

A framework for analysing the microbiological commons

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The plant-patent business is taking right hold, apparently. We know a man who received a birthday present of a nice little azalea. Tied around the azalea's stem, like a chastity belt, was a metal tag from Bobbink and Atkins, reading, "Asexual reproduction of this plant is illegal under the Plant Patent Act". It was Number 147. Our friend, a man of loose personal habits, ripped the tag off angrily, fed it to his dachshund puppy and sent the plant to a friend in Connecticut with instructions to bed it down warmly next to an old buck hydrangea. From *The New Yorker*, 1936 (White 1990)

Ever since God warned Eve to resist the apple, authorities have tried to control information flows. And ever since Eve took that first bite, pioneers have resisted these controls and tried to find ways around them. (Spar 2001, p. 9)

The adaptation of the "commons" to the realm of knowledge and information is a relatively recent phenomenon.¹ Prior to the mid-1990s, the commons referred almost exclusively to shared land and other types of natural resources (Hess 2000). The commons conveys the notion of shared ownership, participation, and responsibility. Where the term "commons" has recently arisen, as with scientific information and the intellectual public domain, it is a rallying cry to protect and sustain free access.

The first workshop devoted exclusively to the microbiological commons (MC) was held in Brussels in 2005 on the theme "Exploring and exploiting microbiological commons: contributions of bio-informatics and intellectual property rights

in sharing biological information". It is very useful in defining the microbiological commons. One can immediately see that the MC is interdisciplinary (combining microbiology, information technology, law, and economics); that it requires further study; that it has possible benefits, and that it has a social and even a moral component. In their background paper for the workshop, coordinators Dedeurwaerdere and Dawyndt (this issue) point to the crucial importance of

scientific data sharing on the interaction of complex social processes in which participants have multiple interests, pressures, and motivations.

Geneticist Gary Zweiger has observed that as recently as 15 years ago "most biologists had little use for computers other than to compare DNA sequences and communicate with each other over the network that later evolved into the Internet" (Zweiger

2001, p. x). Today there has been a radical transformation of *biology* into an *information science* (p. xi).

As information scientists, biologists concern themselves with the messages that sustain life, such as the intricate series of signals that tell a fertilized egg to develop into a full-grown organism, or the orchestrated response the immune system makes to an invading pathogen. Molecules convey information and it is their messages that are of paramount importance.

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By transducing the genome – transferring its information content into an electronic format – Zweigler cautions that “we acquire greater responsibilities, becoming stewards of our own genome” (2001, p. xv). And, we might add, we acquire greater responsibilities as stewards and *preservers* of genomic, indeed, all scientific information.

The MC encompasses micro-organisms as physical objects (resources), the scientific study, the knowledge products, and the human and social capital required to generate that knowledge. The success of freely sharing microbiological data requires an intricate blend of technology, scientific content, metadata and technical standards, open source software packages, negotiated and respected intellectual property rights agreements, sustainability and preservation design mechanisms, evolving rules and institutions, surety from theft, infiltration and terrorism and, ultimately, a firm commitment on the part of providers and users to the common good.

In this article we contribute to this new research agenda by presenting an analytical tool to help better understand this new type of commons. We also argue the critical importance of collective action in the success and ultimate sustainability of this commons. The complexity of the issues is enormous for many reasons: the vast number of players, multiple conflicting interests, rapid changes of technology, the general lack of understanding of digital technologies, local *vs* global arenas, and a chronic lack of precision about the information resource at hand. In order to bring greater clarity to this complex commons, we apply the institutional analysis and development (IAD) framework as an exploratory tool. Applying this framework, we will illustrate that collective action and new institutional design play as large a part in the shaping of scholarly information as do legal restrictions and market forces.

Natural resource commons, such as forests, fisheries, and irrigation systems, have a large body of international, interdisciplinary literature (Hess 2006). Curiously, most of the literature on the knowledge and scientific commons that has been written over the past 10 years is not so much an outgrowth of the traditional commons literature. Rather, the knowledge and scientific commons and its

literature have arisen in direct response to observable enclosure of information and corresponding collective-action initiatives. We refer to the concurrence of these two trends as “duelling revolutions” – two forceful, worldwide movements leading toward opposite or conflicting outcomes. One of the trends is a movement toward enclosure and privatisation of scientific information. The other is a movement toward greater access and exchange of information. Both of these revolutions have been brought on by globalisation and the unprecedented capacities of information technology.

The intellectual history of enclosure of the commons dates back to the European enclosure movements from roughly the fifteenth to the nineteenth centuries. Commons were shared agricultural fields, grazing lands, and forests that were, over a period of 500 years, enclosed. Communal rights to them were withdrawn by landowners and the state. The narrative of enclosure is one of privatisation, the *haves vs* the *have-nots*, the *elite vs* the *masses*. This is the story of Boyle’s (2003) second enclosure movement with the enclosure of the “intangible commons of the mind”, through rapidly expanding intellectual property rights. The occurrence of enclosure is an important rallying cry on the part of legal scholars, librarians, scientists, and anyone who is alert to the increasing occurrence of privatisation, commodification, and withdrawal of information that used to be accessible, or that will never be available in our lifetimes.

