uncoordinated, self-interested consumers and users in some 'common' domain, i.e., free riders, will lead to diminishment of the incentive to invest in their production, because the inventors and creators of those goods will be discouraged by their inability to recover necessary investments in and returns on innovation (Landes and Posner 2003; Hardin 1968). That diagnosis leads to the conclusion that such a tragedy may be solved, if at all, by the creation and assignment of marketable property rights to individual owners of specific resources within what was formerly held 'in common,' or by production and governance of the resource by a state-based authority.

The theoretical assumptions behind the conventional tragedy of the commons model have long been belied by the fact that knowledge-generating institutions based on successful coordination and collaboration among knowledge producers and users have existed for centuries, often despite the absence of IP rights owned by individual creators or inventors. In colloquial terms, knowledge and information resources are naturally shareable, because of their intangibility as a conceptual matter. Institutions founded on precepts of knowledge sharing are as well known as those founded on precepts of exclusivity of right. Universities have long served as knowledge-generating and knowledge-sustaining institutions despite faculty researchers often exercising few conventional market-based IP interests (Madison, Frischmann, and Strandburg 2009). In short, openly accessible knowledge resources do not necessarily pose dilemmas leading to so-called 'tragic' outcomes. Social dilemmas involving knowledge need not be solved by the delineation of private rights exchanged in markets, nor left to strong coordination by the state.

The knowledge commons research framework marries that insight to one of the key lessons of Ostrom's work: the fact that commons research is and should be empirical, rather than simply conceptual (Frischmann 2013). It advances via the premise that details of governance of knowledge sharing institutions matter as much as standard theoretical templates do. The knowledge commons research framework fleshes out that premise by borrowing the empirical orientation of Ostrom's research and by borrowing specifically from

the IAD framework, as a well-tested approach to studying commons governance other than in knowledge and information settings.

III. The Knowledge Commons Research Framework

As research subjects, cases of knowledge and information sharing are typically characterized by three features: (i) the production of knowledge resources (especially innovative and creative things) via one or more modes of collective action, (ii) institutions and other formal and informal structures for sharing information and knowledge resources, and (iii) governance processes that depend significantly on openness (open access to resources and/or open participation by creators and innovators) or that are characterized by a relative absence of the conventional exercise of formal IP rights. The knowledge commons research framework described here unifies these cases under the heading 'commons' in order to enable research to proceed in a systematic way across different specific cases. Research in related domains has also developed under other headings, at times using other conceptual frameworks, at times advancing more via theory than via empirical investigation, and at times not organized in a systematic way. As noted earlier, 'commons-based peer production' is one such category. 'The public domain' in intellectual property law is a second (Boyle 2008). 'Open innovation' (Chesbrough 2003), 'User Innovation' (von Hippel 2005), and 'Intellectual Production without Intellectual Property' ('IP without IP') (Perzanowski and Darling 2017) is a third.

To date, the fragmentation of these fields, both across disciplines (law, management, and economics, for example) and within them (copyright and patent, for example) has placed certain limits on their effectiveness from an empirical standpoint. There has been little systematic effort to identify the virtues and drawbacks of collective action in the knowledge production context from an empirical standpoint, and there has been no comprehensive intellectual framework for doing so. The knowledge commons research framework guides that effort toward systemization.

Ostrom and researchers working in her tradition collected extensive evidence of commons governance used by a wide variety of communities to manage many different types of resources, particularly natural resources, referred to collectively in this body of work as "common pool resources" (CPRs). CPRs are distinguished by the twin propositions that the resource is depletable or rival, and that it is difficult if not impossible to exclude users from consuming the resource. In CPR contexts and elsewhere, establishing and sustaining community-based governance confronts various obstacles to sharing and cooperation. Some of those obstacles derive from the nature of the resources and

others derive from other factors, such as the nature of the community or external influences. Ostrom was awarded the Nobel Prize in Economic Sciences in 2009 for her pioneering research demonstrating that self-governed communities can and often do overcome obstacles through purpose-built or constructed commons as well as emergent commons. Her co-Nobelist, Oliver Williamson, is also celebrated for his work on economic institutions, confirming that the recognition of Ostrom is noteworthy not only for her advocacy of commons governance as such but also for her contributions to the field of comparative institutional analysis.

