The Institutional Economics of Sharing Biological Information

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Introduction

As scientists and user groups become better connected with each other (particularly through the Internet), and as research focuses on issues of global importance (such as climate change, human health, and biodiversity), there is a growing need to systematically address data access and sharing issues beyond national jurisdictions and thereby create greater value from international cooperation. The goal should be to ensure that both researchers and the broader public receive the optimum return on public investment, and to build on the value chain of investment in research and research data (Stiglitz *et al.* 2000).

Integrated and combined access to this multifaceted realm of information opens perspectives for the implementation of new applications. In the field of the life sciences, new sets of tools for studying biological building blocks and pathways will lay the foundation for even more complex future projects. These may include the complete mapping of an organism's protein and metabolism networks, as well as the creation of biological models that can pave the way for theoretical models on bacterial speciation and its complex ecological dynamics (Gevers *et al.* 2005), or the development of tools for automated species identification. These tools undoubtedly require access to sets of skills that are not typically encountered among systematists or within the departments and institutions in which the bulk of formal taxonomic identifications are conducted. Developing solid approaches requires new collaborations between microbiologists, engineers, mathematicians, computer scientists, and people who have significant knowledge of the legal and socio-economic aspects of sharing biological resources and software tools in the public domain.

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For several reasons, micro-organisms are an ideal prototype on which to study the creation of collaborations for the exchange and sharing of biological information. Micro-organisms are the smallest life forms, but together they represent the largest mass of life on earth.[1] They are often overlooked in general biodiversity projects, but (like the role of dark matter that is invisibly distributed across the universe) the role of micro-organisms in the creation, maintenance, and restoration of balance in virtually all ecosystems cannot be neglected. All life on earth is inextricably intertwined with micro-organisms: they are critical to maintaining the health of organisms that depend on them for nutrients, minerals, and energy recycling; conversely some micro-organisms can cause infectious disease when they encounter susceptible hosts. Micro-organisms present a high degree of biological diversity, using biological and chemical processes that exist nowhere else in nature. Consequently, we can look to the world of micro-organisms as a vast, largely untapped source of biotechnological potential, and we can study them to help us understand the majority of life processes and to further unravel the basic mechanisms of life on earth.

Within the field of microbiology, initiatives for sharing information through networking distributed databases have emerged, operating both on a global scale (such as the consortium for Common Access to Biological Resources and Information [CABRI], connecting worldwide microbiological resources) and in more focused networks (such as the European Human Frozen Tumour Tissue Databank [TuBaFrost]). From a governance perspective, these networks face increasing pressure from the development of global markets. In particular, the introduction of new standards of intellectual property protection during the last 20 years has had a profound impact on the sharing of data and resources in the field of the life sciences. Two of the most influential and widely debated changes in this context are the 1980 Bayh–Dole Act in the USA (Rai and Eisenberg 2003) and, more recently, the 1996 EU database directive 96/9/EC (Reichman and Uhlir 1999). The Bayh–Dole Act explicitly gave universities the right to seek patent protection on the results of government-sponsored research and to retain patent ownership. As a consequence, in the period from 1980 to 1992 the number of patents granted per year to universities in the USA increased from fewer than 250 to almost 2,700 (Rai 1999, p. 109). The EC database directive 96/9/EC was a landmark decision that lowered the standards of eligibility to database protection. Indeed the database directive offered copyright protection to databases that were original in the selection or the arrangement of their contents, but also to non-original databases if it could be shown that there had been a substantial investment in obtaining, verifying, or presenting their contents. This extended protection to library catalogues for instance, but also to biological information facilities that network existing databases.

These rulings have to be situated within the wider phenomenon of the globalisation of intellectual property rights that has accompanied the genomic revolution in the life sciences and the digital revolution in information technologies. This new context has played a key role in stimulating innovation and new market developments in the life sciences. However, it is also posing a challenge to life-science research for public purposes, as the research communities have to adapt their strategies and design new institutional arrangements to allow them to provide services of general interest in an increasingly competitive and international environment.

In this article I analyse the models for the institutional design of database sharing in the context of global intellectual property rights. In particular, I rely on contemporary insights from new institutional economics that show the necessity of developing new forms of collective action to deal both with the insufficiencies of market solutions and the limits of the new forms of public regulation, in the context of the construction of a research commons for scientific data (Hess and Ostrom 2003, 2005; Reichman and Uhlir 2003). For instance, within the related field of digital communication, the development of E-print repositories (such as arXiv.org and BioMedCentral) and trusted digital repositories for knowledge of general interest is based on collaboration between groups of scholars and information specialists to build a common knowledge pool. What is new in these initiatives is that researchers are participating in an international epistemic community that is committed to building a global scholarly library, with the aim of obtaining greater joint benefits and reducing their joint harm from the enclosure process. In the case of database fusion in the field of microbiological resources, recourse to such collaborative arrangements seems to be necessary to cope with the problems of uncertainty and the complexity of the innovation process. In particular, collective arrangements in the knowledge networks seem necessary to go beyond the market insufficiencies created by the unpredictable character of the automated knowledge-creation process and to create new partnerships between the diverse set of public and private actors that are involved in the entire innovation chain.

In the rest of this article I build upon these proposals in order to elaborate a framework for the analysis of institutional choice in the field of the microbiological information commons. In the first part I develop a model to describe the transaction situation and then discuss different institutional solutions for data sharing that have been proposed to cope in a cost effective manner with the incentive problems in the field of micro-organisms. In the second part I argue that it is necessary to complete this static approach to economic efficiency, which favours economic incentives through the allocation of intellectual property rights, by adopting a dynamic framework geared towards the enforcement of norms of cooperation in a context of changing social preferences and processes of knowledge acquisition throughout the entire innovation chain.

