Kiel Institute of World Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)

Kiel Working Paper No. 1054

Conserving Biodiversity by Commercialization ?
A Model Framework for a Market for Genetic Resources

by

Oliver Deke

June 2001

Conserving Biodiversity by Commercialization?
A Model Framework for a Market for Genetic Resources

Abstract:

Since naturally occurring genetic information serves as a valuable input for biotechnological R&D, the private provision of genetic resources could generate income for the protection of biodiversity-rich areas. However, there has been a controversy over whether these potential revenues are sufficient to compensate for the costs of protection and, therefore, whether markets for genetic resources can effectively contribute to the conservation of biodiversity. In this paper, a market framework is developed to describe possible market outcomes, each with a different impact on conservation. It turns out that the market-induced incentives to conserve depend on the specific situation on the supply and demand side of the market.

***Keywords**:* Biodiversity, Biotechnological R&D, Conservation, Genetic Resources, Land-Use.

***JEL classification**:* O13, O31, Q1, Q2.

Oliver Deke
Kiel Institute of World Economics
24100 Kiel, Germany
Telephone: ++49-431-8814495
Fax: ++49-431-8814522
E-mail:oliver.deke@ifw.uni-kiel.de

This work particularly benefited from discussions with Gernot Klepper. I am grateful for comments by participants of the 2001 Workshop on ‘Economics of Biodiversity’ in Santa Barbara, especially by Geoffrey M. Heal, R. David Simpson, Jason F. Shogren, and Arthur A. Small. I also would like to thank Ralph P. Heinrich, Andrea Schertler, Julius Spatz, and Natascha A. Weisert for helpful suggestions. Any remaining errors or omissions are the sole responsibility of the author.

1. MOTIVATION

A natural system with a high degree of biodiversity provides a flow of economically valuable and sometimes even vital services. Examples for such services are the support of the functioning of ecosystems or the provision of genetic variety used for the production of seeds or pharmaceuticals. Recently, biodiversity has attracted increasing public awareness because the flow of these services can be expected to cease if the irreversible loss of biodiversity is going to continue.

The main driving force behind this loss of biodiversity can be seen to lie in the destruction of undisturbed natural habitats and the expansion of commercial land uses, such as agriculture or timber harvest (Heywood 1995:715f, WRI 1992). Since human population and resource consumption have grown, the size of relatively undisturbed ecosystems has shrunk dramatically over the past decades. This is especially true for the tropical regions with a high degree of biodiversity. For example, in Central America, 98 percent of the tropical dry forest along the Pacific coast has disappeared. In Thailand, 22 percent of the mangroves were lost only within 4 years (WRI 1992). The increasing conversion of natural habitats has been associated with a loss of biodiversity, which is most noticeably documented in a rapid decline of species diversity. The present rate of species extinction is assumed to be up to 100 times higher than the natural background rate (Barbier et al. 1994:11, Heywood 1995:232).

Given the threats to biodiversity, several concepts and first steps towards its protection of have been developed. Among them, the commercial use of genetic resources has attracted much attention since the information embodied in genetic resources has been perceived as a valuable input in the research and development (R&D) of new products in the promising biotech industry. It is often assumed that the commercial use of genetic resources may effectively contribute to the conservation of biodiversity. More specifically, the use of genetic information may generate income for providers of genetic material, and therefore, create incentives to exclude natural areas from extensive human uses which lead to a loss of biodiversity (cf. Reid et al. 1993, Rubin and Fish 1995). Such a linkage between the conservation of biodiversity on the one hand and economic development by the utilization of the natural resources on the other hand is particularly highlighted in the Convention on Biological Diversity (CBD) (cf. Wolfrum and Stoll 1996:11f., OECD 1997).

An indispensable requirement for the emergence of individual providers is that they are able to exclude potential users from the appropriation of a particular genetic material. Otherwise, he/she could not receive revenues from the maintenance of genetic resources. Excludability is determined by the technical feasibility of exclusion as well as by the entitlement to exclude others from the use of these resources, i.e. the design of the legal system and the degree to which it is upheld.

Especially in developing countries, where great parts of global biodiversity reside, there is often a lack of institutional capacities and mechanisms to facilitate the appropriation of the economic value of biodiveristy. Hence, it is difficult for individuals or corporations to benefit from the provision of biodiversity services. To overcome this situation, political efforts have increased – both on a national and international level – to establish a legal system for the use of genetic resources which reinforces the possibilities of appropriation in biodiversity-rich regions (cf. Biotrade Initiative by UNCTAD, UNCTAD 2001, also Swanson 1995).

Elements of the legal system are rights to access the genetic material, intellectual property rights on goods incorporating genetic information, and rights on traditional knowledge related to genetic resources (Bragdon and Downes 1998). In this respect, the provisions of the CBD represent the relevant framework for establishing property rights in national legislation.

However, some economists have called into question whether the creation of markets for genetic resources by defining property rights does necessarily contribute to an effective protection of biodiversity (cf. Simpson 1997). Moreover, the perspectives of a commercialization of genetic resources for the conservation of biodiversity crucially depend on their possible market value, i.e. on how much the biotech industry is willing to pay for samples of genetic material and on how much revenues a single provider can earn within a market with many potential suppliers.

So far, there have been several empirical studies which attempt to determine the private value of genetic resources on the demand side (for a survey, see OECD 1997). Most of the studies suggest that the willingness to pay of private firms for genetic resources is probably low (Barbier and Aylward 1996, Simpson et al. 1995). From this, it has been concluded that the incentives for private efforts in conserving biodiversity are likely to be overestimated. Nevertheless, since different segments of market demand, such as botanical medicine, pharmaceuticals or agricultural seeds, are considered and the underlying assumptions regarding the use of genetic resources in R&D vary between the studies, predictions about the market value of genetic resources in absolute monetary terms vary quite significantly[1].

In this paper, we develop a formal framework to analyse the underlying factors that determine whether the establishment of a market for genetic resources and their exploitation for commercial purposes contributes to the conservation of biodiversity. In that sense, the study is purely theoretical.