The knowledge commons research framework draws on Ostrom's comparative institutionalism as well as on her research on natural resource commons. The empirical challenge addressed by the framework is constructing and applying a technique that accomplished three goals. One goal is to capture appropriately the range of potentially knowledge commons cases. A second goal is to respect the tradition of open and inclusive inquiry that Ostrom established. A third goal is to distinguish Ostrom's work when appropriate. Knowledge and information resources typically do not exhibit the characteristics of CPRs, for example. The fact that they are believed to exist primarily in intangible form(s) means that knowledge resources are not necessarily depletable.

Some examples illustrate the variety of institutional arrangements and resources that are governed via knowledge commons. Most obvious may be scientific and research commons, given the importance of sharing and collaboration norms within scientific communities (Merton 1973). Reichman and Uhlir (2003) examined scientific data commons, pressures on the "sharing ethos" within various scientific communities, and institutional means for reconstructing commons. Cook-Deegan and Dedeurwaerdere (2006) mapped out relationships between the structure and function of resource commons in the life sciences. Sharing the products of genomics research has been a fruitful area of knowledge commons research (Contreras 2010, 2011; Contreras and Reichman 2015). Reichman, Uhlir, and Dedeurwaerdere (2016) dive deeply into the laws, regulations, and practices governing the scientific communities that they collect under the heading 'microbial research commons.' Strandburg, Frischmann, and Madison (2017) collect qualitative case studies of knowledge commons governance in medical and public health research. Borgman (2015) synthesizes a large number of small qualitative studies of research projects relying on data sets under a commons rubric. Open source software development communities have been examined as knowledge commons (Schweik and English 2012).

Madison, Frischmann, and Strandburg (2010) discuss the following less obvious examples, some of which are discussed in the research literature mentioned above: intellectual property pools, in which owners of patents in a technological domain license their patents to a common 'pool' from which producers of complex products can obtain all of the permissions needed to make and sell goods that use the patents (Shapiro 2000; Merges 1996); Wikipedia, which offers users of this Internet encyclopedia the power to add to and edit its contents (Hoffman and Mehra 2009); wire services for journalism, which allow individual member media outlets the opportunity to publish work produced by other members; and 'jamband' fan communities, which record, share, and comment on musical performances of their favorite groups, with the permission of the artists themselves (Schultz 2006).

The primary challenge of qualitative case studies such as these has been how to approach the process of thick description of each case in a systematic way. Some of the research just described has been conducted using the knowledge commons research framework, but much of it, and in particular older research, has not. Prospectively, such a framework offers obvious virtues. A standardized yet flexible research framework permits research and data collection to proceed under a common set of assumptions and questions, even if specific research methods and disciplinary foundations may vary from researcher to researcher or field to field. In cases of knowledge and information commons, researchers in social sciences, the humanities, and multiple professional fields (law, management) are interested in knowledge commons problems. That diversity of background means that the framework should be usable by researchers in each of those fields. It also means that the framework is neither theory nor model, as an initial matter; it does not, in itself, provide a taxonomy of governance institutions or suggest specific hypotheses to be tested. (For related work categorizing such institutions that build on collective or communal self-governance, see Dusollier 2010; Van Overwalle 2009.) It is sufficiently detailed to enable data collection that supports comparative analysis and permits hypotheses to be generated, but it is not so detailed or prescriptive that researchers are guided to overlook important attributes of cases or to exclude possibly relevant fields of further research.

The knowledge commons research framework builds on the Institutional Analysis and Development (IAD) framework pioneered by Ostrom and her colleagues (Ostrom 2005). The IAD framework has been used principally to structure analysis of solutions to collective action problems in natural resource contexts (so-called action arenas, or action situations, in which commons participants resolve social dilemmas by applying formal and informal 'rules-in-use'), such as forests, fisheries, and irrigation systems. Empirical research has

largely confirmed Ostrom's hypothesis that successful commons governance involves attention to a handful of 'design principles' (Ostrom 1990, 90) that focus on clarity of the attributes of the resource, identity and membership of the relevant community, and the community's adoption and application of proportionate disciplinary rules on resource consumption.

