# On the Distribution of Benefits Arising From Bioprospecting Between the North and the South

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First Version: October 2006

This Version: August 2007

[1]The earlier version of this paper was presented at the 9th Biennial Conference of the International Society of Ecological Economics, 15-19, December 2006, New Delhi, India.

**Abstract**

Bioprospecting is a measure aiming at protecting biodiversity. It is based on the Convention on Biological Diversity (CBD), which states that the benefits arising out of the utilization of genetic resources should be shared on a fair and equitable basis between the contracting countries. The attempt of this paper is to investigate theoretically the issue of distribution of benefits between a developed and a developing country (the North and the South) in bioprospecting for pharmaceutical products by using the genetic resources in the rainforest possessed by the South. We show that the South should gain nothing from the profits obtained from commercialization of the pharmaceutical product if it does not contribute to R&D; in this case, the South should receive monetary transfers only according to the scale of the rainforest conserved. However, this is not true if the North is the leader of the contract and if certain conditions are satisfied. Also, if the South contributes to R&D with traditional knowledge, it is demonstrated that the profits should be shared between the North and the South according to the level of contribution to R&D.

**Key words**: Bioprospecting, the CBD, Benefit-sharing, Equity, Traditional knowledge.

**JEL Classification**: Q56, Q57, Q58.

# 1 Introduction

Bioprospecting is an attractive measure aimed at protecting biodiversity. It is very often an attempt by pharmaceutical corporations or agribusiness in developed countries to develop new drugs or crops by using the genetic resources that are possessed in natural capital stocks, such as rainforests, in developing countries. In exchange for gaining access to the regions, corporations contract to make substantial payments to the source country of the genetic resources, and also pay royalties if products with commercial value result from the project. Roughly speaking, a bioprospecting project gives a developing country an incentive to conserve its own natural capital stock, in that conservation can lead to greater benefits than its opportunity costs; benefits from deforestation for ranching or agriculture, for example, must be smaller than those under bioprospecting for the country.

Bioprospecting is based on the Convention on Biological Diversity (CBD). The CBD acknowledges that the source country has sovereign property rights over its natural resources. Thus, it might be natural to consider that the source country is eligible to share the benefits from bioprospecting. In fact, Articles 1 and 19 of the CBD refer to benefit-sharing; they require that the benefits arising out of the utilization of genetic resources should be shared on a fair and equitable basis between the contracting countries.

However, how should a “fair and equitable” distribution be defined in specific terms? Economics has a long history investigating this issue, but it is still unsolved, mainly because there is no agreement on what fairness or equity points to. This sharply contrasts with the area of efficiency, where, needless to say, the concept of Pareto efficiency is unanimously accepted.

In the literature on bioprospecting, most studies are devoted to other important issues such as the value of biodiversity, rather than distributional questions. In studies on the value of biodiversity for the development of new products, for example, Simpson, Sedjo and Reid (1996) focus on the value of marginal species and show that this value might not be sufficient to encourage the conservation. Costell and Ward (2006) also derive similar implications. On the contrary, Rausser and Small (2000) claim, by numerical simulation, that the bioprospecting value of certain genetic resources could provide a large enough incentive for conservation. Craft and Simpson (2001), using two theoretical models, suggest that the private value of marginal species is likely to be small, but the social value can be large.

On the other hand, Bhat (1999) investigates the protection of intellectual property rights in bioprospecting and demonstrates that it can promote the conservation of biodiversity under a cooperative agreement among the parties involved. Nunes and van den Bergh (2001) examine the methods to value biodiversity under bioprospecting. Artuso (2002) does deal with the problem of benefit-sharing, but does not study monetary distribution under a theoretical framework.

The attempt of this paper is to investigate the issue of fairness or equity in benefit-sharing in bioprospecting from a theoretical viewpoint. But we do not intend to provide our own definition on what a fair or an equitable distribution in bioprospecting means. Instead of doing this, we attempt to show how Pareto efficiency, or the global optimality, determines the way of monetary transfer between contracting countries in an economy with bioprospecting. By showing this, we can claim what types of distributional contract should be selected or should be excluded in terms of Pareto efficiency, if a fair and equitable distributional contract needs to satisfy conditions of efficiency.

We suppose an economy where a firm in a developed country (the North) develops a pharmaceutical product using the genetic resources in a rainforest that a developing country (the South) conserves. We consider a distributional contract between the two countries such that the North pays to the South according to the scale of rainforest conserved for bioprospecting. Moreover, if the new pharmaceutical product is commercially successful, then some part of the profits from the sale of the product goes to the South.

