Is Bioprospecting Contract an Efficient Market-based Policy Instrument for Biodiversity Conservation?

by

Hongyu Ding
Environmental Economics and Natural Resource group, Wageningen University,
The Netherlands

Paulo A.L.D. Nunes
Fondazione ENI Enrico Mattei and University Ca Foscari of Venice
Italy

Ignazio Musu
University Ca Foscari of Venice

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Abstract

Bioprospecting is among the most frequently cited solutions to the natural resource degradation and biodiversity loss, as it promotes the private investments in biodiversity conservation. In order to regulate the proliferated bioprospecting activities and protect the biological diversity in the source countries, the Convention on Biological Diversity established a legal framework for the reciprocal transfer of biological materials between the interested parties in bioprospecting activities. In effect, a remarkable increase in the number of bio-prospecting contracts emerged between the users, notable linked to the pharmaceutical industry (e.g. Glaxo), and suppliers, which most of the times are located on geographical areas where it is registered a high richness of biodiversity (e.g. forest of Costa Rica). This however, gave rise to a wide range of public debate on the nature of bioprospecting and its impact in conservation of biodiversity values.

This paper aims at exploring the overall social welfare changes in the context of biocontracting from the perspective of economic efficiency. It takes account of all the interested parties involved in bioprospecting contracts so as to analyze the respective economic payoffs as well as the consequent impacts on the stocks of natural resources. Particular attention is given to the role of patenting system in moving biocontracting towards an efficient market-based policy instrument for biodiversity conservation.

Keywords: bioprospecting; biocontracting; policy instrument; biodiversity conservation

JEL classificaiton: D21, D23, D61, L14, Q57

1. Introduction

Bioprospecting is among the most frequently cited solutions to the natural resource degradation and biodiversity loss. This is because setting aside land for bioprospecting activities has been revealed a very promising market priced allocation of resources since it can dramatically enhance the commercial value of the genetic resources in agricultural, industrial, or pharmaceutical applications (Simpson et al. 1996).

As a consequence, we have been observing a remarkable increase in the number of bio-prospecting contracts emerged between the users, notable linked to the pharmaceutical industry (e.g. Glaxo), and genetic resources suppliers, which most of the times are located on geographical areas where it is registered a high richness of biodiversity (e.g. forest of Costa Rica). This new market based instrument has given rise to a wide range of public debate on the nature of bioprospecting and its impact on conservation of biodiversity values (Nunes and Bergh 2001).

In order to regulate the proliferated bioprospecting and protect the biological diversity in the source countries, the Convention on Biological Diversity (CBD) was launched after the Earth Summit in Rio de Janeiro in 1992 (CBD 1992; Dedeurwaerdere 2005). The convention established a legal framework for the reciprocal transfer of biological materials between the interested parties in bioprospecting activities, subject to the Prior Informed Content (PIC) principles and a set of mutually agreed items on equitable sharing of benefits (Bhat 1999; Ten Kate and Laird 1999; Dedeurwaerdere 2005).

One of the advantages of the convention is that open access to the biological resources was replaced by setting, clarifying and recognizing the sovereign property rights of each country over the biodiversity within its jurisdiction. In particular, with agreed PIC, the source country is able to obtain the truthful information about the use of the genetic resource, and thus well control the access procedures (e.g. trade in endangered species) and equitably negotiate the benefit-sharing items with the biodiversity prospectors.

From a policy point of view, bioprospecting contracts work as a market-based instrument, pulling in action the conventional demand-supply market mechanisms. The respective equilibrium price will be interpreted as a signal to different economic agents involved in biodiversity conservation, and thus avoid the limitation of conventional command-and-control government interventions such as land access restrictions.

This paper aims at exploring the overall social welfare changes in the context of biocontracting from the perspective of economic efficiency. It takes account of all the interested parties involved in bioprospecting contracts so as to analyze the respective economic payoffs as well as the consequent impacts on the stocks of natural resources. The contract is, therefore, here interpreted as a key element to understand the different stakeholders' motivations, or objective functions. As a consequence, it will allow us to better understand and predict the behaviour of these parties. Finally, particular attention is given to the role of patenting system in moving biocontracting towards an efficient market-based policy instrument for biodiversity conservation.

The present paper is organized as follows. Section 2 provides a throughout review of existing bio-contracts, mapping the key stakeholders involved and identifying the respective market contractual conditions. Section 3 moves the attention to the discussion on the pharmaceutical industry, clarifying the different biocontracting conditions and respective monetary and non-monetary benefits accruing to each stakeholder. Section 4 proposes the use of an economic analysis to model the bioprospecting contracts and respective objective function of each stakeholder. Section 5 provides the discussion of the impacts of biocontracting and patenting on overall social welfare. Section 6 concludes.

2. Biocontracting

2.1 A review of existing bioprospecting contracts

With the signature of CBD, an increasing number of bioprospecting practices have emerged as the commercial use of biological and genetic resources promoted by biotechnological and pharmaceutical companies all over the world. In this section, we review and generalize some of the most well-known bioprospecting contracts (see Table 1) in order to provide an overview of possible contractual parties involved and their respective costs and benefits derived from bioprospecting activities.

Table 1 A review on the existing bioprospecting contracts

Contractors	Year (Duration)	Renewal	Monetary Benefits	Non-Monetary Benefits
INBio &Merck	1991 (2 years)	Yes	- Costa Rica government earned US$1.2 million of revenues and conservation funding - INBio obtained over US$2.5 million from bioprospecting	- Merck was granted the rights of exclusively commercial using the samples (about 2000 has been collected) from the 11 Costa Rica's conservation areas - Lead to improvement in Costa Rica's scientific, technical, and institutional capacity
ICBG & Bristol-Myers Squibb, Monsanto, and Glaxo Wellcome	1993 (5 years)	Yes	- ICBG was paid US$1 million for screening	- In 1997, total 4000 species and over 7000 samples have been collected and screened. More than 140 samples were identified for further investigation, over 170 samples were recollected and more than 35 leads have been found -Benefit sharing between ICBG and host country
U.S. Phytera &European botanical gardens	1996 (N.M.)	No	- Phytera paid US$15/plant specimen and 0.25% of the profit as royalty	- Phytera obtained seeds and tissues from tropical plants in the gardens' collection

Cont.

TBGRI &AVP &The Kani community	1996 (8 years)	No	- TBGRI provided a subsidy of Rs1,000(US$22.5)/household for cultivating T.zeylanicus - Total licence fee was Rs1millioin(US$23,000), and 2% on ex-factory sale of the products against royalty - The Kanis was granted Rs20,000 of the licence fee under the ABS agreement	- TBGRI carry out drug manufacturing by using T.zeylanicus leaves from both collection and cultivation by the Kanis community
Yellowstone National park &Diversa	1997 (5 years)	No	- Diversa paid US$100,000 to the park service; US$75,000 for the rights of conducting research on microorganisms, and annual $35,000 against the royalty - Annual revenues of Diversa from Taq enzymes are over $100 million	- Agreement on the extraction of Thermus Aquaticus (Taq) enzyme from the hotsprings in Yellowstone National Park
CSIR (South Africa) &foreign research organizations and multinational companies &traditional healers	1998 (N.M.)	No	- Benefits sharing with traditional healers - CSIR got revenue from the commercialized genetic resource	- Evaluate the pharmaceutical potential of all 23,000 species of vascular plants native to South Africa - CSIR has obtained technical assistance from foreign institutes (e.g. USNCI) for screening biological extracts - Sharing the developed database of information on traditional uses of South African plants
Glaxo Wellcome &Brazilian Extracta	1999 (3 years)	No	- Glaxo paid US$3.2 million for the right of screening; 25% of royalties to the university research group; 25% of royalties to support community-based conservation, health and ecducation projects, and all the research and development cost in Brazil	- 30,000 compounds of plant, fungus and bacterial origin from several regions were granted to be screened and licensed to any product arising from the discovered compounds

Note: N.M.= Not Mentioned in the literatures

Sources: (Breibart 1997; ICBG 1997; Mulholland and Wilman 1998; Neto and Dickson 1999; Ten Kate and Laird 1999; Merson 2000; Simpson 2001; Artuso 2002; Greer and Harvey 2004; Dedeurwaerdere et al. 2005)

As we can see in this table, the contractual relations between different economic agents and private companies are complex in practice. First, Table 1 shows there is a wide variety among the private sectors which are involved in bioprospecting. This leads to different interests in genetic resources, crucial input for research and development (R&D), and thus resulting in different contractual specifications. For instance, industries of botanical medicines, personal care and commercial agricultural traditionally depend upon plant genetic resources, but pharmaceutical biotechnological companies always acquire material as raw samples, extracts from plant genetic resources or 'value-added' genetic resources (Ten Kate and Laird 1999; 2000).