Setting the stage: the transaction situation and governance models

Data sharing of microbiological information is essential for the quick translation of research results into knowledge, products, and procedures and to improve matters of general interest such as the sustainable use and conservation of biodiversity. At present the widespread national, international, and cross-disciplinary sharing of research data is not merely a technological matter, but also a complex social process in which researchers have to balance different pressures and interests. Purely regulatory approaches to data sharing are not likely to be successful without considering these factors, as technology itself will not fulfil the promise of e-science. Information and communication technologies provide the physical infrastructure. It is up to national governments, international agencies, research institutions, and scientists themselves to ensure that the institutional, economic, legal, cultural, and behavioural aspects of data sharing are taken into account (Arzberger *et al.* 2004).

The key players providing the infrastructure for the sharing of microbiological information are the organisers of the biobanks and culture collections, who organise the collection, conservation, curation, and exchange of biological resources and related data. Those collections are an outgrowth from the conventional pre-genomics *ex situ* collections of biological materials that have progressively developed into multi-service facilities called biological resource centres (BRCs). The concept of BRCs was proposed in an influential OECD report in 2001, which defines them as "service providers and repositories of the living cells and genomes of organisms, and information relating to heredity and the functions of biological systems" (OECD 2001, p. 11). As such, BRCs contain

> collections of culturable organisms (e.g. micro-organisms, plant, animal and human cells), replicable parts of these (e.g. genomes, plasmids, viruses, cDNAs), viable but not yet culturable organisms, cells and tissues, as well as databases containing molecular, physiological and structural information relevant to these collections and related bioinformatics. (OECD 2001, p. 11)

While a BRC is a collection of resources from any origin, including human, the term "biobank" refers more particularly to organised collections of biological samples of human origin and the data associated with them.[2] Like BRCs, biobanks come in many different forms, according to the type of samples that are stored and the domain in which they are collected.

Many different initiatives for sharing knowledge through databases which gather knowledge from different fields of microbiology exist. These include the CABRI (n.d.) and TuBaFrost networks mentioned in the introduction, and the ongoing Global Biodiversity Information Facility (GBIF n.d.) project. These networks face increasing pressure from the development of global intellectual property rights, which has led to competition for the ownership of previously shared resources. At the same time, the role of the state in the provision of services of general interest, such as public collections and databases, is gradually shifting from direct intervention to the regulation of markets or quasi-markets. In the context of this new situation, cost effective access can, for example, be guaranteed by the state by the introduction of a general research exemption for database access for non-commercial research. In a similar manner, the exchange of biological material can be regulated through compulsory clauses in the contractual arrangements for the exchange of biological material, specifying the origin of the resource and/or prior informed consent.

From an economic point of view, microbiological information has been characterised as being part of the public domain (Oldham 2004, p. 59; Smith *et al.* 2004; Williamson 1998, pp. 9–11), implying appropriate public and regulatory institutions for guaranteeing its provision. However, this characterisation is very broad and, as has been shown in recent research (Kaul *et al.* 2003), the notion of the public domain covers a heterogeneous set of transaction situations and incentive problems, which demands a more fine grained approach.

For these reasons I will focus on the following questions:

- What are the characteristics of the good that is exchanged and the related incentive problems for the provision and use of this good?
- What institutional solutions for dealing with these complex incentive problems are currently being proposed?

Microbiological information as a common pool resource

In general, goods that fall into the public domain – or what is often called in the legal literature the "commons" (Benkler 1998; Lessig 1999) – are characterised by non-exclusiveness in consumption (Kaul *et al.* 2003, p. 79). This means that the public domain covers a broad set of phenomena where multiple users share a resource in some way (Hess and Ostrom 2005, p. 1). A useful distinction in this broad category of the commons, allowing a better understanding of the incentives that lead to practices of information sharing, is the distinction between public goods and common pool resources. Both are characterised by non-exclusiveness and hence sharing of resources. However, for public goods, the consumption of the resource by one does not diminish the possibilities of consumption by others. Paradigmatic examples are mathematical formulae, new ideas, technical standards, or virtually unlimited natural resources such as the light of the sun. In contrast, in the case of common pool resources, the resource is available to all, but one person's benefit subtracts from the products available to others. This is typically the case for depletory resources such as forests, nature parks, and clean air.

Individuals involved in the production of public goods face the problems of potentially perverse incentives related to the production process, such as the presence of people benefiting from a public good who have not contributed to its production (Hess and Ostrom 2005, pp. 3–5). For common pool resources, however, since subtractability applies, potentially perverse incentives exist both on the production and the consumption or use side (Hess and Ostrom 2005, p. 3). For instance, all common pool resources are exposed to the risk of "overharvesting" and pollution of the resource.

The microbiological information that is managed and exchanged through BRCs or global information facilities such as GBIF shows

Table 1. Incentive problems for the public good and common pool resource aspects of the microbiological information commons

	Information facility	Information flow	Physical storage system
Type of good	**Public good**	**Common pool resource**	**Common pool resource**
Example	Contribution of information to a global biological information archive	Participation in the exchange of tumour tissue data	Common web server for storing images
Positive incentives	Visibility, public recognition, instant publication	Access to firsthand, high quality information related to the data	Online verification of the diagnosis
Perverse incentives	Under-use: low visibility, lack of use	Misuse: use of the data without contributing to the flow, plagiarism, submitting low quality data	Pollution: storing redundant information that takes a lot of memory space

Source: Examples adapted from Ostrom and Hess (2006, Table 1). For simplicity of presentation I have merged production and use incentives.

characteristics of both public goods and common pool resources. In Table 1 I have illustrated this distinction and the related incentive problems for three components of the knowledge commons: information as a non-physical flow unit that is exchanged within the collaborative networks; the physical flow units or artifacts through which the information is exchanged; and the resource system or facility storing the ideas and the artifacts (Hess and Ostrom 2003, pp. 128–130).

