The institutional economics of biodiversity, biological materials, and bioprospecting

Margaret Polski*

Indiana University, SPEA 201, 1315 E. Tenth Street, Bloomington, IN 47405-1701, United States

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Abstract

This paper analyzes the fundamental economic and institutional issues connected with biodiversity, biological materials, and bioprospecting. The main findings are that biodiversity and biological materials are common pool goods and must be governed accordingly; research and development using biological materials is a dynamic, inter-temporal asset transformation process that has a mixed economic nature, which requires equally diverse and dynamic governance rules and processes; in general, bioprospecting is best governed by relationship contracting principals that are designed to fit specific economic and institutional conditions. However, there are no blueprints for access and benefit sharing: in addition to extensive consultations with a wide range of stakeholders, developing appropriate policy and regulatory solutions requires detailed empirical analyses of specific asset transformation processes in particular technological, cultural, and institutional settings.

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1. Introduction

Designing policies that effectively implement the access and benefit sharing provisions of the Convention on Biodiversity (CBD) requires a clear understanding of the institutional economics of biodiversity, biological materials, bioprospecting, and biotechnological research and development processes. Developing this understanding requires that we grapple more specifically with a number of issues:

(1) What is the nature of biodiversity? Who is involved in either limiting or sustaining it?
(2) What is the nature of biological materials and biospropecting? How are they connected with biodiversity?
(3) What is the value of different types of biological materials and to whom does this value accrue? Bioprospecting? How do these values change over time, if at all?

* Fax: +1 812 855 0184.
E-mail address: mpolski@indiana.edu.

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What do we know empirically about how to sustain biodiversity and what are the implications of these principles with respect to managing biological materials and bioprospecting activities?

What are the principles upon which appropriate regulatory schemes may be designed?

This paper explores these issues and provides a framework for further research and policy design. The analysis proceeds as follows. Section 2 provides background on the Convention on Biological Diversity. Section 3 deals with the nature of biodiversity and focuses the analysis. Section 4 analyzes the economic nature of biodiversity and biological materials and develops the implications for bioprospecting. Section 5 identifies some of the governance problems inherent to bioprospecting and situates these dilemmas in the institutional economics literature. Section 7 concludes.

2. Background

The Convention on Biological Diversity (CBD), which took effect December 29, 1993, aims to conserve biodiversity, encourage sustainable use of the components of biodiversity, and assure fair and equitable sharing of the benefits of biodiversity. It has also generated considerable controversy and presents some very interesting challenges for researchers and policymakers.

At present, the Convention includes 180 countries. A number of provisions pose particular challenges for the Parties including those that require national action to protect indigenous knowledge, provide access to biological materials, assure that the benefits that accrue from the use of biological materials are shared in fair and equitable ways, facilitate technology transfer, cooperate to advance biotechnological developments, and adopt economically and socially sound measures that act as incentives for conservation and sustainable use.

In May 2000, the Conference of the Parties (COP) established a working group to develop guidelines on access and benefit sharing issues. An ad hoc group met in October 2001 in Bonn, Germany. Their work product, the Bonn Guidelines, was subsequently adopted under Decision VI/24 at a meeting of the COP in April 2002.

The Bonn Guidelines, which are voluntary, provide a list of elements for material transfer agreements that arise from bioprospecting and trade. A key element is an action plan for capacity building for access and benefit sharing. Suggested areas for capacity building include strengthening relevant institutions, valuation of genetic resources and market information, and studies of legislative measures. The Guidelines also anticipate the need to harmonize with related Conventions, such as the International Union for the Protection of New Varieties of Plants (UPOV) and the World Trade Organization’s (WTO) agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS). Finally, they urge the World Property Rights Organization to undertake extensive studies of the impact of intellectual property regimes on genetic resources and scientific research, and to make rapid progress in developing model intellectual property clauses.

Many of the activities that the Parties to the CBD will regulate under the Bonn Guidelines pertain to bioprospecting, which is the search for useful biological materials in microorganisms, plants, fungi, animals, and humans. As researchers and policymakers grapple with regulating bioprospecting activities, they are reconsidering classical and indigenous conceptions of property rights and contracting. However, many analyses and proposals are based upon under-researched assumptions about the economic and institutional nature of biodiversity, biological materials, innovation, research and development, the nature of contracting, and the strengths and limitations of alternative organizational and governance schemes. In particular, these proposals often overlook the

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1 The complete Convention is available at [http://www.biodiv.org](http://www.biodiv.org). The Cartagena Protocol on Biosafety, which was adopted by the signatory countries in January 2000, regulates the transboundary movement of living modified organisms (LMOs) resulting from biotechnology. It supplements the Convention by providing a harmonized set of international rules and procedures to ensure that countries have the relevant information to enable them to make informed decisions about importing LMOs. Information about the Protocol is available at [http://www.biodiv.org/biosafety](http://www.biodiv.org/biosafety).