IAD analysis is premised largely on choice-processing and oal-oriented behavior by self-interested individuals. It looks to explain sustainable collective action relative to CPRs, which produces measurable, productive results. The insight from applying the IAD framework to a large number of governance institutions and resources is that commons solutions can be as stable and robust as market-oriented solutions to classic 'tragedy of the commons' overconsumption dilemmas involving depletable natural resources. Shared governance of these CPRs by community members can lead to sustainable fisheries and forests and to regular supplies of usable water.

The knowledge commons framework differs from the IAD framework in certain key respects. First, it does not assume the agency of choice-selecting, self-interested individuals, as the IAD framework tends to do. Second, it accepts the role of historical contingency in the creation and maintenance of commons governance and of both inward-directed (selfish) and outward-directed (selfless, pro-social, or other-oriented) agents in the evolution of collective or commons institutions. Third, at the front end of the analysis, it requires understanding the contingency and human-created character of the underlying resources themselves. The resources subject to natural resource commons are largely given by biophysical processes: fish, trees, water, and the like. Natural or physical forces are variable, and human agency is often part of producing these resources, but natural resources have an unavoidable biophysical foundation. By contrast, knowledge commons research identifies resource design and creation as variables to be described and analyzed; there is no necessary biophysical substrate. As intellectual resources (that is, as forms of knowledge and information), patents, copyrights, and underlying inventions, creations, and data are shaped by a variety of institutional forces, including the state (via the design of IP systems) rather than by nature. Fourth, critically, the knowledge commons framework does not assume that the relevant resources are rival and depletable; these are not, typically, common pool resources. The knowledge commons framework generally begins by assuming precisely the contrary: that intangible information and knowledge resources are nonrival, nondepletable public goods.

Given these distinctions, for knowledge and information resources the basic social dilemma to be solved by a governance institution turns out not to be primarily a classic 'tragic commons' overconsumption problem. Instead, it is

more likely (in part) a free rider dilemma leading to an underproduction problem, in the sense that the prospect of consumption by free riders may discourage creators and inventors from producing intellectual resources, and (in part) a coordination problem, in the sense that productive use of an intellectual resource may require the participation of more than one user or consumer concurrently or sequentially. But these social dilemmas are only starting points. In applying the framework to any particular case, as the description below makes clear, care must be given to describing the authentic character of the social dilemmas present.

Against that background, the knowledge commons framework proposes to undertake comparative institutional analysis by evaluating cases of commons resources via a series of questions, or clusters of questions, to be applied in each instance. The inquiry is conducted in the spirit of Ostrom's IAD framework, with attention to contextual and ecological detail. The ecology is cultural rather than natural (Benkler 2013). Different modes of empirical research may be appropriate, depending on the availability of contemporary and historical documentary sources and living interview subjects.

The case study investigation begins with a general overview description of the history and character of the problem or problems addressed by governance in the specific case or context. One begins, in short, with a summary of the social dilemma posed by the knowledge or information resource. This may be an explanation that is internal to the governed institution(s), in the sense that problems and explanations may emerge from stories told by participants, either today or historically, or both. Or, it may be an explanation that is external to the governed institution, such as the public goods story of the rise of IP law in general and/or with respect to specific markets (copyright for books) or technologies (patents for mechanical devices).

The researcher should ask whether the relevant resource or case is characterized from the outset by patent rights or other proprietary rights, as in the case of a patent pool, or by a legal regime of formal or informal openness, as in the case of public domain data or information collected in a government archive. In other words, one should consider the extent to which a social dilemma might be addressed in part by IP rights. Producing socially valuable inventions in the university setting may entail permitting university researchers to obtain patents. Alternatively, the presence of IP rights might create or exacerbate a social dilemma involving a knowledge resource. In that sense, collaborative open source production of computer programs is complicated by the fact that each programmer receives a copyright in their separate contribution. A particular regime might involve sharing data and information,

or sharing rights in information, or sharing both. The character of the commons solution might involve coordinating holders of different IP interests or holders of different public domain knowledge resources, for example. In many respects, this cluster of queries parallels that investigation of the biophysical attributes of the natural resource that is the first part of examining a common pool resource in the natural environment.