A well-known case is the bioprosecting contract between the INBio-national biodiversity institute of Costa Rica, and the Merck Pharmaceutical Ltd. in 1991. Merck was granted the right to evaluate the commercial prospects of limited number of plant, insect, and microbial samples collected in Costa Rica's 11 conservation areas, from which INBio gained US$1 million over two years and equipment for processing samples and scientific training from Merck. In addition, a share of potential royalties and technology transfer to develop local sample preparation and screening capabilities was addressed in the agreement. INBio agreed to invest 10% of any payments and half of royalties by Merck into the Conservation Areas (Mulholland and Wilman 1998; Merson 2000; Nunes and Bergh 2001; Artuso 2002).

In order to obtain a better understanding of the contractual issues involved in bioprospecting, it is necessary for us to propose an explicit analysis on the contractual relationships, taking account of all the related stakeholders. Therefore, in the following sub-section, we will focus our discussion on a stakeholder analysis.

2.2 Contractual parties in bio-prospecting

Despite the various entities of the existing contracts on bioprospecting, and the respective wide range of stakeholders involved, it is possible to classify the major parties involved in terms of three groups. We refer to source suppliers, intermediaries, and private companies (Ten Kate and Laird 2000).

S*ource suppliers* refer to the parties that originally have the property right over genetic resources or indigenous knowledge. This group consist of source countries governments, local management entities and indigenous people/communities (i.g. the Kanis), some of which have the ability to grant permission on the access to, and use of, genetic resources and their derivatives, such as the national governments/originations(i.g. Brazilian Extracta). Sources suppliers also refer to the stakeholder group that access to traditional knowledge, from which the private companies may directly get profit or making new and improved products (i.g. CSIR South Africa). (See Table 1 for more examples)

Intermediaries generally exist in the form of botanic gardens, universities, research institutions, and gene banks. This contractual party plays a crucial role since they represent a working platform between *source suppliers* and *private companies*. In fact, they are responsible for obtaining a granted permission of access to genetic resources, or

indigenous knowledge, next to the source suppliers and collaborate with the private companies in the development and market commercialization of these resources. In doing this, they have to make separate contracts with both source supplier and private companies. On the one hand, *intermediaries* sign a contract with the *source suppliers* so as to obtain the permission to have private, exclusive rights of access to the genetic resource subject to the PIC. Such permission, therefore, enables *intermediaries* to conduct filed collection and patent the discoveries arise from their genetic screening activities. On the other hand, they have also an important role as a contractor with the *private companies* since they serve private companies with the screened samples, novel compounds and discovered research leads derived from their field collections in association with the appropriate freedom for new drug development (Ten Kate and Laird 1999).

Private companies represent another contractual party. This stakeholder is characterized as its notable research and development (R&D) efforts on the commercial use of the genetic resources. Although various private companies build their business on the commercialization of genetic resources, pharmaceutical industry undoubtedly represents the largest global market. Some figures indicate that global sales of pharmaceuticals are estimated to exceed annual $300 billion, of which the component derived from genetic resources or pure natural products account for some $75-150 billion (Grifo et al. 1997; Ten Kate and Laird 1999). In fact, it is characterized by investing a higher proportion of sales in R&D than most other industries, such as botanical medicines, personal care, commercial agricultural, and crop protection companies, but also incurring a higher risk in drug discovery and development process (See Table 2). For this reason, the pharmaceutical companies play a crucial role as an important steering engine in driving the progress of bio-prospecting contracts. In this context, the present article focuses the economic analysis on pharmaceutical industry only. Therefore, the stakeholder originally referred as *private companies* will represent pharmaceutical companies/industry in the remaining body of the text.

Table 2 comparison of duration and cost of typical research and development programmes in different industry sectors.

Sector	Years to develop	Cost (US$ m)
Pharmaceutical	10-15 or more	231-500
Botanical medicines	Less than 2 to 5	0.15-7
Commercial agricultural seed	8 to12	1-2.5
Transgene	4 or more	35-75
Ornamental horticulture	1 to 20 or more	0.05-5
Crop Protection	2 to 5 (biocontrol agent)	1-5
	8 to 14 (chemical pesticide)	40-100
Industrial enzymes	2 to 5	2-20
Personal care and cosmetic	Less than 2 to 5	0.15-7

Sources: (Ten Kate and Laird 1999), pp.9

In the next section, we will continue our analysis by focusing on pharmaceutical industry, clarifying the different biocontracting conditions and respective monetary and non-monetary benefits accruing to each stakeholder.

3. Pharmaceutical industry and biocontracting

3.1 Introduction

Despite alternative definitions and clarifications available in the literature[1], in this article the pharmaceutical research process will be defined in terms of a dynamic chain of steps including: (1) genetic resources field collection (2) drug discovering, and (3) drug developing (see Figure 1).

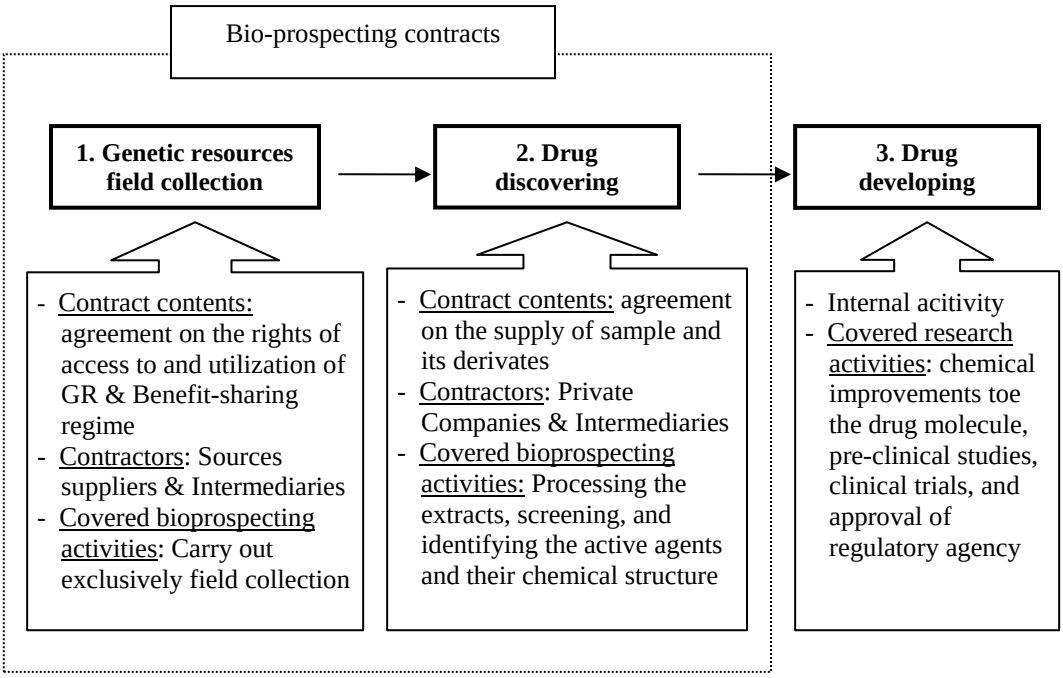

Figure 1 The processes of pharmaceutical research and corresponding bioprospecting activities

It is important to note that the last step of pharmaceutical research, with regards to drug development, is internal R&D activity to the pharmaceutical companies. On the contrary, the other two remaining steps, which include genetic resource field collection and drug discovering, involve conjoint activities with another party. These are clarified

[1] For example, according to Kate and Laird, pharmaceutical research refers to the "process of discovering, developing, and bringing to market new ethical drug products" (ten Kate and Laird, 1999, pp. 49).

with the writing of a contract. All these three steps will be discussed in the following sub-sections.

