

Supply Side Externalities in Markets for Genetic Resources

Oliver Deke

paper to be presented at the

Fourth BIOECON Workshop on the Economics and Biodiversity Conservation

(Venice, 28th -29th August, 2003)

(preliminary)

abstract: A market provision of genetic resources is perceived as an instrument to generate income for the private protection of biodiversity-rich areas. However, there has been a controversy over whether the attainable 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. This paper studies how the market outcome is affected when boundaries of natural habitats do not coincide with boundaries of land property and therefore interactions between profit-maximizing landowners matter. Externalities between natural areas as habitat are modeled in different scenarios. It is shown that, while in the absence of externalities market-induced conservation is quite low and reacts inelastic to an increasing relative value of genetic information, externalities can lead to a comparatively larger extent of conservation.

address: Institute for World Economics, Duesternbrooker Weg 120, D-24105 Kiel

e-mail: oliver.deke@ifw.uni-kiel.de

keywords: Biodiversity, Conservation, Genetic Resources, Land use, R&D

JEL Codes: O13, O32, Q 21, Q24

1 Genetic resources and biodiversity

Naturally occurring genetic information has recently attracted much attention because of its commercial use in the research and development (R&D) in the plant breeding industries and in the pharmaceutical sector (Swanson 1996). Biological materials as their physical carriers, i.e. genetic resources, are allocated in different but parallel existing institutional settings – they are provided as impure public goods or as private goods. Potential suppliers are profit-oriented sellers or public sector institutions. In this paper, we shall study genetic resources traded as private goods between in-situ providers and commercial users in a market framework (ten Kate and Laird 1999).

The markets for genetic resources differ substantially from markets for other natural resources since genetic resources show specific economic properties that other resources do not show - these are uncertainty with respect to the appropriable value and non-rivalry in the use of the contained information (Small 1998): The usefulness of a specific genetic resource is typically revealed only after the material is prospected in the R&D process. This process usually entails several stages where the further prospecting of a particular material is only continued if some promising genetic information has been found in the previous stages (Artuso 1996). However, at the point of time the material is first traded between the in-situ suppliers and the commercial users the actual value it is **uncertain**. Genetic resources are in this sense experience goods. Due to this uncertainty, the actors on the supply side and the demand side must a priori agree on how to share the risk that a resource does not lead to a successful research outcome and hence reveals a value close to zero. A positive value of a genetic resource is in effect determined by the embodied genetic information and not by the biological material itself. The genetic information in turn is **non-rival** in its use, i.e. after it has once been recognized, it can be replicated for a repeated use in R&D at no or at least very low marginal cost. This implies that users of genetic resources can appropriate the value of genetic information without the need of additional material from the original suppliers.

The recent analyses of genetic resources in economics as well as in legal or social sciences have focused on several issues which are interconnected to some extent. A primary question has concerned the design of property rights on genetic material and the embodied information, and by this the task of designing them in such a way that a sustainable supply of genetic information can be maintained (Goeschl and Swanson 2002, Wolfrum et al 2001, Swanson and Goeschl 2000). Specifying property rights at the same time touches the issue of an equitable sharing of the economic surplus that is associated with (naturally occurring) genetic information. On the level of international law, governments of the countries that signed the Convention on Biological Diversity (CBD) have agreed to enforce the principle of benefit sharing between the primary suppliers which are typically located in

biodiversity-rich developing countries and the commercial users which are primarily located in the industrialized countries (Dutfield 2002, Wolfrum and Stoll 1996, Shiva 1995). A related question considers the connection between genetic resources and biodiversity, or more specifically the perspectives of a commercialization of genetic resources as an instrument for biodiversity conservation (Reid et. al 1993, Simpson et al 1996, Rausser and Small 2000). The paper shall address this last issue in more detail.

Biodiversity can be understood as a fundamental characteristic of an ecosystem. Ecologists have explored the relationship between biodiversity and the economically valuable services which ecosystems provide (Tilman 1999). It can be observed that in the majority of cases, those ecosystems with a high degree of biodiversity provide flows of valuable and sometimes even vital services. Examples of such services are the support for the functioning of local ecosystems or the provision of genetic variety used for the production of seeds or pharmaceuticals. This biodiversity-related flow of services at a specific location is usually not confined to one single economic good. Moreover, biodiversity induces a vector of several valuable commodities or services that are made available at the same time. The single compounds of this vector are either marketable goods like genetic resources or are goods which are non-excludable in their use. The vector of services is connected to certain types of land use. Typically, if natural area as a stock is preserved in its pristine state, it will sustainably provide a flow of specific economic services. If else the area is converted for cultivation, the composition of this flow changes: the share of agricultural commodities increases whereas other ecosystem services like the provision of genetic diversity or groundwater purification likely shrinks. Otherwise if natural areas are protected for the market supply of genetic resources, other intangible public goods of biodiversity are provided as well since the single compounds of the vector cannot be separated from each other. In such a way, the commercialization of genetic resources can contribute to the conservation of biodiversity as a whole.

If conserving natural areas in an undisturbed state is connected with some ecosystem services that show public good properties, the individual landowners do not capture the total economic value of biodiversity in their calculus. Consequently, an overall allocative efficiency with respect to biodiversity conservation cannot be attained by a market allocation of genetic resources. Nevertheless, it remains the question about the magnitude of the market's contribution to conservation. More precisely, given the specific economic properties of genetic resources, how many natural areas are withheld from conversion for the market supply of these resources?

To answer these empirical questions, we require information on prices and quantities traded in the market. However, in practice, such contingent data is only available to a very limited extent. The reasons for this could be either that trade is indeed on a very low level perhaps because genetic resources in the marketplace are not that valuable as it has sometimes been supposed, or otherwise that trade is kept strictly confidential between trading partners. In particular, the buyers of genetic

resources seem to be interested in secrecy since they face ownership risks during the R&D process of before any patent is granted for their R&D result and thus, they do not want to disclose their purchasing practices with respect to genetic resources to their competitors (ten Kate and Laird 1999).

Due to lack of the relevant empirical data, studies on the connection between genetic resources and biodiversity conservation have tried to determine prices indirectly by using observable data that are related to genetic resources like revenues in markets for pharmaceuticals or scientific knowledge on the species diversity and the landscape. The studies have tried to determine how much R&D firms as commercial users of (in-situ) genetic material are willing to pay for having access to them. The results in turn should indicate how much income providers of such materials can create in the market and hence whether private conservation of biodiversity for the supply of genetic resources can be a profitable alternative to other land uses.

A couple of studies find that the willingness to pay of on the demand side of genetic resources is quite low (Simpson et al. 1996, Barbier and Aylward 1996). For this reason, it has been concluded that the incentives for private biodiversity conservation by supplying genetic resources is likely to be overestimated. Nevertheless, when considering the overall set of studies, different segments of the market demand are analyzed such as botanical medicine, pharmaceuticals or agricultural seeds (cf. Pearce and Puroshothaman 1995, Artuso 1996, Gollin et al. 2000), and furthermore different assumptions with respect to the use of genetic resources in R&D are made. Therefore predictions about the market value of genetic resources in absolute monetary terms vary quite significantly between the studies leading to different implications with regard to perspectives of markets for genetic resources (OECD 1997). 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 R&D firms to pay for land units in a particular biodiversity hotspot in comparison to the values calculated by Simpson et al..