We consider the following two cases. In the first case, the South does not contribute to R&D of the pharmaceutical product; what it contributes is only the provision of the genetic resources by conserving the rainforest.

In the second case, on the other hand, the South also contributes to R&D; for example, it collects and screens the genetic resources. In this case, therefore, the South expends some part of the R&D costs. For the contribution, the South can use "traditional knowledge" that is inherited in indigenous communities in the country. ten Kate and Laird (1999) survey the studies of the importance of traditional knowledge in drug discovery. According to the survey, "[t]he ethnobotanical approach to drug discovery—the use of people's knowledge and experiences of the medicinal properties of plants and other genetic resources to guide drug discovery—has yielded most of the plant-based pharmaceuticals in use today". [1] That is, the South contributes to R&D, providing traditional knowledge that must be useful in bioprospecting, in addition to conserving rainforest.

In both cases, we examine what kind of the distributional contract will be compatible with efficiency, and in particular what proportion of the profits from the sale of pharmaceutical

[1] See p.61 in ten Kate and Laird (1999).

product should go to the South.

Under conditions of efficiency, we show in the first case that the South should gain nothing from the profits of the pharmaceutical product; the South receives monetary transfers only according to the scale of rainforest conserved, regardless of whether the product is successful or not. But this is not true if the North is the leader of the contract and if certain conditions there are satisfied. In the second case, on the other hand, it is demonstrated that the profits should be shared between the North and the South according to the level of contribution to R&D of the pharmaceutical product. Although "fair" or "equitable" benefit-sharing may require the distribution of the profits to reflect that the South provides the genetic resources and traditional knowledge, efficiency never allows this.

This paper is constructed as follows: the section 2 introduces the model for this paper. Section 3 and 4 study the monetary transfer system in the first and second cases respectively, in terms of efficiency. Section 5 summarizes and presents some conclusions.

## 2 The Model

We consider an economy where there are two countries, $S$ (the South), and $N$ (the North). Country $S$ is a developing country with a rainforest that is rich in biodiversity. On the other hand, country $N$ is a well developed country with advanced scientific technology.

In what follows, the scale of the rainforest is denoted by $\bar{L}$. Country $S$ can transform its rainforest into ranching or agricultural land. The net benefit from this transformation is expressed by

$$\mu = \mu(A), \mu' > 0, \mu'' < 0 \tag{1}$$

where

$$A = \bar{L} - L. \tag{2}$$

On the other hand, the rainforest has direct and indirect economic values for the South, derived from its various functions. This value, $V$, is expressed by

$$V = V(L), V'(L) > 0, V''(L) < 0 \tag{3}$$

The rainforest also may have global environmental value that is not reflected in $V$. This is represented as $G(L)$, with $G'(L) > 0$ and $G''(L) \leq 0$.

Now suppose that both the North and the South jointly try to develop a pharmaceutical product, using the biodiversity of country $S$.

Let $P(R, L)$ represent the probability that the development will result in commercial success. Here $R$ expresses the total R&D expenditure for the new pharmaceutical product and $L$ is the size of the area to be conserved by country $S$ for the project. $R$ involves the cost of collecting the genetic resources from the conserved rainforest, and screening and researching them for the commercial use.

We assume that $P(0, L) = P(R, 0) = 0$, $P_R(\equiv \partial P(R, L)/\partial R) > 0$, and $P_L(\equiv \partial P(R, L)/\partial L) > 0$, $P_{RR}(\equiv \partial^2 P(R, L)/\partial R^2) < 0$ and $P_{LL}(\equiv \partial^2 P(R, L)/\partial L^2) < 0$ for $(R, L) > (0, 0)$. In addition, it is assumed that

$$P_{RR}P_{LL} - (P_{RL})^2 > 0 \tag{4}$$

so that the function $P$ is strictly concave.