Since the conversion of natural habitats is supposed to be the main reason for the irreversible reduction in the endowment of genetic resources, we first focus on the decision of the individual landowner on how to use his/her land. From the individual viewpoint, the benefits received from the provision of genetic resources must at least compensate for the forgone benefits of alternative land uses, namely the conversion of habitats and production of agricultural goods.

In section 2, a simple model for individual land use-decisions is developed. Connected with this, we have to review some biological aspects on species richness and on the distribution of species to make some assumptions about the availability of marketable genetic resources for an individual landowner acting as a provider of genetic material. We consider the case where the number of genetic resources available for the individual landowner depends on the land-use decision of the adjacent landowners, i.e. there are mutual positive externalities on the production side of genetic resources. Section 3 extends the analysis to the market level where we consider the aggregate supply of several providers of genetic resources facing a demand for genetic material by several firms that produce biotechnological goods. The factor demand is derived from a formal description of the market of these final goods. For this, we use a Dixit-Stiglitz model of monopolistic competition. In section 4, the extended model is used to analyse how certain factors on the demand and supply side affect the market outcome and the number of suppliers of genetic resources in the market who withhold biodiversity-rich areas from conversion. Section 5 concludes.

2. INDIVIDUAL LAND-USE DECISIONS IN BIODIVERSITY-RICH AREAS

It is reasonable to assume that the demand for genetic resources for biotechnological production mainly focuses on material that is extracted from areas where biological diversity is highest, i.e. genetic material from developing countries in tropical climate zones (UNEP 1998, ten Kate and Laird 1999). Accordingly, we consider a natural area of a given size within a region of high species diversity as well as genetic diversity. This area represents a single ecosystem which is ecologically homogenous and initially relatively undisturbed.

Property rights on natural areas – particularly on tropical forest areas – are often not properly implemented or not effectively enforced (Mendelsohn 1994)[2]. In the following, we abstract from this problem and simply assume a situation where property rights on areas of natural land are well-defined and perfectly enforceable. Suppose that there are (m_0) owners of plots of biodiversity-rich land (a_l) ($l=1..m_0$), which are of identical size. Without a loss of generalisation we define $a_l=1$, $\forall$ l. Furthermore, the single plots of land are adjacent areas and together form a homogenous area (a_0) of larger size, i.e $a_0 = \sum_{l=1}^{m_0} a_l = m_0$.

Each individual landowner can basically employ his/her plot of land for agricultural production or as a reserve for the supply of genetic resources. In the following, (m) describes the number of landowners who protect their land from conversion. Hence, the preserved natural area is $a = \sum_{j=1}^{m} a_j = m$, with $m \leq m_0$.

For simplicity, genetic resources are defined as the number of different biological species (x) (cf. Simpson et al. 1996:168). A joint production of agricultural goods and material samples is not possible. The plot of land is either completely excluded from agricultural use or the vulnerable species with potential genetic information get lost in this plot.

Genetic resources are directly sold to the biotech industry.[3] If landowners decide to provide genetic resources, they enter into a local competition with other providers. For a description of this local competition, we must define how many genetic resources can be found within the entire area and how they are distributed across the plots of the individual providers.

Note that the single plots of land are adjacent and that the borders of natural habitats of individual species are not identical to the borders of individual land property, i.e. some species will be distributed across property borders. Therefore, it is reasonable to assume that the availability of species for the single provider of genetic resources is not only determined by his/her own plot of land, but also by the magnitude of the surrounding reserve area. In that sense, the providers exercise mutual positive externalities on the availability of genetic resources by withholding plots of natural land from conversion though they are competitors in the market.

For simplicity, we suppose that the availability of genetic resources depends on the magnitude of the entire area that is conserved. Therefore, we have to establish a relationship between the size of the area and the quantity of genetic resources. This so called species-area-relationship has been the subject of many studies in natural science (Connor and McCoy 2001, Heywood 1995:90f). It can be observed that the number of different species within a homogenous ecosystem increases with the size of area. However, the gain in species richness usually decreases with increasing size of the reserve area (a=m). In the non-linear species-area-relationship in equation (1), the number of species existing in the area is denoted by (x_e), (δ represents the elasticity of species richness with respect to size of the area

(1) $x_e = m^d$ with $0<\delta<1$.

After it is known how much genetic resources exist altogether in the area, we have to determine how many of them an individual provider can access in his/her plot of land. To keep the aspect of spatial distribution of species tractable, we make a strong simplifying assumption saying that all species are evenly distributed across the plots of land, i.e. all species occur in each plot

(2) $x_{e,j} = x_e$.

The number of available genetic resource in the entire area as well as in the plot of the single provider depends on the overall number of providers who withhold biodiversity-rich land from conversion.

So far, we only have considered the availability of genetic resources. In order to sell them in the market, samples of genetic material have to be extracted from the land. In this extraction process, the input of factor (v_j) is needed. We suppose that factor (v_j) shows decreasing returns to scale in the "production" of marketable samples, i.e. the more genetic resources have already been extracted, the harder it is to find an additional species. The total number of available genetic resources represents the upper bound for the total supply on the market

(3) $x_j = \mathrm{v}_\mathrm{j}^{a}$ with $0 < a < 1, x_\mathrm{j} \le x_{e,j}$.

Genetic resources are considered to be homogenous goods, i.e. samples of different biological material yield the same market price. An individual provider is able to serve the entire market given the assumed homogenous distribution of every genetic resource across the plots of land. There is no genetic resource outside his/her plot that can be also found within the plot. However, this ability to serve the entire market holds true for all (m) suppliers. Thus it is reasonable to assume that price competition drives the asking price of the providers to the marginal cost of extraction.

The underlying calculus for the individual supply of genetic resources can, in essence, be described by the marginal cost (MC_j) (see supply curve in the Figure 1 below). However, two other factors affect the individual supply. Firstly, the availability of genetic resources determines the upper limit of supply. Secondly, the opportunity costs of providing genetic resources, i.e. the forgone profits from alternative land uses.

It is evident that a single landowner always chooses the land-use option that provides him/her with the greatest benefits. We define benefits as net profits which can be realized either on the market for genetic resources or on the market for agricultural goods.

