The Institutional Economics of Sharing Biological Information

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Abstract

Within the field of biodiversity governance, initiatives for sharing knowledge through networking distributed databases have emerged, operating both on a global scale, such as the Global Biodiversity Information Facility (GBIF) connecting world wide biodiversity resources in a searchable database portal, and in more focused issue networks, such as the European Human Frozen Tumour Tissue Bank (TuBaFrost). In this paper, we analyze the institutional conditions for the development of these institutions for sharing information in the particular case of microbiological resources. Two main results come out of this analysis. First, microbiological information has to be considered as a complex good, having both public good aspects and common pool resources aspects. Second, to solve the incentive problems of this complex good, one has to go beyond a static conception of efficiency, favoring economic incentives through the allocation of intellectual property rights and adopt 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. Extending the methodologies of successful research programs on dynamic efficiency in other fields of new institutional economics, we discuss a framework for defining a robust set of design rules for the governance of the microbiological commons.

Key words: biodiversity, intellectual property rights, knowledge commons, new institutional economics, dynamic efficiency

1. 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 jurisdiction 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 information realm opens perspectives for the implementation of new applications. In this field of the life sciences, new set 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 their complex ecological dynamics (Gevers *et al.*, submitted) 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 novel collaborations between microbiologists, engineers, mathematicians, computer scientists and personnel who have significant knowledge of the legal and socio-economic aspects of sharing biological resources and software tools in the public domain.

For several reasons, the particular case of microorganisms is an ideal prototype to focus on for the analysis of the setup of collaborative endeavours for the exchange and sharing of biological information. Microorganisms are the smallest life forms, but together they represent the single largest mass of life on earth[1]. They are often stepmotherly treated in general biodiversity projects, but analogous to the role of dark matter that is invisibly hidden across the universe, microorganisms cannot be neglected for the creation, maintenance and restoration of balance in virtually all ecosystems. All life on earth is inextricably intertwined with microorganisms as they are critical to maintaining the health of organisms that depend on them for nutrient, mineral and energy recycling, while conversely some microorganisms can cause infectious disease when they overlap with susceptible hosts. Microorganisms 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 microorganisms as a vast, mostly untapped resource of biotechnological potential, and we can study them to understand the majority of life processes 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 world wide microbiological resources, and in more focused issue networks, such as the European Human Frozen Tumour Tissue Databank (TuBaFrost). From a governance perspective, these networks face the increasing pressure from the development of global markets. In particular, the introduction of new standards of intellectual property protection during the last two decades 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 US (Rai and Eisenberg, 2003) and, more recently, the 1996 EU database directive 96/9/EC (Reichmann and Uhlir, 1999). The Bayh-Dole act explicitly gives 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 US increased from fewer than 250 to almost 2700 (Rai, 1999, p. 109). The EC database directive 96/9/EC is a landmark decision that lowered the standards of eligibility to database protection. Indeed the database directive offers copyright protection to databases that are original in the selection or the arrangement of the contents, but also offers protection to non original databases if one can show that there has been a substantial investment in either the obtaining, the verification or the presentation of their contents. So this extends protection to library catalogues for instance, but also to biological information facilities that network different existing databases.

These rulings have to be situated within the wider phenomenon of the globalization of intellectual property rights that has accompanied the genomics 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 key challenge to life sciences research for public purposes, as the research communities have to adapt their strategies and design new institutional arrangements allowing

[1] The world of microorganisms, or microscopic organisms, includes bacteria and archaea, yeast and fungi and unicellular animals (protista). In practice however, the term microorganism also refers to microscopic parts of organisms, such as plasmids, phages, DNA probes, plant cells and viruses and animal and human cell lines.

to provide services of general interest in an increasingly competitive and international environment.

In this paper, we will analyze the models for institutional design of database sharing in this context of global intellectual property rights. In particular, we will rely on contemporary insights in new institutional economics that show the necessity to develop 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 (Reichman and Uhlir, 2003; Hess and Ostrom, 2003; Hess and Ostrom, 2005a). For instance, within the related field of digital communication, the development of E-print repositories such as arXiv.org and BioMedCentral or the development of trusted digital repositories for knowledge of general interest is based on the coordination between groups of scholars and information specialists for the building of a common knowledge pool. What is new in these initiatives is that authors are participating in an international epistemic community that is committed to building an interoperable global scholarly library –with the goal to obtain higher joint benefits and to reduce their joint harm from the enclosure process. In the case of database fusion in the field of microbiological resources, the recourse to such collaborative arrangements seems also necessary, in order to cope with the problems of uncertainty and complexity of the innovation process. In particular, collective arrangements in the knowledge networks seem necessary to go beyond market insufficiencies created by the unpredictable character of the automated knowledge creation process and to create new partnerships between the diverse set of both public and private actors that are involved in the entire innovation chain.