3.2 Genetic resources field collection

The general conditions for the collection of genetic resources are stipulated in the form of a contract between source suppliers and intermediaries. This contract explicitly clarifies a set of mutually agreed terms upon: (a) the access to and the use of genetic resources in the source country, which subject to the PIC and benefit-sharing treaty, and (b) the restricted manner, in which field collection and follow-up research will be conducted. The outcome of the field collection will be further elaborated by intermediaries and private companies. As we can see in Figure 2, genetic resources have an important role in the discovery of new natural drugs or serving as a source of leads for synthesising new compound structures or products (Ten Kate and Laird 2000; Onaga 2001).

By contracting with source suppliers, the intermediaries are granted exclusively access to the genetic resource and patent their discoveries from the area under consideration. In many cases, these intermediaries refer to local research institutes or universities. This geographical affinity contributes to the formation of a firm, close relationship with the national or local government in the source country. As a matter of fact, these same institutions often represent the country to negotiate international cooperation agreements with the private companies in practise.

As far as benefits-sharing rules are concerned, the transference of technology from the intermediaries to the source suppliers is helpful to strength the research ability and efficiency of the source-based institutes. In effect, we can observe a potential increase in the added-value of genetic resources, increasing the possibilities to re-new the existing contract or to set-up new ones. From Table 1, we can identify major international institutes that have been involved into biocontracting as a role of intermediary. In this context, they contribute to generating additional funding for bioprospecting projects and supply technical assistance in capacity-building to the source suppliers. One important characteristic is that many international research organizations (such as ICBG) carry out several research programs in different countries. For this reason, the research results and database generated in all collaborative countries will be shared within the involved institutes. As a consequence, the sharing of systematic information on the processing genetic resources can contribute to reduction of the financial costs on the field collection for both companies and institutes. In other words, it will be possible to provide higher quality samples or synthetic compounds, or obtain the same sample processing results with a lower field collection effort, and thus reduce the pressure of habitat loss and species extinction. (ICBG 1997; Rausser and Small 2000)

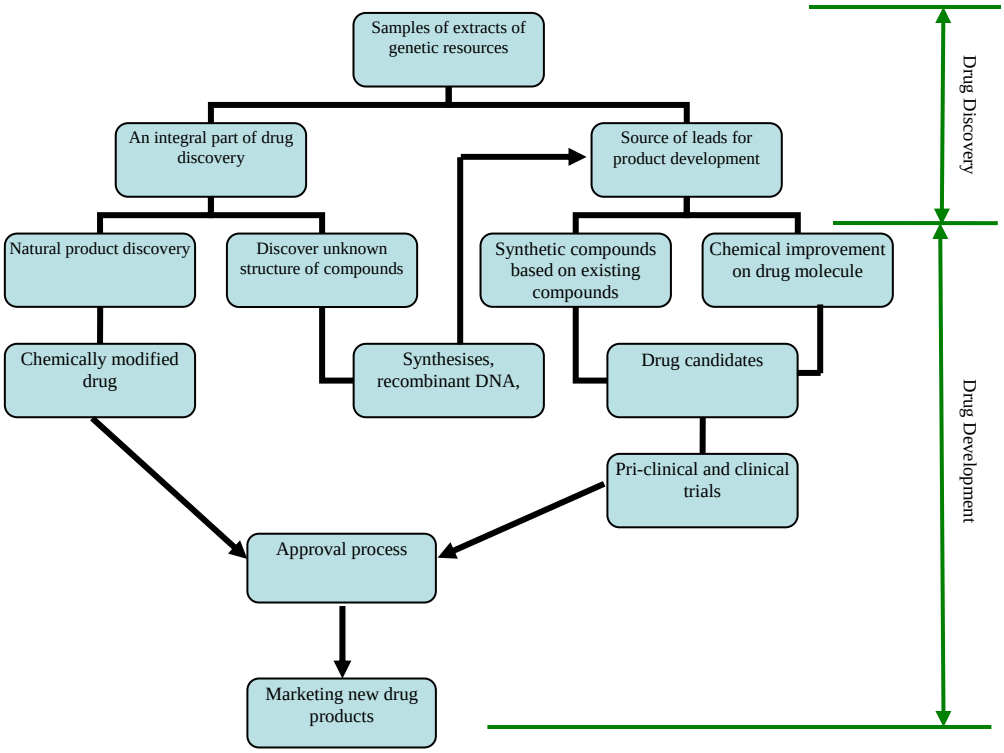

Figure2 the contribution of natural products to pharmaceutical research

Source: adapted from Ten Kate and Laird 1999

In the perspective of source suppliers, they have significant incentives to engage in the bioprospecting contracts due to the direct returns, which are expressed in monetary terms and known in the literature as sample fees (Ten Kate and Laird 1999). Such financial revenues are much greater than the forgone economic benefits in association with other land allocations, including timber harvesting and agriculture (Merson 2000). In addition, the source supplier can share the profits from the successfully commercialized genetic products with intermediaries as well as industry, depending on the contract specifications. These are known in the literature as royalties (Neto and Dickson 1999; Ten Kate and Laird 1999; Merson 2000; 2000; Dedeurwaerdere 2005). In many cases, part of the royalties goes to the natural conservation funds in the source country, in addition to some direct investments (e.g. Glaxo Wellcome & Brazilian Extracta contract in 1999[2]).

Moreover, source suppliers can derive important non-monetary benefits from biocontracting. For instance, a bioprospecting contract includes the items of providing the source suppliers with scientific and technical assistance, training and capacity-building, technology and information transfer, as well as the creation of local employment opportunities (Ten Kate and Laird 1999). All in all, these will ultimately increase the total economic value of the genetic resources. From an distributive perspective, these effects

[2] See Table 1 for more details

can be assumed of particular public significance since they stimulate local economic development in the areas where it is most needed (Rosenthal et al. 1999; Artuso 2002).

3.3 Drug discovering

Drug discovering refers to the set of fundamental research activities carried out by the intermediaries, and includes the processing of extracts and the screening of samples. The expected output of these activities is the identification of active compounds and their chemical structure, exploring its potential value in pharmaceutical products. As showed in Figure 3, the novel compounds derived from the collected samples can directly contribute to a new natural drug on the market. However, most of the collected genetic materials will serve as a source of leads for drug development (see Section 3.4), and closely relate to the success in drug research and development (R&D). For example, high quality samples are helpful for discovering valuable research leads, which will increase the efficiency of innovation activities (e.g. increase the probability of generating a market product success with R&D). In addition, research leads derived from high quality samples can provide adequate taxonomical, geographical, and ecological information, so that increase the productivity of discoveries, reduce the requisition of new field collection, and ultimately result in a decrease in searching costs.

Therefore, an accurate selection of contractual partners to carry out sample collection and processing activities becomes very important to pharmaceutical industry. Generally speaking, the criteria taken into account by companies include *inter alia* the ability of the intermediaries in providing biologically and chemically diverse samples, the simplicity and legislation of the process to obtain samples, and the prices of the samples (see Ten Kate and Laird 2000 for more details). In return, the companies will share both monetary and non-monetary benefits with the contract partner, i.e. the intermediaries (see Table 1).

A direct monetary payment is transferred from the pharmaceutical companies to intermediaries (or sample suppliers) in the form of sample fees[3], advanced payments, milestone payments and the royalties. In this case, it is important to note that the price of genetic resources increases when the collected material is subject to additional screening and processing activities performed by the intermediary. In short, intermediaries can be responsible for the creation of market added-value to the original extracted genetic resources. In addition, an advanced payment is undertaken for compensating the general operational cost of the research institutes, a milestone payment is required when new discoveries are found in the research and development (R&D) phase. In many cases, a royalty is also calculated based on the net sales for commercialized products. Obviously, the amount of milestone and royalties payments depends upon the success in R&D.