As long as the gains from conservation are below the profits from agricultural land use, the individual landowner decides to convert his/her plot of land. From this relationship, we can derive a cut-off price, i.e. the market price for genetic resources for which the provision of genetic resources becomes more profitable than the conversion of the plot. Therefore, the net-profit from the sale of genetic material ($p_{B,j}$) is set equal to the net-profit from agricultural activities ($p_{A,j}$)

$$(4) \qquad p_{B,j}\left(p_x^*\right) = p_x^* x_j - P_v v_j = p_x^* x_j - P_v \left[x_j\right]^{\frac{1}{a}} = p_{A,j}\,.$$

($p_{B,j}$) is the revenue of the (j)-th provider of genetic resources net of the factor costs for extraction. ($p_{A,j}$) represents the exogenous net-profit from converting the natural land, i.e., the (m_0) landowners act as price taker on agricultural factor and output markets. Solving equation (4) for (p_x^*), we have a hyperbolic function of the price and the quantity of individual supply (x_j), where both regimes of land use yield the same profits for the individual landowner. She/he is indifferent between conservation and conversion for any combination of market price and individual supply that fulfills equation (4.1)

$$(4.1) \; p_x^*\left(x_j\right) = \frac{p_{A,j}}{x_j} + P_v \left[x_j\right]^{\frac{1-a}{a}}\,.$$

The cut-off price (p_c) and the associated supply (x_c) is then derived by equalizing the function of equal profits with marginal cost

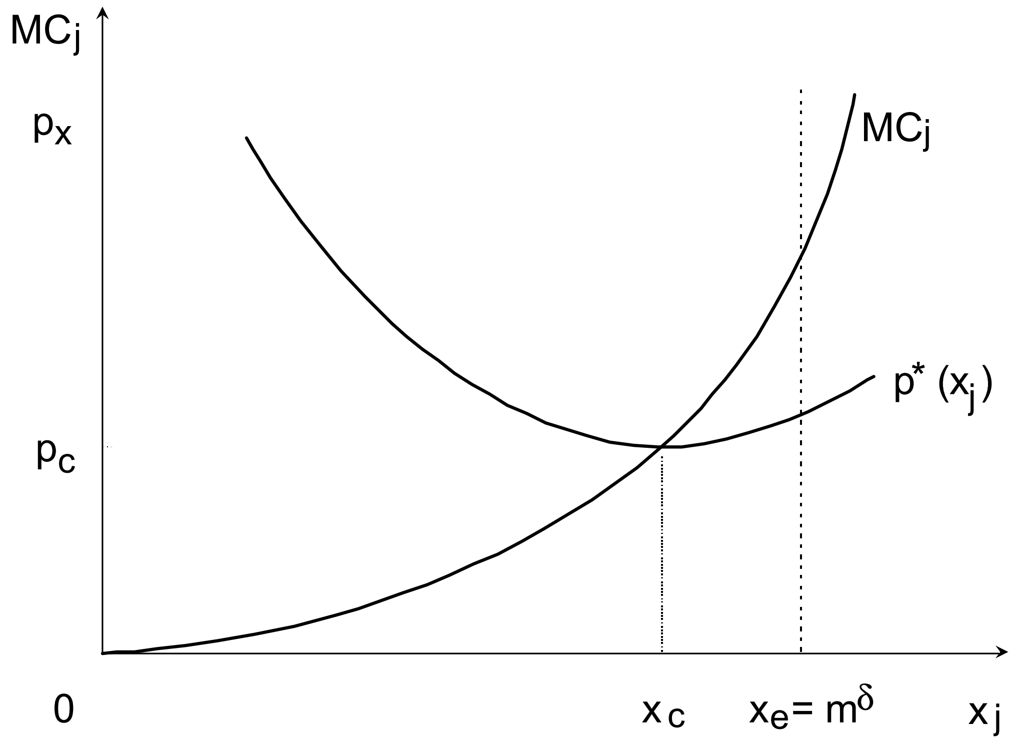
$$(4.2) \qquad x_j = x_c = \left\lfloor \frac{p_{A,j}}{P_v\left(\frac{1}{a} - 1\right)} \right\rfloor \qquad \text{with} \; p_x^*\left(x_j\right) = MC_j\left(x_j\right),$$

$$(4.3) \qquad p_c = MC_j\left(x_c\right) = \frac{P_v}{a} \left\lfloor \frac{p_{A,j}}{P_v\left(\frac{1}{a} - 1\right)} \right\rfloor \qquad .$$

The three factors that describe the individual supply decision are summarized in the figure below. The iso-profit curve is denoted (p_x^*). At any point below this curve, conversion would be more profitable while in any point above the curve, conserving the area in its initial natural state would be profit-maximizing. The intersection of this curve with the upward-sloping marginal cost curve determines the cut-off-price. Above the cut-off-price, the supply curve coincides with the marginal cost. Above the intersection point of the marginal cost function with the availability restriction, the supply curve is a vertical line.

Having described the individual optimisation problem for the land-use decision and the individual supply of genetic resources, we return to our starting point: To what extent could the commercial trade in genetic resources support biodiversity conservation? Considering the described behavior of the individual landowners, we ask how many of them decide to conserve their plot of land in its natural state and how many convert it to agricultural use. In other words, how many suppliers can act in the market for genetic resources, i.e. given the demand for genetic resources – for how many of the potential providers is it profitable to supply genetic resources ?

Figure 1 — Individual Supply of Genetic Resources



3. THE MARKET FOR GENETIC RESOURCES

We begin with a description of the demand and supply side of the market for genetic resources and then derive the equilibrium price which determines the profit of a single landowner in the case that he/she decides to provide samples of genetic material. To provide the reader with an intuition of the individual choices and the adjustments on the market, we start with a simple graphical description in Figure 2 below. After that the market equilibrium is derived in an algebraic form.