2 Decision VI/24, which includes the Bonn Guidelines, is available at [http://www.biodiv.org](http://www.biodiv.org).
complex nature of biodiversity, biological materials, and bioprospecting and the types of collective action problems that are associated with management and governance.

3. Biodiversity

Before we can understand how to regulate biological materials and bioprospecting, we must first understand them in the context of sustaining biodiversity. The CBD defines biological diversity to include “all aspects of variability evident within the living world, including diversity within and between individuals, populations, species, communities, and ecosystems.” This is a very broad definition that potentially includes all nonhuman biological materials (NHBMs) as well as all human biological materials (HBM)s in the world as we know it at a given time. For example, the scope of the CBD potentially includes all the organisms on the Earth and those we discover as we explore our Universe. This is a lot of organisms and a very complex regulatory challenge: in addition to humans, organisms exist in natural habitats, in laboratories, in special repositories, and in our homes, offices, and cars—they even travel with us and with our animals.

While the language of the Convention provides a broad scope for action, CBD discussion documents suggest that the Parties are at present focusing on NHBMs and their natural habitats: the most recent report of the Secretariat of the Convention asserts that the diversity of nonhuman species is the most useful measure of biodiversity. The report, which analyzes bacteria, protoctists, animals, fungi, and plants in different types of habitats on the Earth’s surface, indicates that around 1.75 million species have been described and formally named.

However, there is reason to believe that several million more species exist but remain undiscovered and undescribed. While these species exist in many different types of habitats, they are not evenly distributed over the planet. The most species rich environments holding 60–90% of all species and accounting for nearly one third of global terrestrial annual net primary production are tropical forests that extend over about 7% of the Earth’s land surface. Most tropical forests are located in developing countries in Africa, Asia, Central America, the Caribbean, and South America. The “megadiversity countries,” which are believed to contain 70% of the world’s species diversity are Mexico, Columbia, Ecuador, Peru, Brazil, Zaire, Madagascar, China, India, Malaysia, Indonesia, and Australia.

It is quite difficult to accurately calculate changes in biodiversity because scientific knowledge of the world’s species is so incomplete. Scientists estimate that, over geological time as a whole, biodiversity has increased even though virtually all the species that have ever existed are now extinct. Extinction of species is a natural and expected event however evidence from the fossil record indicates that the extinction rate over the past 400 years is 100–200 times higher than in prior periods. While the reliability of this estimate is undermined by the inherent bias in the fossil record, the general trend is supported by other estimations. Most predictions of the contemporary extinction rate are based on combining estimates of species richness in tropical forests with estimates of rate of loss of these forests. Species extinction is then predicted on the basis of the general species–area relationship, increasing or declining as area increases or declines.

Few actual species extinctions have been observed in tropical forests however, monitoring species in these habitats is quite difficult. Rates of deforestation are high in both absolute and proportional terms, implying a relatively high rate of species extinction. Moreover, there appears to be an interactive link between changes in biodiversity and the question of science and technology in the international community.
in land cover and climate change, which places additional stress on ecosystems and species, e.g. global warming can contribute to diminishing land cover and diminishing land cover can contribute to global warming. Even without these changes, species in these habitats are under stress due to over-harvesting, pollution, and incursions by invasive species.

In summary, for the purpose of grappling with the challenges of implementing the CBD, biodiversity is nonhuman species variation that results from reproduction in natural resource habitats, particularly moist tropical forests in “megadiverse” countries in Africa, Asia, Central America, the Caribbean, and South America. While there is limited evidence that biodiversity is diminishing, we do know that human activities in natural resource habitats can adversely affect species variation when they are poorly managed.

4. The economic nature of biodiversity

Modern economic theory posits four classes of goods and services: private; public; club or toll; common pool. The differences among these types of goods have important implications for estimating and allocating the value of producing and providing them, and for efficiently organizing and governing supply and demand. An overview of these assumptions may be useful in following the arguments in this section: a summary is provided in Appendix A. Forewarned and with the tools to forearm, the analysis proceeds without further explanation.10

Biodiversity is a bi-product of reproduction among living organisms in natural resources. Hence, we can think of it as an outcome of the physical structure of a natural resource as well as the way that the resource is managed and governed. Natural resources are common pool goods: one user’s consumption subtracts from the supply available for others yet the physical nature of the resource makes it very difficult to exclude users. NHBMs are discrete living organisms in common pool resources (CPRs) that are integral components. In other words, they are part of the value chain that produces and provides common pool resources, which in turn are part of the value chain that produces and provides biodiversity. Finally, NHBMs may be components of the value chains of other types of goods and services such as drug therapies, religious practice, or furniture. However, until they are used as inputs to produce and provide other types of goods and services (and are transformed from one type of good to another), we can think of them as common pool goods.11

Bioprospecting is the search for useful biological materials (NHBMs) in CPRs. Whereas biodiversity is an outcome of the way that reproduction occurs in CPRs and NHBMs are discrete components of these systems, bioprospecting is a productive activity that takes place in a CPR. But bioprospecting is only one of a number of economic activities that can take place in CPRs.