On the other hand, let $M$ stand for the prospective profit from the pharmaceutical product if the joint venture succeeds in developing and commercializing it. The global welfare, $W_G$, is represented by

$$W_G = P(R,L)M - R + \mu(A) + V(L) + G(L) \tag{5}$$

Here $PM$ is the expected profit from the bioprospecting. Thus, the (ex ante) global optimum is attained if the following conditions are met.

$$\begin{aligned} P_R M &= 1, \\ P_L M - \mu' + V'(L) + G(L) &= 0 \end{aligned} \tag{6}$$

We denote the global optimum by $(R^*, L^*)$, and $P_L$ and $P_R$ there by $P_L^*$ and $P_R^*$. [2]

## 3 Global optimality under a monetary transfer system when the South does not contribute to R&D

Let us start our analysis by supposing that the North pays all the R&D costs. Under this supposition, all the South does is to conserve the rainforest for R&D. Suppose that the joint venture is pursued under the following monetary transfer contract system from the North to the South. In this system, the North transfers to the South $\alpha(>0)$ per hectare of rainforest conserved for the project. That is, the more rainforest the South conserves, the more the North will pay for it.

Moreover, if the project succeeds, then both countries share the profit $M$; the North receives $\theta_N M$ and the South $\theta_S M (\equiv (1-\theta_N)M)$, where $0 < \theta_N \leq 1$. That is, $\theta_S M$ can be interpreted as royalties for the use of genetic resources by the North.

In what follows, we refer to this transfer system as $(\theta_N, \alpha)$. In the transfer system, the

[2] We assume that $(R, L)$ that satisfies (6) exists. From our assumptions on $P, \mu$, $V$ and $G$, the second order condition $P_{RR}M(P_{LL}M + \mu'' + V'' + G'') - (P_{RL}M)^2 > 0$ is satisfied there.

expected net benefit for country $N$, $W_N$, is expressed by

$$W_N = \theta_N P(R, L)M - R - \alpha L \tag{7}$$

Also, that of country $S$, $W_S$, is defined as:

$$W_S = (1 - \theta_N)P(R, L)M + \alpha L + \mu(A) + V(L). \tag{8}$$

Can this transfer system $(\theta_N, \alpha)$ attain the global optimum $(R^*, L^*)$? If so, what values do $\theta_N$ and $\alpha$ take? The next proposition answers this.

**Proposition 1** *Suppose that the transfer system in the project is prescribed by* $(\theta_N, \alpha)$*. Then it attains the global optimum if and only if* $\theta_N = 1$ *and* $\alpha = P_L^* M + G'(L^*)$*.*

*Proof*: The firm in country $N$ maximizes its profit so that it holds

$$\theta_N P_R M = 1 \tag{9}$$

and country $S$ maximizes $W_S$ so that we have

$$(1 - \theta_N)P_L M + \alpha + V'(L) = \mu'(A) \tag{10}$$

If it holds

$$\begin{aligned} \theta_N &= 1 \\ \alpha &= P_L^* M + G'(L^*) \end{aligned} \tag{11}$$

then (6) is satisfied by (10) and (9), so that $(R^*, L^*)$ will be attained.

On the other hand, suppose that the optimum $(R^*, L^*)$ is attained. Then $\theta_N$ should be unity if we compare (9) with (6). Moreover, under $\theta_N = 1$, it should be from (6) and (10) that

$\alpha = P_L^* M$. ♣

Thus, the South should not share in the benefit of any successful development; global optimality is not compatible with the distribution of profits from the sale of the pharmaceutical product even if it is developed from the genetic resources of the South.

On the other hand, the expected contribution of conserving the rainforest must be reflected in $\alpha^*$, since $P_L^* M + G' L^*)$ expresses the marginal expected revenue from the conservation of the rainforest.

## 3.1 Stackelberg equilibrium

The above discussion supposes that no country is a leader or a follower. In a project involving two players, it is sometimes true that one is the leader of the project. In what follows, we examine this case and suppose that one of the two is a leader and the other is a follower.

To begin with, we suppose that country $N$ is a leader and country $S$ is a follower. That is, country $N$ chooses $R$ by taking into consideration the response of country $S$ against the level of $R$.

### 3.1.1 Country N is the leader

The North's net benefit maximization in this case leads to

$$\theta_N (P_R M + P_L M \frac{dL}{dR}) - \alpha \frac{dL}{dR} = 1 \tag{12}$$

where $dL/dR$ is the response of the South against the level of R&D chosen by the North. Under this supposition, country $N$ decides $R$, taking into consideration that country $S$ decides $L$ to maximize her profit given $(\theta_N, \alpha, R)$, which also leads to the condition (10). By differentiating

(10) with $R$, we can see

$$\frac{dL}{dR} = -\frac{(1-\theta_N)P_{LR}M}{(1-\theta_N)P_{LL}M + \mu''(A)} \tag{13}$$

Since $P_{LL} < 0$ and $\mu'' < 0$, the sign of $P_{LR}$ determines that of $dL/dR$ if $\theta_N < 1$. Otherwise, $dL/dR = 0$.