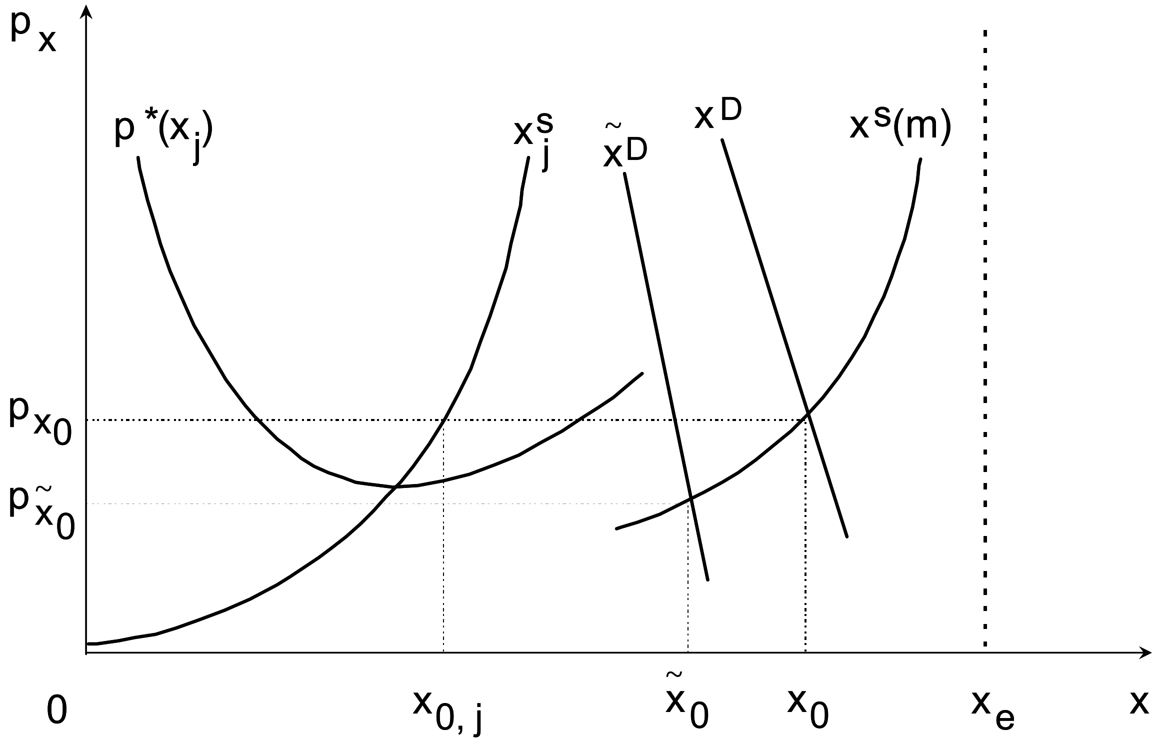
3.1 A Simple Graphical Description

The size of the area and, therefore, the number of landowners is (m_0). For practical reasons, suppose that initially all landowner intend to enter market for genetic resources since they expect to earn greater profits from selling samples than from agricultural activities. Only after their expectations have not been fulfilled, they convert their plot to agricultural use.

Hence, the individual supply is first described by the marginal cost without considering the cut-off-price due to opportunity costs of conservation. In this sense, the marginal cost curve represents the individual short-run supply curve. The market supply of genetic resources (x^S) is then simply the aggregation of the individual supply curves (x_j^S) across the number of providers. Furthermore, the restriction in the availability of genetic resources is assumed to be non-binding at first.

The market demand for genetic resources is derived in more detail below. For the moment, let us suppose that the market demand is represented by (x^D). Hence, in market equilibrium, (x_0) genetic resources are sold at a price (p_{x_0}).At

Figure 2 — Market Supply and Demand of Genetic Resources and Individual Supply Decision



price (p_{x_0}), each individual landowner sells ($x_{0,j}$) units of genetic resources. Since this market outcome lies above the iso-profit curve, conserving the plot of land for the supply of genetic material is the preferred choice of every landowner. As a consequence, all of the initial (m_0) plots of land are withheld from conversion. The quantity in market equilibrium (x_0) is assumed to be smaller than the available quantity denoted by (x_e).

Next, suppose that the demand for genetic resources for a given price is comparatively low, i.e., the demand curve is represented by ($\tilde{x}^D$) in Figure 2. If there were still (m_0) providers of genetic resources, the equilibrium price would be

($p_{\tilde{x}_0}$) and the corresponding equilibrium quantity ($\tilde{x}_0$). Since this market outcome lies below the iso-profit curve, it would be optimal for the individual landowner not to conserve the plot of natural land, but to convert it for agricultural use.

The individual decision to convert the plot has consequences for the number of species living in the natural area as well as for the market equilibrium. When an individual landowner clears the land, the natural habitat shrinks and, therefore, the number of available species/genetic resources decreases. Furthermore, since the number of providers, (m), decreases the marginal cost of supplying genetic resources increase due to decreasing factor productivity in extracting samples on a single area, i.e., in the figure above, the supply curve shifts upwards. If more and more landowners convert their plots, genetic resources become increasingly scarce, thereby raising their market price.

Suppose that the landowners make their land use decision sequentially. The conversion of biodiversity-rich areas then stops when the profits of conservation cover the forgone profits from agriculture. Thus, in equilibrium, the market price is equal to the cut-off price which is determined by the intersection of the iso-profit curve and the individual supply curve in Figure 2.

The cut-off price, then, represents the long-term equilibrium: (m) landowners conserve their land for the provision of genetic resources, while the other (m_0–m) landowners have converted and produce agricultural goods. Note that the latter cannot revise their decision since it is assumed that natural habitats for sensitive species cannot be restored and, therefore, the withdrawal of species from a single plot of land is irreversible once the land is converted.

Finally, the number of providers of genetic resources, (m), which by definition equals the number of conserved plots of biodiversity-rich land represents the contribution of the commercialization of genetic resources to the conservation of biodiversity. Next, the underlying factors that determine the extent of conservation are considered in more detail. Therefore, the possible market equilibria are described in an algebraic form.