Answering that question sets a baseline against which a commons governance regime has been constructed. Within that regime, one next asks more specific definitional questions. First, what is the relevant resource and subsidiary resource units, taking into account both intangible and tangible resources and their individual or social character? Knowledge and information resources are presumptively intangible, but it is possible that their production and use depends significantly on related material resources. What are the relationships among these resources? What is the baseline with respect to what is characterized as a resource in a given setting, and what modifications are made by any relevant legal regime? For example, what a scientist considers to be an invention, what patent law considers to be an invention, and the boundaries of the patent itself are three related but distinct things, managed by different communities. Second, what are the boundaries and constitution (membership) of the community or communities that manage access to and use of those resources? How is membership acquired? This may be informal, formal, or a blend of the two. How is membership and participation governed? What is good behavior within the group, what is bad behavior, who polices that boundary, and how?

Next are questions concerning explicit and implicit goals and objectives of commons governance, if any such goals and objectives exist. It is possible that commons governance regimes emerge from historical contingency rather than via planning, and it is possible that commons governance lacks an explicit account of the goals of governance via modes of knowledge sharing. It is also possible that goals and objectives may change over time. Is there a particular resource development or management dilemma or collection of dilemmas that commons governance is intended to address, and what commons strategies have been used to address those dilemmas?

How "open" are the knowledge and information resources and the community of participants that create, use, and manage them? The details of the relevant aspects of "openness" should be specified, along with their contributions to the effectiveness of commons. Some commons and commons resources have precise and fixed definitions of both resources and community

membership. Either resources or membership or both may be more fluid, with boundaries defined by flexible standards rather than by rules.

A large and critical cluster of questions concerns the dynamics of commons governance. Following Ostrom, the knowledge commons research framework refers to these as the "rules-in-use" of commons: the interactions of commons participants and resources, implementing and adapting both formal and informal rules. Included in this cluster of questions are: (1) details of stories of the origins, histories, and operations of commons; (2) formal and informal (norm-based) rules and practices regarding distribution and coordination of commons resources among participants, including rules for appropriation and replenishment of commons resources; (3) the institutional setting(s), including the character of the regime's possibly being "nested" in larger scale institutions and being dependent on other, adjacent institutions; (4) relevant legal regimes, including but not limited to IP law; (5) the structure of interactions between commons resources and participants and institutions adjacent to and outside the regime; and (6) dispute resolution and other disciplinary mechanisms by which commons rules, norms, and participants are policed.

Ostrom's IAD framework directs attention to the action arena in which commons participants interact via the rules-in-use. The framework also directs attention to the significance of polycentricity, in which resource governance is exercised concurrently by multiple communities with overlapping and/or interlocking spheres of responsibility. Researchers using the knowledge commons research framework should be alert to the possible existence of multiple action arenas in Ostrom's sense in addition to the presence of polycentric governance arrangements, including the fact that smaller commons governance institutions may be 'nested' within larger governance institutions. The knowledge commons research framework does not emphasize the dynamics of single or concentrated action arenas to the same extent that the IAD framework may be understood to do.

In principle, at this point it becomes possible to identify and assess outcomes. In the IAD framework, outcomes are typically assessed in terms of the resources themselves. Has a fishery been managed in a way that sustains fish stocks over time? Do commons participants, such as the members of a fishing community, earn returns in the commons context that match or exceed returns from participation in an alternative governance context? In knowledge commons, resource-based outcome measures may be difficult to identify and assess. Sustaining the resources and their uses, individually or in combination, may be the point. In a patent pool, pooled resources may constitute components of larger, complex products that could not be produced but for the pooling

arrangement that reduces transactions costs among participants. Outcomes take different forms. It may be the case that patterns of participant interaction constitute relevant outcomes as well as relevant inputs. Sustaining the community itself, via its relationship to particular resources, may be the point of knowledge commons governance. Agency, in a manner of speaking, may be less important than identity; the group and its participants, in a particular institutional setting, may be ends as well as means (Kelty 2008). In addition, different levels and types of interaction and combination matter. Participant interaction in the context of a shared resource pool or group may give rise to (or preserve, or modify) an industrial field or a technical discipline. In that specific case, such spillovers may be treated as relevant outcomes.