Facing the limitations in observable market data, the analysis in this paper approaches the market for genetic resources on a theoretical basis. We focus on the extent of conservation that can be induced in a market economy where land use regulation to protect biodiversity is absent. More specifically, we attempt to explain why this induced conservation is sometimes only of a limited extent and identify scenarios in which the market's contribution to conservation is quite substantial. For this purpose, we develop a formal model for trade with genetic resources which takes the framework presented in Simpson et al. (1996) as a starting point but extends it by an explicit description of the supply side with externalities among suppliers.

Externalities refer to spatial interactions in the hosting of biological species on private lands (Parkhurst et al. 2002). The essential point in this regard is that boundaries of natural habitats of individual species do not coincide with the boundaries of individual land property, i.e. some biological species

will be distributed across property boundaries. It can be assumed that if their habitat shrinks, they more likely become extinct or are at least crowded out at the considered site.

So far existing studies on markets for genetic resources - except for Bergeron and Polasky (2000) - have not considered spatial externalities. Basically, externalities lead to a situation in which the potential endowment of biological species for market supply of an individual landowner is not only determined by his own land use decision but also by the decisions of landowners in the neighborhood, i.e. by the total size of the surrounding conserved area. In that sense, the providers - though competitors in the market - exercise mutual positive externalities on the availability of genetic resources by withholding natural land from conversion. Otherwise landowners who have decided not to enter the market may exercise negative externalities by their alternative land uses.

The paper proceeds in the following way: Section 2 defines a theoretical framework for a market for genetic resources with spatial externalities among providers. The further analysis in this part is limited to the monopsony case, i.e. one firm on the demand side determines how many providers are contracted for the purpose of conservation. Section 3 describes the market outcome in two different settings with respect to the underlying species-area-relationship. Furthermore the impact of biological thresholds with respect to species-area-relationship are studied. Section 4 provides a numerical simulation for the derived outcome in the varying settings. Section 5 gives a brief discussion on the resulting impact when the simplifying assumption on the dispersal of genetic resources is relaxed. In Section 6, some concluding remarks follow. It is found that the contribution of trade with genetic resources to the overall conservation of biodiversity-rich areas is fairly modest in cases where non-rivalry in the use of genetic information holds and an even dispersal of biological species at the local scale prevails. Otherwise fragile ecological conditions in in-situ habitats of genetic resources likely increase the market-induced extent of conservation while at the same time increasing the level for the economic value of genetic information that needs to be exceeded for bioprospecting to become profitable.

2 Spatial aspects of providing genetic resources:

The theoretical framework

Generally, there is good reason to suppose that land use pattern and the ability to provide in situ genetic resources are linked with each other in some specific way. Existing economic studies in this respect rely on the assumption that the endowment of genetic resources respectively biological species is related to the size of a natural habitat in a way that ecologists describe by species-area-relationships (Simpson et al 1996, Barrett 1993).

Let habitats be represented by unmanaged natural areas, i.e. human land uses destroy the living conditions of certain biological species. The size of the habitats then results from decentralized private decisions on land uses. Furthermore since boundaries of species' habitat typically do not coincide with boundaries of land property the conversion and cultivation of a previously unmanaged area on one property may seriously impact the living conditions of species on adjacent properties even if these areas are withheld from conversion (Bergeron and Polasky 2000).

In this sense the landowners exercise mutual externalities on the availability of genetic resources¹. If only a small number of landowners conserve their areas, negative externalities from conversion in the neighboring places could limit the endowment of species that are of interest for a market supply of genetic resources. Otherwise if many landowners within one region conserve they may possess rather identical endowments of species. Then the profits from supplying them as resources may be quite small due to competition in the market. Given these characteristics of a market supply for genetic resources, what is actually the individual incentive to conserve land and to enter the market?

These mutual externalities among landowners eventually describe ecological linkages between their lands. These linkages may be less pronounced in some cases, i.e. an ecosystem on a private land property is relatively stable in its functioning and species richness regardless what happens in the surrounding areas, while in other case the choice of land use in neighboring properties causes impacts on the ecosystem that lead to a decline in species diversity. This varying degree of ecological sensitivity with respect to species diversity shall be explicitly considered in the following analysis.

The theoretical framework we present considers trade with genetic resources in an environment of locally acting individuals rather than in an environment of sovereign states. This perspective seems appropriate to investigate in how far markets contribute to the conservation of biodiversity as a whole when regulation of land uses for the purpose of biodiversity conservation is absent.

¹ There is empirical evidence that such mutual dependency in conservation prevails at the regional or national level: Externalities are a reason for the recent combination of protected areas in Mozambique and Zimbabwe with the South African Krueger National Park to a transfrontier park. It is reasonable to assume that these externalities also prevail at the local level where, for example, individuals or village communities compete with each other for selling genetic material to commercial users.

The model framework

Let us assume that **R&D firms**² bargain with a group of **landowners** whose natural areas contain genetic material of potentially valuable genetic information³. The landowners as potential suppliers of genetic resources face a single firm on the demand side. Such a situation of a **monopsony** at the local level is often reported in case-studies on bioprospecting⁴.

Furthermore we assume that the R&D firm is going to collect genetic material herself⁵. In this sense, she pays for a particular flow of economic services, i.e. the right to extract the material in a natural area of specific size within a certain period of time. If the firm and an individual landowner reach an agreement on access rights, the parameters about the spatial extent and the time period of access are fixed in a contract.

The firm's willingness to pay for these access rights depends on the expected usefulness of the genetic resources that are available in a contracted area. Let this usefulness be correlated with species richness. For simplicity, assume that the more species are available and thus the more distinct genetic resources the firm could extract, the higher the probability that the extracted material includes some useful genetic information. The probability that a single genetic resource leads to a success in R&D is statistically uncorrelated with the probability of any other resource in the collection (Rausser and Small 2000, by contrast cf. Polasky and Solow 1995).

² With the notion 'R&D firm', we express that users of genetic material in this model framework encompasses firms in the pharmaceutical and chemical industries as well as in the plant breed breeding industry. The effect of indigenous or other local users of genetic resources shall be neglected, even though it is recognized that their share in the market could be quite significant in specific cases. Furthermore we are aware that technologies and types of uses of genetic material vary between the different industrial sectors, especially in the later stages of the vertical R&D and production process (ten Kate and Laird 1999). However, since both sectors make use of genetic material from in-situ conditions (Swanson 1996), we believe that we are allowed to abstract from these differences for the research question we analyze here.

³ It is reasonable to assume that the demand for genetic resources for this biotechnological R&D 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 (ten Kate and Laird 1999).