3.2 The Supply Side of the Market of Genetic Resources

The market supply is obtained from the aggregation of the individual supply curves (x_j^S) across the (m) providers. The individual supply is initally given by marginal cost of extraction

$$(5) \qquad x^S = \sum_j^m x_j^S = m\left[\alpha \frac{p_x}{P_v}\right]^{\frac{\alpha}{1-\alpha}} .$$

3.3 The Use of Genetic Resources in Biotechnological R&D

Modeling the demand for genetic resources is quite complicated because of the special features of genetic resources in commercial use. Therefore, we have to elaborate on this aspect in more detail: As already mentioned earlier, genetic resources are demanded by firms producing biotechnological goods. Two aspects are of particular importance in this context.

The first one is related to the use of genetic material in the production process. Rather than being used as raw material input in the manufacturing of biotechnological goods, genetic resources are used in the development of new products (cf. ten Kate and Laird 1999:49f). Thus, in order to derive the demand for genetic resources, the R&D process of biotechnological goods has to be modeled. Innovation processes are typically a very complex phenomenon, which is difficult to model. Since we concentrate on the role of genetic resources in the process of biotechnological R&D, we try to keep this description as simple as possible.

The second aspect concerns the market structure of biotechnological goods which clearly affects the demand for genetic resources as inputs. Biotechnological goods are supposed to be differentiated goods which are good substitutes among themselves, e.g., while a drug produced by one firm differs in its active substances from a drug produced by another firm, they may nevertheless both be used in anti-cancer treatment. Furthermore, the production of biotechnological goods typically involves high fixed costs of product development and low mariginal cost of production, e.g., in the pharmaceutical industry, it takes many years and high research expenditures to develop a prototype of a new drug but after a development process has been successfully completed, this prototype can be easily reproduced for commercial sale. Due to these characteristics, it is reasonable to describe the market structure of biotechnological goods as one of monopolistic competition with decreasing average costs.

We suppose that there are (n) firms in the biotech industry which on the one hand, supply intermediate and/or final goods and on the other hand, demand genetic resources as input factor. Each firm employs the same technology and sells a single product variety, which is differentiated from the other (n-1) goods.

In order to enter the market, a firm has to spend (f) units of resources on research activities to develop a new product variety. The production of a successfully developed product involves unit costs (C). Furthermore, the individual firm takes the product choices and pricing strategies of other firms in the industry as given and sets a price to maximize profits (Helpman and Krugman 1996:132). The demand function for a single differentiated biotechnological good is derived from a CES-utility function of a representative household with symmetric preferences for the (n) goods (cf. Dixit and Stiglitz 1977, Krugman 1979). (E) denotes the total expenditures for them. The elasticity of substitution between a pair of them is (σ).[4] The profit function for a representative firm is

$$(6) \qquad p_i = [p_{y_i} - C]y_i(p_{y_i}) - f = [p_{y_i} - C]\left[\frac{p_{y_i}^{-s}}{\sum_j^n p_{y_j}^{1-s}}E\right] - f .$$

The first-order condition for a maximum profit of the (i)-th firm yields the pricing relation

$$(7) \qquad p_{y_i} = \frac{C}{\beta} \qquad \text{with } \beta = \left(1 - \frac{1}{\sigma}\right).$$

Due to the symmetry assumption, each firm sets an identical mark-up. Hence, the price for every product variety is identical, i.e. $p_{y_i} = p_y$ for i=1..n. Then, profits of the (i)-th firm simply depend on the expenditures (E), the demand elasticity (σ), the number of differentiated goods in the market (n) and the fixed costs for R&D (f)

$$(6.1) \qquad p_i = \frac{E}{sn} - f .$$

If we suppose that market entry is not restricted, new firms supplying biotechnological goods will enter the market, i.e. (n) is increasing until the profits in the market for biotechnological goods have dropped to zero. Hence, in the long-run equilibrium the fixed costs for R&D (f) are equal to $\frac{E}{\sigma n}$.

3.4 The Demand Side on the Market for Genetic Resources

After this description of the output market, we return to the input market for genetic resources. This requires to specify the R&D process of biotechnological goods, which has been represented by the fixed costs block (f) so far, more explicitly.

Suppose that the basis of each product innovation is one specific genetic information generated from the exploration of genetic resources. In the context of monopolistic competition, each firm supplies only one but unique biotechnological good. Hence, each firm demands only as much genetic resources as are necessary to find one useful and yet undiscovered information that enables the firm to develop its product variety. Thus, purchasing genetic resources at a price (p_x) in a certain quantity (x_i) represents the fixed costs a firm has to bear if it intends to enter in the output market. For convenience, we assume that the costs of purchasing genetic resources just represent the costs of R&D

$$f = p_x x \,. \tag{8}$$

In the next step, we have to consider a functional R&D relationship between genetic information and genetic resources (x_i). In the real world, a biotechnological firm usually has to examine many genetic resources, before it finds a marketable genetic information in a particular genetic material. When it begins with the research, it cannot be sure how many genetic resource have to be examined until a discovery is made. Related to this, the so called „hit-rate“ (ϕ), is often mentioned, which denotes the probability of finding one useful genetic information within a single sample of genetic material (cf. Pearce and Puroshomantan 1995).

This arrival of a successful R&D output is typically modeled as a stochastic process (cf. Simpson et al.1996, Goeschl and Swanson 1999). However, a stochastic relationship would add much complexity to the model at this stage. Therefore, we just take the reciprocal value of the hit rate to determine the amount of genetic resources necessary to find one useful genetic information[5].

$$(9) \qquad x_i = \frac{1}{f}.$$

Equations (7) and (9) are then used to derive the profit of the representative firm as a function of the price for genetic resources (p_x)

$$(6.2) \qquad p_i(p_x) = \frac{E}{sn} - \frac{p_x}{f}.$$

The factor demand for genetic resources of an individual firm is a discontinuous function. Each firm demands the fixed quantity as long as the price (p_x) is below a certain level where profits are positive or zero. If (p_x) exceeds this level, demand drops to zero

$$(10) \qquad x_i^D = \begin{cases} \frac{1}{f}, \text{ for } p_i(p_x) \geq 0 <=> p_x \leq \frac{Ef}{sn} \\ 0, \text{ for } p_i(p_x) < 0 <=> p_x > \frac{Ef}{sn} \end{cases}.$$

The total demand for genetic resources is obtained from an aggregation across the (n) individual firms

$$(11) \qquad x^D = \sum_i^n x_i^D = \begin{cases} \frac{n}{f}, \text{ for } p_x \leq \frac{Ef}{sn} \\ 0, \text{ for } p_x > \frac{Ef}{sn} \end{cases}.$$

The total demand for genetic resources in equation (11) depends on the quantity which is necessary to find a genetic information, but also on the number of biotech firms, and thus, on the number of differentiated goods supplied in the output market.