We will further 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, we will 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 will argue for the necessity to complete this static approach of economic efficiency, which favours economic incentives through the allocation of intellectual property rights, and argue in favour of the adoption of 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.

2. Setting the stage: the transaction situation and governance models

Data sharing of microbiological information is essential for expedited 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 no longer 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 consideration of 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, and 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 bio-banks and culture collections, which organise the collection, conservation, curation and exchange of biological resources and related data. Those collections are an outgrowth of the conventional pre-genomics *ex situ* collections of biological materials that have progressively developed into multi-service facilities called Biological Resource Centres. The concept of Biological Resource Centres (BRCs) was proposed in an influential OECD report in 2001, which defines BRCs as "service providers and repositories of the living cells and, genomes of organism, 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" (*Ibid*.). While "BRC" refers to collections of resources from any origin, including human origin, the term "biobank" refers more particularly to organized collections of biological samples from human origin and the data associated with them[2]. Like BRC, biobanks come in many different forms, according to the type of samples that are stored and the domain in which they are collected.

Different initiatives for sharing knowledge through databases, gathering knowledge from different fields of microbiology exist, such as within the CABRI or the TuBa Frost network mentioned in the introduction or the ongoing Global Biodiversity Information Facility (GBIF) project[3]. These networks face the increasing pressure from the development of global intellectual property rights, which has lead to a competition for the ownership of previously shared resources. In 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 regulation of markets or *quasi*-markets. In the context of this new role of the state, cost effective access can for example be guaranteed through introducing a general research exemption for database access for non-commercial research. In a similar manner, 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 characterized as being part of the public domain (Oldham, 2004, p.59; Williamson, 1998, pp. 9-11; Smith *et al.*, 2004), 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, calling for a more fine grained approach.

That's why we will focus on the following questions: What are the characteristics of the good that is exchanged and the related incentive problems for provision and use of the good? (2.1.); what are the institutional solutions for dealing with these complex incentive problems that are currently being proposed (2.2.)?

[2] One can for example refer to many facilities in the field of cancer research that initially only were conserving cancer cell lines, but which have organised themselves on the model of BRCs in integrated service provider facilities. A good example of such a reform based on the BRC concept is the European network of blood cord facilities coordinated by the "Ospedale Maggiore" hospital in Milan (prof. Paolo Rebulla).

[3] Cf. www.cabri.org and www.gbif.org

2.1. 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" (Lessig, 1999; Benkler, 1998) – are characterized by non-exclusiveness in consumption (Kaul *et al.*, 2003, p. 79). That means, the public domain covers a broad set of phenomena where multiple users are in some way sharing a resource (Hess and Ostrom, 2005a, 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 characterized by non-exclusiveness and hence sharing of resources. However, in the case of public goods, the consumption of the resource by one does not diminish the possibilities of consumption by others. Paradigmatic examples are mathematical *formula*, 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 substracts from the products available to others. This is typically the case of depletable resources such as forests, nature parks and clean atmosphere.

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 persons benefiting from a public good who are not contributing to its production (Hess and Ostrom, 2005a, pp. 3-5). In the case of common pool resources, however, since there is subtractability in use, potentially perverse incentives exist both on the production and the consumption or use side (*Ibid*., 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 characteristics both of public goods and common pool resources. In table 1, we have illustrated this distinction and the related incentive problems for three components of the knowledge commons : the information as a non-physical flow unit that is exchanged within the collaborative networks, the physical flow units or artefacts 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 an immaterial 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-depletable. The use of an idea by someone does not substract form the capability of another individual from using the same idea at the same time. As such, in a similar manner as in the case of the self-archiving initiatives in the field of scholarly communications (Hess and Ostrom, 2003, p. 143), researchers that are participating in the building of the global biological information facilities are building a universal public good for which the more who have access, the greater the benefit to everyone (*Ibid.*). Positive incentives that play a role in the self-archiving initiatives, such as cost reduction of publication and access, scientific recognition and credibility that comes with public disclosure, increased visibility of information and instant publication and dissemination (Hess and Ostrom, 2005, p. 5), also have been documented in the field of the microbiological information commons (Rai, 1999, p. 92-95).

Second, information as a non-physical flow unit has also been characterized as a depletable resource and hence presents characteristics of a common pool resource. Indeed, the value of the information for the users is not only related to their possibility to access a stock or a pool of accumulated knowledge somewhere in an *encyclopaedia* or a digital repository, but is also related 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 the compliance with a set of rules, such as the verification of the quality of the information that is submitted in return to the common pool, appropriate citation of the source of the information and cross-lining of the information with the information generated by the users' communities of the concerned field of knowledge. Non compliance or violation of these rules deteriorates the common knowledge base and can lead to the "dry out" of the information flow. The distinction between the stock of information and the flow is very crucial in the field of the microbiological information commons, because of the increasing role of databases as a flow resource in the organisation of the information exchange.