New types of enclosures are often caused, in part, by the ability of new technologies to capture resources that were previously unowned, unmanaged, and thus, unprotected. This is the case with outer space, the electromagnetic spectrum, and, of course, with digital information. The capturability of previously uncapturable public goods is what transforms them from public goods into commons.

The case of distributed digital technologies is particularly complex and problematic as many stakeholders seek to renegotiate their interests in the new digital environment. The enclosure of scientific information is occurring at breakneck speed. Much of it has been brought on by corporate and private interests that have influenced the rapid increase of intellectual property rights legislation that diminishes the public

domain and accelerates the number of patents in science. Copyright terms have been extended and the definition of what is patentable has been widened. The time-honoured tradition of open science is crumbling with the increasing corporatisation of higher education, where university-corporate partnerships seek private revenue from publicly funded research. But the enclosure of scientific information that once was freely available has other causes: from governments' removing information and online resources to the simple lack of preservation of databases and websites.

The antithetical trend of building free and open access (OA) to scientific information has been accomplished primarily through collective-action initiatives. Collective action is action taken by a group for the purpose of attaining some shared goal or objective. It requires cooperation and if sustained over time, it usually includes rules: decision-making structures and some kinds of monitoring and sanctioning mechanisms.

The traditional commons literature is rife with studies on the problems of collective action and social dilemmas, such as the Prisoner's Dilemma, free riding, poaching, polluting, and general non-cooperation. It is therefore quite interesting to see the varieties of successful types of collective action that have arisen in the relatively new arena of the knowledge commons: Free/Open Source Software (FOSS) movement, the Open Archives Initiative, the Berlin Declaration, and the OA movement are familiar examples.

This trend of unfencing and opening up access to information is rooted in the concept of commons as shared spaces, free speech and the democratic process, as with the US New England town commons. This is the narrative of Benkler's commons-based production, where cooperation is achieved through "social mechanisms other than price signals or managerial directions. Large-scale instances of such cooperation are 'peer production'" (Benkler 2004, p. 1110). This trend utilises inter-operability, open science, collaboratories and scholarly networks, voluntary associations and collective action for the common good.

Defining the commons

Commons is a general term that refers to a resource that is shared by a group of people. In a

commons, the resource can be at the local level, such as the workplace water cooler or a town's pavements and playgrounds, where the community of users are limited and usually identified. Commons can also exist on regional, national, and global levels, such as regional and national highways, deep-sea oceans, the atmosphere, the Internet, and scientific knowledge. In extremely large commons, the user community is diverse and unidentified. The commons can be well-bounded (community forests, irrigation systems, libraries); transboundary (Zambezi River, migrating wildlife, the electromagnetic spectrum); or without clear boundaries (knowledge, the ozone layer).

Much of the traditional, natural-resource commons literature is focused on commons as a property regime or as an economic good. Common property is a formal or informal regime and, as shared property, it is distinct from private, public, and other forms of property. Common-pool resources (CPRs) are economic goods that are subtractable or rivalrous and are difficult to exclude others from use. These characteristics distinguish CPRs from private, public, and club goods, as illustrated in Table 1.

Natural resource commons usually tend to be rivalrous while knowledge has traditionally been fairly non-rivalrous. The unifying thread in all commons is that the resource is jointly used and managed by groups of varying sizes and interests. Core to all commons are issues of collective action, efficiency, equity, and sustainability.

Participation in the knowledge and MC commons requires increased responsibilities upon all members: greater understanding of the resource, better communication, evolving

TABLE 1. Types of goods

		Subtractability	
		Low	High
Exclusion	Difficult	<i>Public Goods</i> Sunset Common knowledge	<i>Common-Pool Resources</i> Irrigation systems Libraries
	Easy	<i>Toll or Club Goods</i> Day-care centres Country clubs	<i>Private Goods</i> Doughnuts Personal computers

rules and norms, greater security and effective monitoring and sanctioning in order to protect, sustain, and preserve the resources.

In Hess and Ostrom (2003), we examine the role of collective action in countering trends of enclosure and privatisation of the intellectual public domain. We give examples of authors writing their own copyright agreements, negotiating with their publishers and self-publishing their articles and papers. The OA movement is a clear example of individuals and communities of authors working outside traditional legal and economic constraints in order to build new systems and networks. OA means “immediate, permanent, free online access to the full text of all refereed research journal articles” (Harnad 2005). It is a dynamic example of collective action working effectively to build a global knowledge commons. In the same article we try to develop some insights on collective-action initiatives that have developed along with new information technologies, legislation, markets, and practices.