Since tropical forests are the richest sources of NHBMs, we can use forest resources as a concrete starting point for exploring further the economic nature of NHBMs and bioprospecting. Forests serve a number of productive purposes. In addition to supporting biodiversity and bioprospecting, forests are a source of other goods and services that support local and global economies including:

Goods
- Wood products, including timber
- Energy, including fuel wood and charcoal
- Non-wood products, e.g. wild game, rattans and fibers, honey, edible and collectable plants, medicinals, aromatics, dyes

Services
- Recreation
- Religious practice and spiritual enjoyment
- Climate amelioration
- Regulation of local and regional hydrological cycles
- Mediation in the carbon cycle
- Soil stabilization and watershed protection

Forest area is often converted to other economic purposes as well including agriculture, roadways, mining, or residential and industrial development.

10 For applications of these principles in the institutional economics literature, see Coase (1960) and Ostrom et al. (1961).

11 Biodiversity and NHBMs are important in a wide range of productive activities including agriculture, biotechnology, drug and other types of medical therapies, scientific research, and so on.
On the surface, bioprospectors are not markedly different than other forest users. Bioprospectors may compete or collaborate with others who harvest forest goods and services. Harvesting and other immediate consumption activities in CPRs are well described by existing theories and evidence. However, a finer analysis reveals some important differences between some types of bioprospecting activities and the other types of harvesting activities that take place in CPRs.

In general, we can say that there are three types of bioprospectors who harvest NHBMs: knowledge creators, entrepreneurs, and collectors. Each type has distinct but often overlapping objectives, which are summarized in Table 1. Knowledge creators, such as shamans, teachers, and scientists, bioprospect to advance knowledge. In the process, they may create new knowledge, products, processes, or applications, create profitable products, and add to collections of NHBMs. They harvest a commodity from a CPR, which has a static value, but they do so to create knowledge and solve problems. The economic nature of creating knowledge and solving problems is quite different than simply extracting an NHBM from a forest resource, a point we will subsequently explore in more detail.

Entrepreneurs, such as farmers, vendors, and biotechnologists, bioprospect for NHBMs to build businesses, which may be small, medium, or large scale enterprises organized inside or outside the country in which the resource is located. While their primary objectives are to survive and develop profitable products, in the process they may advance knowledge, solve problems, and develop new processes and applications. They may also add to a collection of NHBMs or sell specimens.

Collectors have more limited purposes: they harvest specimens to expand their own collection or to sell to others. Their bioprospecting activities have a single and relatively static economic dimension—harvesting an NHBM for immediate consumption—whereas the bioprospecting activities of knowledge creators and entrepreneurs are multi-dimensional and involve static and dynamic economic activities.

Like other forest users who harvest goods or consume personal services like recreation and spiritual enjoyment, collectors add little economic value to that which they consume. They invest in harvesting the NHBM for immediate consumption: their own or the person to whom they sell the specimen. The NHBMs they collect are commodities that we can assume they will continue to harvest until the marginal cost of harvesting exceeds the benefit. Since the material they harvest has a known, specific use, it is relatively easy to calculate the value of this type of bioprospecting and design incentives to protect biodiversity. Implementing and sustaining effective incentives is another matter entirely and one we must put aside for the time being.

By contrast, knowledge creators and entrepreneurs seek to discover and transmit the value of the NHBMs they harvest. In the process, they may add value to the NHBM, transforming it from one type of asset to another. Their investment includes not only the cost of harvesting, but also the costs of learning what to harvest and how to harvest, transforming the NHBM, which is a commodity with a known, specific use, into a new product with an unknown use. In the process of making this transformation, they create new knowledge that has a value that depends upon their investment in studying the NHBM but that is distinct from the value of the NHBM and the product they create by applying their new knowledge. In other words, at the successful conclusion of a knowledge or entrepreneurial transformation process, there are at least three, potentially separable economic goods:

1. The original NHBM (commodity)
2. New knowledge (idea)
3. Product, process, or application (invention)

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Table 1

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Knowledge creator</th>
<th>Entrepreneur</th>
<th>Collector</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advance knowledge</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Solve problems</td>
<td>Maybe</td>
<td>Yes</td>
<td>No</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Create new products, processes, applications</td>
<td>Maybe</td>
<td>Yes</td>
<td>No</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Develop profitable products</td>
<td>Maybe</td>
<td>Yes</td>
<td>No</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Expand collection</td>
<td>Maybe</td>
<td>Maybe</td>
<td>Yes</td>
<td>Static</td>
</tr>
<tr>
<td>Sell specimen to others</td>
<td>No</td>
<td>Maybe</td>
<td>Yes</td>
<td>Static</td>
</tr>
</tbody>
</table>

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12 See for example, Ostrom (1990), Ostrom et al. (1994), and Dietz et al. (2003).
I have argued that NHBM exists in nature as common pool goods. By contrast, new knowledge—the creation of a person’s mind—is by nature a private good until or unless the creator shares this knowledge with others. That is, consumption has high excludability and high subtractability (the creator can refuse to share new knowledge with others and once new knowledge is consumed by someone other than the creator it is no longer new). Similarly, the products produced from applying new knowledge are by nature private goods until or unless the inventor relinquishes control over production and provision.