	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 to the exchange of tumour tissue data	Common web server for storing images
Positive incentives	Visibility, public recognition, instant publication	Access to first hand high quality information related to the data	On line verification of the diagnosis
Perverse incentives	Underuse: 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 large portions of memory space

Table 1. Incentive problems for the public good aspects and common pool resource aspects of the microbiological information commons (examples adapted from Hess and Ostrom, 2005b, table 1; for the simplicity of the presentation we merged production and use incentives).

As has been argued by Reichman in his work on database policies, the information contained in the 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 on the possibility to link databases back to "local knowledge", for instance the knowledge about the behavioural properties of a resource in the environment or the laboratory or, conversely, to test a possible path of innovation by confronting it with the downstream user communities.

Third, as we mentioned above, sharing microbiological information through microbiological information facilities is a complex endeavour that involves also the sharing of 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, both on the level of 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 the biological resources and numerical identifiers for a persistent identification of the data throughout the process of data exchange with different user communities. Some of these resources are non-depletable in nature, such as common standards, and can appropriately be described as public goods. Others are depletable, such as the bandwith of the transmission infrastructure or the memory space on a common database webserver, 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[4]. The TuBaFrost network is gathering data of high quality frozen tumour tissue samples with a corresponding accurate diagnosis, stored in major European cancer centres and universities, by making 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 by all without restriction, and that the access to the search engine of the database is open to all science users, under the condition that they register to the website. The control of misuse of the information is done through the registration protocol : everybody can register through a simple web-interface, if he provides his name, e-mail and the reason why he uses the database. This allows an *ex ante* verification of the intent of the users and, through keeping track of the identity profile, an *ex post* control of misuse.

The access to other tools, such as self-archiving and the use of a service for the exchange of tumour tissues, is reserved to the project participants. One of the positive incentives to become full participant on the production side is indirect. Through being involved in the generation of a high quality information flow on tumour tissue samples, the partners expect to have access to first hand high quality information related to the data in question[5].

A key physical resource that is shared in the project is the Nanozoomer, which allows to store representative histology images in a central database, enlarge them 20x or 40x and access them through the virtual tumour bank. The advantage is that, through the addition of images to the virtual tumour bank, diagnosis can be verified on line. However, this creates also a depletable resource to be shared, which is 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, in which one has to deal with different types of goods, pure public goods, such as the information itself that is contributed to the stock of common knowledge, and common pool resources, such as the self-archiving facility and the Nanozoomer.

2.2. Institutional solutions to the incentive problems

In the previous section we argued that data sharing in the microbiological commons implies the provision of different goods, most importantly the information facility, the information flow and the physical storage system for the digital artefacts. Providing these goods implies to deal with a complex incentive problem, facing a set of potentially perverse incentives such as free riding on the public maintenance of the information stock or misuse and misappropriation of the common information flow. In this section, we will analyze some of the collective actors' arrangements that have been currently considered for organising the data sharing in the

[4] www.tubafrost.org last visited 4th of July 2005.
[5] Conversation with the project coordinator, Peter Riegman.

microbiological commons, focusing more particularly on the role of property rights and contractual arrangements.

Institutional economics shows the role of well-defined property rights in helping to reinforce a long term perspective in the management of a resource and to stimulate investment in the design of institutional rules that can cope with the incentive problems (ref. Schlager and Ostrom, 1993; Demsetz, 1967). 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 it has been shown, well-defined rights on a good, such as a natural resource, can for example include exclusion and management rights attributed to a private organisation, but the resource itself remaining in state ownership. In a similar manner, data sharing through a data portal can imply the exercise of management and exclusion rights by a dedicated organisation, without necessarily having to transfer the full ownership of the original databases to this entity. That's why economist have analysed property rights as a "bundle" of use and decision rights attributed to certain economic agents. Such bundle of rights specifies a set of operational rights (the use that one can make of a resource) and a set of collective choice rights (who can decide upon the future exercise of the rights on the resource). In their framework article, Hess and Ostrom (2005a) distinguish seven major types of property rights that are most relevant for the digital knowledge commons (cf. table 2).

1. **Access**	The right to enter a defined physical area and enjoy nonsubtractive 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.

Table 2. The bundle of rights in the digital knowledge commons (source: Hess and Ostrom, 2005a, p. 14-15). Number 1 till 4 are operational rights, number 5 till 7 collective choice rights[6].