In addition, the non-monetary payment (e.g. technology transfer and capacity-building) incurred by pharmaceutical companies is widely recognized far more important than financial benefits of intermediaries from pharmaceutical activities (Rosenthal et al. 1999;

[3] According to Artuso (2002), the value of raw biological material as an input in the research or production of these products is significantly lower than the value of finished products containing or derived from biochemical resources.

Ten Kate and Laird 2000; Onaga 2001). By collaborating with international pharmaceutical industries, the intermediaries can enhance their scientific database and biotechnology in sample screening via a set of non-monetary benefit-sharing terms in the contract, including technology transfer, internal personnel training, capacity-building, and the share of research results and biological database.

For instance, the sharing of database on the indigenous genetic resource and chemical structure of the samples provided by the research institutes can directly provide useful, valuable information for the efficient design of future sample guidelines. In other words, this contributes to fine tuning of the scope sample collection activities, saving money and alleviating the stock of genetic resources from unnecessary filed collection efforts. Moreover, the shared technology can improve the overall sample quality, when it is applied to sample extraction and screening. This will not only contribute to a higher probability of generating success in drug discovery, but also increase the long-term benefits for intermediaries due to the higher value-added samples.

3.4 Drug developing

Drug developing is normally carried out within the pharmaceutical companies and based on the pharmaceutical research efforts or commitments (see Figure 1). The first target is to discover productive research leads, associating their role in reducing the production costs. Another target refers to the increase in the probability of success in developing a new drug. In both cases, research and innovation activities contribute to increasing the competitiveness of the private company and their products.

Some authors argue that the innovation capability is closely dependent on the research capacity of individual companies as well as their additional investments in R&D process (DiMasi et al. 1991; Ten Kate and Laird 1999). The latter, however, requires a strong financial commitment by private companies. Empirical analysis of the estimated R&D costs to develop new drugs consist of the costs related to on-going discovery and development activities as well as the costs of failed projects (DiMasi et al. 1991; Simpson et al. 1996). Recent calculation indicates that more than a billion dollars are spent per year on the pharmaceutical research and development activities by largest companies (ICBG 1997). Finally, in the scenario where R&D reveals to be successful, the private company incurs additional costs that allocated to apply for the approval from the regulatory agency, and royalties.

Independently of the sum of R&D investment, one cannot *ex ante* guarantee the marketable success of each research leads. Instances like INBio and ICBG projects, and marine bioprospecting projects all point out that the current sampling and synthesis techniques are very expensive processes with limited success. Similar findings obtained by Polski (2005) indicate that, in the U.S., on average 10 years are needed to bring a new drug to market at cost of 800 million dollars. Large amount of money are spent on the research and development, in which only one very 5,000 compounds may be identified and marketed as a drug. Finally, less than 15% of all drugs can generate revenues large

enough to compensate the cost of research development (Polski 2005; Standard and Poor's Corporation 2003).

If, however, the R&D succeeds, the private company receive large monetary returns from the successful new commercial product. According to the statistics from International Development Research Centre in 1994, many of the most commonly used drugs in the Western medicine are derived from tropic plants and are worth 32 billion dollars a year in sales worldwide (Merson 2000). In 2002, an estimated 2.4 billion dollars was obtained from global sales of marine biotechnology products (Ruth 2006). This forms one of the main incentives that big industries are keen on investing in bio-prospecting, and keep land aside for the conservation of the genetic resources for future research.

3.5 The role of Intellectual Property Rights

The issue regarding intellectual property rights (IPR) is central to the debate concerning the utilization of genetic resources and their derivates in bioprospecting contracts. Especially, in pharmaceutical research, the clarification of intellectual property rights is essential to facilitate the R&D collaboration and protect knowledge before the formalisation of technology exchange arrangements, so that the security, distribution and exploitation of the initial inventions can be guaranteed by legislations (Thumm 2005).

It is clear that the most important component that drives the evolvement of the pharmaceutical research in biocontracting is the high quality research leads derived from the extraction, processing and screening activities provided by intermediaries. As a matter of fact, pharmaceutical research on natural products, according to some authors (e.g. Simpson et al. 1996), is more often intended to develop "leads" than to identify natural products. Moreover, the IPR on the novel compounds and chemical structures discovered in pharmaceutical research are always associated with the patenting rights on their downstream applications by the contractual partners. This, thus, raises a need of intermediary for protecting the IPR over their new discoveries, and guaranteeing the benefits in the form of royalty payments arising from their patented innovations. The royalty payments therefore can be interpreted as the economic price to use the patented research lead compounds.

In addition, for the pharmaceutical industry alone, it also has significant incentives on patenting his product innovations so as to protect the past investment efforts and against the market competitors, e.g. free riders. Generally speaking, internal R&D is a costly activity in associated with high risks. Some figures have shown that, despite of a slim probability (about 10 of 10000) for synthesized chemical compounds to research clinical development, pharmaceutical companies have to patent each compound in anticipation that may be the one can lead to the next blockbuster. In effect, only one of the ten might reach the final market products (Cardinal and Hatfield 2000). Therefore, there is an increasing need of pharmaceutical company for the Intellectual Property Protection so as to generate high revenues from their new drugs against the large investment efforts in the

past and potential new competitors in the market. In next section, we shall discuss the role of patenting in more details.

Considering the effects of IPR, we have to analyze it from two aspects. On the one hand, patent rights grant the holder exclusion power from research or exclusion market power, therefore spur the creation of new, economically valuable knowledge and achieve more competitiveness within an appropriate regulatory framework (Musu 2005; Thumm 2005). On the other hand, many critics stress that patent system also create entry barriers and might result in overly strong monopoly positions and therefore hinder the development of new knowledge (Lawson 2004; Musu 2005; Thumm 2005).

In the next section, we shall propose the use of formal economic analysis so as to identify the different patenting schemes involved in pharmaceutical biocontracting as well as their economic impacts on stakeholders' objective functions, overall level of genetic resource protection and human welfare.

4. Modelling bioprospecting contracts

4.1 Introduction

This section provides an empirical economics perspective to identify, characterize and discuss the interrelationships between stakeholders, which are linked by the bilateral contracts. Each contract, and respective setup, is therefore interpreted as a key element in revealing the underlying motivations of the interested parties to subscribe bioprospecting. As a consequence, the contract enables us to better understand the strategic behaviour of stakeholders, and ultimately evaluate the performance of biocontracting as a market based instrument for biodiversity conservation.

As we have discussed, two types of bioprospecting contracts are involved in the purchase of genetic resources and their derivates. These are referred in the literature as material transfer agreements (MTA) (ICBG 1997). One MTA aims at ensuring the exclusive access to the genetic resources, upon the equitable and fair sharing of the benefits between the involved parties, i.e. the source country and scientists, or private organizations – the intermediary stakeholder. Whereas the other contract concerns the provision, or transfer, of the samples, chemical compounds and genetic information derived from extracting and screening activities in the research institutes or universities. It therefore links the intermediaries with the private companies through a set of mutual agreements on the sharing of both monetary and non-monetary benefits on the use of genetic materials and their derivates. (See Figure3)

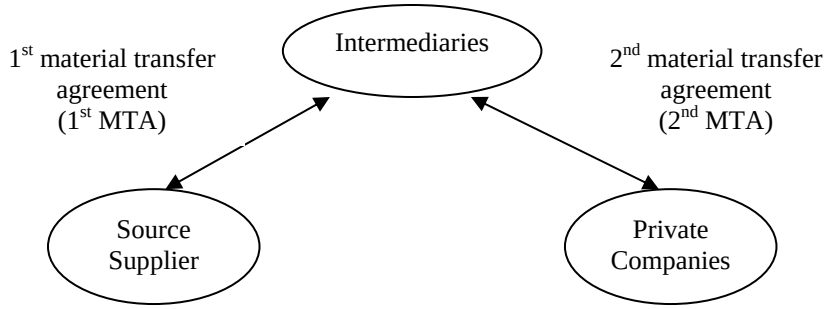

Figure 3 Bio-prospecting contracts

Source: adapted from Onofri (2003)

One can not say that one of the two contracts is more important than the other because of their specific objectives and respective impact on the overall bio-prospecting process. However, the MTA set between the intermediaries and private companies can not only directly influence the progress of drug discovery and development, but also may place certain impacts on the terms of the other contract, and thus affect the efforts of collecting, sampling and assembling the genetic resources.