First, information as a non-material good stored in a facility clearly has the characteristics of a public good. It is a resource shared by multiple individuals in a non-exclusive way and it is non-depletory. The use of an idea by someone does not subtract from the capability of another individual to use the same idea at the same time. As such, in a manner similar to the self-archiving initiatives in the field of scholarly communications (Hess and Ostrom 2003, p. 143), researchers who participate in building global biological information facilities are building a universal public good of which the more people have access, the greater the benefit to everyone (Hess and Ostrom 2003, p. 143). Positive incentives that play a role in self-archiving initiatives, such as the reduction in costs of publication and access, the scientific recognition and credibility that comes with public disclosure, the increased visibility of information, and instant publication and dissemination (Hess and Ostrom 2005, p. 5), have also been documented in the field of the microbiological information commons (Rai 1999, pp. 92–95).

Second, information as a non-physical flow unit has also been characterised as a depletory resource and hence presents the characteristics of a common pool resource. Indeed, the value of information to users is not only related to the opportunities they have to access a stock or pool of accumulated knowledge somewhere in an encyclopaedia or digital repository, but also to the quality of the flow of the information. By exchanging the information, it is consumed, verified, completed, and interlinked with other information. It is this complex process of exchange and quality management that makes the information valuable to the users of the common knowledge pool. Sustainable management of this flow depends on compliance with a set of rules, such as the verification of the quality of information submitted to the common pool, appropriate citation of the source of the information and cross-linking to the information generated by the users' communities in the field of knowledge concerned. Non-compliance with or violation of these rules harms the common knowledge base and can lead to the information flow drying up. The distinction between the stock of information and the flow is crucial in discussing the microbiological information commons, because of the increasing role of databases as a flow resource in the organisation of information exchanges.

As has been argued by Reichman in his work on database policies, the information contained in databases is both the input of the knowledge generation processes in the information economy and the output of former knowledge generation and innovation processes (Reichman 2002). Moreover, the use of the information in the microbiological commons often depends either on the possibility of linking databases back to "local knowledge" (for instance, knowledge about the behavioural properties of a resource in the environment or the laboratory) or, conversely, of testing a possible innovation path by confronting it with the downstream user communities.

Third, as mentioned above, sharing microbiological information through microbiological information facilities is a complex endeavour that also involves sharing physical flow units and information technologies. For example, providing taxonomic or genetic data to a common database such as GBIF requires the use of a common data format, at the level of both the encoding formats and the transmission protocols. These common formats and protocols depend in turn on the design and permanent evolution of appropriate software specific to the common knowledge pool. Other non-exclusive resources that play an important role in the microbiological information commons are standardised technologies for the identification of biological resources and numerical identifiers for the persistent identification of the data throughout the process of data exchange with different user communities. Some of these resources (such as common standards) are non-depletory in nature and can appropriately be described as public goods. Others (such as the bandwidth of the transmission infrastructure or the memory space on a common database webserver) are depletory, and should be considered as common pool resources.

To illustrate some of the incentive problems associated with the microbiological information commons as a common pool resource it is interesting to consider a concrete example, the TuBaFrost network. This gathers data on high quality frozen tumour tissue samples with an accurate diagnosis, which are stored in major European cancer centres and universities, and makes it accessible and searchable through an uncomplicated query system on the Internet. The TuBaFrost database is published in the restricted public domain. That means that the project portal can be accessed without restriction, and that access to the search engine of the database is open to all users, on the condition that they register with the website. Control of misuse of the information is carried out through the registration protocol: anyone can register through a simple web-interface, if they provide their name, e-mail, and the reason why they want to use the database. This allows verification in advance of the user's intentions and, by keeping track of the identity profiles, *ex post* control of misuse. Access to other tools such as self-archiving and the exchange of tumour tissues is reserved for the full participants in the project.

One of the positive incentives for becoming a full participant in the production side is indirect. Through being involved in the generation of high quality information on tumour tissue samples, the partners expect to have first-hand access to a good flow of information from the data in question.[3] A key physical resource that is shared in the TuBaFrost project is the Nanozoomer, which allows representative histology images to be stored in a central database, enlarged 20-fold or 40-fold and accessed through the virtual tumour bank. The advantage is that, through the addition of images to the virtual tumour bank, diagnoses can be verified on line. However, this also creates a depletory resource to be shared: the disk space of the central database. Because of these different layers of resources to be shared, the organisation of the TuBaFrost network depends on the solution of a complex incentive problem. This involves both pure public goods (such as the information that is contributed to the stock of common knowledge) and common pool resources (such as the self-archiving facility and the Nanozoomer).

Institutional solutions to the incentive problems

In the previous section I discussed the perverse incentives involved in data sharing in the microbiological commons. In this section I analyse some of the collective arrangements that are currently being considered for organising data sharing in the microbiological commons, focusing more particularly on the role of property rights and contractual arrangements.

Institutional economics has clarified the role of well-defined property rights in helping to reinforce a long-term perspective in the management of a resource and in stimulating investment in the design of institutional rules that can cope with incentive problems (Demsetz 1967; Schlager and Ostrom 1993). However, it is important to qualify this statement.

Firstly, well-defined property rights do not necessarily imply full ownership, nor a fortiori private ownership. As has been shown, well-defined rights to a good, such as a natural resource, can, for example, include exclusion and management rights attributed to a private organisation, while the resource itself remains in state ownership. In a similar way, data sharing through a data portal can imply the exercise of management and exclusion rights by an organisation, without the full ownership of the original databases necessarily being transferred to this entity. This is the reason that economists have analysed property rights as a ‘‘bundle’’ of use and decision rights attributed to certain economic agents. Such a bundle of rights specifies a set of operational rights (the use that can be made of a resource) and a set of collective choice rights (who can decide on the future exercise of the rights over the resource). In their framework article, Hess and Ostrom (2005) distinguish seven major types of property rights that are relevant for the digital knowledge commons (see Table 2).