⁴ In the following analysis, we use the male pronoun for single landowners and the female pronoun for the monopsony firm. This is for reasons of simplicity only and it is not intended to have any further implications.

⁵ Case studies on bioprospecting suggest that this is a familiar way for R&D firms to acquire samples for R&D (UNEP 1998). Moreover, firms often rely on sub-contracted intermediaries who carry out the on-field collection of in-situ material for them.

To describe the firm's potential benefits of bioprospecting, some assumptions about the total number of species within the considered areas as well as about their distribution across the total area have to be made. Suppose that the region considered in the model is divided into N parcels of identical size and assigned to N landowners. The size of a single parcel is normalized to 1. The number of species (X) in the total area (N) is described by a continuous species-area-relationship, i.e. the total number of species strictly increases with the size of the total area. However, the gain in species richness decreases with increasing size of the total conserved area (Connor and McCoy 2001).

To appropriate the available in-situ genetic resources, the firm naturally approaches the landowners who host the highest shares of the (X) available species in their parcels. For this, we basically need to know how individual species are dispersed across the conserved parcels. To enable a tractable analysis, we start with a very simple assumption saying that biological species are evenly distributed across the areas of the individual landowners and that all species occur in each parcel, i.e. ($x=X$) with (x) denotes species richness within a single parcel⁶.

Land use decision

There are typically competing land uses for each parcel. We distinguish two polar types of land use - conservation for the provision of genetic resources and conversion for the production of agricultural commodities. Suppose that a joint production of both categories of goods is not possible, i.e. land is either completely excluded from human land uses or biological species with potentially valuable genetic information get lost in the parcel⁷.

Since individual decisions on land uses are made in a decentralized way, a heterogeneous land use pattern is likely to occur which implies that the total conserved area may not be a homogeneous area but is fragmented to some extent. A high degree of fragmentation in turn may challenge the

⁶ An alternative and more realistic approach for modeling the dispersal of species would be to assume that in every single parcel, there are some common species that occur in many parcels and some rare species that can only be found in one particular parcel. Existing studies implicitly assume that only rare (endemic) species matter, i.e. the competitive supply of common species yields a price close to zero. By contrast, we explicitly capture this competition in common species and its implication for conservation is in our model framework. In Section 5, we shall briefly discuss the impact on the allocation when the assumption of a homogeneous spatial distribution is relaxed and there is a mixture of common and rare species in the parcels.

⁷ Considering the extensive literature on land use decisions, there is a set of recent studies which have focused on land use decisions in time and temporal development of land use pattern (Irwin and Bockstael 2002, Cervigni 2001, Parks et al. 1998). However, for our purpose, we start studying the allocation of parcels in a simple static framework and refer to temporal aspects in the outlook in section 6.

assumption that the endowment of biological species is described by a continuous relationship that is strictly increasing in the size of the total conserved area: for example, total species diversity across many small reserves within an otherwise cultivated region may be different compared to species diversity in one large homogenous conserved area when the size of the aggregated conserved area is identical in both cases. To avoid problems with fragmentation, let us assume that it is not profitable to divide the area of a single parcel into several sub-parcels which are allocated to different land uses. Each parcel can only be allocated to one unique land use. By this, potential fragmentation is confined to a level where the described species-area-relationship is supposed to hold.

Each individual landowner, $i=1..N$, has to make his choice between the two types of land use. Either he conserves his parcels and sells biodiversity in terms of access rights to the R&D firm or he converts the parcel and receives a payoff (π_i) from selling commodities others than genetic resources. Let (y_i) denote the decision variable of the (i)-th landowner taking possible values of ($y_i=1$) for conservation or ($y_i=0$) in case of conversion.

Accordingly, (n) denotes the number of landowners who withhold their lands from conversion. Hence, the preserved natural area is also (n), and the converted area used for agricultural production is ($N-n$),

$$(1) \quad n = \sum_{i=1}^N y_i .$$

Landowners act as price takers. They choose the type of land use that provides them with the highest payoff. Let each landowner who has converted his parcel produce one homogenous composite good that yields a net-payoff (π_i) with $i=1..N-n$, $\pi_i > 0$. This payoff is exogenously given, i.e. ($\pi_i = \pi$)⁸.

If a landowner has decided to conserve his parcel, he receives the payoff for conservation depending on whether the R&D firm chooses him among the potentially many landowners with conserved parcels. Let (c_i) $\in [0,1]$ describe the interaction between the R&D firm and landowner (i). ($c_i=1$) denotes the case where this landowner is offered a contract, ($c_i=0$) denotes the case where he is not. Furthermore (p) is the price the R&D firm pays for access. The behavior of an individual landowner is then given by the following objective function where (Z_i) denotes the net-payoff for the landowner (i)

⁸ Assume, for example, that identical landowners supply goods on world markets with a perfectly elastic demand. In an alternative scenario (which is not considered here) landowners may compete in a local market which is somehow separated from the world market and thus the payoff is endogenously depending on how many landowners decide to convert their parcels and produce agricultural goods.

$$(2) \quad \max_{y_i} Z_i(y_i) = \begin{cases} p & \text{for } (y_i = 1), (c_i = 1) \\ \pi & \text{else} \end{cases}.$$

The objective function entails the assumption that the individual land use plans can be perfectly adjusted. Any landowner who is not offered a contract, i.e. ($c_i=0$), converts his parcel for cultivation. Even if he has at first conserved his parcel he can revise a land use decision from ($y_i=1$) to ($y_i=0$), after negotiations with the R&D firm have failed. Furthermore if he revises his decision, he does not have a lower payoff than in a situation where he would have converted immediately, regardless of a potential demand for genetic resources⁹. Given this assumption there is a clear incentive for every landowner to first provide access to a conserved parcel whenever the price paid by the users is going to equal or greater than the payoff from agriculture.

Willingness to pay for access

Let us turn to the demand side. As mentioned, the willingness to pay for access in essence depends on species richness, i.e. the number of genetic resources in each parcel (x) which is given by non-linear species-area-relationship (cf. (3)). (δ) represents the elasticity of species richness with respect to the size of the conserved area and (v) is a scale parameter.

$$(3) \quad x(n) = v * n^\delta \quad \text{with } v > 0, 0 < \delta < 1, 0 < n \leq N.$$

From the view of the R&D firm, a collection of a given number of species (x) yields a value ($V(x)$) which is derived from the development of a new product. We define that value according to Simpson et al. (1996) (cf. (4)): the genetic resources are tested in a sequential research. Only one potential innovation or new product can be derived from the extracted genetic material. (η) is the probability that a single genetic resource carries the promising genetic information which leads to the successful

⁹ Suppose for example, that both conversion and cultivation of a parcel take some handling time within which the R&D firm's action can take place. Then, each landowner does not need to commit himself to any type of land use. He can prepare for both types and wait until it is revealed which one actually provides the higher individual payoff. In an alternative scenario, the sequence between land use decision and the firm's occurrence can be the other way round. In this case, landowners must ex ante commit themselves to one type of land use facing uncertainty over the firm's decision when they decide to conserve. In fact, in this case, conserving biodiversity for the supply of genetic resources entails some "sunk" investment costs for the individual landowner. We shall consider the incentives for conservation and supply and the market outcome that results hereof in another paper.

development of a new product. The net revenues from that product are denoted by (V) ¹⁰. (r) is the variable cost of R&D.

$$(4) \quad \begin{aligned} V(x) &= \eta * V - r + (1 - \eta) * (\eta * V - r) + (1 - \eta)^2 * (\eta * V - r) \\ &\quad + \dots + (1 - \eta)^{x-1} * (\eta * V - r) \\ &= \frac{\eta * V - r}{\eta} * (1 - (1 - \eta)^x) \end{aligned}$$

with $0 < \eta < 1$, $V > 0$, $r > 0$.