Originally, the tasks referring to collection, discovery and development are sequential processes in pharmaceutical research, but now trends to be parallel conducted by both pharmaceutical industry and some collaborative intermediate institutes in order to reduce the development time. The industry alone is responsible for conducting the drug development, but requires some intermediaries to complete the fundamental research for drug discovery, including the field collection, establishment of screening libraries, and discovery of active compounds for pharmaceutical research. This however, will involve a MTA for the transaction of the initial collection (also known as samples) or the extracts of natural resource between the two parties. In this phase, it is important to note that this contract also include a PIC consistent with the first MTA between intermediaries and sources suppliers. Hence, the Pharmaceutical companies obtain the legal title of exclusively using the given samples in association with the freedom of developing these samples into natural products, research leads or the synthetic compounds for new drug discovery.

In the context of contracting bioprospecting activities, we differentiate the preferences of all contractual partners, and assume that the biotechnological innovations at each stage of the pharmaceutical research are discrete, but interrelated. Therefore, in our analysis, the patent protection will be distributed to the specific stakeholders targeting at different emphasises, and lead to the changes in costs and benefits for all involved contractors. As a consequence, it enables us to observe, for example, the positive effects of patenting the upstream innovations (from the research institutes) on accelerating the further downstream innovations in the firm-internal drug development, and thus contribute to the formulation of bioprospecting contracts.

In the present analysis, the impact of patent will be formalized in terms of the specific effects among the three stakeholders and considerations, and respective impacts on the costs and benefits for all involved contractors. In next subsections, we shall identify and assess the magnitude of such impacts.

4.2 Modelling the Intermediary's objective function

The production function for intermediate research institutes can be formally expressed by equation (1):

$$y_{Inter} = F[s(B_1), L, T(B_2)] \tag{1}$$

where y_{Inter} represents the yields from screened samples as supplied by intermediary. This yield is modelled as dependent on the accessible stocks of genetic resources, denoted by term *s*, human efforts, *L*, and the technological inputs, *T*. The accessible stocks of genetic resources are, in turn, a function of the terms of first MTA, for this reason is expressed in equation (1) as $s(B_1)$. This term captures, for example, the number of samples or the number of the years that the intermediary has access to. Following the same line of reasoning, the technological input at the disposal of the intermediary is modelled as a function of the terms of second MTA, for this reason is expressed in equation (1) as $T(B_2)$. The non-monetary sharing-benefits identified in section 3.3, such as technology transfer, constitute an illustration of this expression.

We can model the intermediary objective function as profit maximization, i.e.

$$\begin{aligned}\pi_{Inter} = {} & P_s \cdot F\left(s(B_1), L, T(B_2)\right) - \left[C(y_{Inter}) + C(B_1) + C(pat_1)\right] + \\ & + \left[Roy\left(B_2(pat_1)\right) - Roy\left(B_1(pat_1)\right)\right]\end{aligned} \tag{2}$$

The first term in equation (2), $P_s \cdot F\left(s(B_1), L, T(B_2)\right)$ refers to the intermediary revenues. The second term represents the total costs, which consist of the (i) production cost, $C(y_{Inter})$, the (ii) costs associated to the first MTA, $C(B_1)$, which includes both the costs for the exclusive right to the access to genetic resources, and the (iii) patenting costs $C(pat_1)$, indicates the fixed costs of claiming for the patents on their research discoveries. The last term in equation (2), refers to the financial turnover due to royalty. $Roy\left(B_2(pat_1)\right)$ denotes the royalty benefits on the basis of the successful pharmaceutical products derived from the supplied patented compounds, which is established in the second MTA. Finally, $Roy\left(B_1(pat_1)\right)$ denotes the potential payments to the source supplier arising from the exclusive access to the genetic resources, which is established in the first MTA.

In a one period model that ignores the effects of biocontracting on future bioprospecting activities, the intermediary maximizes its profits through the choice of

making two types of MTA, human efforts, and claiming the patents for their discoveries, denoted by B_1, B_2, L, and pat_1, respectively.

$$\underset{B_1,L,B_2,pat_1}{Max} \quad \pi_{Inter} = P_s \cdot F\left(s(B_1), L, T(B_2)\right) - \left[C(y_{Inter}) + C(B_1) + C(pat_1)\right] + \\ + \left[Roy(B_2(pat_1)) - Roy(B_1(pat_1))\right] \tag{3}$$

The four first order conditions are:

$$\frac{\partial \pi_{Inter}}{\partial B_1} = P_S \frac{\partial F}{\partial s}\frac{\partial s}{\partial B_1} - \frac{\partial C}{\partial B_1} - \frac{\partial Roy}{\partial B_1} = 0 \tag{4}$$

$$\frac{\partial \pi_{Inter}}{\partial L} = P_S \frac{\partial F}{\partial L} - \frac{\partial C}{\partial y_{Inter}}\frac{\partial y_{Inter}}{\partial L} = 0 \tag{5}$$

$$\frac{\partial \pi_{Inter}}{\partial B_2} = P_S \frac{\partial F}{\partial T}\frac{\partial T}{\partial B_2} + \frac{\partial Roy}{\partial B_2} - \frac{\partial C}{\partial B_2} = 0 \tag{6}$$

Finally, as far as patenting is concerned, we have that

$$\frac{\partial \pi_{Inter}}{\partial pat_1} = \frac{\partial Roy}{\partial B_2}\frac{\partial B_2}{\partial pat_1} - \frac{\partial Roy}{\partial B_1}\frac{\partial B_1}{\partial pat_1} - \frac{\partial C}{\partial pat_1} = 0 \tag{7}$$

The optimal B_1^*, B_2^*, L^*, and pat_1^* for the intermediary must simultaneously satisfy equations (4)-(7). Equation (4) states that the intermediary institute is willing to write the first MTA until the marginal revenues resulting from this bioprospecting contract equal to the marginal costs. According to equation (4), the respective marginal benefits captures the value of this contract in terms of increasing the productivity of the intermediary, $P_S \frac{\partial F}{\partial s}\frac{\partial s}{\partial B_1}$. These need to be compared with the financial costs associated to the writing of such a contract, i.e. $\frac{\partial C}{\partial B_1}$, and whether a royalty payment occurs from the exclusive access to the genetic resources, $\frac{\partial Roy}{\partial B_1}$. Following the same line of reasoning, equation (6) shows that the intermediary is willing to write the second MTA, if and only if, the expected marginal benefits, which includes the value of increasing the productivity due to non-monetary benefits sharing rules, $P_S \frac{\partial F}{\partial T}\frac{\partial T}{\partial B_2}$, and royalty revenues arising from writing such a contract, $\frac{\partial Roy}{\partial B_2}$, are higher than the expected costs, denoted by $\frac{\partial C}{\partial B_2}$. Finally, equation (7) shows that the intermediary endorses a patenting strategy, if and

only if, the returns of this action, expressed by the royalties revenues $\frac{\partial Roy}{\partial B_2}\frac{\partial B_2}{\partial pat_1}$, are, at the margin, larger than the respective costs. This includes both the patenting costs, $\frac{\partial C}{\partial pat_1}$, and the royalty payments to the source supplier, $\frac{\partial Roy}{\partial B_1}\frac{\partial B_1}{\partial pat_1}$, as established in the first MTA.