Second, from the point of view of new institutional economics, property rights are considered in relation to the outcomes that result from the attribution of these rights to

TABLE 2. The bundle of rights in the digital knowledge commons

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

Remark: numbers 1–4 are operational rights, numbers 5–7 collective choice rights.[4]
Source: Hess and Ostrom (2005, pp. 14–15).

certain economic agents in a specific domain and a certain action situation. In particular, these outcomes depend on the effective institutional rules that are defined and enforced by the agents who exercise these rights. Property rights as such only authorise particular actions, but they still need a set of workable institutions to make them effective in a particular situation. The consequences of a set of property rights will hence depend on the cost and availability of institutional arrangements that specify the exercise of the rights and the impact of the institutional arrangements on the actors' behaviour. For instance, in many cases of exclusive-use goods, the exercise of private property rights has led to the most efficient outcomes. However in other cases, the costs implied in the exercise of private property rights (such as the creation and enforcement of rules for market exchange and contractual arrangements) can be too high and have to be balanced against alternative institutional rules and property regimes. Most importantly, this means that no "one size fits all" property rights regime can be found.

In the field of microbiological commons three main institutional solutions are discussed in the literature: a model of free dissemination and two models based on conditional deposits for commercial and non-commercial use. All three are based on a form of decentralised ownership and include a certain level of collective management and exclusion rights. Such an institutional arrangement for the governance of the information flow is in accordance with the results that have been obtained from case studies within the field of natural resource management. Indeed, these studies show that in order to deal with collective action problems within a common pool resource, there have to be common rules, at least for exclusion and management. These rules are necessary in order to delimit the boundaries of the common pool and impose graduated sanctions for non-compliance with the rules of use so as to prevent depletion of the resource.

Facilitating free dissemination with decentralised ownership

In a first model of data sharing, ownership – and hence the right to alienation – remains with the individual data providers. However, the providers transfer a part of their management and exclusion rights to a common data portal. Some key features of this first model can be analysed through the example of the Global Biodiversity Facility (GBIF). In the GBIF, data are provided to a collaborative database from a variety of sources; the database in turn makes the data freely available to non-commercial users, as illustrated in Fig. 1. The ownership of the data, and any related conditions on the use of the data, remain with the original providers. This means that GBIF does not assert any intellectual property rights to the data that are made available through its network. Moreover, all the data are made available on the terms and conditions that data providers have identified in the metadata. However, even if GBIF does not assert any ownership rights, each data provider transfers some of the management and exclusion rights to GBIF as specified in the Memorandum of Understanding establishing the organisation. This transfer agreement allows different incentive problems related to the governance of the information flow as a common pool resource to be dealt with:

1. When registering their services with GBIF, the data provider has to sign the GBIF data sharing agreement. This stipulates that the data provider will make reasonable efforts to

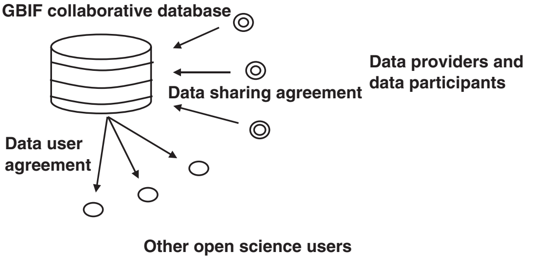

FIGURE 1. The GBIF model of data sharing
Source: the author.

ensure that the data are accurate and will include a stable and unique identifier with the data (Articles 1.4 and 1.5 of the *Data sharing agreement*).

2. The data provider has to be endorsed by a GBIF participant. GBIF participants are the signatories of the GBIF-establishing Memorandum of Understanding. Data participants maintain stable computer gateways (the data nodes) that make data available through the GBIF network. The GBIF participants maintain services that enable new and existing data providers in their domain to be integrated within the GBIF network (Articles 1.8 and 2.4 of the *Data sharing agreement*).
3. The GBIF participants empower the GBIF secretariat to enter into contracts, execute the work programme and maintain central services for the GBIF network. In particular, the GBIF secretariat may provide full or partial data to other users, together with the terms and conditions for use set by the data provider (Article 1.7 of the *Data sharing agreement*).
4. Using data through the GBIF network requires agreement to a *Data use agreement* when accessing the search engine. This agreement stipulates that users must publicly acknowledge the data providers whose biodiversity data they have used (Article 1.4 of the *Data use agreement*).

Through this collective arrangement, GBIF facilitates the free dissemination of biodiversity related data. In practice, GBIF pools data that are, in most cases, already in the public domain or that have been commissioned explicitly for public purposes and can receive a wider audience by being accessible through the data portal. Elsewhere, more sophisticated two-tiered models have been developed to satisfy both public research interests and commercial opportunities.

Organising the licensing of data through a collective licence organisation

The GBIF model is probably not appropriate for all types of microbiological data sharing. Indeed GBIF focuses on biodiversity-related data (including substantial microbiological databases) but not on the wealth of microbiological data that is relevant for research but not directly relevant for biodiversity conservation purposes (such as plasmids, viruses, or human cell lines for cancer research). Moreover, certain types of data are relevant both for public research purposes and private research and development (R&D) and would benefit from a more coordinated approach to the conditions of data licensing to commercial partners.

The report of an OECD working group on data sharing in neuroinformatics states some of the conditions under which a more stringent coordination of the conditions for commercial and non-commercial use of the database is called for. Indeed, for public domain databases and/or in the absence of collective management of the conditions of follow-on use, data sharing does not always guarantee credit to the researchers who originally produced the data, nor does it provide them with any reward if extensions to their work are commercialised (Eckersley *et al.* 2003, p. 155). Moreover, it only provides weak protection against the broader problem of "patent thickets" (Eckersley *et al.* 2003, p. 156).