Using this equation it can be found that the value of a marginal biological species is positive but decreasing the more species are already contained in the collection (cf. Appendix).

Suppose the firm has complete information about the species-area-relationship, i.e. she knows how many genetic resources can be found within a single parcel and how land use decisions impact the endowment of available genetic resources. Her maximum willingness to pay for the right to access parcels for collecting genetic material equals the value of these resources depending on the preserved parcels $V(n)$,

$$(5) \quad V(n) = V' * (1 - (1 - \eta)^{x(n)}) \quad \text{with} \quad V' = \frac{\eta * V - r}{\eta}.$$

The task for the R&D firm is then to decide to whom of the landowners she will offer a contract and what price to pay to each of them to compensate for foregone payoffs from alternative land uses. Let the firm be risk neutral with respect to the R&D output and (Z_j) denote the expected payoff then her behavior can be described in a generalized form like it is presented in (6).

$$(6) \quad \begin{aligned} \max_{c_1, \dots, c_N, p} Z_j(c_1, \dots, c_N, p) &= V(x) - p * c \quad \text{with} \quad c = \sum_{i=1}^N c_i \equiv n \quad \text{and} \quad x = x(n) \\ \text{s.t.} \quad c_i &\leq y_i \\ p &\geq \pi. \end{aligned}$$

The first constraint in (6) states that contracts can only be concluded with landowners who have

¹⁰ Like in Simpson et al. (1996), this value shall be considered as a constant. It denotes the net-payoff a R&D firm can appropriate by supplying an innovative product at world markets. By this, it is implied that the potential value from prospecting genetic resources is independent of how many firms occur in the market for R&D products. Alternative modeling approaches in this respect dealing with (dynamic) competition in product markets have been employed by Craft and Simpson (2001) and Goeschl and Swanson (2002).

conserved their parcels. The second constraint describes the participation constraint for the landowners. The generic function for species richness, i.e. $x(n)$, is going to be specified according to the different ecological scenario that is studied (cf. section 3).

Given that land use plans can be perfectly adjusted and each landowner first decides to conserve, (6) can be simplified in the following way: Since there are no differences in individual land use decision, (c_i) and (y_i) are omitted while (c) is substituted by (n) which now simultaneously describes the number of the contract partners and the extent of conservation. Furthermore the number of contracts the firm can offer is still limited by the number of landowners who have conserved which is now (N) .

$$(6.1) \quad \max_{n,p} Z_j(n,p) = V(x) - p * n \quad \text{with } x = x(n)$$

$$\text{s.t.} \quad n \leq N$$

$$p \geq \pi \quad \text{if } n > 0.$$

Concerning the price (p) it is reasonable to suppose that every landowner only conserves if (p) exceeds the alternative payoff (π) at least by a small positive margin. Since the R&D firm has bargaining power and the cost for compensating a marginal landowner are constant she always set a price equal to (π) plus that margin. For simplicity, let the margin converge to zero. Hence, $(p=\pi)$.

Returning to the above mentioned economic properties of genetic resources, we briefly review how they are considered in the model. Non-rivalry is implicitly considered in the static structure of the model: the R&D firm has no subsequent material needs for attaining the potential R&D payoff once she has extracted all available genetic resources. Concerning the property of uncertainty, there is the risk that none of the available genetic resources will yield a new development in R&D and that consequently the firm cannot recover its costs for the access to genetic resources and for the subsequent testing. This risk is shared in the way that the risk-neutral firm offers a fixed payment to each suppliers in return for genetic material (instead of a variable payment depending on the R&D output).

The sequence of the steps in which the R&D firm and the landowners interact can be described in the following way: All steps take place in a one-period-setting. At the beginning of the period, all parcels are conserved. But they will all be converted at the end of the period, if landowners are not compensated for foregone payoffs in case of conservation. Before conversion activities start, the R&D firm approaches landowners and negotiate over access rights and compensations for conservation. In the next step, all potential contracts are executed and the collection of genetic material starts in the contracted areas. Simultaneously, landowners who have not entered into contract begin to convert their parcels.

3 Applying the model:

The impact of habitat conversion in adjacent areas

Given the spatial externalities in providing genetic resources, an important question is what happens to the natural area contracted for bioprospecting when landowners without a contract convert their parcels for the production of agricultural goods. Does this cause a diminishing quality of biodiversity in the area under contract? If so, there is clearly an incentive for the R&D firm to offer contracts to more than one landowner. Otherwise if the ecosystem in the contracted area is at least relatively stable for the period the firm collects the genetic material, there is no need for the firm to approach additional landowners as contract partners. Thus, the answer apparently depends on the extent and speed of ecological adjustments that arise when some landowners convert their parcels, or in other words, whether noticeable spatial externalities are present or not.

In the following, two stylized outcomes will be distinguished: In the first one, the collection of genetic resources is completed before any noticeable impact results from the conversion in adjacent places. In the second scenario, the extraction of genetic material is still ongoing, while neighboring landowners convert and cultivate their parcels. In this case, the R&D firm cannot rule out harmful impacts on the endowment of genetic resources within the area under contract unless she can make other landowners conserve their parcels as well. Both possibilities shall be considered in separate sub-scenarios.

Strong ecological stability: No impact from habitat conversion

First, assume that the R&D firm finishes the extraction before negative externalities from the conversion in adjacent areas arise.

Here, the optimal choice of the R&D firm can be described straightforward: Due to the (short-term) ecological stability within the natural area under contract and the even distribution of different genetic resources, it is payoff-maximizing for the R&D firm to conclude not more than one contract. Contracting for any additional parcel would only provide her with redundant species. The available set of biological species ($X = v \cdot N^\delta$) then yields a success in R&D with a probability ($H = 1 - (1 - \eta)^X$). The firm sets a price for the right to access ($p = \pi$). In return, she extracts (X) genetic resources. This is a first, rather trivial market equilibrium with only one parcel preserved.