Social dilemmas

What we have learned from the traditional commons research is that it is characteristic of all of the phenomena broadly linked under the term “the commons” that multiple users are in some way sharing a resource. Whenever multiple individuals share a resource, potential problems exist. Enormous energy and work must be devoted to producing and effectively managing any resource. Since a group of individuals will benefit, there can be incentives to free ride on the production process or to carelessly generate pollution. Free riding occurs when one person seeks their self-interest at the expense of others by not contributing to a joint effort when the person will benefit from the contributions of

others. Free riding occurs in a variety of ways including not contributing to the production and provision process at all, contributing only a little, or finding ways of grabbing products-in-process in such a way that one can privatise them for one’s own benefit in the long run. While free riding is borrowed from the economics literature, the fairly synonymous term “social loafing” is frequently used by sociologists and other social scientists to describe online behaviour.

Ownership

As a commons or a common-pool resource, different parts of the MC may be owned by national, regional, or local governments; by communal groups; by private individuals or corporations; or used as OA resources by whomever can gain access. Each of the broad types of property regimes has different sets of advantages and disadvantages, but at times may rely upon similar bundles of operational rules. Examples exist of both successful and unsuccessful efforts by governments, communal groups, cooperatives, voluntary associations, and private individuals or firms to govern and manage common-pool resources. Thus, no automatic association exists between common-pool resources and common-property regimes – or any other particular type of property regime.

The list of seven bundles of rights shown in Table 2 is open to further examination. We suspect there could be many more types of ownership arrangements with digital information.

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A colleague once wrote, “public problems, like all genuine problems, are surrounded by

TABLE 2. Bundles of rights

Access	The right to enter a defined physical area and enjoy non-subtractive benefits.
Contribution	The right to contribute to the content.
Extraction	The right to obtain resource units or products of a resource system.
Removal	The right to remove one’s artifacts from the resource.
Management/participation	The right to regulate internal use patterns and transform the resource by making improvements.
Exclusion	The right to determine who will have access, contribution, extraction, and removal rights and how those rights may be transferred.
Alienation	The right to sell or lease management and exclusion rights.

confusion” (Oakerson 1978, p. 50). The two main resources required for problem solving, he continued, are theory and information. Scholars associated with the Workshop in Political Theory and Policy Analysis at Indiana University have found that employing a framework helps to organise analytical and prescriptive inquiry (Gibson 2005, p. 229; Imperial and Yandle 2005). The IAD framework (see Fig. 1) has been used for over three decades as the general theoretical structure that scholars have used to study a diversity of human-physical world relationships.

One can think of the IAD framework as scaffolding that holds a universal set of intellectual building blocks. This analytical tool can be used to investigate any broad subject where humans repeatedly interact so that rules and norms guide their choice of strategies and behaviour. It is quite adaptable and has been used in hundreds of disparate subjects, such as understanding how best to restore the Great Lakes (Sproule-Jones 1999); monitoring fishery management (Rudd 2004); analysing environmental governance (Myint 2005); modelling operational decision making in public organisa-

tions (Heikkila and Isett 2004) and studying the interactions of local irrigation systems (Lam 2001). The scaffolding orients the analyst to ask particular questions about a nested set of variables that frequently helps one to dig into a problem and identify why a particular distribution of interactions and outcomes is generated. As such, the framework helps to more clearly manifest human-technology-resource relationships and reveal how decisions and behaviour lead to outcomes. Its foundations are drawn from the field of political economy, where understanding the effects of rules and decisions on performance is critical. A methodology such as the IAD framework can help better understand knowledge gaps as well as the governance issues.

Institutional analysis looks at the artisanship-artifact relationships. Policy analyst Vincent Ostrom has often likened this type of analysis to the process of breadmaking where a baker (the artisan) applies decisions and methods in the mixing, kneading, rising, and baking (artisanship) in order to produce a loaf of bread (the artifact). The complexity of the coordination, actions, and decisions increases