Under these conditions, the OECD working group advised that different contractual conditions for access to the database be adopted for commercial and non-commercial use. In this model, which is analogous to the dual licensing model employed by some software developers,[5] non-commercial redistribution is permitted by a copyleft licence,[6] under the usual conditions of mentioning the source of the data (guarantee of credit). Commercial use of the data is permitted only when a specific contract that includes restrictions on this commercial use and specifies a licence fee has been

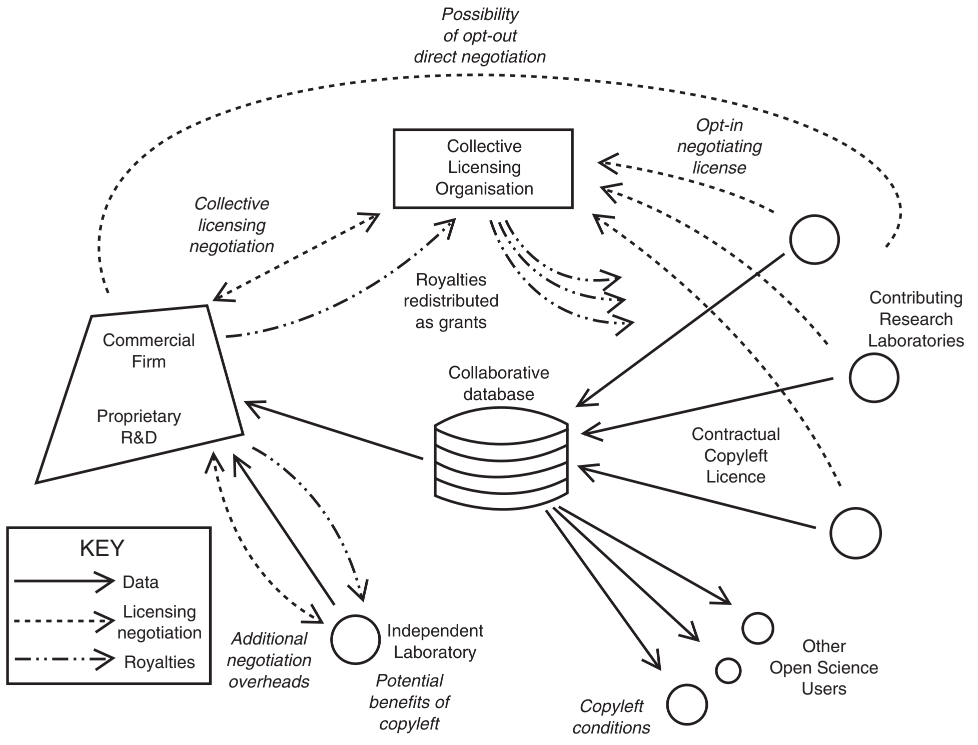

FIGURE 2. A two-tiered system for data sharing based on the transfer of property rights to a collective licensing organisation

Source: Eckersley *et al.* (2003).

negotiated. Negotiating these ownership licences could be the task of a collective licensing organisation administering the database (Fig. 2).

Organising the licensing of data through agreed contractual templates

The proposals for a dual licensing model for neuroinformatics data sharing is in many respects similar to the conditional deposits model suggested by Reichman and Uhlir in the broader context of the sharing of governmental funded scientific research data. However, they consider a negotiated solution, rather than having recourse to a collective licensing organisation (Fig. 3).

As Reichman and Uhlir point out, because of the potential problems of leakage (moral hazard) and enforcement (accountability) in collective licensing organisations, the data providers may very well balk at participating in collectively managed collaborative databases (Reichman and Uhlir 2003, p. 433). Moreover, in the case of commercially valuable data, they might prefer to retain some autonomy in negotiating the terms of their private transactions and/or they might want to impose restrictions on the uses of the data for commercial purposes. Under such conditions, data sharing on the basis of a multilateral negotiated agreement is to be preferred. The core of Reichman and Uhlir's proposal is a common agreement on the contractual templates to be used in transactions with public or private partners. To succeed,

> these templates must be acceptable to the universities, the funding agencies, the broader scientific community, and the specific sub-committees – all of whom must eventually weigh in to ensure that academics themselves observe the norms that they would thus have collectively implemented. (Reichman and Uhlir 2003, p. 439)

A Ph.D. student works in the mobile microbiological laboratory in Senegal. IRD / Patrice Cayré

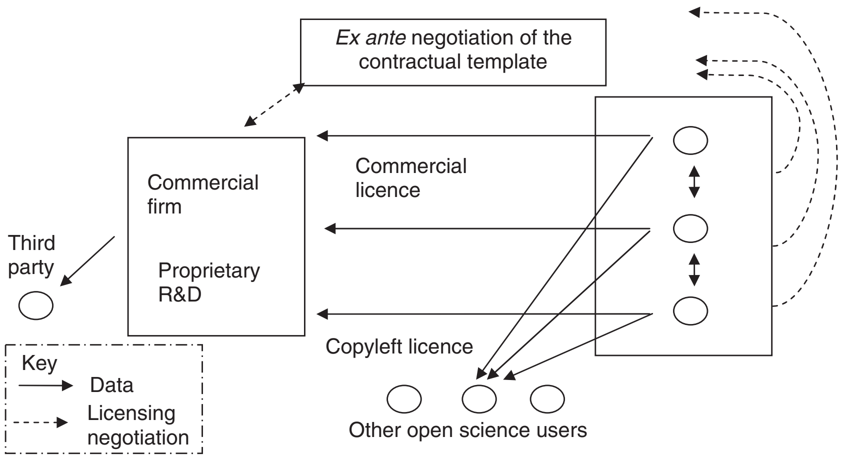

FIGURE 3. Two-tiered system for data sharing based on a multilateral agreement on contractual templates
Source: based on the proposals in Reichman and Uhlir (2003).