Depending on the value (V) relative to alternative profits (π), it is well possible that any bioprospecting activities at that location is not profitable and the firm prefers to offer no contract. This is the case if the amount which is needed to compensate a single landowner for conservation exceeds the expected private value of the available genetic resources (cf. Appendix).

Weak ecological stability: Negative externalities from habitat conversion

We now relax the assumption of strong ecological stability and allow for immediate adjustments due to conversion in parcels adjacent to the contracted area. The R&D firm must fear that she cannot extract all the species that have existed in the total area at the point of time when the contract was concluded - unless more than one landowner is compensated for his costs of conservation (π).

Remember that the firm has complete information about the ecological adjustments that take place when the total size of the natural area shrinks (cf.(3)). The firm's maximization problem is described by (6.1). When the price (p) is always set marginally above or - like it has been assumed for simplicity - equal to the opportunity cost of conservation (π), the firm's essential choice variable is the number of contracts (n). Considering that every parcel is indivisible and can only be allocated to one unique land use, the optimal number of contracts (n) is reached when the firm's benefit of a marginal conserved parcel which is represented by the LHS of (7) is equal to marginal cost (π).

$$(7) \quad \frac{\eta * V - r}{\eta} * \left[(1 - \eta)^{\nu * n^\delta} - (1 - \eta)^{\nu * (n+1)^\delta} \right] = \pi .$$

The benefit of a marginal conserved parcel is the value of a conserved area of size ($n+1$) minus the value of a conserved area of size (n). This representation is derived from the concept of marginal species. Since the benefit of a marginal conserved parcel is monotonously decreasing with an increasing number of parcels and marginal cost for conservation are constant, there is a unique interior solution for the optimal number of contracts the firm offers (cf. Appendix for the proof).

The number of contracts determines the size of the conserved natural habitat and by this the number of species the firm can collect. The actual magnitude of conservation in the market equilibrium is determined by the values that are assigned to the parameters that describe the biogeographic conditions and the R&D technology.

Depending on these parameter values, it may occur that all (N) parcels are conserved. This is the case if the benefit of a marginal parcel is equal or still greater than the cost of conservation at the (N)-th parcel. The optimal number of contracts is then ($n=N$). Otherwise it is again possible, that no contract is concluded if the value of available genetic resources does not exceed the costs of compensating one single landowner (cf. Appendix for a formal discussion).

To resume, when considering the cases with strong ecological stability and weak ecological stability in the monopsony market, we can say, that on the one hand the mentioned positive externalities from conserving genetic resources are internalized in the latter case of weak ecological stability. This is for two reasons: firstly, the firm as user of genetic resources has a self-interest in ecological stability - at least for the period of bioprospecting. She therefore contracts for more parcels as necessary for the

actual bioprospecting process. Secondly, the firm is a monopsonist here and consequently has no incentive to free-ride, i.e. she cannot rely on competitors on the demand side to conserve parcels for the purpose of ecological stability¹¹.

On the other hand, in case of strong ecological stability, there is no need for the firm to assure stability. Moreover, no noticeable externalities from conservation are presented among the landowners' parcels. The fact that species have existed in a conserved parcel at the beginning of the period may be attributed to externalities among conserved areas in the past. However, this preceding conservation has not caused any costs to the landowners if it is assumed that cultivation was not profitable in the past and thus the existence of biological species is a by-product of not having converted the natural area. If now the R&D firm emerges on the demand side for genetic resources, only one landowner gets into contract for conservation and receives the payoff (p). In this sense, the contracted landowner earns windfall profits from supplying in-situ genetic resources. Nevertheless, the contribution of commercial uses of genetic resources to overall biodiversity conservation is quite small in such a setting.

Biological thresholds

The continuous species-area-relationship in the scenario of weak ecological stability implies that a reduction in the size of natural habitats leads to relatively smooth and predictable reactions with respect to the survival of biological species. In the real world, such smoothness may not prevail. Moreover, in certain case, a strong and abrupt decline in species population and in species richness may occur when ecosystems are sustainably disturbed by human interventions. It is believed that such drastic changes can be attributed to the loss of specific 'keystone species' which are of importance for the biological interactions among the species. If these keystone species are destroyed at one place, their disappearance leads to repercussions which negatively affect the survival chances of many other species (Chapin et al. 2000).

In this regard the conversion of a marginal parcel can lead to a more than proportional decrease in species richness in the region if by converting this particular parcel the natural habitat of a keystone species is reduced below a critical limit. In other words, allocating any additional parcel to agricultural land use when a number of parcels has already been converted will cause that the biological threshold is exceeded and the drastic changes to biodiversity occur. However, the actual threshold level and thus the precise size of a natural area that has to be conserved for the provision of genetic resources is typically unknown - or at least not known with certainty (Perrings and Pearce 1994).

¹¹ Hence, in a setting of competitive demand, there could be some potential for a market failure due to free-riding depending on the interaction among R&D firms. However, we do not analyze the competitive demand here.

In the following, we investigate the effect of a potential biological threshold on the allocation of natural areas: Using the model framework from above, the species-area-relationship in (3) is slightly modified. Let us assume that the previous continuous function describes the endowment of biological species as long as the number of conserved parcel (n) does not fall below a threshold. If this, however, happens, all species which would be of potential value for the R&D process become extinct (Li and Löfgren 1998).

Let the critical size of the natural area that represents the threshold level be a random variable. Its value (\hat{n}) is drawn from the interval $[0, N]$ according to a distribution function $F(\hat{n})$ with a density function $f(\hat{n})$ ¹². Then, $F(\hat{n})$ denotes the probability that the threshold is less than (\hat{n}) or equal to (\hat{n}). If now (n) parcels are conserved the expected species richness in these parcels is

$$(3.1) \quad E(x(n)) = F(n) * x(n)$$

Before proceeding let us briefly motivate the different concepts for ecological interactions that have been introduced. Externalities basically describe ecological effects due to reallocation of physical resources from natural ecosystems towards human-used modified ecosystems. Thresholds in turn explain ecological sensitivity in the broader sense of resilience, i.e. an ecosystem may absorb human-caused disturbances to a certain amount, however if this amount is exceeded changes to the system structure occur (Mäler 2000).

Weak ecological stability and biological thresholds

The R&D firm who is interested in accessing bioprospecting areas now faces the problem that when the overall size of the total conserved area is too small, the ecosystem with an initially high species diversity could somehow collapse and she may not be able to find any valuable genetic resources within the degraded ecosystem - even in the case where she has paid some landowners for conserving their parcels.

It basically holds that the more parcels are conserved the higher the probability that the threshold is not exceeded and species richness is preserved. Otherwise, given that initially all parcels are conserved, the probability of an ecological flip to a degraded ecosystem increases with every parcel that is not contracted for conservation.

Suppose that the threshold is uniformly distributed on the interval, i.e. $F(n) = \frac{n}{N}$ and $f(n) = \frac{1}{N}$.