Having identified relevant outcomes, it is important to look back at the social dilemma(s) that defined knowledge commons governance in the first place. Has the regime solved those problems, and if not, then what gaps remain? How do the outcomes produced by commons governance differ from outcomes that might have been available if alternative governance had been employed? Has commons governance created costs or risks that should give policy makers and/or institution designers pause? Costs of administration might be needlessly high; costs of participation might be high. A collection of industrial firms that pool related patents in order to produce complex products may engage in anticompetitive, collusive behavior. Commons governance may facilitate innovation; it may also facilitate stagnation. If commons governance appears to lead to negative outcomes or problems, researchers should consider re-examining their diagnosis of the social dilemmas associated with the resource. It is possible that negative outcomes produced by a commons solution to one social dilemma are, instead, productive outcomes produced by a different social dilemma associated with the same resource. Or it is possible that commons governance is less productive or socially beneficial than alternative resource management schemes. Systems of exclusive IP rights and schemes that depend on state participation in the supply or management of knowledge resources may be superior to commons governance or may be coordinated effectively with commons. Governance is not necessarily an either/or proposition.

The foregoing summary of the knowledge commons research framework may be presented in bullet-point form as follows:

Background Environment

- *What is the background context (legal, cultural, etc.) of this particular commons?*

- *What is the "default" status, in that background context, of the sorts of resources involved in the commons (patented, copyrighted, open, or other)?*

Attributes

Resources

- *What resources are pooled and how are they created or obtained?*
- *What are the characteristics of the resources? Are they rival or non-rival, tangible or intangible? Is there shared infrastructure?*
- *What technologies and skills are needed to create, obtain, maintain, and use the resources?*

Community Members

- *Who are the community members and what are their roles?*
- *What are the degree and nature of openness with respect to each type of community member and the general public?*

Goals and Objectives

- *What are the goals and objectives of the commons and its members, including obstacles or dilemmas to be overcome?*
- *What are the history and narrative of the commons?*

Governance

- *What are the relevant action arenas and how do they relate to the goals and objective of the commons and the relationships among various types of participants and with the general public?*
- *What are the governance mechanisms (e.g., membership rules, resource contribution or extraction standards and requirements, conflict resolution mechanisms, sanctions for rule violation)?*
- *Who are the decision makers and how are they selected?*
- *What are the institutions and technological infrastructures that structure and govern decision making?*
- *What informal norms govern the commons?*
- *How do nonmembers interact with the commons? What institutions govern those interactions?*
- *What legal structures (e.g., intellectual property, subsidies, contract, licensing, tax, antitrust) apply?*

Patterns and Outcomes

- *What benefits are delivered to members and to others (e.g., innovations and creative output, production, sharing, and dissemination to a broader audience, and social interactions that emerge from the commons)?*

- *What costs and risks are associated with the commons, including any negative externalities?*

(Adapted from Frischmann, Madison, and Strandburg 2014)

IV. Results and Implications

Knowledge commons case studies conducted so far consist primarily though not exclusively of those collected in Frischmann, Madison, and Strandburg (2014) and Strandburg, Frischmann, and Madison (2017). The subject matter of those case studies is both broad and diverse, extending from the production of modern free and open source software (Schweik 2014) to the early technological development of powered flight during the 19th century (Meyer 2014), and from citizen science groups in contemporary astrophysics (Madison 2014) to peer production of online visual content (Morell 2014). The entirety of Strandburg, Frischmann, and Madison (2017) is directed to knowledge commons case studies in these collections are directed to research in medicine and public health, building on the example documented in Strandburg, Frischmann, and Cui (2014). Taken as a group, the studies collected in those two volumes suggest a number of promising but provisional research results with respect to the eventual goal of producing a more or less comprehensive understanding of the mechanisms for effective or successful and less effective or unsuccessful knowledge commons. Those results include the following:

Research counsels an expansive view of the problems to be solved by governance institutions. Knowledge commons may confront diverse obstacles or social dilemmas, many of which are not well described or reducible to a tragedy of the commons, to a free rider dilemma, or to some other generic collective action problem. Close analysis of relevant obstacles tends to suggest multiple social dilemmas that create demand for governance institutions. Strandburg, Frischmann, and Cui (2014), in a case study of a medical research consortium housed in the Rare Diseases Clinical Research Network, describe multiple dilemmas addressed by governance of a shared knowledge resource. In that case, the resource consisted of the research results of medical research on diseases that affect small patient populations. The results of that case suggest the importance of casting a wide net in general. Relevant social dilemmas may include:

(i) in the case of scientific research, dilemmas attributable to the nature of the research and/or the research problem. Researchers and their subjects may be few in number and/or widely distributed, other research inputs such as funding and time may be scarce or, in the case of large datasets, unmanageable via traditional analysis conducted by human beings.