Of course, this only applies to the case where market entry is restricted, and hence the number of firms is given exogenously. Otherwise, if new firms are able to enter the market, the factor price (p_x) does not only determine the costs of R&D, but also the number of firms in the output market. Thus, if market entry is not restricted, the number of biotech firms and goods negatively depends on the price (p_x)

$$(6.1) \qquad p_i = 0 <=> n = \frac{Ef}{sp_x}.$$

From equation (6.1) and (11) we then derive the market demand for an endogenous number of biotech firms

$$(11.1)\quad x^D = \frac{E}{sp_x}.$$

The demand depends on households' expenditures for biotechnological goods and the preferences for them. The production technology within the biotech industry is only expressed in qualitative terms, i.e., the input genetic resources does not serve as raw material in the production of the biotechnological good but as a medium of the relevant genetic information which can be easily reproduced without any further demand of the initial genetic material.

4. SCENARIOS OF POSSIBLE MARKET OUTCOMES

The supply function in equation (5) and the demand function in (11.1) are used to determine the market outcome for genetic resources which enables us to derive some implications for its contribution to the conservation of biodiversity. However, the supply function only contains the costs of extraction of genetic resources but not the opportunity costs due to forgone profits from agriculture. This is because we have assumed that at first all of the (m_0) landowners provide genetic resources but then some start to convert their land if agricultural production turns out to be more profitable than supplying genetic resources, i.e. the individual landowners consider the opportunity costs of conservation after some time lag.

The question then is whether an equilibrium outcome, derived from the identity of demand and (short run) supply, i.e., $x = x^D = x^S$, and its associated natural land area (m_0) is sustainable or not. The answer depends on the relationship between the market price (p_x) and the cut-off price (p_c). The latter is determinded by variables which are exogenous to the model (cf. equation 4.3) while the former is derived from the interaction of demand and supply in the market for genetic resources

$$(12) \qquad p_x = \left[\frac{E}{sm}\right]^{1-a}\left[\frac{P_v}{a}\right]^{a}.$$

As we have shown in the graphcial description in Figure 2 above, (m_0) units of natural land will be preserved when the market price is *above* the cut-off-price of the individual provider. In this situation every landowner earns more profits by preserving biodiversity than by destroying it for alternative land uses. Therefore, all plots of land are maintained in their natural state and none of the providers quits the market. The short-run market outcome represents a sustainable long-term equilibrium. We use equations (4.3) and (12) to describe this scenario analytically

$$(12.1) \quad m = m_0 \qquad ,\text{for } \frac{E}{s} \geq m_0\left[\frac{p_{A,j}}{1-a}\right].$$

Next, we consider the other case where the market price is at first *below* the cut-off price, i.e., for the individual landowner, it is more profitable to convert the area. Since several landowners start to convert, and therefore withdraw from being a provider of genetic resources, there is an adjustment of the market price and the quantity sold in the market. The short-term equilibrium is not sustainable. Furthermore, as landowners convert their plots of natural land, there are also negative impacts on the endowment of genetic resources and biodiversity as a whole. When a market outcome with (m_0) providers is not sustainable in this circumstances, the question is what the long-term equilibrium will look like – if there is one.

There may be at least one possible equilibrium with the lowest extent of conservation: Suppose that (m_0-1) landowners have converted their plots one after the other. Consequently, the (m_0)-th landowner remains as the only provider of genetic resources at site. She/he is then able to capture a monopolistic rent. If this rent covers the forgone profits from agriculture, there is no incentive to convert the remaining plot of land. Hence, the magnitude of conserved natural land area is m=1.[6] Again, we can express the conditions under which this monopoly scenario occurs

$$(12.2) \quad m = 1 \qquad \text{for } \frac{E}{s} \leq \left[\frac{p_{A,j}}{1-a}\right].$$

In between the two polar cases described in equations (12.1) and (12.2), there may be a sustainable interior solution for (m), i.e. some landowner convert their plots of land, but more than one plot is conserved. As explained in graphical description in the previous section, the equilibrium price equals the cut-off price (p_c) in this interior solution,

$$(12.3) \quad m = \frac{E(1-a)}{s p_{A,j}}, \text{ for } \left[\frac{p_{A,j}}{1-a}\right] < \frac{E}{s} < m_0 \left[\frac{p_{A,j}}{1-a}\right].$$

Which one of the three different scenarios for a market outcome occurs depends on exogenous parameters. On the one hand, there is the households' expenditures for biotechnological products (E) discounted by the elasticity of substitution between them (σ). This term reflects the demand for new biotechnological products. An increasing demand for these products leads to comparably larger R&D efforts in the biotech industry, and therefore, to a higher demand for genetic resources as inputs.

On the other hand, there is the product of (m) times the term $\left[\frac{p_{A,j}}{1-a}\right]$, which refers to the degree of competition on the supply side and the supply costs each provider has to bear. Both terms together determine the availability of genetic resources on the market.

The relationship between demand and availability of genetic resources reflects the relative scarcity of genetic resources. Thus, we can relate the magnitude of the area (m) which is conserved in equilibrium directly to the degree of scarcity of genetic resources.

For example, in the last scenario with an interior solution for (m), genetic resources are not sufficiently scarce to allow all (m_0) landowners to act as profitable providers in the market, and thus, some of them convert their plots. The reason for this could be that households only spend relatively small amounts on biotechnological products, so that the demand for genetic resources as an input in R&D is comparatively low. Furthermore, competition among many providers leads to relatively low market prices, and therefore, to relatively low earnings from the provision of genetic resources. In contrast to the first scenario, this competition on the supply side makes the market price drop to a level where it is not profitable for the individual landowner to withhold natural land area from alternative uses so that some landowners convert their plots of land (cf. Aylward 1993, Vogel 1996). Another reason for the conversion of natural habitats may be that the opportunity costs of conservation in terms of forgone net-profits from agricultural production are comparatively large. This is expressed by relatively high values for ($\pi_{A,j}$). In this case, scarcity prevails not so much for genetic resources but for land as an input into agricultural production. Obviously, this is especially true in the second scenario where almost all landowners convert their area (m=1).