In sum, the two types of MTA all contribute to the productivity differentiation of intermediary. Firstly, the intermediary has to obtain a granted permission of exclusively access to genetic resources, or indigenous knowledge, and the relevant patenting rights to protect their IPR over discovered novel compounds and chemical structures by means of writing the first MTA. This, in turn, gives rise to a potential royalty payment to the source supplier. One the other hand, this patenting right also plays an essential role as to guarantee the intermediary's benefits (e.g. royalty revenues) from the downstream application of their patented research discoveries by the collaboration private companies. This will be put into force with the signature of the second MTA.

4.3 Modelling the private company's objective functions

The production function for pharmaceutical industry can be described by the following equation:

$$y_{Pharm} = G\left[y_{Inter}(B_2), K, TI(pat_2)\right] \tag{8}$$

in which, y_{Pharm} is the yield of successfully developed drugs in the pharmaceutical company, which is modelled as a function of the supplied samples, y_{Inter}, the accumulated knowledge in the research process, K, and technological investments, TI. K has a positive effect on y_{Pharm} since it plays an important role in increasing the probability of successfully developing new drugs. In a similar way, TI influences the outcome of the pharmaceutical industry. It however, relies on the patentable innovations in the drug development process or the new products with respect to the writing of a second MTA. For this reason, this effect is expressed in equation (8) as $TI(pat_2)$.

Therefore, the objective function of a pharmaceutical company can be modelled as follows:

$$\pi_{Pharm} = P_D \cdot G\left[y_{Inter}(B_2), K, TI(pat_2)\right] - \left[C(y_{Pharm}) + C(B_2) + C(pat_2)\right] - Roy(B_2(pat_1)) \tag{9}$$

The first term, $P_D \cdot G[y_{Inter}(B_2), K, TI(pat_2)]$ in the equation (9) represents the total revenues of successful new drugs in the market. The second term calculates the total costs incurred by the pharmaceutical company: $C(y_{Pharm})$ denotes the production costs (e.g. pre-tax cost of new drug, including the continual investments in discovery and development; the costs of failed projects, as well as the time value of funds investments); $C(B_2)$ is the cost conducted in the context of second bioprospecting contract, such as the fees for samples, non-monetary benefits transfer to the intermediary, and so on; $C(Pat_2)$ represents the costs of patent application and renewal fees for the new drug products. Finally, $Roy(B_2(pat_1))$ is the royalty payments issued in the second MTA on the basis of the patented compounds supplied by intermediaries.

Hence, the company can maximize its net benefits through the choice of B_2, K, and pat_2.

$$\underset{B_2,K,pat_2}{Max} \quad \pi_{Pharm} = P_D \cdot G[y_{Inter}(B_2), K, TI(pat_2)] - [C(y_{Pharm}) + C(B_2) + C(pat_2)] - \\ - Roy(B_2(pat_1)) \tag{10}$$

The three first order conditions are

$$\frac{\partial \pi_{Pharm}}{\partial B_2} = P_D \frac{\partial G}{\partial y_{Inter}} \frac{\partial y_{Inter}}{\partial B_2} - \frac{\partial C}{\partial B_2} - \frac{\partial Roy}{\partial B_2} = 0 \tag{11}$$

$$\frac{\partial \pi_{Pharm}}{\partial K} = P_D \frac{\partial G}{\partial K} - \frac{\partial C}{\partial y_{Pharm}} \frac{\partial y_{Pharm}}{\partial K} = 0 \tag{12}$$

$$\frac{\partial \pi_{Pharm}}{\partial pat_2} = P_D \frac{\partial G}{\partial TI} \frac{\partial TI}{\partial pat_2} - \frac{\partial C}{\partial pat_2} = 0 \tag{13}$$

Therefore, the optimal B_2^*, K^*, and pat_2^* for the pharmaceutical company must simultaneously satisfy equations (11)-(13). Equation (11) states that the private company intends to make the second MTA, if and only if, the marginal revenues arising from this bioprospecting contract, $P_D \frac{\partial G}{\partial y_{Inter}} \frac{\partial y_{Inter}}{\partial B_2}$, can fully offset the marginal costs. The latter includes both the costs of writing this contract, $\frac{\partial C}{\partial B_2}$, as well as the costs related to royalty payments as expressed by the second MTA, $\frac{\partial Roy}{\partial B_2}$. In addition, equation (13) shows that the pharmaceutical company has the incentive to patent their new products, and pharmaceutical inventions, as long as its financial returns, which are expressed in

terms of the value of increasing productivity, $P_D \frac{\partial G}{\partial TI} \frac{\partial TI}{\partial pat_2}$, are larger than the total costs when applying for the patents, $\frac{\partial C}{\partial pat_2}$. Equation (13) also shows that the patenting has an impact on investments in biotechnology, since their research discoveries and pharmaceutical innovations are protected by the legislation. The improved genetic technology, in turn, can increase the utilization potential of genetic resource and their value in reducing the time and cost of screening for pharmaceutical and other uses (Craft and David Simpson 2001). As a consequence, the accumulated knowledge and improved techniques in R&D will decrease the requirement of genetic origins from field collection, and thus less pressure on genetic resources, but associated to an increase in the probability of generating success in drug discovery and development (Simpson et al. 1996).

Moreover, we can also consider that patenting may lead to product differentiation. In this case, patenting can be used as a tool to increase the company's market power. Therefore, the firm is no longer a price taker. The properties of the inverse demand curve, will define the magnitude of the market power. In formal terms, this is defined by

$$\mu = \frac{P_D^*\left(y_{pharm}, pat_2^*\right) - P_D^*\left(y_{pharm}\right)}{P_D^*\left(y_{pharm}\right)} \tag{14}$$

$$\text{with } \mu > 0 \text{ and } P_D^*\left(y_{pharm}, pat_2^*\right) > P_D^*\left(y_{pharm}, pat_2 \equiv 0\right)$$

According to equation (14), patenting the new pharmaceutical products and innovations is responsible for the determination of a "monopolistic price overcharge", whose magnitude is captured by μ, also denoted in the literature as price mark-up.

Against this background, we can re-write equation (13) as

$$\frac{\partial \pi_{Pharm}}{\partial pat_2} = P_D\left(y_{pharm}, pat_2\right)\frac{\partial G}{\partial TI}\frac{\partial TI}{\partial pat_2} + \frac{\partial \mu}{\partial pat_2} G(.) - \frac{\partial C}{\partial pat_2} = 0 \tag{15}$$

Therefore, when the private company signs the second MTA, this same contract can be used by the company as a tool to increase its market power, and thus earn greater profits. This constitutes an additional incentive for the private company to endorse patenting, which was not originally foreseen in equation (13).

4.4 Modelling the objective function of source suppliers

Genetic resources are provided by source suppliers as production input for intermediary institutes. Thus, we can model the supply function for the source supplier as follows:

$$y_{SS} = Q[s(O), s(B_1)] \tag{16}$$

$$\text{with } s(O) + s(B_1) = GR$$

Equation (16) shows that the source supplier can allocate the total stocks of genetic resources within their jurisdiction, denoted by *GR*, to the contractual bioprospecting activity, which is captured by $s(B_1)$, or to other economic activities (e.g. agriculture, timber production), which is denoted by *s(O)*. The allocation rule is determined here by *Q*.

In the presence of bioprospecting activity, we can model the objective function for the source supplier as follows:

$$\pi_{SS} = P_{GR} \cdot s(B_1) + Roy(B_1(pat_1)) - C(s(B_1)) \tag{17}$$

where, the total revenues of source suppliers for engaging in the biocontracting consist of two segments: the received payments for the allowance of prospecting in the accessible genetic resources, denoted by $P_{GR} \cdot s(B_1)$, and the royalty benefits derived for granting the patenting rights to the contractual intermediary through the first MTA, denoted by $Roy(B_1(pat_1))$. The costs incurred by the source supplier refer to the depletion of the stocks of genetic resource due to the contractual bioprospecting activities, which is expressed as $C(s(B_1))$ in equation (17).