Second, from the point of view of new institutional economics, property rights are considered in relation to the action outcomes that result from the attribution of these rights to certain economic agents regarding a specific domain and in a certain action situation. In particular, these outcomes depend on the effective institutional rules that are defined and enforced by the agents to exercise these rights. Property rights as such only authorize particular actions, but still need a set of workable institutions to make them effective in a particular action situation.

[6] Full ownership is only acquired in the case of the possession of the full bundle of 7 major property rights, which includes the right of alienation of the resource.

The consequences of a set of property rights will hence depend on the cost and the 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 proven to lead to the most efficient outcomes. However, in other cases, the costs implied in the exercise of the private property rights, such as the creation and the 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 the 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 the 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 has to be at least common rules for exclusion and management. These rules are necessary in order to delimitate the boundaries of the common pool and impose graduated sanctions for compliance with the rules of use preventing depletion of the resource.

a. Facilitating free dissemination with decentralized ownership

In a first model of data sharing, ownership remains with the individual data providers – and hence the right to alienation – but the providers transfer a part of their management and exclusion rights to a common dataportal.

Some key features of this first model can be analysed through the example of the Global Biodiversity Facility (GBIF). In the case of GBIF, different data providers provide data to a collaborative database, who makes the data in turn freely available to non commercial users, such as illustrated in figure 1 (cf. figure 1 at the end of the document). The ownership of the data and the related conditions on the use of the data remain with the original providers. That means that GBIF does not assert any intellectual property right in the data that is made available through its network. Moreover, all data are made available with 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 to deal with different incentive problems related to the governance of the information flow as a common pool resource :

1. When registering their services with GBIF, the data provider has to sign the GBIF data sharing agreement. This agreement stipulates that the data provider makes reasonable efforts to ensure that the data are accurate and that the data provider includes a stable and unique identifier in 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 a stable computer gateway (the so-called data nodes) that makes 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 program and maintain the central services for the GBIF network. In particular, GBIF secretariat may serve full or partial data further 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 agreeing with 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 action arrangement, GBIF facilitates the free dissemination of biodiversity related data. In practice, GBIF is pooling data that are in most of the cases already in the public domain or that have been commissioned explicitly for public purposes and can receive wider audience through being accessible through the data portal. That's why some more sophisticated models have been developed to satisfy both the public research interests and the commercial opportunities, in so-called "two-tiered" models.

b. Organizing the licensing of data through a collective license organisation

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

A 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 of commercial and non-commercial use of the database content is called for. Indeed, under public domain databases and/or in the absence of collective management of the conditions of follow-on use, data sharing does not guarantee under all circumstances credit to the individual researchers originally producing the data, nor provide them with any reward if extensions of their work are commercialised (Eckersley *et al.*, 2003, p. 155). Moreover, it only provides weak protection against the broader problem of "patent thickets" (*Ibid.,* 156).

Under these conditions, the OECD working group advices to use different contractual conditions for access to the database in the case of commercial and non commercial use. In this model, which is analogous to the dual licensing model used by some software developers[7], non commercial redistribution is permitted by a copyleft license, under the usual conditions of mentioning the source of the data (guarantee of credit). Commercial use of the same data is permitted, under the condition to negotiate a specific contract that includes the restrictions upon this commercial use and specifies the license fee. The negotiation of these ownership licenses could be done with a Collective License Organisation administering the database (cf. figure 2 at the end of the document).

[7] As for example in the case of the successful MySQL database software.

c. Organizing licensing of data through agreed upon contractual templates

The proposals of a dual licensing model for neuroinformatics data sharing is in many respects similar to the conditional deposits model argued for by Reichman and Uhlir in the broader context of the sharing of governmental funded scientific research data. However, in their work, they consider a negotiated solution, rather than the recourse to a Collective License Organisation (cf. figure 3 at the end of the document).

As argued by Reichman and Uhlir, because of the potential problems of leakage (moral hazard) and enforcement (accountability) in the Collective License Organizations, the data providers may very well balk at participating to 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 negotiating the terms of their private transactions and / or they might want to impose restrictions on the uses of the data deposited for commercial purposes. Under such conditions, data sharing on the basis of a multilateral negotiated agreement is to be prefered. The core of their proposal is a common agreement on the contractual templates to be used in the 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-commities – all of whom must eventually weigh in to ensure that academics themselves observe the norms that they would thus have collectively implemented" (*Ibid* : 439).