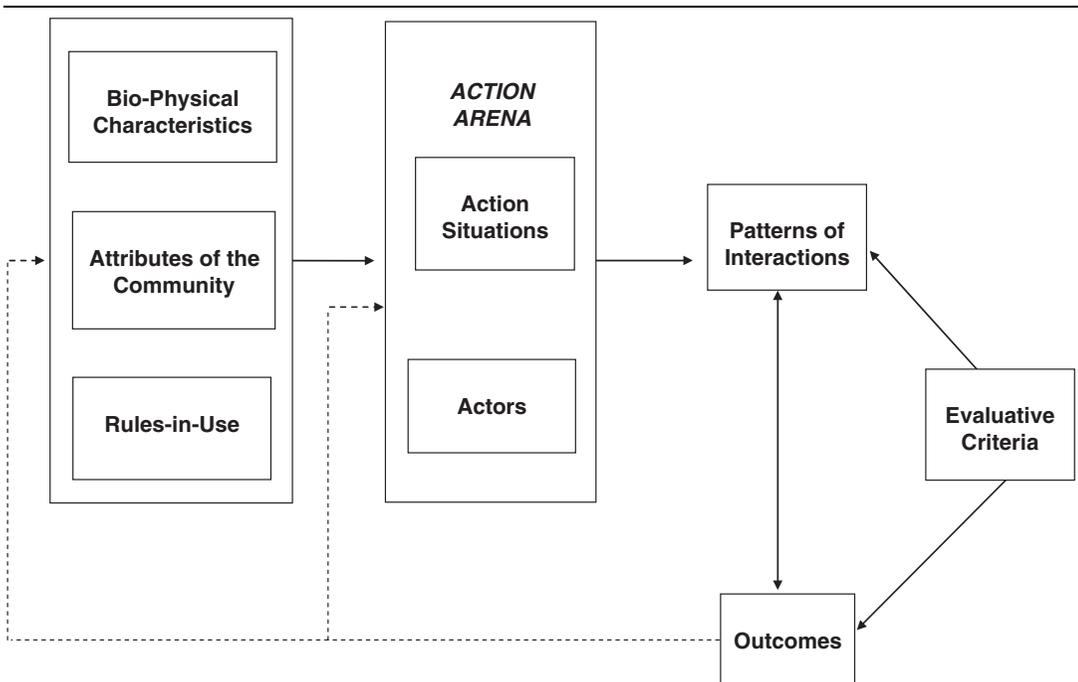


FIGURE 1. Institutional analysis and development (IAD) framework

dramatically when the loaf of bread is being produced by a large bakery rather than a lone baker. In adapting the IAD framework to the microbiological commons, we will start at the large bakery level and scale up from there, although individual behaviours do matter. For this analysis, we apply the framework to the digital (*in silico*) material that is shared in the global microbiological commons, not the biological material that has different rules and levels of complexity.

The physical and institutional characteristics

The left side of the framework in Fig. 1 focuses on the physical and institutional aspects of the resource. The physical characteristics include the material conditions of the commons, the attributes of the community and the formal and informal rules-in-use. These variables on the left of the framework are exogenous factors in the analysis.

Physical characteristics: ideas, artifacts, and facilities

With the distributed nature of digital information, the complexity of the physical characteristics may be daunting. With many natural resources, the physical characteristics can remain constant until the introduction of new technologies (one need only think of the impact of chainsaws on forest ecology). Starting with conversion of data to zeros and ones and packet switching with TCP/IP in the 1960s, the physical characteristics of the artifacts holding knowledge were changed dramatically. The introduction of interoperable, distributed data also radically changed the community of users from an elite group of scientists to a global, heterogeneous group from all strata of society.

In traditional commons research, scholars have found it helpful distinguishing between the *resource system* and *resource units*. In groundwater, for instance, the groundwater basin is the *facility*, while the shared portion of the water is the *flow*. The complex nature of knowledge as a commons requires a threefold distinction because it is made up of both human and non-human materials (Hess and Ostrom 2003). The “physical” characteristics of the knowledge

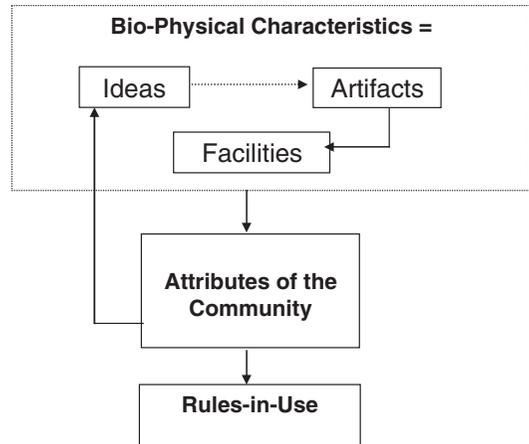


FIGURE 2. The bio-physical characteristics

commons are ideas, artifacts, and facilities (see Fig. 2).

Ideas are coherent thoughts, mental images, creative visions, and innovative information. Ideas are the intangible content and the non-physical flow units contained in artifacts. There are certain idea-types such as mathematical formulae, scientific principles, grammar, names, words, numbers, and facts that are not protected by copyright and are considered to be in the public domain (Samuelson 2003, p. 151). Ideas in digital form, however, do not have the same protections as they did in the pre-digital world (Samuelson 2003, p. 164). The most notable characteristic of an idea is that it is a pure public good and, therefore, non-rivalrous. One person's use of it does not subtract from another's. Traditionally, ideas are part of the public domain.