Under this case, let us derive $(\theta_N, \alpha)$ from (10) and (12), which is compatible with the global optimality. Does some $(\theta_N, \alpha)$ admit that $\theta_N$ is less than one, which says that the South can gain something from $M$? The next proposition answers this.

**Proposition 2** *Suppose that the firm in the country N behaves as a leader. Then, the global optimum is always attained by*

$$(\theta_N, \alpha) = (1, P_L^* M + G'(L^*)),$$

*and*

$$(\theta_N, \alpha) = (1 - \frac{G'(L^*)P_{LR}^* M - \mu''(A^*)}{P_{LL}^* M}, \theta_N P_L^* M + G'(L^*))$$

*if* $P_{LL}^* M + \mu''(A^*) < G'(L^*)P_{LR}^* M < \mu''(A^*)$ *holds.*

*Proof*: From the second equation of (6) and (10), it holds for $\alpha$ to achieve the optimum

$$\alpha = \theta_N P_L(R^*, L^*)M \tag{14}$$

This leads (12) to,

$$\theta_N(P_R M + P_L M \frac{dL}{dR}) = 1 + \theta_N P_L M \frac{dL}{dR} \tag{15}$$

which is reduced to, under $(R^*, L^*)$ where $P_R^* M = 1$,

$$\theta_N = 1 - G'(L^*)\frac{(1-\theta_N)P_{LR}M}{(1-\theta_N)P_{LL}M + \mu''(A)} \tag{16}$$

By solving $\theta_N$ at the global optimum, we obtain

$$\theta_N = \frac{-(G'P_{LR}M - 2P_{LL}M - \mu'') \pm (G'P_{LR}M - \mu'')}{2P_{LL}M} \tag{17}$$

Therefore, it is easy to see that the optimum is attained at $\theta_N = 1$ or at

$$\theta_N = 1 - \frac{G'P_{LR}M - \mu''}{P_{LL}M} \tag{18}$$

Hence $0 < \theta_N < 1$ is possible at the optimum if and only if the following both hold

$$\begin{aligned} P_{LR} &< 0 \qquad (19) \\ P_{LL}M + \mu'' &< G'P_{LR}M < \mu'' \end{aligned}$$

♣

From this proposition, $\theta_N$ can be less than unity only if $P_{LR} < 0$. Let us specify $P(R, L)$ as

$$P(R, L) = 1 - e^{-R^a L^b}, 1 \geq a > 0, 1 \geq b > 0 \tag{20}$$

Under this probability function, $P_{LR} = abR^{a-1}L^{b-1}e^{-R^a L^b}(1 - R^a L^b)$ so that it can take any sign, depending on the value of $R^a L^b$. Thus, $P_{LR} < 0$ is equivalent to $R^a L^b > 1$. That is, if $P(R, L)$ is more than 0.63 at the optimum, then $\theta_N$ can be less than 1. In this case, the probability that the project will succeed is more than about two-third at the optimum.

Furthermore, another condition of (19) says that $G'(L^*)$ should be neither too low nor loo high. For example, if $G(L)$ is almost constant for each $L(\geq 0)$ so that $G' = 0$, then it is impossible for the condition to be met. That is, if global environmental value is defined not to be poorly sensitive to the change of $L$, then the condition is not satisfied.

### 3.1.2 The country S is the leader

On the other hand, if country $S$ is in turn the leader, then the North maximizes $W_N$ given $L$ so that (9) must hold. From this, it is straightforward that it must be $\theta_N = 1$ for optimal conditions to be achieved. Therefore, we have the next proposition:

**Proposition 3** *Suppose that country S behaves as a leader. Then the global optimum is attained by* $\theta_N = 1$ *and* $\alpha = P_L^* M + G'(L^*)$.

In this case, there is no possibility that we have $\theta_N < 1$ at the optimum.

## 4 Optimal monetary transfer system when the South can contribute to the R&D with traditional knowledge

The results in the previous section say that it may be impossible to achieve the global optimum under a simple transfer system in which $\theta_N < 1$ is required, since $\theta_N < 1$ holds only if certain conditions are met. Thus, it is not easy to attain equal distribution of benefits, $\theta_N = 1/2$.