NHBM and the goods and services that knowledge creators and entrepreneurs create by investigating potential applications of NHBM have different investment characteristics. While NHBM may be a source of information about life (but are not always), this information does not exist until someone creates it and transmits it. NHBM is potential inputs into creative processes that supply new ideas and inventions: they have one value on a stand alone basis, which may be less than or equal to \( x \), and another, unknown value when they are placed in the hands of an experienced knowledge creator or entrepreneur. Similarly, the new knowledge that emerges from a creative or entrepreneurial process is an intangible asset that may be quasi-specific or specific. That is, an idea often has a number of potential applications (quasi-specific); however, an invention has just one potential application (specific). The value of new knowledge, which may be equal to or greater than 0, is not known until it is disseminated and is quite difficult to estimate until further investments are made to apply the idea to address demand. However, a new product, process, or application is a tangible, specific asset with one identified use. Its value can be estimated but will not be known in toto until it is fully disseminated.\(^{13}\)

In economic terms, knowledge creation is a high risk inter-temporal asset transformation process. As knowledge creators and entrepreneurs make specific investments to develop knowledge about an NHBM and the NHBM is transformed from one type of asset to another, the focus of attention shifts from the material input to knowledge creation. The ability to appropriate economic value from knowledge creation depends not only on innovative capacity, but on the property rights that are assigned to the products of these processes. Moreover, the economic value of knowledge changes as it develops and is transformed into specific inventions. We know from experience in many fields that this asset transformation process is lengthy, expensive, and risky. It is filled with false starts, dead-ends, and death valleys. Even with well-defined and well-enforced intellectual property rights, the appropriability of knowledge assets cannot be protected indefinitely: at some point, it diminishes to zero either because intellectual property rights have expired or further innovation has made them redundant.\(^{14}\)

The drug discovery process, which can involve both nonhuman and human biological materials, is a good example of high risk inter-temporal asset transformation. In the US, it takes knowledge creators and entrepreneurs on average 10 years to bring a new drug to market at a cost of US$800 million. Only one of every 5000 compounds that are investigated in research and development is marketed as a drug, and fewer than 15% of all drugs that do go to market generate enough revenues to cover the cost of research and development.\(^{15}\)

Stylized, the transformation process works as follows. A knowledge creator, who possesses general knowledge (a public good with low subtractability and low excludability) and specific knowledge (a private good), has an idea (a private good) about how an immunological process may work. In order to develop this idea, s/he wishes to investigate the properties of a particular organism that thrives in tropical forests. After considerable effort and some direct expense, s/he obtains the required NHBM (a common pool good) and designs and launches a research project.

\(^{13}\) It may be that additional uses can be discovered for a particular product, process, or application, however, discovering these new uses requires new investment in specific knowledge and so we can think of this as an iteration of the asset transformation process.

\(^{14}\) For an analysis of some of the dilemmas posed by this process, see Polski (2000).

\(^{15}\) Standard and Poor’s Corporation (2003).
After several fits and starts, the knowledge creator is able to demonstrate theoretically that the idea under research shows promise for developing a better understanding of the immunological process. However, additional investment is required to develop this understanding: a team of knowledge creators with specific knowledge in several disciplines, more lab space, equipment and instrumentation, and so on. In order to obtain this investment, the knowledge creator must selectively share the specific knowledge s/he has developed and organize an expanded research effort.

The knowledge creator expends further effort, obtains additional finance, and expands the research project. S/he shares unpublished methods and results (private goods) with the new team, at which point they are transformed into jointly owned club goods, which have low subtractability but relatively high excludability. The team makes good progress and begins to publish the results of their research in peer-reviewed journals. One of these publications attracts the attention of an entrepreneur who has an idea (a private good) that the research in which these knowledge creators are engaged can be successfully applied to combat a disease that greatly threatens public health.

The entrepreneur, who has successfully launched several new drug therapies and has specific knowledge about how to do this (a private good), gets in touch with the knowledge creators. After a series of exploratory discussions, the knowledge creators and the entrepreneur pool their resources, transforming a combination of private and club goods into a new club good. After conducting some more research, they discover the potential for a new product (an invention). They then form a corporation (a legal person under US law), transfer the invention to the corporation, and obtain finance to fund product development. At this point, the invention is transformed from a jointly owned club good to a private good owned by a unified entity.