Artifacts are discrete, observable, nameable representations of ideas, such as articles, research notes, books, databases, maps, computer files, and web pages. To use the term from copyright law, they are the expressions of the ideas. Traditional knowledge artifacts (such as books and journals) are rivalrous. Digital artifacts can often be used concurrently by multiple users. Artifacts are the physical flow units of a facility. Artifacts are the expressions of the ideas presented in a myriad number of formats, from the traditional paper, binding, microfilm, video, and so on to state-of-the-art computer graphics, text files, holograms, MIDI files, searchable databases, and so forth.



Children pass by a stall with booklets about generally modified organisms at the World Social Forum held in Bamako in January 2006. AFP/Jean-Philippe Ksiazek

Facilities store artifacts and make them available. Traditional facilities have been libraries and archives containing books, journals, papers, and other knowledge artifacts. These facilities had physical limits. The physical network infrastructure includes the optical fibre, copper wire switches, routers, host computers, and end-user workstations (Bernbom 2000). It also includes the amount of bandwidth, free space optics, and wireless systems. The new technologies that have made electronic, distributed information possible are also a part of the evolving physical conditions of the knowledge commons.

Seen from one perspective, a taxonomic database, for instance, would logically be an artifact of ideas, data, and metadata. Seen as an integrated entity, the same database could be considered a facility. Nevertheless, there is a challenge in understanding the physical characteristics of scientific data in order to begin integrating it. Computer scientist Joe Futrelle (2001) talks about scientific data exploding in

terms of resolution, complexity, heterogeneity, and volume. Gerstein and Junker describe the gradual blurring of boundaries between scientific texts and biological databases:

complex scientific data sets will become tightly integrated and entwined with the literature, with the interface to publications moving away from simple keyword search models to one reflecting the structure of biological information itself. People will increasingly browse databases arranged around chromosomal location, biochemical pathways and structural interactions that are linked to relevant articles, or parts of articles such as individual paragraphs, tables or figures. One might 'fly through' a large three-dimensional molecular structure, such as the ribosome, where various surface patches would be linked to publications describing associated chemical binding studies. (Gerstein and Junker 2001)

Identifying the bio-physical characteristics should be one of the first tasks in analysing the MC. One must identify and clarify the nature of the resource. This elementary step is often

overlooked in the knowledge/scientific commons literature. Authors frequently write about the Internet as a commons. The Internet, the worldwide network of inter-operable computer networks, however, can be many commons: the computer infrastructure and protocols can be thought of as a commons; chat rooms, discussion groups and listservs are types of social commons; the information content can be a commons; institutional repositories are types of commons; and even university budgets for information technology can be viewed as a commons. These and other disparate aspects of the Internet can be considered commons when they are shared resources that require stewardship by a group.

It is important to remember that all knowledge and all information – whether hard copy or digital – is a human artifact, with agreements and rules strongly tied to the rules of language itself.² Thus, knowledge has an important cultural component as well as intellectual, economic, and political functions. As such, it is a flow resource that must be passed from one individual to another to have any public value. The artifacts and facilities function as the conduits of expressed ideas that serve to replenish the creation of new ideas. The MC content will be shaped by the scope of the subject. The basic characteristics can be summarised as text documents (ideas/artifacts), primary data (artifacts), software (facilities), and (biological resource) centres/laboratories/libraries (facilities). There are literally thousands of microbiological collections.

Attributes of the community

Who exactly shares this resource? One way to identify the community is to look behind who is doing the data production, data management, and data processing (Desmeth and Dedeurwaerdere 2005) as well as who is participating in data sharing (Dedeurwaerdere, this issue). The MC community would be an international epistemic group composed primarily of scientists, teachers, technologists, and information specialists. The production, management, and processing communities would be *nested* at various levels within this global commons.

Whether the values of a community are shared or divided substantially affects the

strategies adopted within action arenas and the resulting patterns of interactions. Formerly, academics were unified in their quest for the creation and production of new knowledge, even if divided by discipline. Today, there are conflicting values within the academy. This is also an era of rapid change in the values pursued by individuals who participate in the knowledge arena. In an earlier and slower world, the community using any of the components of the knowledge commons usually shared common values related to the creation of new knowledge, teaching students the knowledge they would need in order to be productive members of a community, a society and an economy and providing general information necessary for the sustenance of a democratic society. If these values erode or change dramatically, the resulting physical conditions and action arenas are also strongly affected.

Traditionally, with commons, research has shown that homogeneity within a community can be an important ingredient in the ultimate robustness of a commons. The size and familiarity of a community are also critical factors in the analysis of traditional commons. In the global networked environment, one might well ask, what makes an online community homogeneous (or not)? One could also ask, what is local? If a community of providers and decision-makers is unified as to the purpose and goals of the resource, then the community can be said to be homogeneous. It could be that for online MC communities, epistemic cohesion serves as a virtual locality.