5. CONCLUDING REMARKS

In this paper, we have taken a closer look at the question whether the commercial use of genetic resources can create significant incentives for private efforts in the conservation of biodiversity. It is currently debated whether a market for genetic resources can effectively contribute to conservation. If this is not the case, it might be better to allocate funds to other conservation strategies that are deemed more effective in this regard (Simpson 1997). In this context, we have developed a theoretical framework for a market for genetic resources, which we have used to outline different scenarios of possible market outcomes. Each market outcome is associated with a different level of biodiversity-rich area that is conserved for the private provision of genetic resources.

The results from the model show that whether a market for genetic resources can effectively support the conservation of biodiversity essentially depends on the scarcity of genetic resources. It is often assumed that the scarcity of genetic resources is rising as demand for them increases due to current advances in biotechnology, while at the same time availability decreases as genetically diverse organism become increasingly extinct (cf. von Braun and Virchow 1997). In this circumstances, a linkage between commercialization and the conservation of biodiversity as proposed by the Convention of Biodiversity may succeed.

However, in a more detailed analysis, scarcity of genetic resources does also depend on several other factors such as the final demand for biotechnological products or the way genetic resources enter in the process of R&D, and therefore, on the economic characteristics of genetic information. On the supply side, the costs of providing genetic material including the opportunity costs of conserving natural land areas are of relevance as well as competition among suppliers of genetic resources.

We have considered these factors within our model to analyse their impact on the market outcome, and thus, on the incentive to the conserve biodiversity. Since some factors increase the incentive for private conservation while other factors have a contrasting impact, the expressions for the range of parameter values which we have derived for each scenario can serve as a description of the counteracting effects between these factors. As, for instance, shown in the second scenario with (m=1), a decrease in the number of providers, and therefore, a decline in the availability of genetic resources does not necessarily have a significant impact on the incentive to conserve if the demand for genetic material is relatively low. Thus, what we have shown with this theoretical model framework is that assessing the contribution of a market for genetic resources to the conservation of biodiversity has to be treated very differentiated. The specific situation on both sides of the market always has to be considered.

Note that we have kept the model very simple to enable the description of several parameters on the supply side and demand side of genetic resources. It might be useful to analyse some extentions of the model like a more explicit modeling of uncertainty in the R&D process or the treatment of genetic resources as differentiated goods with different hit probabilities. Furthermore, it may also be interesting to consider potential incentives for collusive action among providers, i.e. to relax the assumption of perfect competition on the supply side of the market and to analyse the consequential impact on private efforts to conservation.

Two more things have to be mentioned. First, market prices and quantites only reflect the scarcity of genetic resources from the viewpoint of utility-maximizing individuals. This does not imply that a low market price reflects an equally low economic value of genetic resources. Rather, the market cannot capture all aspects of the value because genetic resources encompass certain characteristics like public good-properties or flows of services that occur over a very long time horizon, which are thus not reflected in the actual market price (Heal 1995).

Second, we have looked at the market for genetic resources as a possible mechanism to conserve biodiversity. However, under some circumstances, the harvesting of genetic materials for biotechnological R&D can also have negative impacts on biodiversity, e.g., if the in-situ extraction of samples is done in a non-sustainable way (cf. OECD 1999, Cunningham 1995).[7] Nevertheless, we have considered the case where the conversion of natural habitats is the outstanding threat to biodiversity and the commercialization of genetic resources may in a specific situation represent a means to create incentives for withholding natural areas from conversion.

REFERENCES

Aylward, B.A. (1993). The Economic Value of Pharmaceutical Prospecting and Its Role in Biodiversity Conservation. LEEC Paper DP 93-05. International Institute for Environment and Development, London Environmental Economic Centre.

Barbier, E.B., and B.A. Aylward (1996). Capturing the Pharmaceutical Value of Biodiversity in a Developing Country. Environmental and Resource Economics 8: 157-181.

Barbier, E.B., J.C. Burgess, and C. Folke (1994). Paradise lost? The Ecological Economics of Biodiversity . London: Earthscan.

Barrett, C.B., and T.J. Lybbert (2000). Is Bioprospecting A Viable Strategy for Conserving Tropical Ecosystems ? Ecological Economics 34: 293-300.

Bragdon, S., and D. Downes (1998). Recent Policy Trends and Developments Related to the Conservation, Use and Development of Genetic Resources. Issues in Genetic Resources (7). IPGRI. Rome.

Connor, E. F. and E. D. McCoy (2001). Species-Area-Relationship. In S. Asher Levin , and R.e. Colwell (ed.), Encyclopedia of Biodiversity, Vol. 5:397-411. Academic Press. San Diego.

Cunningham, A.B. (1993). African medicinal plants. Working Paper published by UNESCO. UNESCO Nairobi Office.

Dixit, A. K. and J.E. Stiglitz (1979). Monopolistic Competition and Optimum Product Diversity. American Economic Review 67(3):297-308.

Goeschl, T. and T. Swanson (1999). Endogenous Growth and Biodiversity: The Social Value of Genetic Resources for R&D. Centre for Social and Economic Research on the Global Environment. Working Paper GEC 99-11.

Heal, G. M. (1995) Markets and Biodiversity. Working Paper. Graduate School of Business. Columbia University.

Helpman, E. and P.R. Krugman (1996). Market Structure and Foreign Trade: Increasing Returns, Imperfect Competition, and the International Economy. MIT Press. Cambridge.

Heywood, V.H. (ed. (1998). Global Biodiversity Assessment. Published for the United Nations Environment Program. Cambridge University Press. Cambridge.

Krugman, P. R. (1979). Increasing Returns, Monopolistic Competition, and International Trade. Journal of International Economics 9(4):469-479.