The corporation obtains a patent that makes knowledge about the invention a public good but grants it the exclusive right to appropriate economic benefits for 20 years. Research and development continues until the corporation can demonstrate that its prototype satisfies regulatory requirements, a nontrivial process that involves sharing knowledge about the potential product with a large number of people including potential competitors. Once regulatory approvals are obtained, the corporation brings the product to market—another nontrivial process that involves sharing knowledge about the potential product with an even larger number of people, including all known and potential competitors. Twenty years later, the corporation’s patent expires regardless of whether it has fully appropriated economic value from the protected invention and the private good this corporation has developed is transformed into a public good. If the corporation does not have other new products to replace this product, it is or will soon be out of business.

This stylized example demonstrates the dynamic and varied economic nature of the knowledge creation process and the potential role of NHBM. Fig. 1 illustrates this process and characterizes the economic nature of the inputs. In the first phase, a bundle of public, private, and common pool goods is potentially transformed into an idea about how things work, which is a club good. In the second phase, the idea is potentially transformed into an invention, which is a private good. In the final phase, when the patent expires, the invention is transformed into a public good.

Five implications arise from this analysis: (i) the economic nature of NBHMs and knowledge assets change as they are transformed; (ii) transformation requires investment and investment is risky; (iii) as the specificity of assets increase, it is easier to estimate their economic value and risk is reduced, which is illustrated in Fig. 2; (iv) the technological, cultural, and institutional context of asset transformation is very important in determining the economic nature of NHBM and knowledge assets as well as for creating incentives to invest in augmenting these values; (v) appropriating economic value from NHBM in international markets requires local knowledge and special expertise including detailed knowledge about the properties of the NHBM and its potential applications, production and provision, marketing and sales, regulatory requirements, international trading requirements, and so on.

In our example of knowledge creation, the NHBM is a commodity that is studied by a knowledgeable expert in order to create new knowledge. It is a source of inspiration for a creative process: it may or may not be a source of information or a material input into a
production process. In fact, a number of outcomes from studying the NHBM are possible.

- Observation reveals no useful information at all
- It provides an interesting analogy: by studying certain properties, the knowledge creator develops new ideas about how to solve a problem
- Observation reveals useful information that can be obtained from other sources or replicated synthetically
- Observation reveals useful information that cannot be obtained from any other known source or from any other known method
- It has tangible properties that are used in a production process that could be obtained from other sources or replicated synthetically

- It has tangible properties that are used in a production process that cannot be obtained from any other source.

Depending upon what the knowledge creator or entrepreneur discovers about the NHBM and how it is used, it may be possible to return it to its habitat unharmed or somewhat disabled, or it may be destroyed. The demand for the NHBM may be quite small or very large. The point is that until we finance investigation of the use of an NHBM in knowledge creation, we cannot know the relative value of removing it from its habitat.

The knowledge creator or entrepreneur locates and studies the NHBM to advance theoretical and practical knowledge. In the process, s/he may identify and describe a living organism. This information may or may not already exist—recall that it is widely believed that millions of species remain undefined and undescribed. While this is not the intended purpose of the research, it is yet another product of the research effort that has potential value. However, its value may be in fields that are outside the knowledge creator’s or entrepreneur’s area of expertise. Moreover, there is a potential conflict among these different uses, e.g. keeping this knowledge secret may be required by customary law or contract, or it may give the knowledge creator or entrepreneur a competitive advantage that s/he is not willing to relinquish at all or until some period of time has passed.
Finally, the capabilities, traditions, rights, and incentives of knowledge creators, entrepreneurs, and collectors are influenced by their physical and technological environment, cultural traditions, institutions, managerial practices, and government. While we have many centuries of experience with bioprospecting, we have very few studies of this experience and much to learn from each other about how to effectively manage and govern these activities in particular settings.

In summary, determining the economic nature and hence the economic value of NHBMs requires a great deal of specific knowledge about NHBMs, their importance in their habitats, their supply, their potential uses, and the cultural traditions and property rights that govern their potential uses. Given the state of knowledge about biodiversity, it is premature to describe and treat all living nonhuman organisms as a single class of economic goods. It is particularly misleading to conceptualize them as public information goods as investigation may reveal that they contain no information at all. Until we have evidence to the contrary, the most sensible starting point is to classify biodiversity and the components of biodiversity as common pool goods that are tangible, specific assets. One among many competing uses of these assets is to attempt to transform them into intangible assets that are more or less specific and that are private, club, or public goods.

5. Institutional dilemmas

The economic nature of biodiversity, biological materials, and bioprospecting activities presents two distinct sets of governance dilemmas: (1) the contracting problems associated with sustaining CPRs and (2) the contracting problems that arise from high risk inter-temporal asset transformation. Let us begin by analyzing the first set of dilemmas, where we have good theory and evidence, and then move to the next set of dilemmas, where we have good theory but considerably less evidence.