Rules-in-use

Rules are shared, normative understandings about what a participant in a position must, must not, or may do in a particular action situation, backed by at least a minimal sanction ability for non-compliance (Crawford and Ostrom 2005). When these normative instructions are merely written in administrative procedures, legislation, or a contract and not known by the participants or enforced by them or others, they are considered rules-in-form. Rules-in-use are generally known and enforced and generate opportunities and constraints for those interacting.

New rules or laws can be made based on lack of adequate information, awareness, or

understanding of the true nature of the issues. Often the rules are hard to see, as is the case with protocols, standards, and computer code. Numerous obvious and non-obvious rules apply to different levels of digital resources, such as institutional repositories and the microbiological commons. There are rules about who makes the rules and who enforces the rules. There are usually rules about who may contribute to the resource and who may not. Subject and institutional boundaries would need to be defined. Rules for sustaining and preserving the resources would need to be constantly evolving.

Much has been written about the nature and levels of rules.³ The rules are the institutional underpinning of the resource. Whether the rules are generally understood and followed can determine the outcome and success of the commons.

The action arena

Action arenas are composed of participants making decisions in a situation affected by the physical and institutional characteristics that will then result in varying outcomes. Many theorists choose to start the IAD analysis with the action arena, focusing on the actors and the parts they play in an action situation. Variables to be considered are what actions are taken and how do those actions affect outcomes; how much control does each participant have and how much information do they have about the situation? Are decisions being made to address short-term dilemmas or are long-term solutions being sought? What are the possible outcomes? What are the transaction costs?

One of the more puzzling action situations in the OA movement within the whole knowledge commons arena concerns the establishment of institutional repositories and the seemingly ubiquitous dilemma of non-compliance and how to get authors/scientists to contribute their research artifacts to an institutional repository (IR). While it is relatively fast and cheap to set up an IR, it is not easy to populate it with voluntary contributions from the author community. The incentives for authors to make their works available online with free and open access have been demonstrated repeatedly.⁴ Some analysts have indicated that lack of information may be a barrier; that once authors know the

facts about self-archiving, they will comply (see Rowlands *et al.* 2004; Suber 2002, 2004). Some institutes and universities have endorsed the Berlin Declaration⁵ by establishing mandated OA publishing for their communities. But for many universities, mandates for author publishing systems are too far of a leap into radical institutional change.

The analysis of the action arena with specific actors and action situations, along with a minimal number of variables, is a crucial step in assessing patterns of interactions and ultimate outcomes.

Patterns of interaction

In a commons, how the actors interact strongly affects the success or failure of the resource. Are the participants able to gain sufficient information about the structure of the situation, the opportunities they and other participants face and the costs of diverse action? Do they develop increasing trust that the situation helps to generate productive outcomes and in the expected behaviour of others? Patterns of interaction can be strongly conflictual, however, especially when there is hyperchange in the community of users and their values and goals. In addition to conflict, interactions may be simply unfocused and unthinking – a part of a growing “culture of carelessness” (Barron 2000) where quick-fix solutions take the place of collaborative analytical processes. In the university community, patterns of interaction may be influenced by hierarchies, lack of respect, and distrust that often accompanies the tribalism of disciplines and subdisciplines (Thorin 2003).

Outcomes

In some cases it is easier to apply the framework by starting with the outcomes. The outcomes are often the initial question-raisers. Why are global biodiversity efforts failing? Is the digital divide increasing? Analysis can also be motivated by confusing and conflicting outcomes, such as why some IRs are well populated while so many others are not. Frequent outcomes addressed in the commons literature are those concerning the enclosure of formerly open and public information and the creation of new digital commons that provide better access to information.

TABLE 3. Potential positive or negative outcomes in various knowledge commons

Negative outcomes	Positive outcomes
Proprietary scientific databases (enclosure)	Open access research libraries (access)
Digital divide and information inequity (inequity)	Global use, provision, and production (equity)
Lack of standards across collections (degradation)	Standards and interoperability of digital information (diversity and rich commons)
Conflict and lack of cooperation	Cooperation and reciprocity (social capital)
Lack of quality control (pollution)	Quality control of content (richness)
Overpatenting and anti-commons (enclosure)	Open science (enhanced access/communication)
Non-compliance (weak resource)	Compliance and participation (well-populated repositories)
Withdrawal of information (instability, degradation, depletion)	Preservation of information (access)
Spam (pollution)	Scholarly blogs (enhanced quality information and communication)

Writers tend to point to outcomes that they like – such as widespread access to scientific data – or dislike – such as children having ready access to pornographic materials, without much analysis of the complex interactions that led to these outcomes. The IAD framework leads one to factor in the physical and institutional nature of a resource to better understand the context of specific actions. The variables in an action situation lead to patterns of interaction that ultimately lead to outcomes.

Within the broad spectrum of the knowledge commons, there are a myriad number of competing outcomes – some of which are considered negative, while others are seen as positive (see Table 3).