(ii) dilemmas attributable to the need to coordinate knowledge sharing among multiple constituencies and stakeholders that collaborate with respect to creation and management of the resource. With respect to scientific research, interests to be accounted for include researchers, their subjects, funders, commercial partners, and the public.

(iii) dilemmas arising from the need to manage rivalrous or depletable resources that are necessary inputs into production and use of the shared knowledge resources. These may include funding, time, and labor; and

(iv) dilemmas arising from (or mitigated by) the broader systems within which a knowledge commons institution is situated or nested. For example, knowledge production in the modern research university is situated in the broader context of knowledge production to serve the interests of society at large. Commons approaches and reliance on formal IP systems offer different modes of governance that may complement each other or that may conflict.

Relationships among governance systems are critical. Researchers should be alert to potentially complex relationships between knowledge commons and the systems within which they operate and/or are nested. The knowledge commons framework suggests a focus on the background legal rights associated with commons resources. Those legal rights may influence the shape of commons governance and/or interact with other framework inquiries in diverse ways. In some cases, the background contexts (that is, the presence or absence of formal IP rights) seem to act as external constraints on commons governance much as biophysical characteristics of the resource do in the natural resource context. In others, background contexts shape participants' goals and objectives, participants' roles, and action arenas in diverse and dynamic ways. For example, knowledge commons and market-based institutions (or institutions for knowledge production based on different hierarchies or histories, such as government, or the military) may operate as complements, as stages in the evolution of a product or technology, or in opposition to each other.

Shared infrastructure may play a key role. Shared infrastructure appears to be often central to the success of knowledge commons institutions. In some cases, technical or technological infrastructures (such as technology platforms, databases, and bibliographies) may substitute for formal rule-based governance and discipline, easing, though perhaps also obfuscating, decision making processes. Organizational infrastructures, such as shared coordination mechanisms (task forces, steering committees, technical standards and the like), may lower the costs of participation, collaboration, and research among commons participants. Ownership and/or control of infrastructure or platforms that support knowledge commons may have significant impact on knowledge commons governance. The state itself may supply important infrastructural

resources for knowledge commons, consisting of funding processes, regulatory processes, or coordination institutions.

Informal governance institutions, and especially trusted leadership and shared normative framing, contributes a great deal. Informal or 'social' governance, especially involving trusted leaders or decision makers, complements and at times may substitute for formal or public disciplinary institutions in many knowledge commons cases. Reliance on informal governance may grow out of relationships or norms predating the emergence of commons governance, such as norms among scientific researchers, or norms of university-based researchers and teachers, and it may evolve further, toward greater formality. A close relationship may exist between informal governance mechanisms and the need to tailor governance to the needs of small and/or local commons communities. Notwithstanding the frequent characterization of commons governance as a mode of community self-governance or collective action, knowledge commons researchers should be alert for the roles and impacts of social hierarchies on commons.

Commons governance often evolves over time, and commons may play an especially important role in the early stages of some industries and technologies. Commons governance may evolve as the number of participants grows or as innovation affects the nature of the shared knowledge or the balance between competition and cooperation within the community. The pattern of evolution may not necessarily follow a path from more informal to more formal governance mechanisms. Smaller or larger-scale feedback loops between smaller-scale governance institutions and larger-scale systems may be implicated.

Knowledge commons governance does not necessarily depend on one strong type or source of individual motivations for cooperation. Knowledge commons entail cooperation in the building, sharing, and preservation of knowledge resources, but the reasons individuals cooperate in particular knowledge commons may vary. Different individuals cooperate for different reasons, and sometimes a single individual had multiple motivations for cooperating. Motivations may be partly intrinsic and partly extrinsic, or social. Participants may have both competitive and cooperative motives, and the balance between the two may vary between individuals or change over time, depending in part on participants' overlapping roles as creators, maintainers, and/or users of shared knowledge resources. This variety of motives seems to be partially responsible for the variety of social dilemmas that arise in governing knowledge commons.