Thus, the profit-maximizing problem for the source supplier can be resolved through the choice of B_1:

$$\underset{B_1}{Max} \qquad \pi_{SS} = P_{GR} \cdot s(B_1) + Roy(B_1(pat_1)) - C(s(B_1)) \tag{18}$$

The first order condition is expressed in equation (19) as:

$$\frac{\partial \pi_{SS}}{\partial B_1} = P_{GR} \frac{\partial s}{\partial B_1} + \frac{\partial Roy}{\partial B_1} - \frac{\partial C}{\partial s} \frac{\partial s}{\partial B_1} = 0 \tag{19}$$

As we can see, the source supplier will engage in bioprospecting if, at the margin, the benefits of writing this contract, i.e. $P_{GR} \frac{\partial s}{\partial B_1} + \frac{\partial Roy}{\partial B_1}$, are larger than the total financial

costs, $\frac{\partial C}{\partial s}\frac{\partial s}{\partial B_1}$. In particular, the first term, $P_{GR}\frac{\partial s}{\partial B_1}$, indicate that by signing the 1st MTA the source supplier stakeholder will get financial payments arising from granting the right to the intermediary in having access to local genetic resources and indigenous knowledge. In addition, source supplier can benefit from royalty revenues, $\frac{\partial Roy}{\partial B_1}$, due to *inter alia* the protection of intellectual property rights on indigenous knowledge and their potential in drug innovation. Both may be shared by the source supplier with the local community.

In addition, by definition, we know both *s(O)and s(B_1)* will involve the use of genetic resources, and thus reducing its total stocks. However, the respective impact in terms of biodiversity depletion is assumed to be lower when the allocation regime refers to bioprospecting. Formally, we have that $\frac{\partial GR}{\partial s(O)} < 0$, with $\frac{\partial GR}{\partial s(O)} < \frac{\partial GR}{\partial s(B_1)} \cong 0$, where $\frac{\partial GR}{\partial s(B_1)}$ refers to the changes of the total stocks of genetic resources in the field as a result of the contractual bioprospecting activities. In other words, the contractual bioprospecting activity, when compared to other resource allocation regimes, is associated to a less intensive use of the genetic resources, and thus to a reduction in biodiversity loss.

5. Discussion of the impacts of biocontracting and patenting on welfare

In the previous subsections we have shown that biocontrating and patenting reveal to be convenient profit-maximizing operations for all stakeholders under consideration. The perspective of higher individual profits, and market power, can stimulate the pharmaceutical company to endorse in bioprostecting and patenting. Therefore, the government, which wants to replace open access to the biological resources by clarifying and recognizing the sovereign property rights over biodiversity, should "let the market play", allowing the private company to engage in bioprospecting and patenting activities, and thus also allowing the company to capture the monopolistic rents, in change of a reduction in biodiversity loss. This reciprocal obligation would constitute the main content of the 1st and 2nd MTA between the involved stakeholders.

Such agreements may have a very positive effect on social welfare. This is because the companies, when engaging in bioprospecting activities, contribute to the protection of the stock of genetic resources, which society might not have otherwise. However, the contracts can cause a negative impact on the social welfare because of the anti-

competitive drawbacks. The following analysis will formally assess the total welfare impacts involved and its distribution among the stakeholders.

Let us assume that the total welfare function is given by:

$$
\begin{aligned}
W &= \pi_{Inter} + \pi_{pharm} + \pi_{SS} + v(x, y_{Pharm}, GR) \\
&= P_s \cdot F(s(B_1), L, T(B_2)) - [C(y_{Inter}) + C(B_1) + C(pat_1)] + \\
&+ [Roy(B_2(pat_1)) - Roy(B_1(pat_1))] \\
&+ P_D \cdot G[y_{Inter}(B_2), K, TI(pat_2)] - [C(y_{Pharm}) + C(B_2) + C(pat_2)] - \\
&- Roy(B_2(pat_1)) \\
&+ P_{GR} \cdot s(B_1) + Roy(B_1(pat_1)) - C(s(B_1)) + v(x, y_{Pharm}, GR)
\end{aligned}
\tag{20}
$$

with $P_D > P_S > P_{GR}$.

Equation (20) shows that the welfare function is given by the aggregation of stakeholder's objective functions and consumer's utility expressed in monetary terms, *v(.)*. The latter increases with the consumption of all other goods, *x*, the consumption of pharmaceutical products, y_{Pharm}, and with the stock of genetic resources, *GR*. It is important to note that we can observe a lowest market price, P_{GR} for the raw materials supplied by source suppliers. After extracting and processing in the intermediate institute, the price of the raw sample is increased embedded an added-value, which is expressed by P_S in equation (20). Not surprisingly, the highest price, P_D, is observed on the final drug products provided by the pharmaceutical company.

As discussed in the previous sections, the royalty payments are paid by the pharmaceutical company to both intermediary and source supplier, and in accordance to the two MTAs contractual specifications. As a consequence, we can rearrange equation (20) as follows:

$$
\begin{aligned}
W &= \pi_{Inter} + \pi_{pharm} + \pi_{SS} + v(x, y_{Pharm}, GR) \\
&= P_s \cdot F(s(B_1), L, T(B_2)) - [C(y_{Inter}) + C(B_1) + C(pat_1)] + \\
&+ P_D \cdot G[y_{Inter}(B_2), K, TI(pat_2)] - [C(y_{Pharm}) + C(B_2) + C(pat_2)] - \\
&+ P_{GR} \cdot s(B_1) - C(s(B_1)) + v(x, y_{Pharm}, GR)
\end{aligned}
\tag{21}
$$

Therefore, we want to maximize this welfare function:

$$\underset{B_1,B_2,pat_1,pat_2}{Max} \quad W = \pi_{Inter} + \pi_{pharm} + \pi_{SS} + v(x, y_{Pharm}, GR) \tag{22}$$

$$= P_s \cdot F(s(B_1), L, T(B_2)) - [C(y_{Inter}) + C(B_1) + C(pat_1)] +$$

$$+ P_D \cdot G[y_{Inter}(B_2), K, TI(pat_2)] - [C(y_{Pharm}) + C(B_2) + C(pat_2)] -$$

$$+ P_{GR} \cdot s(B_1) - C(s(B_1)) + v(x, y_{Pharm}, GR)$$

A) The effects of the 1st MTA on social welfare:

$$dW = P_S \frac{\partial F}{\partial s(B_1)} \frac{\partial s(B_1)}{\partial B_1} dB_1 - \frac{\partial C}{\partial B_1} dB_1 + P_{GR} \cdot \frac{\partial s}{\partial B_1} dB_1 - \frac{\partial C}{\partial s(B_1)} \frac{\partial s(B_1)}{\partial B_1} dB_1 + \frac{\partial v}{\partial GR} \frac{\partial GR}{\partial B_1} dB_1$$

Where, $P_S \frac{\partial F}{\partial s(\partial B_1)} \frac{\partial s(\partial B_1)}{\partial B_1} > 0$, shows that writing the 1st MTA can lead to an increase in the productivity of the intermediary sector. The monetary magnitude of this expression can be interpreted as one of the positive impacts on the social welfare. In addition, $P_{GR} \cdot \frac{\partial s}{\partial B_1} > 0$ refers to the impact of the 1st MTA on the profits of source supplier. The monetary magnitude of this expression can be interpreted as another positive impact on the social welfare. The term $-\frac{\partial C}{\partial B_1} < 0$ is negative and captures the financial costs involved with the signature of the 1st MTA. The monetary magnitude of this expression can be interpreted as a negative impact on the social welfare. The final term, $\frac{\partial v}{\partial GR} \frac{\partial GR}{\partial B_1}$, captures the impact of the 1st MTA on the genetic stocks. As we have seen before, the allocation of genetic resources in bioprospecting is associated to a decline in the stocks of this same resource. For this reason, this term is negative, and its magnitude is interpreted as an additional negative welfare impact. It is important to note, however, such a negative impact is here set at the lowest magnitude since we consider $\frac{\partial GR}{\partial s(O)} < \frac{\partial GR}{\partial s(B_1)} \cong 0$. To conclude, the overall effect of 1st MTA on social welfare is unknown but most likely to be positive whenever $\frac{\partial C}{\partial B_1} \cong 0$ and $\frac{\partial GR}{\partial s(B_1)} \cong 0$.