In this section, we assume that the South contributes to R&D. This may involve a contribution by the South to collect and screen primarily the genetic resources, instead of the North. We express the contribution of the South as a fraction $\beta$ of R&D; the contribution amounts to $\beta R$ and a higher contribution means a higher $\beta$, given $R$.

In general, R&D has several elements. According to ten Kate and Laird (1999), in addition to the collection and primary screens, other elements include isolation and characterization, secondary screens, structural elucidation, preclinical development and clinical testing. These are not possible for a developing country to contribute, so the rate of contribution $\beta$ must have a maximum, which is less than one. We denote the maximum by $\bar{\beta}$.

In the contribution, the South can utilize "traditional knowledge" that is inherited in the indigenous communities in the conserved rainforest. The utilization might increase the probability of a commercially success in bioprospecting, since, for example, the knowledge can tell the wild species that may own the genetic resources for pharmaceutical products, so that the efficiency of R&D might be raised. We express the effect of inputting traditional knowledge as follows.

$$P = P(\lambda R, \gamma L), \lambda, \gamma \geq 1 \tag{21}$$

Here $\lambda$ and $\gamma$ are multipliers that increase the effect of $R\&D$ and conserving rainforest. We suppose that the multipliers depend on the rate of contribution of the South to R&D and the usefulness of knowledge. That is,

$$\begin{aligned} \lambda &= \lambda(\beta, k), \\ \gamma &= \gamma(\beta, k), \end{aligned} \tag{22}$$

where $k (k \geq 0)$ represents the usefulness of traditional knowledge in bioprospecting. We express that the knowledge is useful by $k$ being positive. We assume

$$\lambda(0, k) = \lambda(\beta, 0) = \gamma(0, k) = \gamma(\beta, 0) = 1, \tag{23}$$

That is, if the South does not contribute to R&D so that traditional knowledge cannot be employed, then the probability is unchanged. In addition, we suppose that the more the South contributes to R&D with traditional knowledge that is useful for R&D, the more the efficiency of R&D increases. That is, $\frac{\partial \lambda}{\partial \beta} > 0$ and $\frac{\partial \gamma}{\partial \beta} > 0$ if $k > 0$. We refer to the monetary transfer system under the contribution of the South to R&D as $(\theta_N, \alpha; \beta, k)$.

Global welfare in this system is changed into $\bar{W}_G$ below:

$$\bar{W}_G = P(\lambda R, \gamma L)M - R + \mu(A) + V(L) + G(L) \tag{24}$$

Here we assume that traditional knowledge is costless. The optimum is represented as: [3]

$$\begin{aligned} \lambda P_R M &= 1, \\ \gamma P_L M + V'(L) + G'(L) &= \mu'(A) \end{aligned} \tag{25}$$

The optimum $(R, L)$ above is referred to as $(R^{**}, L^{**})$.

Under the contribution of the South, the expected net benefits for country $N$ is changed into $\bar{W}_N$

$$\bar{W}_N = \theta_N P(\lambda R, \gamma L)M - (1-\beta)R - \alpha L \tag{26}$$

which leads to, by maximizing $\bar{W}_N$,

$$P_R M = \frac{1-\beta}{\lambda \theta_N} \tag{27}$$

For country $S$, on the other hand, the net benefit in this case $\bar{W}_S$ is expressed:

$$\bar{W}_S = \theta_S P(\lambda R, \gamma L)M + \alpha L + V(L) + \mu(A) - \beta R \tag{28}$$

from which it holds:

$$\alpha = \mu'(A) - \gamma \theta_S P_L M - V'(L) \tag{29}$$

It is easy to see that (25) is satisfied under any $(\theta_N, \alpha; \beta, k)$ if and only if

$$\theta_N = 1 - \beta \tag{30}$$

[3]Hereafter, without loss of generality, we express $\partial P/\partial(\lambda R)$ by $P_R$. $P_L, P_{RL}, P_{RR}$ and $P_{LL}$ are expressed similarly.

and

$$\alpha = \gamma\theta_N P_L^{**} M + G'(L^{**}) = \gamma(1-\beta)\theta_N P_L^{**} M + G'(L^{**}) \tag{31}$$

where $P_L^{**} \equiv \partial P(R^{**}, L^{**})/\partial L$. Thus, we have the following proposition.