5.1. Governing common pool resources

Recall that the physical nature of CPRs makes it very difficult for owners to control access to the resource. When access is not controlled, resource users cannot be excluded from consuming the resource and they are able to consume without contributing to the cost of replacement. When resource owners do not capture returns on consumption, funds are not available to invest in sustaining the resource over the long-term, which leads to under-investment and resource degradation. This misalignment of incentives creates a collective action problem that can only be solved by implementing special institutions.

Looking at evidence on governance in a wide range of CPRs located all over the world, Lin Ostrom (1990) argues that, while difficult, CPR governance dilemmas can be effectively addressed with self-governing institutions that are custom designed to address property rights issues and involve users in resource management. For example, Dietz et al. (2003) argue that evidence on forest resources suggests that there is no best way to own or effectively manage common pool resources. This is because there is considerable variation among CPRs and the conditions within which they are situated. Moreover, many of our most important resource systems are continually evolving and they are subject to global pressures such as climate change or international trade—tropical forests are a prominent example. These types of resources require complex, nested forms of government that include contracting within and among self-governing user groups and other interested parties, local, national, and regional governments, and international bodies.

Dietz et al. propose that the best way to meet the challenges involved in sustaining contemporary forest resources is to devise flexible and adaptable institutional arrangements, which are congruent with specific resource conditions, and that address the following issues:

- **Information.** High quality, reliable information about the state of the resource is required to effectively regulate the resource, including information about stocks, flows, processes, interactions, and human activities, uncertainty, and values. Information should be congruent with the scale of environmental events and decisions, as well as decision-makers’ needs.
Consultation and conflict management. Inclusive, participatory processes are more likely to produce appropriate information, decisions, commitment, coordination, and cooperation than more authoritarian processes.

Rule compliance. The most effective approach to insuring rule compliance is to consistently deliver progressive sanctions that include a variety of informal and formal mechanisms, which requires adequate resources for monitoring and enforcement. Mechanisms like Tradable Environmental Allowances (TEAs) can contribute to effective compliance if a number of conditions are met, e.g. stocks and flows are predictable; users/ producers are relatively homogeneous and the size of the group is controlled; permits are clearly defined and fully exchangeable, and they are used in combination with community-based systems. Voluntary approaches can be effective when combined with other strategies that provide incentives for compliance.

Infrastructure. Appropriate physical, technological, and institutional infrastructure is required to create accountability. It may also facilitate conflict resolution and coordination.

Change. Codified rules, which rely on current knowledge and static conditions, are less effective in coping with long-run change than more general principles that address objectives and consequences and allow for adaptation.

The principles that Dietz et al. extrapolate from data on forest resource management experience are based upon observing situations in which resource owners and users have been able to create a kind of society within a society that has a complex array of rules and norms that extend beyond economic exchange and its immediate consequences. In other words, situations in which economic exchange in the resource focuses more on developing and sustaining constructive relationships through time than on executing particular contracts to exchange goods and services.

The empirical evidence on effective governance in CPRs is consistent with theories of exchange in institutional economics, which hypothesize that the nature of economic activity determines the nature of transacting, which in turn determines the most efficient form of governance. Williamson (1985) presents a typology that is based upon the frequency of interaction among transacting parties and the investment characteristics of the assets with which the parties are concerned. In this typology, when interaction is recurrent and assets have a mixed or very specific investment character, the most efficient form of governance is relational contracting, using either bilateral or unified mechanisms. Relational contracting refers to privately ordered exchange in a quasi or non-market mode that is participatory, evolutionary, and self-regulated. While some CPR transactions may be governed using other types of governance such as market (classical contracting) or trilateral (neoclassical contracting) governance, Dietz et al. suggest that for these mechanisms to be effective in managing and governing forest resources, transacting must be nested in what the institutional economics literature describes as a relational contracting structure.

5.2. Governing high risk inter-temporal asset transformation

Despite the plethora of contracting arrangements suggested by empirical work on CPR governance, there appears to be a dearth of comparable empirical knowledge of high risk inter-temporal asset transformation. One way to address this problem is to apply theory to stylized facts and then speculate about appropriate governance principles. Returning to the example of asset transformation developed in Section 3, let us decompose this process into discrete transactions and apply Williamson’s classification scheme for organizing efficient governance.

Table 2 shows the decomposition and theoretical application. Several observations can be made from this analysis. First, the transactions described in our stylized example are nested in other transactional situations, e.g. transactions between a CPR owner and a knowledge creator are potentially influenced by contracting between the CPR owner and the knowledge creator.

16 See for example Coase (1960, 1937), North (1993), and the extensive work of Oliver Williamson.
17 Williamson’s theory of efficient governance is described in Chapter 3 in Williamson (1985).
nation state within which the resource resides; the nation state and the CBD; and the CBD and other international bodies such as the WTO or the UPOV. Similarly, transactions between a corporation and a patent provider, commercial investors, and a regulator are potentially influenced by contracting with Polities.