3. Enhancing dynamic efficiency

In the first section I argued for the importance of considering the microbiological information commons both in its public good aspect and its common pool resource aspect. The latter is especially related to the "flow" character of the resource, which is depletable in nature and depends on appropriate contribution of each network partner and clear rules for dealing with opportunistic behaviours. However, the proposed institutional options that we considered still are situated in a static conception of economic efficiency. Indeed the *rationale* is 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 (Young, 2001; Brousseau, 2000). In particular, in situations of changing and controversial social contexts, one of them cannot make an *ex ante* evaluation of the best possible institutional solution. That's why several authors argue in favour of adopting a dynamic approach to economic efficiency (Ostrom, 1998; Eggerston, 1990; Denzau & North, 1994; Knight & North, 1997; Rai, 1999). Such an approach is not geared towards the *ex ante* allocation of resources and institutional means, but rather to creating incentives for permanent adaptation and innovation through reflexive processes of social learning and institutional experimentation. We have illustrated this distinction between static and dynamic efficiency in table 3.

Especially in the situation of complex global interlinkages that characterizes the microbiological information commons, dynamic efficiency plays a key role in enhancing the effectiveness of governance arrangements. The viability of the collaborative databases crucially depends 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 the new rules of intellectual property rights has lead to a decline of the *sharing ethos* in the science communities, and hence new cooperative networks and norms have to be developed in order to sustain the practices of data sharing. In other cases, important changes have occurred on the level of the beliefs of different actor communities. For example, the new concepts that resulted from the work in the OECD working group on the relationship between bioinformatics and biodiversity was one of the key factors that allowed innovative partnerships to emerge between institutions having very different institutional policies at the outset.

	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 (*ex ante*) definition 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

Table 3. Some key features of the difference between static and dynamic efficiency (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 one can call “structuralist” models, focuses on a set of cases where particular configurations of rules and norms have lead to sustainable outcomes and enhanced welfare (Ostrom, 1986). From an in depth analysis of the conditions of 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 we one can call “process”, focuses on the historical processes of continuous change in rules (North, 1990). Here the stake is to analyse the conditions that have lead to an enduring process dynamic interaction between rules and changing beliefs in a given transaction situation. Through this analysis, the goal is to identify certain bottlenecks or deadlocks of the learning processes that have lead to suboptimal outcomes in the past such as the restriction of 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 pointing to a double dynamic role of governance institutions in influencing the social context of the collaborative database initiatives: first, their role in enforcing the norms of cooperation and within the network of concerned actors of the self-governed collective action 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.

3.1 Dynamic efficiency of norm change

The introduction of new rules of intellectual property rights for results of governmentally funded basic research had a major impact on the norms of the science community. First, the norms that characterize fundamental research such as common cumulative heritage, independent inquiry and originality (Merton, 1973) have to compete since with norms of exclusion and profit raising that gain ground in the researchers' community. An often cited example is the survey by Blumenthal among life science faculty, showing that participation by academics to industry funded research is associated with a delay in publication of their research results greater than six months because of issues of intellectual property rights (Blumenthal, 1997).

The design of self-governed collective action institutions has also to take into account this changing social context. However, under conditions of changing norms, the institutional rules that one would like to adopt will alter in turn the norms of the concerned actors and hence one cannot establish any more a linear relationship between a given set of rules and their outcomes. Under such conditions, comparative analysis has proven useful to study the interaction between rules and the social context. As has been shown in the case of the research on common pool resources, focusing on effective "social possibilities", where particular configurations of rules and norm have lead to sustainable outcomes and enhanced welfare, allows to define a set of robust design rules that are common to the successful endeavours. This "structuralist" methodology has also proven useful in the field of the knowledge commons. In their seminal research, Hess and Ostrom (2003; 2005a) show that some of the features of this comparative analysis can be adapted for the study of the new digital knowledge commons. For instance, a report of the Research Library Group and OCLC, cited by Hess and Ostrom in their initial paper (2003), defines the required actions and rules for creating a succesfull cooperation in the particular case of trusted digital libraries as having (a) audibility, security, and communication; (2) compliance and conscientiousness; (3) certification, copying controls, and following rules; (4) backup policies and avoiding, detecting and restoring lost/corrupted information; (5) reputation and performance; (6) agreements between creators and providers; (7) open sharing of information about what it is preserving and for whom; (8) balanced risk, benefit, and cost; (9) complementarity, cost-effectiveness, scalability and confidence; and (10) evaluation of system components (*Ibid*., p. 144). These principles give an example of the design rules for enhancing cooperative behaviours and system resilience that are needed to sustain the global knowledge commons.
Nevertheless, further comparative analysis is needed to gain insights in the specific design characteristics of data sharing in the digital environment.

One of the most advanced attempts in this direction, in the field of the microbiological commons, is the empirical research of Arti Rai on the intellectual property rights and the norms of science (Rai, 2005). In her comparative research on data sharing initiatives, she 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 both in the field of open-software and biotechnology, her analysis shows that the chances of success of self-governed collective action initiatives for data sharing is the highest where reputational effects are important and the capital input that is required for participating into the data sharing very low. A case in point is the success of the open-source software. Indeed, in this case, transaction costs for establishing reputional mechanisms remain low, because the informational inputs of large numbers of individuals can be readily evaluated and integrated in the on line environment. In the same time, volunteers must not invest resources for participating other than time.