**Proposition 4** *Suppose that the monetary transfer system for bioprospecting is prescribed by $(\theta_N, \alpha; \beta, k)$ where $P = P(\lambda R, \gamma L)$. Then it attains the global optimum if and only if $\theta_N = 1-\beta$, i.e., $\theta_S = \beta$ and $\alpha = \gamma(1-\beta)P_L^{**}M + G'(L^{**})$.*

From the determination of $\theta_S$, the rate of profit sharing increases with $\beta$ but independent of $k$. That is, the rate of profit sharing is the same as that of the contribution of the South to R&D, regardless of whether traditional knowledge is useful or not. Note that if $\beta = 0$, then this case is equivalent to the optimal monetary transfer system $(\theta_N, \alpha)$ in the previous section. Note also that if $k = 0$, then $(R^*, L^*) = (R^{**}, L^{**})$ for any $\beta$, since $\bar{W}_G = W_G$ $(\forall \beta)$.

However, if $k > 0$, $R^{**}$ and $L^{**}$ in general change with $\beta$ and $k$. Obviously global welfare at the optimum increases with $\beta$ and $k$ in terms of the definition of $\bar{W}_G$. But regarding the South's net benefit, we cannot judge from proposition 4 whether $\bar{W}_S$ will increase with them or not; since $\theta_S = \beta$, $\theta_S PM$ increases with $\beta$ but it is not certain whether $\alpha L (\equiv ((1-\theta_S)\gamma P_L L + G'(L))L)$ also increases. Let us see this aspect below.

Totally differentiating (25) with respect to $\beta$ leads to

$$\begin{aligned} (\lambda P_{RR} dR + \gamma P_{RL} dL)\lambda M &= -(\lambda_\beta P_R + \lambda_\beta \lambda P_{RR} R + \lambda \gamma_\beta P_{RL} L)M \qquad (32) \\ (\gamma\lambda P_{RL} dR + \gamma^2 P_{LL} dL)M + H'' dL &= -(\gamma_\beta P_L + \gamma\lambda_\beta P_{RL} R + \gamma\gamma_\beta P_{LL} L)M \end{aligned}$$

from which we have

$$\frac{dR}{d\beta} = -\frac{(\gamma^2 P_{LL} M + H'')(\lambda_\beta P_R + \lambda\lambda_\beta P_{RR} R) - \lambda\gamma P_{RL} M(\gamma_\beta P_L + \gamma\lambda_\beta P_{RL} R)}{\phi} M \tag{33}$$

$$+ \quad \frac{H''\lambda\gamma_\beta P_{RL}L}{\phi}M$$

$$\frac{dL}{d\beta} = -\frac{\lambda^2 P_{RR}M(\gamma_\beta P_L + \gamma\gamma_\beta P_{LL}L) - \lambda\gamma P_{RL}M(\lambda_\beta P_R + \lambda\gamma_\beta P_{RL}L)}{\phi}M$$

where

$$\phi = \lambda^2\gamma^2 M^2(P_{RR}P_{LL} - (P_{RL})^2) + \lambda^2 P_{RR}H'' > 0 \tag{34}$$

and

$$H'' = V'' + \mu'' + G'' \tag{35}$$

The sign of $\phi$ is unambiguous to be positive since we assume (4) and that $V'', G''$ and $\mu''$ are all non-negative. From (33), however, the signs of $\frac{dR}{d\beta}$ and $\frac{dL}{d\beta}$ are not definite. To make the argument clearer, we add the following assumptions on $P$:

$$P_{RL} \geq 0, P_{RRR} \geq 0, P_{LLL} \geq 0, G'' = 0 \tag{36}$$

That is, $R$ and $L$ are not complements, $P_R$ and $P_L$ are convex, and $G$ is linear with respect to $L$. Under (36), it holds that

$$P_R + \lambda P_{RR}R \geq 0 \text{ and } P_L + \gamma P_{LL}L \geq 0 \tag{37}$$

Using this property, it is easy to see

$$\frac{dR^{**}}{d\beta} > 0 \qquad \frac{dL^{**}}{d\beta} < 0 \tag{38}$$

We claim this result as the following lemma.