Inserting the distribution function $F(n)$ in (3.1) yields the expected species richness

¹² It holds $f(\hat{n}) = \frac{dF(\hat{n})}{d\hat{n}}$ respectively $F(\hat{n}) = \int_0^{\hat{n}} f(t) dt$.

$$(3.2) \quad E(x(n)) = \frac{n}{N} * v * n^\delta.$$

If we substitute the species-area-relationship in the equilibrium condition for weak ecological stability in (7) by this expected species-area-relationship (3.2) we get a modified equilibrium condition for weak ecological stability when biological thresholds prevail.

$$(7.1) \quad \frac{\eta * V - r}{\eta} * \left[(1 - \eta)^{v * N^{-1} * n^{\delta+1}} - (1 - \eta)^{v * N^{-1} * (n+1)^{\delta+1}} \right] = \pi.$$

With respect to the firm's demand for parcels we can infer the following: Species diversity is sustained with certainty if all parcels are conserved. In this respect, the value of a collection of species $x(N)$ with (N) conserved parcels has to be the same for the threshold scenario and for the scenario where thresholds are absent. However, in the threshold case, the value of a single marginal parcel that is conserved when $(N-1)$ parcels are converted is comparatively low since the probability that the threshold is not exceeded and valuable species will be preserved is relatively low. Furthermore, note that in the non-threshold case, the value of a marginal conserved parcel is positive but decreasing the more parcels are conserved. Combining these points, the benefit of a marginal conserved parcel in the threshold case is non-negative, increasing and reaches its maximum at the capacity constraint $(n=N)$. As shown in the Appendix, this conclusion depends on the actual numbers that are assigned to the parameters. However, for a reasonable set of parameter values this result holds.

Contracting landowners for conservation has then two positive effects on the number of available genetic resources in this respect: Firstly, the more parcels are conserved the more biological species can be expected to exist. This relationship prevails in the non-threshold case as well as in the threshold case. Furthermore it has been shown that since the gains in species richness decrease with the size of the total conserved area, the value of a marginal conserved parcel is relatively decreasing. Secondly, the more parcels are conserved the more likely will the expected endowment exist. This relationship prevails only in the threshold case and causes that the value of a marginal parcel is relatively increasing. Considering our result from above, the second effect apparently dominates the first effect if we assume a uniform distribution for the threshold level.

Let us then consider a situation where the benefit of a marginal conserved parcel is equal to marginal cost which presents the equilibrium in case without thresholds. Given now the property of an increasing benefit of a marginal conserved parcel, the firm can increase her payoff by offering further contracts for conservation. Actually, it is optimal to offer (N) contracts and thus preserve the whole area if the benefit of a marginal conserved parcels at $(n=N)$ is equal or above marginal cost (π) . Otherwise if marginal benefit is below marginal cost, it is optimal to offer no contract. Hence, if the

value of the genetic information relative to agricultural payoffs exceeds a certain level it is profitable to conserve the entire area. Otherwise for any relative value below that level, bioprospecting is not profitable for the firm.

4 Results from a numerical simulation

Having derived the equilibria in the different settings on a theoretical basis, it is now interesting to see how the extent of conservation in equilibrium varies among them when different numbers are assigned to the exogenous parameters, in particular to the value of genetic information. Let us therefore define the value of genetic information respectively the value of a new product derived thereof in relative terms of the costs of conservation which equal the economic surplus from alternative land uses (π), i.e. $V=k*\pi$.

For the biogeographic parameters (δ) and (υ), we take numbers employed by Goeschl and Swanson (2002). The parameters that represent the R&D process, (r) and (η), are assigned according to values in Simpson et al. (1996). Furthermore we make the ad hoc assumption that (π) is \$10,000. The total number of parcels (N) is normalized to 100. Let us define this vector of parameters as baseline scenario. All parameter values are displayed in the table at the end of the section. The following figures depict the number of conserved parcels in equilibrium for each of discussed settings. For this, we consider a range of the relative value of useful genetic information (k) that spans from 10,000 to 100,000.

Figure 1 shows that in case of strong ecological stability, only one parcel is conserved if the relative value (k) passes a certain level. When weak ecological stability prevails and thresholds are absent, the number of conserved parcels basically increases with an increasing value for (k). Eventually, the entire area is conserved whenever the relative value approaches 90,000. When biological thresholds are introduced and a uniform distribution for the threshold level is assumed, the figure indicates a complete conservation in equilibrium if (k) passes a certain trigger value. This result is essentially attributed to the increasing benefit of marginal conserved parcels.