Enhancing dynamic efficiency

In Section 2 I argued for the importance of considering both the public good and the common pool resource aspects of the microbiological information commons. The latter is especially related to the "flow" character of the resource, which is depletory in nature and depends on appropriate contributions from each network partner and clear rules for dealing with opportunistic behaviour. However, the proposed institutional options that were considered there were situated in a static conception of economic efficiency. Indeed their rationale was to look for the optimal institutional design, given a certain transaction situation. Nevertheless, as has been shown elsewhere, this static approach to institutional choice has some important weaknesses (Brousseau 2000; Young 2001). In particular, in changing and controversial social contexts, no evaluation in advance of the best possible institutional solution can be made. For this reason several authors (Brousseau 2005; Denzau and North 1994; Eggerston 1990; Knight and North 1997; Ostrom 1998; Rai 1999) have argued in favour of adopting a dynamic approach to economic efficiency. Such an approach is not geared towards the allocation of resources and institutional means in advance, but rather towards creating incentives for permanent adaptation and innovation through reflexive processes of social learning and institutional experimentation. I have illustrated this distinction between static and dynamic efficiency in Table 3.

Especially in a situation of complex global inter-linkages, such as characterises the microbiological information commons, dynamic efficiency plays a key role in enhancing the effectiveness of governance arrangements. The viability of collaborative databases depends crucially on the enforcement of norms of cooperation and the presence of learning mechanisms that allow the emergence of common beliefs. For example, the introduction of new rules for intellectual property rights has led to a decline in the sharing ethos of science communities, and hence new cooperative networks and norms have had to be developed to sustain the practices of data sharing. In other cases, important changes have occurred at the level of the beliefs of different actor communities. For example, the new concepts that resulted from the work of the OECD working group on the relationship between bioinformatics and biodiversity were some of the key factors that allowed innovative partnerships to emerge between institutions having very different institutional policies at the outset.

TABLE 3. Some key features of the difference between static and dynamic efficiency

	Assumptions	Role of institutions
Static efficiency	Bounded rationality and opportunistic behaviour Preferences are given and known Alignment of the economic coordination structures to the transaction situation	Optimisation of transaction costs through the definition in advance of property rights and (*ex post*) supervisory mechanisms ensuring cooperative behaviour
Dynamic efficiency	Bounded rationality and opportunistic behaviour Evolving distribution of preferences Co-determination of political environment and economic coordination structures	Sustaining the dynamics of innovation and adaptation through learning and addressing a plurality of social valves

Source: adapted from Dedeurwaerdere (2005, p. 489).

In the field of institutional economics two important families of models have been developed for studying dynamic efficiency (Dedeurwaerdere 2005, pp. 481–484). A first family of models, which can be called ‘‘structural models’’, focuses on a set of cases where particular configurations of rules and norms have led to sustainable outcomes and enhanced welfare (Ostrom 1986). From an in-depth analysis of the conditions for success of these configurations a set of ‘‘design rules’’ can be defined for creating institutional incentives for enforcing norms of cooperation. A second family, which can be labelled ‘‘process models’’, focuses on the historical processes of continual change in rules (North 1990). Here the aim is to analyse the conditions that have led to an enduring dynamic interaction between rules and changing beliefs in a given transaction situation. Through this analysis, the goal is to identify any bottlenecks in the learning processes that have led to suboptimal outcomes in the past (such as restricting the learning process to established interests or the absence of a clear institutional mandate for learning).

The distinction between these two types of models allows the double dynamic role of governance institutions in influencing the social context of the collaborative database initiatives to be identified: first, their role in enforcing the norms of cooperation within the network of actors in the self-governing collective arrangements and second, their role in building a process of social learning geared towards common beliefs among different actor networks and institutional settings. In this section, I will argue for the importance of considering these two types of dynamic efficiency in developing a dynamic framework of analysis for the governance of information sharing in the microbiological commons.

The dynamic efficiency of norm change

The introduction of new rules governing the intellectual property rights resulting from government-funded basic research have had a major impact on the norms of the science community. First, the norms that characterise fundamental research (such as common cumulative heritage, independent inquiry and originality (Merton 1973)) now have to compete with norms of exclusion and profit raising that have gained ground in the research community. An oft-cited example is Blumenthal *et al.*’s (1997) survey of life science academics, showing that participation in industry-funded research is associated with a delay in publication of research results by more than six months, because of intellectual property rights’ issues.

The design of self-governing collective action institutions also has to take into account this changing social context. Under conditions of changing norms, any proposed set of institutional rules will affect the norms of the actors concerned; hence a linear relationship between a given set of rules and their outcomes can no longer be established. Under such conditions, comparative analysis has proved useful in studying the interaction between rules and their social context. As has been shown by research on common pool resources, focusing on effective ‘‘social possibilities’’, where particular configurations of rules and norm have led to sustainable outcomes and enhanced welfare, allows a set of robust design rules that are common to the successful endeavours to be defined.

This structural methodology has also proved useful in the field of knowledge commons. In their seminal research, Hess and Ostrom (2003, 2005) showed that some features of this comparative analysis could be adapted for the study of the new digital knowledge commons. For instance, a report by the Research Library Group and the Online Computer Library Center, cited by Hess and Ostrom in their initial article (2003), defines the required actions and rules for creating successful co-operation in the particular case of trusted digital libraries as being: (i) audibility, security, and communication; (ii) compliance and conscientiousness; (iii) certification, copying controls, and rule following; (iv) backup policies and avoiding, detecting, and restoring lost/corrupted information; (v) reputation and performance; (vi) agreements between creators and providers; (vii) open sharing of information about what is being preserved and for whom; (viii) balanced risk, benefit, and cost; (ix) complementarity, cost-effectiveness, scalability, and confidence; and (x) evaluation of the system's components (Hess and Ostrom 2003, p. 144). These principles illustrate the design rules for enhancing the cooperative behaviour and system resilience needed to sustain the global knowledge commons. Further comparative analysis is needed to gain insights into the specific design characteristics of data sharing in the digital environment.