An important example of data sharing in the field of microbiology that complies with this model is the PIPRA consortium for agricultural biotechnological research for developing countries (Public Sector Intellectual Property Resource for Agriculture)[8]. 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 to systematically preserve the availability of intellectual property rights for developing countries related research, when licensing technologies to the private sector. According to Rai, it is a good example of a case where the expected reputational benefits outweigh the potential financial loss of data sharing policies. Indeed, as stated by Roger Beachy, one of the initiators of the consortium, "[a]lthough 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" (Beachy, 2003, p. 473). A related example in the field of low value 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 researchers all over the world can freely access and use.

These cases of low use value present the clearest similarities with the free software model of data sharing. By extension, reputational benefits could also enable data sharing, where there is high uncertainty on the use value of research 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 proprietary rights in raw human genome sequence data. As argued by Rai, the presence of potentially high reputational benefits for the involved universities played an important role in the success of the Human Genome Project. Moreover, in this context of uncertain, but potentially high, use value, the likelihood of gain from strategic behaviour is lower than in the context of high-value research. By contrast, another initiative for data sharing, the multilateral agreement on non-restrictive material transfer agreements amongst Technology Transfer Offices, "UBMTA[9]", failed to generate the expected policies. In this case, unlike the scientists working on the Human Genome Project, the university technology transfer offices are motivated in significant part by the desire to increase licensing revenue. Hence reputational effects played only a minor role.

3.2 *Dynamic efficiency of change 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 in the rules (North, 1990). Here the stake is to analyse the conditions that have lead to an enduring learning process.

Process of social learning over conflicting beliefs also play a key role in the field of the microbiological commons. Some particular hard issues of ongoing discussion are the protection of traditional knowledge, the regulation of "pre-CBD" resources or the discussions

[8] www.pipra.org last visited July 2005.
[9] UBMTA stands for "Uniform Biological Material Transfer Agreement". It is a voluntary agreement reached in 1995 between university technology transfer offices from more than 100 institutions in the US, but with limited success.

about the most appropriate transmission and identification protocols to be used in data sharing. For instance, on the issue of pre-CBD resources, some argue that the rules for governing the flow of resources have to 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 area that do not longer exist (Fowler, 2004, p. 51). Others however point to the issue of returning equity to countries of origin, especially in the case of biogenetic resources with associated traditional knowledge, or, more simply, to the potential usefulness of 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 Darwin Core or ABCD respectively, is also a complex issue, especially because of the variety of different types of resources that can be exchanged.

The adoption of common institutional rules for data sharing, by a sufficiently broad range of economic actors, will depend on organizing learning processes that allow going beyond these antagonistic beliefs determining the perceptions of what is the most appropriate action to undertake. Within new institutional economics, this influence of beliefs on the behaviour of the 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 organizes learning process among the economic actors that allow them to perceive new action opportunities. These new perceptions create in turn an incentive for the actors to engage in a process of "incremental modification of economic and political rules" (*Ibid.*, p. 23-24). For example, organizing a learning process between private companies and local communities on the role of traditional knowledge in local innovation can lead to overcome misunderstanding and opportunistic behaviour and lead to develop new partnerships around issues of common concern.

However, in a situation of controversy over the validity of the antagonistic beliefs, it is not possible to analyze ex ante what learning process will produce the most optimal outcomes. Hence, a more sound endeavour for studying the dynamic efficiency of change in beliefs is to compare historically successful cases of dynamic interaction between rules and beliefs. This method is at the heart of the study of economic history by North, but has more recently also been applied successfully in the study of the regulation of climate change (Haas and McCabe, 2001). Examples of successful design principles that came out of these studies are the independence of the learning process from the policy process, the importance of an institutional mandate of the learning community (*Ibid.*) and the participation by the widest possible community to the learning process, in order to go beyond the blocking by the vested interests (North, 1995).

An interesting example of a successful case of learning within the field of the microbiological commons is the role of the OECD in the establishment of the Global Biodiversity Facility (GBIF). The idea of the creation of the GBIF came out of the discussions organised in the context of the OECD Megascience Forum[10], an intergovernmental forum where scientific ideas can be exchanged and consensus reached on the best way either to acquire new

[10] Now called the OECD Global Science Forum

knowledge or to take advantage of a significant scientific development (James, 2002, p. 5). The discussions that have lead to the GBIF took place in the Working Group on Biological Informatics between April 1996 and September 1998[11] and allowed to develop new ideas integrating the concerns of two related communities : the already established conservation community on the one hand and the emerging bioinformatics community on the other. 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 lead to the establishment of the GBIF in autumn 2001.