Figure 1- Conservation in the market equilibrium

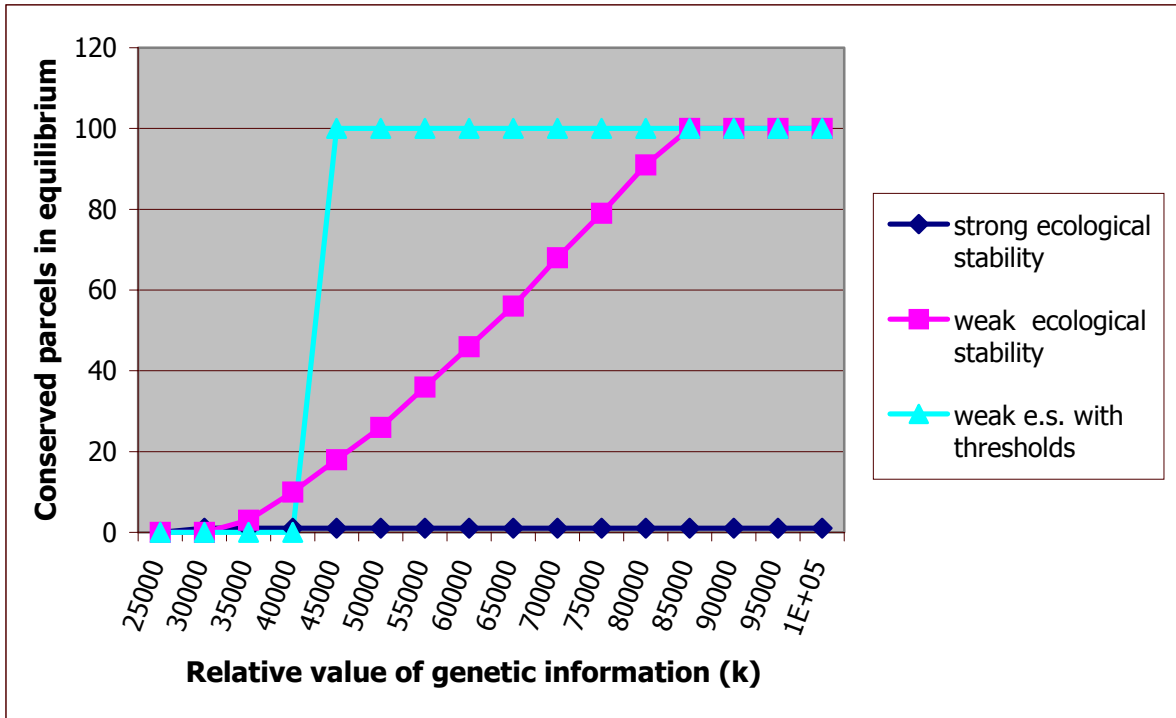
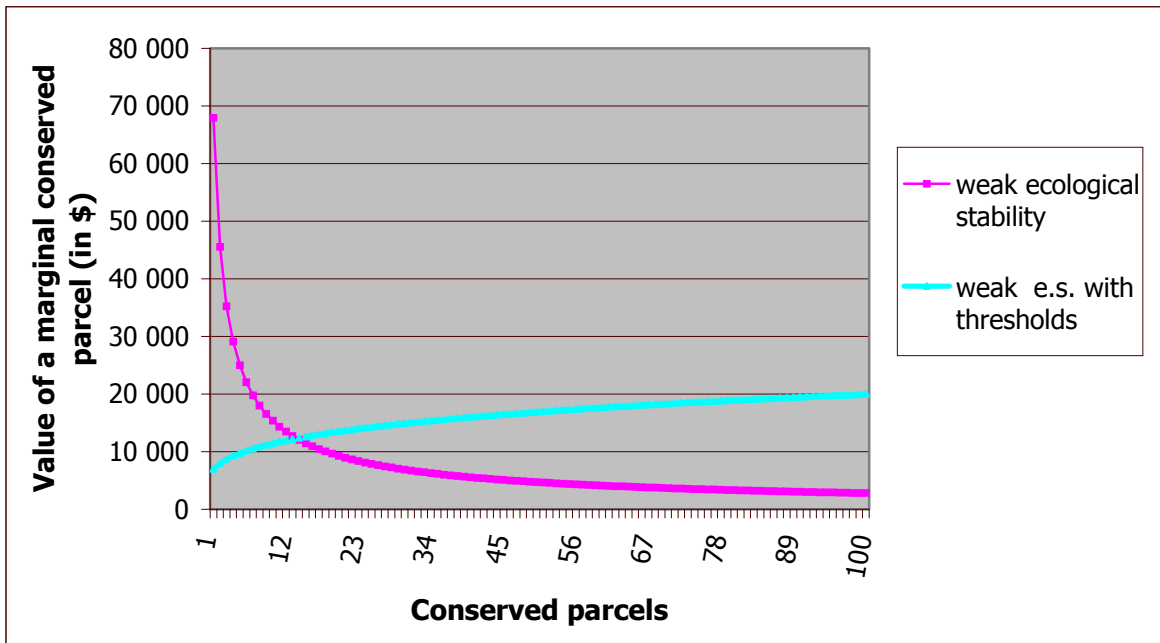


Figure 2 : Value of a marginal conserved parcel

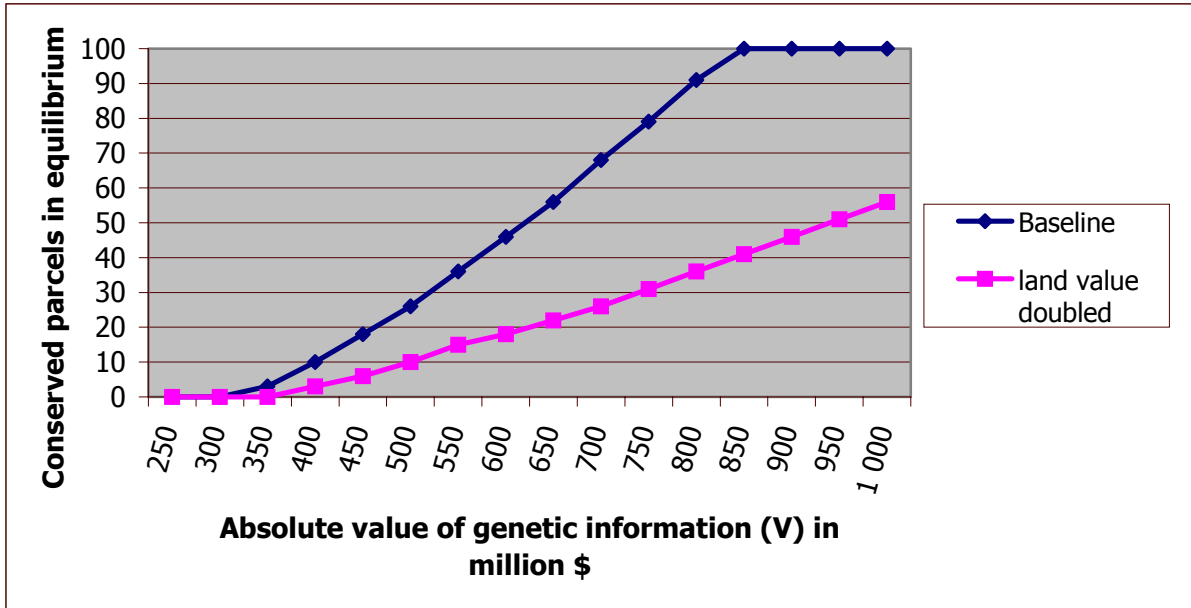


For illustration, Figure 2 depicts that benefit of a marginal conserved parcel in monetary terms for two of the three settings when (k) is fixed at 45,000 which corresponds to the absolute value (V) of \$450 million that is assumed in Simpson et al. (1996). The figure leaves out strong stability since the value is \$1.13 million for the first parcel and then drops to zero for all subsequent parcels. In the case of weak ecological stability without thresholds, the value is strictly positive but decreasing since species diversity increases non-linearly on the size of the conserved area. For the threshold case, the figure shows a monotonously increasing value.

Next, we investigate the level for (k) that has to be passed for that bioprospecting is profitable. This level actually represents the minimum requirement for any contribution of commercial uses of genetic resources to biodiversity conservation. Comparing the different settings, we find that there is already conservation in the market equilibrium in case of strong ecological stability when (k) exceeds 30,133 while in the case of weak ecological stability without thresholds the relative value needs to be at least 32,208 for a (first) parcel to be conserved. Turning to the threshold setting, the trigger value for (k) is 40,609.

Combining these results with the ones on the extent of conservation in equilibrium from above, we conclude that for the considered range of (k) , none of the three settings strictly dominates another setting with respect to the level of conservation that is induced in the market equilibrium: for a comparatively low relative value, conservation is only induced in the strong ecological stability setting. For a range of (k) between 32,208 and 40,608 the setting of weak ecological stability shows the highest extent of conservation whereas above that range the setting with biological thresholds yield even a larger extent of conservation.

These results actually rely on the assumed baseline set of parameter values. In particular, the definitions of the value of a marginal conserved parcel and of the relative value of genetic information imply that the absolute value of agricultural payoff (π) which represents the land value scales the level of conservation in market equilibrium. This scaling effect for weak ecological stability without thresholds is depicted in Figure 3. The horizontal axis in the figure now describes the absolute values for (V) . It is shown that when it is assumed that (π) doubles, the curve of the extent of conservation *ceteris paribus* shifts downward for a given level of (V) .