Mendelsohn, P. (1994). Property Rights and Tropical Deforestation. Oxford Economic Papers 46: 750-756.

OECD(Organisation for Economic Co-operation and Development) (1999). Economic Issues in Benefit Sharing: Concepts and Practical Experiences. OECD Working Papers VII/69. Paris.

OECD(Organisation for Economic Co-operation and Development) (1997). Issues in the Sharing of Benefits Arising out of the Utilisation of Genetic Resources. OECD(Organisation for Economic Co-operation and Development) (1997) Issues in the Sharing of Benefits Arising out of the Utilisation of Genetic Resources. Unclassified Paper OCDE/GP(97)193. Paris.

Pearce, D., and S. Puroshothaman (1995). The Economic Value of Plant-based Pharmaceuticals. In T. Swanson (ed.), Intellectual Property Rights and Biodiversity Conservation: An Interdisciplinary Analysis of the Values of Medicinal Plants. Cambridge University Press. Cambridge.

Rausser G. C., and A.A. Small (2000). Valuing Research Leads: Biosprospecting and the Conservation of Genetic Resources. Journal of Political Economy 108 (1).

Rausser, G.C., and A.A. Small (1998). Bioprospecting with Patent Race. PaineWebber Working Paper Series in Money, Economics and Finance PW-98-07. Columbia Business School.

Reid, W.V., S.A. Laird, C.A. Meyer, R.S.A. Gamez, D.H. Janzen, M.A. Gollin, and C. Juma (1993). A New Lease on Life. In W.V. Reid, et al. (eds.) Biodiversity Prospecting: Using Genetic Resources for Sustainable Development. World Resources Institute. Washington, DC.

Rubin, S.M., and S.C. Fish (1994). Biodiversity Prospecting: Using Innovative Contractual Provisions to Foster Ethnobiological Knowledge, Technology, and Conservation. Colorado Journal of International Environmental Law and Policy 5 (1): 29-62.

Siebert, H. (1998). Economics of the Environment. 5., rev. and enlarged edition. Springer. Berlin.

Simpson, R.D. (1997). Biodiversity Prospecting: Shopping the Wilds Is Not the Key to Conservation http://www.rrf.org/resources_articles/files/ bioprospect.htm.

Simpson, R.D., R.A. Sedjo, and J.W. Reid (1996). Valuing Biodiversity for Use in Pharmaceutical Research. Journal of Political Economy 104 (1): 163-185.

Swanson, T. (1995). The Appropriation of Evolution's Value: An Institutional Analysis of Intellectual Property Regimes and Biodiversity Conservation. In T. Swanson (ed.), Intellectual Property Rights and Biodiversity Conservation: An Interdisciplinary Analysis of the Values of Medicinal Plants. Cambridge University Press. Cambridge.

ten Kate, K., and S.A. Laird (1999). The Commercial Use of Biodiversity – Access to Genetic Resources and Benefit-Sharing. Earthscan. London.

UNCTAD(United Nations Confercence on Trade and Development) (2001). The Biotrade Initiative – An Integrated Approach Towards Trade, Biodiversity Conservation and Sustainable Development. http://www.biotrade.org/initiative.htm.

UNEP(United Nations Environment Program) (1998). Synthesis of Case-Studies on Benefit Sharing. Paper presented at the Conference. UNEP/CBD/COP/4/Inf.7 – 4 May 1998.

Vogel, J.H. (1996). The Successful Use of Economic Instruments to Foster Sustainable Use of Biodiversity: Six Case Studies from Latin America and the Caribbean – Case Study 6: Bioprospecting (White Paper). Paper presented at the Conference Summit of the Americas on Sustainable Development, Biodiversity Support Program on behalf of the Inter-American Commission on Biodiversity and Sustainable Development. Santa Cruz de la Sierra, Bolivia.

von Braun, J., and D. Virchow (1997). Conflict-Prone Formation of Markets for Plant Genetic Resources: Institutional and Economic Implications for Developing Countries. Quarterly Journal of International Agriculture 36 (1): 6-38.

Wolfrum, R., and P.-T. Stoll (1996). Access to Genetic Resources under the Convention on Biological Diversity and the Law of the Federal Republic of Germany. Berichte des Umweltbundesamt 8/96: Erich Schmidt Verlag. Berlin.

WRI (World Resources Institute) (1992). Biodiversity – Safeguarding Natural Systems that Support Life on Earth. http://www.wri.org/

Footnotes:

---

[1] For example, Rausser and Small (2000) employ the same basic theoretical model and the same empirical data as Simpson et al. (1996), expect that they consider prior information and selective screening methods. This assumption leads to a 400-fold increase in the maximum willingness of the biotech industry to pay for land units in a particular biodiversity hotspot in comparison to the values calculated by Simpson et al. (1996).

[2] In cases of imperfect property rights on natural land areas, it is usually rational for individual users to exploit as much resources on her/his plot of land as possible in the short term and not to consider any possible benefits that occur only in the long term since uncertainty prevails whether they can be appropriated by them (Siebert 1998:61). As all individuals are supposed to face the same incentives, their behavior altogether leads to deforestation of large forest areas and connected with this to an irreversible loss of biodiversity.

[3] A market for genetic resources is here considered as a market for material samples for research. Alternatively, it is possible to consider a market for land use rights where biotechnological firms compete with agriculturalists for undisturbed natural land areas. In this case, the firms would pay for access and extract genetic material on their own.

[4] (σ) serves as an approximation of the price elasticity of demand faced by the single firm which produces (y_i) (Helpman and Krugman 1996:116f).

[5] For a discussion of the concept of the marginal value and the average value of species see Rausser and Small (1998) and OECD (1999:18f).

[6] Alternatively, it can be assumed that the plot of land of an individual landowner is to small to serve as a habitat for any (valuable) species, i.e., the species-area-relationship contains an ecological threshold where a marginal reduction of the habitat area leads to an extensive reduction in species richness. In this case, even the the (m_0)-th landowner has no incentive to conserve since there no species left for a market supply.

[7] Other socio-economic effects of the commercialization of genetic resources with potential negative impact on biodiversity have been considered by Barrett and Lybbert (2000).