V. Conclusion

The knowledge commons research framework is intended to be an evolving research tool, and may be improved with use over time. The framework may be refined, or its application improved, or both, via considering the following perspectives. These are necessarily preliminary directions for future research, given the relative youth of this field of research.

First, the knowledge commons research framework may be applied usefully to some institutions that are not core or conventional examples of 'knowledge commons.' Researchers may cast a wide net in defining proper subjects for study. Because the framework is primarily methodological rather than normative, it has proved useful to date in guiding study of a broad range of cases, some that were closer to what many researchers would identify as 'typical' institutionalized knowledge sharing regimes (such as scientific research consortia) and others that may seem, at first glance, to be unusual subjects for a study of knowledge commons. One notable example considers law-making processes as knowledge commons (Daniels and Hudson 2015).

Second, researchers using the framework should take a broad approach to identifying relevant resources and participants. The framework helps researchers to avoid tunnel vision in identifying relevant resources and participants merely by prompting researchers to ask explicitly "What are the resources?" and "Who are the participants?" Research to date includes case studies that report on a broader range of resources and participants than one might associate with a typical (or stereotypical) knowledge commons.

Third, researchers should account explicitly for evolution of knowledge commons governance over time. It is to be expected that knowledge commons should change over time as resources, communities of participants, and relevant formal and informal rules evolve through the decisions and actions of actors in various action arenas. Research to date suggests a broader question about how the character and stability of some knowledge commons may be affected by changing interactions with the background environment or changes in the knowledge resources themselves.

Fourth, researchers may vary the sequence in which clusters of research questions are asked, and may focus from the beginning on goals and objectives and identifying action arenas. The basic summary of the knowledge commons research framework does not fully anticipate the potential complexity in identifying resource attributes and defining action arenas for knowledge commons. In the natural resource context, the primary operational action arena

for a commons regime generally is the use of a specified natural resource by a community defined by geographic proximity. (Other action arenas operate at a rule-making or governance level.) Because knowledge resources are intangible and often are created by a self-selected group of commons participants, knowledge commons often form around particular goals and objectives rather than around preexisting resources tied to particular communities or particular geographies. When that is the case, several primary action arenas may exist at the operational level, and the most important action arenas may not be immediately evident at the outset of research. To analyze a knowledge commons regime it may be most sound analytically to begin with goals and objectives, rather than resources, then to identify action arenas related to those goals and objectives, and then to identify resources, participants, rules, and so forth associated with each action arena. In practice, use of the framework is likely to be an iterative process, in which collecting data about particular knowledge resources may lead to the identification of additional goals and objectives, which may lead to the identification of additional participants or additional shared resources and so on.

Fifth, the framework anticipates identifying multiple social dilemmas. Knowledge commons governance responds to a wide variety of social dilemmas in addition to traditional tragic commons or free rider problems. To analyze an action arena, it is helpful to identify the social dilemmas faced by participants. To understand the social dilemmas faced by a group of commons participants, it is also useful to study their motivations, especially since a theme that frequently appears in the case studies documented so far is diversity of participant motivation.

Sixth, research results so far suggest the importance of highlighting shared infrastructure, as an attribute of knowledge commons that is not otherwise prioritized in the framework in its basic form. Future case studies may focus specifically on identifying infrastructural resources created or used by the commons institution. In some cases, such as open source software, it will be important to include infrastructural constraints in the analysis of an action arena's 'rules-in-use' in order to get a complete picture of commons governance.

Seventh, both nonrivalrous and rivalrous resources should be included and described. Although the study of knowledge commons focuses on the sharing of intangible, nonrivalrous resources, it is important to identify any rivalrous resources that are important to a particular action arena. Social dilemmas for knowledge commons governance can and do arise from competition or conflict over the allocation of scarce or rivalrous resources.

Eighth and finally, because of the potential multiplicity of communities, social dilemmas, and action arenas, boundary management concerns are important topics of study. Knowledge commons may have different types and degrees of "openness." In particular, because knowledge resources are nonrivalrous, knowledge commons likely must deal with multiple constituencies, including users, creators, managers, curators, and subjects of the knowledge resources. These different constituencies may make different and sometimes conflicting demands on commons resources. It is important when identifying goals and objectives and action arenas to be aware of the possibility that important action arenas may be devoted to managing overlaps among these interests and boundary conflicts among different participants.

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