The learning process that has lead to the GBIF can be characterized by (1) the existence of an explicit institutional mandate, through the OECD, for developing new knowledge among different communities and (2) a certain degree of independency of the learning community from the policy process in the different member countries[10]. The criterion of independence seems to be very important in the case of GBIF. Indeed, the initiators of GBIF insisted on the importance of establishing the GBIF secretariat as an autonomous legal entity. This secretariat has been mandated with the task of elaborating its own working programs for coordinating data sharing in the field of biodiversity. For instance, recently the GBIF enlarged its operations to civil society organizations, through opening its data portal to the dissemination of the results of the yearly bird counting in New-York and Berlin Tiergarten.

The real stake however, in the field of the microbiological commons, is to establish learning processes that can generate common understanding on the issues involved in organizing the conditions for downstream use of the data and/or the related biological resources. The GBIF is an interesting example of learning processes, 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 is already occurring on the issue of downstream applications in other organisations, such as 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 remain organised on an *ad hoc* basis. More research is needed on the functioning of successful and failed 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 the microbiological commons.

Conclusion

The object of this paper is the building of a framework for the analysis of the governance of the microbiological information commons, relying on contemporary insights in new institutional economics. In this paper, we argued for the importance of considering the microbiological information commons both in its aspect of a public good and as a common pool resource, the first referring to its characteristic of being a common stock of ideas, hence

[11] The report was published in January 1999. In this report, the sub-group 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.

[10] These characteristics are also found back in other well studied historical examples of institutional learning, such as in the case of climate change, where the Villach Group played a key role in the organization of an enduring learning process. This group was composed of a group of international climate scientist that worked on the basis of an institutional mandate of the UNEP secretariat at the wake of the 1992 Rio Conference. The Villach Group was transformed in 1993 in an intergovernmental panel that became increasingly dependant of policy pressure and lost some of its credibility in the second half of the 90ies (Haas and McCabe, 2001).

non-substractable in nature, and the second to the conditions of the organisation of the information flow, which is depletable.

Innovative proposals have been made to deal with the complex incentive problems related to the organization of the data sharing, especially in a context where the existent networks have to face the increasing pressure of a globalized intellectual property regime. We considered more closely the successful endeavour 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 paper is the importance of taking into account the dynamic interaction between these proposed institutional rules for data sharing and the changing social context of norms and beliefs. As we attempted to show, this implies to go beyond the assumptions of the static framework of institutional design, which allocates a set of institutional rules to obtain the desired behavioural outcomes. Indeed, there is no *ex ante* optimal solution 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.

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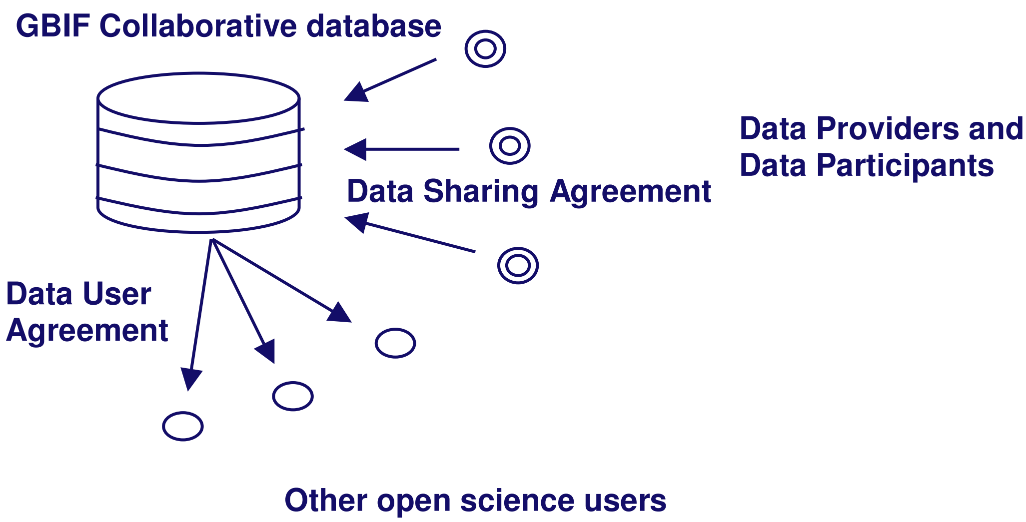

Figure 1. The GBIF Model of data sharing (figure of the author).