One of the most sophisticated attempts to do this in the field of microbiological commons is the empirical research of Arti Rai on intellectual property rights and the norms of science (Rai 2005). In her comparative research on data-sharing initiatives, Rai has shown the importance of reputational benefits as a key factor in determining the viability of these initiatives in a highly protectionist intellectual property environment. More precisely, relying on cross-field case studies in both open software and biotechnology, her analysis showed that the chances of self-governing collective action initiatives for data sharing succeeding is highest where reputational effects are large and the capital input that is required for participating in the data sharing is very small. A case in point is the success of open-source software. In this case, the transaction costs for establishing repútional mechanisms remain low, because the information inputs of large numbers of individuals can be readily evaluated and integrated in the on-line environment. At the same time, volunteers do not have to invest any resources other than time in participating.

An important example of data sharing in the field of microbiology that complies with this model is the Public Sector Intellectual Property Resource for Agriculture (PIPRA) consortium for agricultural biotechnological research for developing countries. In this consortium, 21 non-profit institutions (mainly universities) and the US Department of Agriculture have committed themselves to articulating a non-restrictive licensing policy for research oriented towards the developing world. One important policy tool that this consortium aims to promote is the systematic preservation of the availability of intellectual property rights for research related to developing countries when licensing technologies to the private sector. According to Rai, this is a good example of a case where the expected reputational benefits outweigh the potential financial loss from data-sharing policies. Indeed, as stated by Roger Beachy (2003, p. 473) one of the initiators of the consortium,

> Although there may be a modest financial cost of taking such a position, the potential benefits in terms of regaining public trust, and ultimately of deploying technologies where they may be needed most, far outweigh the financial or opportunity costs [of low commercial value].

A related example in the field of biotechnology research is a consortium for marker-assisted wheat breading (Rai 2005, p. 301). This consortium manages a website that contains research protocols and marker sequences that can be freely accessed and used by researchers all over the world.

These cases of low commercial value present the clearest similarities to the free software model of data sharing. By extension, reputational benefits could also enable data sharing, where there is great uncertainty over the commercial value of research output into microbiology. Here the paradigmatic case is the Human Genome Project, where academic scientists, working with the US National Institutes of Health agreed not to seek property rights to raw human genome sequence data. As argued by Rai, the presence of potentially high reputational benefits for the universities involved played an important role in the success of the Human Genome Project. Moreover, in this context of uncertain, but potentially high, value, the likelihood of gain from strategic behaviour is lower than in the context of research of high commercial value.

By contrast, another initiative for data sharing, the multilateral agreement on non-restrictive material transfer agreements between university technology transfer offices (Uniform Biological Material Transfer Agreement [UBMTA]),[7] failed to generate the expected benefits. In this case, unlike the scientists working on the Human Genome Project, the university technology transfer offices were motivated in significant part by the desire to increase licensing revenue. Hence reputational effects played only a minor role.

The dynamic efficiency of changes in beliefs

A second family of models for studying the dynamic relationships between rules and the social context focuses on the historical processes of sustained adaptation of rules (North 1990). Here the aim is to analyse the conditions that have led to an enduring learning process.

The process of social learning about conflicting beliefs also plays a key role in the field of microbiological commons. Some particularly difficult issues which are the subject of continuing discussion are the protection of traditional knowledge, the regulation of pre-CBD (the Convention of Biological Diversity) resources, and the most appropriate transmission and identification protocols to be used in data sharing. For instance, on the issue of pre-CBD resources, some people argue that the rules governing the flow of resources should focus on modern germplasm exchange related to contemporary needs and interests and that these rules cannot apply to flows of resources from the pre-genomic era which no longer exist (Fowler 2004, p. 51). Others point to the importance of returning equity to countries of origin, especially in the case of biogenetic resources associated with traditional knowledge, or, more simply, to the potential usefulness of the repatriation of certain resources to the provider countries as a means of capacity building or strengthening the links between scientific institutions in developing and developed countries (Muller 2004, pp. 38–40). On the issue of transmission protocols for data sharing, the discussion about the appropriate standard for global data sharing among competing systems (such as the Darwin Core or Access to Biological Collection Data [ABCD] Schema is also a complex issue, especially because of the variety of different types of resources that can be exchanged.

The adoption, by a sufficiently broad range of economic actors, of common institutional rules for data sharing will depend on organising learning processes that supersede these antagonistic beliefs about the most appropriate action. Within new institutional economics, the influence of beliefs on the behaviour of economic actors has been modelled in terms of their influence on the change in the perception of action opportunities. In terms of rational action theory, beliefs influence the actors' behaviour through modifying the weights attached to the different outcomes in the pay-off matrix. According to North (1995, pp. 25–26), dynamic efficiency in a context of changing beliefs is determined by a flexible institutional matrix that organises learning process in a way that allows the economic actors to perceive new action opportunities. These new perceptions in turn create an incentive for the actors to engage in a process of "incremental modification of economic and political rules" (North 1995, pp. 23–24). For example, organising a learning process between private companies and local communities on the role of traditional knowledge in local innovation can help to overcome misunderstanding and opportunistic behaviour and lead to new partnerships being developed around issues of common concern.