B) The effects of the 2nd MTA on social welfare:

$$dW = P_S \frac{\partial F}{\partial T}\frac{\partial T}{\partial B_2} dB_2 + P_D \frac{\partial G}{\partial y_{Inter}}\frac{\partial y_{Inter}}{\partial B_2} dB_2 - \frac{\partial C}{\partial B_2} dB_2$$

where $P_S \frac{\partial F}{\partial T}\frac{\partial T}{\partial B_2} > 0$. This expression shows that the 2nd MTA can stimulate the technological transfer between the private company and the intermediary, and thus increase the productivity of intermediary. Such a technological transfer can be put forward by the setup of an efficient genetic database. Against this background, if the required specimens have been obtained and information is available on the database, this will consequently decrease the requirement of genetic origins from field collection, and thus also contribute to biodiversity conservation (Simpson et al. 1996). As a consequence, this effect has a positive welfare impact. $P_D \frac{\partial G}{\partial y_{Inter}}\frac{\partial y_{Inter}}{\partial B_2} > 0$, indicates that making the 2nd MTA will also have a positive impact on the utility of private company, due to the use of the high quality samples supplied by the intermediary. This effect is indirect but significant, because the success of drug development relies on the sample quality, which can be directly influenced by the non-monetary benefit-sharing rules addressed in the 2nd MTA.

Finally, $-\frac{\partial C}{\partial B_2} < 0$ shows that the 2nd MTA is, however, a costly activity, and this negatively affects the utility of private company. To conclude, the overall effect of 2nd MTA on social welfare is unknown but most likely to be positive. The lower is the magnitude of $\frac{\partial C}{\partial B_2}$ and the higher is the magnitude of $P_S \frac{\partial F}{\partial T}\frac{\partial T}{\partial B_2}$ and $P_D \frac{\partial G}{\partial y_{Inter}}\frac{\partial y_{Inter}}{\partial B_2}$.

C) The effects of patenting on social welfare:

$$dW = \frac{\partial W}{\partial pat_1} dpat_1 + \frac{\partial W}{\partial pat_2} dpat_2 =$$

$$= -\frac{\partial C}{\partial pat_1} dpat_1 + P_D \frac{\partial G}{\partial TI}\frac{\partial TI}{\partial pat_2} dpat_2 - \frac{\partial C}{\partial pat_2} dpat_2 + \frac{\partial v}{\partial y_{Pharm}}\frac{\partial y_{Pharm}}{\partial pat_2} dpat_2$$

where we have $-\frac{\partial C}{\partial pat_1} < 0$ and $-\frac{\partial C}{\partial pat_2} < 0$. The monetary magnitudes of these expressions can be interpreted as a negative impact on the social welfare and indicates the relevance of the administrative costs when claiming for patent, which are incurred

respectively by the intermediary and pharmaceutical company. As we can see, even though patenting is a costly activity for both stakeholders, they still insist on doing so. This can be analyzed from two aspects.

First, we have that patenting generates benefits amounting to $P_D \frac{\partial G}{\partial TI}\frac{\partial TI}{\partial pat_2}$. The monetary magnitude of this expression can be interpreted as a positive impact on the social welfare and indicates the relevance of patenting on the productivity of pharmaceutical company, and respective profits. This is particular the case when proposing the 2nd MTA for exchanging the processing samples between the intermediary and the pharmaceutical company. These purchased samples are isolated and identified genetic compositions, known as upstream innovations in the literatures (Heller and Eisenberg 1998; Willison and MacLeod 2002). They are essential for the success of drug development in the sequence research process. Generally speaking, patenting the upstream innovation, at most of the time, covers a class of materials and their broad applications (Lawson 2004). It, therefore, must lead to a more active patenting behaviour in response to the application or imitation of the patented inventions by the external collaborators and competitors (Peeters and Van Pottelsberghe De La Potterie 2006).

Second, we patenting may also generate an additional benefit towards the pharmaceutical company, $\frac{\partial v}{\partial y_{Pharm}}\frac{\partial y_{Pharm}}{\partial pat_2}$, which captures the impacts of patenting the pharmaceutical products on the consumers' utility. An increase in the number of patented pharmaceutical products is likely lead to a decrease in the consumer's utility of consuming these products with additional payments for the "monopolist overcharge", and its magnitude is interpreted as another negative welfare impact. In summary, the overall effects of patenting on social welfare are unknown but most likely to be positive. Respectively, the lower is the magnitude of $\frac{\partial C}{\partial pat_i}$ and the higher is the magnitude of $P_D \frac{\partial F}{\partial TI}\frac{\partial TI}{\partial pat_2}$ and $\frac{\partial v}{\partial y_{Pharm}}\frac{\partial y_{Pharm}}{\partial pat_2}$.

6. Conclusions

The present paper has discussed the fundamental issues related to the proliferated biocontracting activities and their potential impacts on biodiversity. We first reviewed a number of the existing bioprospecting contracts worldwide in order to identify the different parties involved in biocontracting as well as their motivations of making the related contracts. As a consequence, we identified that the pharmaceutical industry as a private sector involved in bioprospecting activities, representing the largest global market of genetic resource products. For this same reason, this stakeholder is identified as having an important role formulating the current bioprospecting contracts on the

commercial use of genetic resources. Hence, we move our research emphasis particularly to the pharmaceutical industry.

By clarifying the pharmaceutical research process, and the specific contractors involved, it enables us to get insight into the contract contents and the covered bioprospecting activities at each stage respectively. Our analysis shows that biocontracting and patenting activities plays an essential role in the objective function of the pharmaceutical firm, and thus one can evaluate whether such management practice is an efficient market-based policy instrument for promoting biodiversity conservation. If one agrees that biocontracting can play an important role in promoting the efficient use of genetic resources, patenting works as an activator to accelerate the formulation of bioprospecting contracts and facilitate the equitable benefits-sharing among all involved contractors. This is because the profits delivered by bioprospecting agreements are associated with the patent rights to explore the resource for the sequent innovations, and thus affect the individual decisions and behaviours of all related parties concerning natural resources management. Against this background, we provide a formal economic analysis for exploring the overall social welfare changes put forward by biocontracting. As we have observed in Section 4, the effects of biocontracting on social welfare are unknown but most likely to be positive, because they may lead to an increase in the productivity of pharmaceutical products and boost the biotechnology development. This, in turn, has a positive impact on biodiversity conservation as a result of a significant decrease in the field collection effort. As far as patenting is concerned, we acknowledge the limitations of existent patenting system (e.g. the associated anti-competitive power), but we also have to recognize that patenting plays a crucial role of promoting private investments in biocontracting and thus in biodiversity conservation. First of all, at the field collection stage, the samples without any legal title are sold at a misleadingly lower price in marketplace (Simpson et al. 1996). This however, will increase the difficulty of controlling the intensive exploration of genetic species. In addition, the compensation for access to samples is often made in the form of royalty, and partly contributes to the natural conservation. Nevertheless, this basic funding for biodiversity conservation can not be guaranteed without appropriate protection of the legal legislation. Furthermore, without legal protection on ‘inventions’, companies typically have no incentives to continue to invest multi-million dollars to bring a derivative to late development, clinical trial, and ultimately to market (Artuso 1997; Rosenthal et al. 1999; Ten Kate and Laird 1999). This however, may lead to potentially negative impacts on the future research, in particular on the simulation of advanced biotechnology, because the development of biotechnology may have a positive effect on the genetic resource by reducing the searching efforts in the wild.

Finally, our analysis demonstrates that pharmaceutical companies may also have a strong incentive to protect the great biodiversity in source country for the future drug development. This is because natural products have their unique values in both discovering new drug products and serving as a source of leads for drug development. Such new compound structures may never be synthesised by classical and combinatorial chemistry (Onaga 2001). Therefore, the government, which wants to replace open access to the biological resources by clarifying and recognizing the sovereign property rights over biodiversity, should “let the market play”, allowing the private sectors to engage in bioprospecting and patenting activities.

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