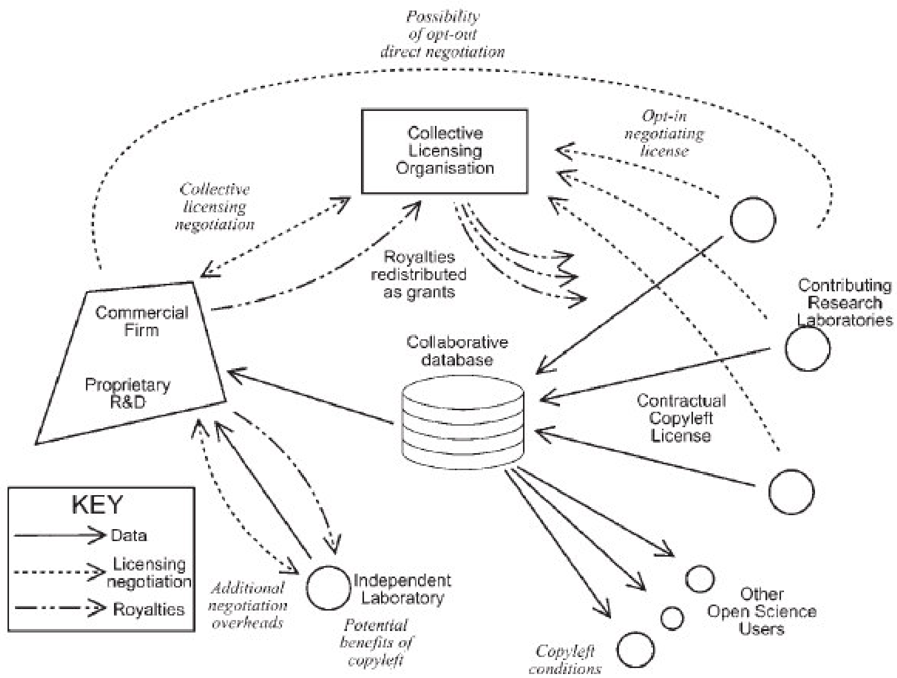

Figure 2. A two tiered system for data sharing based on the transfer of property to a collective licensing organization (source of the figure : Elckersley *et al.*, 2003).

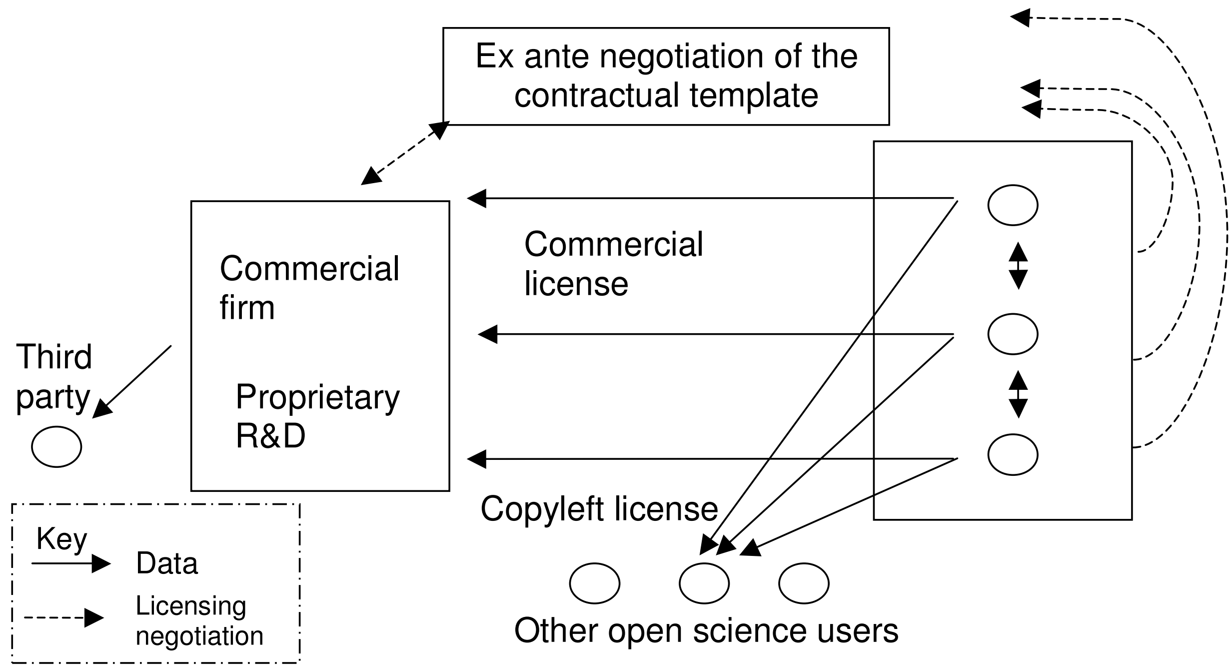

Figure 3. Two tiered system for data sharing based on a multilateral agreement on contractual templates (Figure of the author, based on the proposals develop in Reichman and Uhlir, 2003).