However, in a situation of controversy over the validity of the antagonistic beliefs, it is not possible to decide in advance which learning process will produce the optimal outcomes. Hence, a better way of studying the dynamic efficiency of changes in beliefs is to compare historically successful cases of dynamic interaction between rules and beliefs. This method is at the heart of North's study of economic history, and has more recently also been applied successfully in the study of the regulation of climate change and pollution control (Haas 1990; Haas and McCabe 2001). Examples of successful design principles that emerged from these studies are the independence of the learning process from the policy process, the importance of an institutional mandate in the learning community (Haas and McCabe 2001) and the participation of the widest possible community in the learning process, so as to prevent vested interests blocking progress (North 1995).

An interesting example of a successful case of learning within the field of microbiological commons is the role of the OECD in the establishment of the GBIF. The idea of creating the GBIF developed from the discussions organised in the context of the OECD Megascience Forum (now called the OECD Global Science Forum), an intergovernmental forum where scientific ideas can be exchanged and consensus reached on the best way either to acquire new knowledge or to take advantage of a significant scientific development (James 2002, p. 5). The discussions that led to the GBIF took place in the Working Group on Biological Informatics between April 1996 and September 1998[8] and allowed new ideas integrating the concerns of two related communities (the established conservation community on the one hand and the emerging bioinformatics community on the other) to develop. As a result of the recommendations of this working group, an interim steering committee was set up in 1999 under the auspices of the OECD ministers, which finally led to the establishment of the GBIF in autumn 2001.

The learning process that led to the GBIF can be characterised by: (i) the existence of an explicit institutional mandate through the OECD for developing new knowledge among different communities and (ii) a certain degree of independency of the learning community from the policy process in the different member countries.[9] The criterion of independence seems to be very important in the case of the GBIF. Indeed, the initiators of the GBIF insisted on the importance of establishing its secretariat as an autonomous legal entity. This secretariat has been given the task of elaborating its own working programmes for coordinating data sharing in the field of biodiversity. The GBIF recently enlarged its operations to civil society organisations by opening its data portal to the dissemination of the results of the yearly bird count in New York and Berlin's Tiergarten.

The real stake, however, in the field of microbiological commons, is to establish learning processes that can generate a common understanding of the issues involved in organising the conditions for downstream use of data and/or the related biological resources. The GBIF is an interesting example of a learning process, because it is an adaptive organisation and provides some insights into the design rules for dynamic efficiency. However, as stated earlier, it leaves both the ownership rights and the decision rights on the conditions of use of the data and/or the resources to the original data providers. Some institutional learning on the issue of downstream applications is already occurring in other organisations, for example in the 1997–1998 working group of the US National Institutes of Health (NIH) on the transfer of proprietary research tools in biomedical research. However, this and other examples are only organised on an ad hoc basis. More research is needed on the functioning of successful and unsuccessful instances of enduring processes of interaction between beliefs and rules so that we can adapt our knowledge of design rules from other fields to the field of microbiological commons.

Conclusion

The aim of this article is to build a framework for the analysis of the governance of the microbiological information commons, relying on contemporary insights in new institutional economics. I have argued here for the importance of considering the microbiological information commons both as a public good and as a common pool resource, the first referring to it as a common stock of ideas (hence non-subtractable in nature), and the second to the conditions of the organisation of the information flow (which is depletory).

Innovative proposals have been made to deal with the complex incentive problems related to the organisation of data sharing, especially in a context where the existing networks have to face increasing pressure from a globalised intellectual property regime. I considered more closely the successful endeavours of the Global Biodiversity Information Facility and the proposals for a two-tiered regime for governing the conditions of follow-on use of the data and related biological resources.

The main argument of this article is the importance of taking into account the dynamic interaction between institutional rules for data sharing and the changing social context of norms and beliefs. As I attempted to show, this implies going beyond the assumptions of a static framework of institutional design, which allocates a set of institutional rules to obtain the desired behavioural outcomes. Indeed, there is no optimal solution to be found in advance for institutional design in situations of changing norms and controversial beliefs. However, through comparative research, a robust set of design rules can be defined that enforces norms of cooperation and fosters the emergence of common understandings.

Notes

1. The world of micro-organisms, or microscopic organisms, includes bacteria and Archaea, yeast and fungi, and unicellular animals (Protista). In practice however, the term "micro-organism" also refers to microscopic parts of organisms, such as plasmids, phages, DNA probes, plant cells, and viruses, and animal and human cell lines.

2. There are, for example, many facilities in the field of cancer research that initially only conserved cancer cell lines, but which have reorganised themselves as integrated service providers on the BRC model. A good example of such a reform is the European network of blood cord facilities coordinated by Professor Paolo Rebulla at the Ospedale Maggiore in Milan.

3. Peter Riegman (project coordinator), pers. comm. 29 June 2005.

4. Full ownership is only acquired by the possession of the full bundle of seven major property rights, which includes the right of alienation of the resource.

5. See, for example, the successful MySQL database software.

6. Under a copyleft regime for software, all users have the right to modify and adopt the program freely upon the condition that their resulting development is also made freely available for use and further adaptation. The proposal of the OECD working group is to use the same licence provision for non commercial use of databases.

7. This is a voluntary agreement reached in 1995 between university technology transfer offices from more than 100 institutions in the USA. However its success was limited.

8. The report was published in January 1999. In it, the Subgroup on Biodiversity Informatics of the Working Group on Biological Informatics recommended the establishment of an international coordinating body and a new data network called the Global Biodiversity Information Facility.

9. These characteristics are also found in other well-documented historical examples of institutional learning, such as climate change, where the Villach Group played a key role in the organisation of an enduring learning process. This group was composed of international climate scientists who worked on the basis of an institutional mandate from the UNEP Secretariat in the wake of the 1992 Rio Conference. In 1993 the Villach Group was transformed into an intergovernmental panel. It became increasingly susceptible to policy pressure and lost some of its credibility in the second half of the 1990s (Haas and McCabe 2001).

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