Second, there are many potential transactions that are not addressed by our stylized facts that occur in the naturally occurring world, e.g. we assume our knowledge creators are solo agents but they may be employed by a university, a government research laboratory, a private research laboratory, or some other type of organization that has a material interest in their activities; our facts do not address the agreements among the knowledge creators or the knowledge creators and the entrepreneur with respect to ownership and control of their joint research products; our facts do not address the agreements between the knowledge creators, the entrepreneur, and the corporation to which they transfer their invention and for which they conduct additional research and development.

Third, in toto, this is a very complex governance situation that cannot be addressed with a single governance solution. Instead, it would appear to require a strong sensitivity to particular transactions and a mix of different solutions.

Fourth, many of these asset transformation transactions involve high degrees of asset specificity and uncertainty. This implies that relational contracting principles, which are consistent with the principles Dietz et al. articulate for good CPR governance, are the best overall approach to governing exchanges that involve inter-temporal asset transformation.

6. Evidence on governing bioprospecting

In the late 1990s, the Secretariat of the Convention on Biodiversity issued a call for case studies on experience with bioprospecting under the CBD. Fifteen cases were submitted to the Conference of the Parties at its Fourth meeting in 1998.18 While these studies do not provide rigorous empirical evidence, the results are interesting and they are consistent with the accumulated theory and evidence on CPR governance.

All 15 of the cases submitted to the Secretariat involved materials derived from biodiversity-rich ecosystems in countries located in Africa, Asia, Central, North, and South America. The Secretariat reports that most of these countries do not systematically evaluate flora and fauna. Moreover, most countries had not yet enacted legislation consistent with their participation in the CBD; hence, most contracting commenced in a legal, policy, and administrative vacuum.

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Twelve cases involve bioprospecting, 10 involved drug development, 1 involved micro-organisms, and 2 involved animal biological resources. All 15 cases describe long-term, relational contracts, and the main actors involved in contracting are governments, researchers, and communities where the NHBMs are located.

In all 15 cases, the benefits stipulated by contracting are based on the needs of the participants and include a wide variety of arrangements related to start-up, processes, products, and moral/relational arrangements. The most common financial mechanism for benefit sharing is royalties paid into trust funds: amounts vary based on the extent to which the NHBM contributes to developing a commercialized product. While all cases allowed for the possibility of developing a commercialized product, in no case had such a product been developed. The benefits that had been realized were gained from spillovers from the research and development process including transfer of equipment, know-how, and training; capacity building; relational benefits. All cases aim for sustainable use; however, assessments of the impacts of bioprospecting on conservation had not been made at the time that the cases were submitted.

While more rigorous studies of bioprospecting are required, we can extract several implications from these cases that are relevant to this analysis. First, the cases suggest that it is possible to create enforceable contracts in countries with very limited rule of law and among stakeholders with very different capabilities, traditions, and institutions. This appears to have been accomplished by using relational contracting principles and involving representatives of key groups that have an interest in the resource system within which bioprospecting occurs.

Second, even though none of these countries had implemented policies in conformance with the CBD, groups were able to develop arrangements that appear to be consistent with the provisions of this Convention and in particular, those provisions and voluntary guidelines associated with access and benefit sharing and traditional knowledge. Moreover, the difficulties and controversies surrounding these matters did not preclude agreement nor did they appear to strongly influence the outcome of negotiations.

Third, each of these cases appear to address infrastructure and capacity building requirements in the communities within which they are situated. How they address them and how well they address them over time remains to be discovered.

Finally, the cases underscore the importance of relational contracting in economic development. Too often economic development initiatives use market or classical contracting principles to stimulate exchange. Yet our analysis of the kind of exchange involved in managing and governing biodiversity, biological materials, bioprospecting, and bio-based research and development suggests that if there is a role for markets and neo-classical contracting, it is quite limited. Moreover, it occurs further along the value chain when a commercial product has been developed, approved for use, and taken to market.

7. Conclusions

This paper explores the analytical issues involved in regulating bioprospecting and the use of NHBMs to develop new products, processes, and applications. The main findings from this analysis are:

(1) Biodiversity is an outcome of the physical structure of common pool resources and their management and governance, mainly in tropical forests located in developing countries in Africa, Asia, the Caribbean, and Central and South America.

(2) Bioprospecting for nonhuman biological materials is only one of a number of economic activities that take place in common pool resources. The economic value of bioprospecting depends upon who is harvesting the NHBM and how they plan to use it.

(3) Nonhuman biological materials (NHBMs), which are tangible, specific assets that are harvested from common pool resources, are common pool goods.

(4) Bioprospecting for NHBMs and research on NHBMs can but does not necessarily contribute to creating new knowledge or inventions.

(5) Harvesting NHBMs for research and development is a complex contracting situation that
involves high risk inter-temporal asset transformation and potentially three economically separable goods that have different investment characteristics and contracting requirements: the NHBM, an idea, and an invention.