The conflicting outcomes reflect a highly complex resource where new technologies have increased capabilities to harvest information as a commodity. There are now multiple uses by expanded communities for the same resource – not just scholarship, but entrepreneurship, competition, and financial gain. Because the outcomes are often the result of numerable actions, it is helpful to keep an interdisciplinary frame of mind. The desired outcome may be the dissemination and preservation of the scholarly record, but contributing factors in the outcome formula are new computer technologies, financial constraints, university corporatisation, declining numbers of tenured faculty, lack of information, and new intellectual property-rights legislation.

How does the community protect the information from private interests that could collect the information and repackage it in a new, for-profit, database? What types of intellectual property rights will apply?

The outcomes for institutional repositories – all still in their infancy – are as yet unclear. Will they take hold and become rich scholarly resources that contain an accurate record of an institution's output over time? Or, will they be patchy, inconsistent facilities that more accurately reflect non-compliance and indifference?

Evaluating outcomes

In addition to predicting outcomes, the analyst may also evaluate the outcomes that are being achieved as well as the likely set of outcomes that could be achieved under alternative institutional arrangements. Evaluative criteria are applied to both the outcomes and the interaction among participants that leads to outcomes. While there are many potential evaluative criteria, some of the most frequently used criteria are (i) increasing scientific knowledge, (ii) sustainability and preservation, (iii) participation standards, (iv) economic efficiency, (v) equity through fiscal equivalence, and (vi) redistributive equity.

Increasing scientific knowledge

One of the core evaluations made of scientific research is whether it leads to an increase in the knowledge that has been recorded and made available to other scholars, students, and the public at large. The evaluation of increasing scientific knowledge can be based on the amount of high-quality information available; the quality and usefulness of the common pool; the local and global usage of the information and the percentage of free OA information *vs* closed, proprietary information. One can also evaluate the mark-up

language, metadata, and format standards that facilitate or restrain interoperability.

Sustainability and preservation

Sustainable systems are those that meet current needs of many individuals involved in producing, deciding, and using a commons (for example, students, faculty, researchers, librarians, administrators, citizens, public officials) without compromising the ability of future generations also to meet their needs. Thus, when evaluating the sustainability of a system, one needs to examine the processes involving interactions among participants and whether they increase the physical, social, and human capital involved or slowly erode that capital. In regard to ecological systems, sustainability has usually meant the maintenance of the capacity of an ecological system to support social and economic systems over time (Berkes *et al.* 2003, p. 2). When applied to a knowledge commons, one is asking whether these systems can themselves survive over time as well as supporting ecological, social, and economic systems through increased access to relevant information. Are there preservation strategies in place? Such strategic plans will need to factor in changing actors and participants, adaptive software systems, and constantly evolving rules. One also needs to examine institutional long-term commitments to the preservation of the resource.

Economic efficiency

Economic efficiency is determined by the magnitude of the change in the flow of net benefits or costs associated with an allocation or reallocation of resources. The concept of efficiency plays a central role in studies estimating the benefits and costs or rates of return to investments, which are often used to determine the economic feasibility or desirability of public policies. When considering alternative institutional arrangements, therefore, it is crucial to consider how revisions in the rules affecting participants will alter behaviour and, hence, the allocation of resources. Many studies have already shown the economic efficiency of OA publishing, but finding the appropriate rules for sharing the new costs of this form of publication is still under development.

Equity through fiscal equivalence

There are two principal means to assess equity: (i) on the basis of the equality between individuals' contributions to an effort and the benefits they derive and (ii) on the basis of differential abilities to pay. The concept of equity that underlies an exchange economy holds that those who benefit from a service should bear the burden of financing that service. Perceptions of fiscal equivalence or a lack thereof can affect the willingness of individuals to contribute toward the development and maintenance of resource systems.

Redistributional equity

Policies that redistribute resources to poorer individuals are of considerable importance. Thus, although efficiency would dictate that scarce resources be used where they produce the greatest net benefit, equity goals may temper this objective, resulting in the provision of facilities that benefit particularly needy groups. This is relevant to the ever-widening digital divide. International scientific collaboration is steadily increasing, but the information divide between the haves and have-nots is also increasing. Should universities from developed countries take a more active role in providing access services with partners in developing countries?⁶ Redistribution objectives, however, tend to conflict with the goal of achieving fiscal equivalence, and tough decisions must frequently be made to prioritize distribution needs.

Requirements of adaptive governance in a complex system

Researchers who have focused on the governance of natural resources have struggled with the question of why some self-governing systems have survived for many years (some as long as 1,000 years), while others collapse within a few years, or even after a long and successful era. There is no simple answer. One of the core problems that has been documented is that rapid change in the environment and in the community is always a major challenge for any governance system. Over time, scholars have come to a general level of agreement that there are several requirements that somehow need to be met for a governance system to be adaptive

and robust over time. These are providing information, dealing with conflict, inducing rule compliance, providing infrastructure, and being prepared for change (see Dietz *et al.* 2003). A wide diversity of specific ways of meeting these requirements has been observed. Let us briefly discuss each of these requirements.