**Lemma 1** *Suppose that traditional knowledge is useful, i.e., $k > 0$. Then, under (36), a higher contribution of the South to R&D increases the optimal R&D, but decreases the optimal scale of conservation of rainforest. That is, $\frac{dR^{**}}{d\beta} > 0$ and $\frac{dL^{**}}{d\beta} < 0$ hold.*

With respect to the welfare effect, it holds:

$$\frac{d\bar{W}_S}{d\beta} = (PM - R) + \beta\lambda_\beta P_R RM + \beta\gamma_\beta P_L LM + L\frac{d\alpha}{d\beta} \tag{39}$$

Here,

$$\begin{aligned} L\frac{d\alpha}{d\beta} &= -\gamma P_L LM + (1-\beta)\gamma LM(\lambda P_{RL}\frac{dR}{d\beta} + \gamma P_{LL}\frac{dL}{d\beta} \\ &+ \lambda_\beta P_{RL} R) + (1-\beta)\gamma_\beta LM(P_L + \gamma P_{LL} L) + G'' L\frac{dL}{d\beta} \end{aligned} \tag{40}$$

Since we have lemma 1 so that $L\frac{d\alpha}{d\beta} > 0$ and since $PM - \gamma P_L LM - R > 0$ by strict concavity of $P$ [4], we obtain

$$\frac{d\bar{W}_S}{d\beta} > 0 \tag{41}$$

Thus, we have the following proposition.

**Proposition 5** *Suppose that traditional knowledge is useful, i.e., $k > 0$. Then, under (36), a higher contribution of the South to R&D increases its net benefit, i.e., $\frac{d\bar{W}_S}{d\beta} > 0$.*

Note that this also holds even if $k = 0$, which means $\lambda_\beta = \gamma_\beta = 0$ so that $\frac{dR}{d\beta} = \frac{dL}{d\beta} = 0$. Thus, even when the South does not use traditional knowledge, the South's welfare increases with the rate of contribution.

Let us express the level of the South's net benefit under $(\beta, k)$ by $\bar{W}_S(\beta, k)$. Since $\bar{W}_S(0, k) = \bar{W}_S(0, 0)$ $(\forall k \geq 0)$, we obtain from proposition 5

$$\bar{W}_S(\beta, k) > \bar{W}_S(0, 0), \forall\ (\beta, k) >> (0, 0) \tag{42}$$

$\bar{W}_S(0, 0)$ is the South's net benefit when the South does not contribute to R&D. That is, the net benefit of the South will increase by taking part in R&D with traditional knowledge. In summary, we can claim:

[4]Note that $\lambda P_R MR = R$ by (25), so that $PM - \gamma P_L LM - R = (P - P_L(\gamma L) - P_R(\lambda R))M > 0$.

**Corollary 1** *Suppose (36). Then, the South will be better off by contributing to R&D with traditional knowledge.*

Hence, the South should contribute to R&D as much as possible, which will raise the South's net benefit. Thus, the maximum rate of contribution $\bar{\beta}$ maximizes the benefit.

## 5 Concluding Remarks

This paper investigates how efficient bioprospecting contracts should be designed with respect to monetary transfers from the North to the South. In particular, the paper focuses on the sharing of profits from the sale of pharmaceutical products.

If fair or equitable sharing is interpreted as "equal division" of profits, our results seem to imply that such a division is not compatible with efficiency. Far from equal division, the share for the South should be low if the contribution of the South to R&D is also low. In fact, the rate of division of profits must be equivalent to the rate of the contribution to R&D, regardless of the amount of genetic resources and regardless of usefulness of traditional knowledge provided by the South.

In our analysis, the maximum rate of the contribution to R&D is expressed by $\bar{\beta}$. The exact value of $\bar{\beta}$ is not available. However, ten Kate and Laird (1999) say, "[a]bout 37% of R&D budgets in the USA are allocated to discovery-related research, the remaining 63% to the development stage". [5] Since the South can contribute to only a part of discovery-related research, $\bar{\beta}$ might be low enough. Thus, it is possible that the requirement of the CBD concerning the benefit-sharing is not compatible with efficiency, if fairness or equity is interpreted as the equal division of the

[5] See ten Kate and Laird (1999), p. 47.

profits, or as requiring that the rate of profits sharing should reflect the provision of the genetic resources by the South.

However, our analysis is carried out under a simple model that does not involve other aspects of non-monetary transfer, such as biotechnology. Also if we consider that the South is comprised of several actors such as the private and public sectors, intermediaries (e.g. universities, botanic gardens or research institute) and the local communities, [6] and if they behave in different ways, then the analysis will become much more complicated so that the results may not be identical to those derived in this paper. These are left for interesting future studies.

[6] See ten Kate and Laird (1999) for more details on bioprospecting.

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