(6) Incentives to use NHBMs to create new knowledge are linked to infrastructure, cultural tradition, and property rights regimes.

(7) It appears that biodiversity, NHBMs, and bioprospecting are best governed by relationship contracting principals that are designed to fit specific contracting conditions; however, empirical analysis of high risk inter-temporal asset transformation involving NHBMs would improve the reliability and validity of this prediction.

In summary, while the institutional economics of biodiversity, biological materials, and bioprospecting present some interesting estimation and governance problems, they are not new problems. Moreover, many of these problems are well-described by existing theoretical and empirical literatures. It would be helpful to have more empirical evidence on managing and governing high risk inter-temporal asset transformation processes, including those that involve biomaterials and bioprospecting activities. In the meantime, our analyses should focus on creating property rights regimes that are consistent with relational contracting and the dynamics of inter-temporal asset transformation, and solving the management and governance problems associated with sustaining common pool resources.

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A.1. Analyzing the economic nature of goods and services

Following standard theory, the economic nature of a good or service can be determined by two attributes (1) the extent to which one person’s consumption reduces the supply available to others (subtractability) and (2) the extent to which access to consumption can be controlled (excludability). Arraying these attributes in a two-by-two matrix with a high/low scale gives us a taxonomy of goods and services that typically includes private goods, which have high subtractability and high excludability; public goods, which have low subtractability and low excludability; club or toll goods, which have low subtractability but high excludability; and common pool goods, which have high subtractability and low excludability (Fig. A1).

If a good or service has high subtractability, then the supply of the good or service is reduced in direct proportion to consumption, e.g. there is a one-to-one relationship. When consumption is perfectly subtractable, institutions must provide incentives to sustain an adequate supply of the good or service to meet consumption demand.

High excludability means that access to a good or service can be controlled at low cost, which implies that consumers will have difficulty consuming the good or service without contributing to the cost of production and provision and producers have adequate incentives to make the investments required.
to consistently meet demand. However, when it is costly to control access to a good or service, consumers may be able to “free-ride” on investments in production and provision, reducing or eliminating producers’ incentives to invest in future production. Free-riding is a collective action problem that can only be cured by special institutions.\textsuperscript{19}

Consumption is more or less subtractable or excludable depending upon the physical characteristics of a good or service, technology, the scale and scope of activity, and production and provision processes including storage and distribution. Aggregate consumption behavior is also influenced by the types of people who participate in production, provision, and consumption, and the way that these activities are governed and managed. This means that the economic nature of a good or service can change as the mix of participants change, and with technological, institutional, and managerial innovation.

Theoretically, the economic nature of a good or service dictates the way in which it is most efficiently owned and governed (Fig. A2). When the conditions associated with standard economic assumptions exist, self-governance or market relations provide adequate incentives for sustaining appropriate levels of goods and services with high subtractability and high excludability.\textsuperscript{20} On the other hand, goods and services with low subtractability and low excludability that have important social benefits are likely to be under-supplied in the private sector. Hence, they are best owned and governed in the public sector, by governments and special purpose entities. Intermediate or quasi-public goods and services are best owned and governed collectively by those who benefit from economizing on production and provision.

Alas, actual political and economic conditions rarely conform to standard economic assumptions; hence, we find that goods and services are frequently owned and governed in ways that are inconsistent with our theoretical assumptions. Empirically, we observe considerable variety in the ways in which CPRs are owned and governed. CPRs are owned privately by both individuals and groups, and publicly by governments. Property rights may be secure or insecure depending upon how well governing institutions function in a particular setting. Governing institutions are always nested. Types of governance systems include unified forms such as self-governance by individuals or collective unified entities, e.g. corporations, non-governmental organizations, or authoritarian governments; collective governance using centralized, decentralized, or polycentric organizational structures; market mechanisms such as Tradable Environmental Allowances.

The empirical research on standard economic theories of management and governance in a wide variety of common pool goods is inconclusive: it turns out that there is no single best way to own or govern common pool goods. Instead, it appears that effective ownership and governance structures meet the demands of the physical and social environment within which the resource is located in such a way that they allow the individuals and groups who are involved in using the resource to consistently solve the collective action problems that are associated with information processing, participation, conflict management, rule making and compliance, infrastructure, and adaptive change. And this means that policy makers who accurately investigate resource conditions and craft policies based upon rigorous analyses of actual physical, technological, cultural, institutional, and social psychological circumstances are more likely to achieve the policy goals of the CBD than those who idealize or take analytic shortcuts.

\textsuperscript{19} For an analysis of free-riding and collective action problems, see Olson (1965). For analyses and examples of the types of special institutions required to overcome free-riding and collective action problems in CPRs, see Ostrom (1990) and Ostrom et al. (1994).

\textsuperscript{20} I define markets in the classical sense, e.g. bilateral or trilateral trading relations.
References