Providing information (reflexivity of knowledge basic to all systems)

All effective governance systems at multiple levels depend on good, trustworthy information about stocks, flows, and processes within the entities being governed, as well as about the relevant external environment. This information must be matched with the level of aggregation that individuals are using to make decisions. All too often, large flows of data are aggregated. Decisions are, however, frequently made by much smaller units where there is substantial variance from the average reported in the aggregated data. Information must also fit with decision-makers' needs in terms of timing, content, and form of presentation. Informational systems that simultaneously meet high scientific standards and serve ongoing needs of decision-makers and users are particularly useful.

Dealing with conflict

Sharp differences in power and in values among interested parties make conflict inherent in all choices of any importance. Conflict resolution can be as important a motivation for designing institutions as is the concern with building and maintaining a resource itself. People bring varying perspectives, interests, and fundamental philosophies to problems of the scholarly commons. Conflicts among perspectives and views, if they do not escalate to the point of dysfunction, can spark new understandings and better ways of accomplishing outcomes. The core problem is designing conflict-resolution mechanisms that enable participants to air their differences and to achieve resolutions that they consider legitimate, fair, and scientifically sound.

Inducing rule compliance

As we have learned, effective governance also requires that, whatever rules are adopted, they

are generally followed, with reasonable standards for tolerating small variations that always occur due to errors, forgetfulness, and urgent problems. It is generally most effective to impose modest sanctions on first offenders and gradually increase the severity of sanctions for those who do not learn from their first or second encounter (Ostrom 1990). The challenge in designing a new governance system is how to use informal strategies for achieving compliance at the beginning that rely on participants' commitment to a new enterprise and the rules they have designed and subtle social sanctions. When a more formal system is developed, those who are the monitors and those who impose sanctions must be seen as effective and legitimate by participants or rule evasion will overwhelm the governance system.

Providing infrastructure

Infrastructure includes physical and institutional structures and technology. Thus, the infrastructure affects how a commons can be utilised, the extent to which waste can be reduced in resource use and the degree to which the physical conditions of a resource and the behaviour of users can be effectively monitored. Indeed, the ability to choose institutional arrangements depends in part on infrastructure – largely in regard to ways of storing and communicating information. Infrastructure also affects the links between local commons and regional and global systems.

Be prepared for change

Institutions must be designed to allow for adaptation because some current understanding is likely to be wrong, the required scale of organisation can shift and biophysical and social systems change. Fixed rules are likely to fail because they place too much confidence in the current state of knowledge, while systems that guard against the low probability, high consequence possibilities and allow for change may be suboptimal in the short run but prove wiser in the long run. This is a principal lesson of adaptive management research.

Conclusion

The premise of this article has been that the application of the IAD framework provides a useful, tested method for analysing commons dilemmas. We expect that the framework will evolve to better fit with the unique attributes of the production and use of a knowledge commons. We have illustrated the advantage of factoring in the exogenous conditions of the physical characteristics, community attributes, and rules-in-

use in order to better understand the processes at play with certain actions and those involved in those actions. The framework can then lead one to recognise how those factors, in combination with patterns of interactions, can influence outcomes. Over time, it will be possible to extract design principles for robust, long-enduring knowledge commons. After more efforts succeed and others fail, it will be easier to understand what makes the MB commons work and how best to govern, protect, and sustain it.

Notes

1. This is a revised version of the paper presented at the workshop on “Exploring and Exploiting Microbiological Commons: Contributions of Bioinformatics and Intellectual Property Rights in Sharing Biological Information”, Brussels, Belgium, 7–8 July 2005. We would like to thank the Andrew W. Mellon Foundation for their generous support.

2. Vincent Ostrom has repeatedly emphasised the artifactual nature of knowledge and institutions: “Every development – street sweeping, production of fertilizers, irrigation works, the development of new seed stocks –

a component to it that is concerned with how the activities of people are organised in relation to one another” (1969, pp. 2–3).

3. See Ostrom (2005, chapter 2) for a discussion of operational, collective-choice, and constitutional-choice levels of rules.

4. See the Open Citation Project (2005) for a compilation with links to these studies.

5. Conference on Open Access to Knowledge in the Sciences and Humanities, 20–22 October 2003, Berlin, available from

<http://www.zim.mpg.de/open-access-berlin/berlindeclaration.html> [Accessed 22 November 2006].

6. This draws on the idea of “common but differentiated responsibilities” frequently applied in international law and promoted in the World Summit on Sustainable Development, Johannesburg, August 2002. See A CISDL Legal Brief, Centre for International Sustainable Development Law, available from http://www.cisd.org/pdf/brief_common.pdf [Accessed 22 November 2006].

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