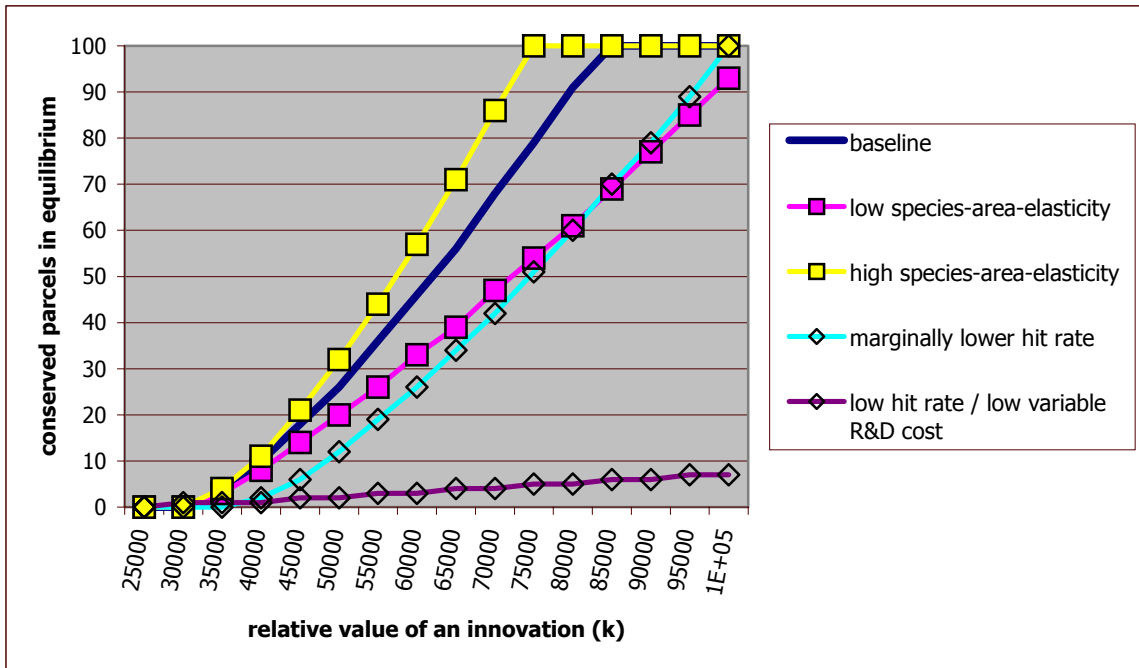
Figure 3 : Scaling effect by land values

Next, the comparative statics with respect to other parameters are studied to show to how the model reacts on changes in these parameter which in effect represent the differences in the surroundings of the market for genetic resources. For this, we focus on the setting of weak ecological stability without thresholds which has provided us with interior market solutions in the baseline scenario.

Considering first the biogeographic parameters, let the species-area-elasticity (δ) take a comparatively low value of 0.175, respectively a comparatively high value of 0.3. The scale parameter (ν) is adjusted in a way that the overall species richness (X) in (N) conserved parcels is identical across the baseline and the two biogeographic scenarios. By this proceeding, it is possible to isolate the assumed impact of a varying sensitivity to conversion in adjacent areas.

The results described in Figure 4 indicate that a high elasticity value (together with a low value of the scale parameter) yields a comparatively larger extent of conservation in the market equilibrium for given number on (k) than in the baseline. Therefore also complete conservation in equilibrium can be sustained with a comparatively low relative value (k). By contrast, a low elasticity value, and thus less pronounced externalities among the parcels lead to a comparatively lower extent of conservation in the market outcome. Furthermore these differences relative to the baseline increase with an increasing relative value (k) as long as complete conservation has not been reached in the baseline.

Figure 4: Comparative statics



Finally, we consider variations in the values of parameters that represent the R&D process. In the first step, the hit probability (η) is only changed slightly from 0.000012 to 0.00001 (Artuso 1996). As shown in Figure 4, the level of conservation in the market equilibrium relative to the baseline is then shifted downward for any given value of (k). Considering the very small change in (η) and the noticeable impact relative to baseline, the sensitivity of the outcome to changes in the R&D surroundings is apparently substantial. This is also indicated by the second sub-scenario on R&D processes which assumes a hit probability of 0.000001 (Goeschl and Swanson 2002). Since for the given value on variable R&D (r), an outcome with zero conservation would result, we take an ad hoc value of \$10 for (r). Using these parameter numbers, the figure shows that the level of conservation in equilibrium is generally very low and reacts comparatively inelastic on changes in the relative value of genetic information.

For completeness, the table below summarizes the parameter assignments in the different sets.

	Baseline	Biogeography		R&D process	
species scale parameter:(v)	200	290	160	200	200
species-area-elasticity:(δ)	0.25	0.175	0.3	0.25	0.25
Hit probability:(η)	0.000012	0.000012	0.000012	0.00001	0.000001
variable R&D costs:(r)	3600	3600	3600	3600	10

5 Bioprospecting when natural areas are heterogeneous:

Some brief remarks

So far, the modeling has assumed that species are evenly dispersed on the conserved areas, i.e. if a specific species exists within the large scale conserved area, it is also found in any of the small-scaled parcels that constitute that area. This assumption has enabled a tractable analysis of the impact of externalities on the market outcome, however, it can be challenged from an ecological perspective. In practice, species diversity or more generally the set of species is likely to vary between the parcels, or to put it differently, there are some common species which may occur in almost every parcel while some rare species may occur only in one or at least very few parcels.

In the following, we briefly discuss the implications that arise when parcels are not identical. For this, we continue with the assumption that the R&D firm shall at first have complete information about the dispersal of species among the parcels. Furthermore distinctive biological species - no matter if they are common or rare - are still perceived as homogenous goods for the use in R&D. Then the task for the monopsonistic R&D firm can be described as follows: For maximizing her payoff she has to choose parcels for conservation in such a way that species richness is maximized in the resulting total conserved area given the constraint that each contracted landowner has to be compensated for the forgone payoff (π).

Other than in the case of identical parcels, the firm's task is not limited to choosing the right number of contracts to be offered to landowners but also to order the potential contract partners with respect to species diversity they host within their parcels. This proceeding which somehow resembles the task of site selection in protected area policies (Polasky et al. 2001) would generally hold for the case of strong ecological stability. If weak ecological stability prevails, the firm's task would get more complicated since interaction among ecological components in the different parcels have to be taken into account. In this regard, it could intuitively be optimal to include parcels that host less species richness if those parcels can assure stability in the hotspot parcels. To solve the optimization problem, the R&D firm would be in need of very specific and detailed information which may not be available in a reliable way. In this context, the assumption of complete information for the firm can certainly be challenged.

However, if we abstract from the problem of incomplete information, heterogeneity of the parcels can lead to more conservation. In the case of strong ecological stability, for example, the R&D firm now realizes that when she contracts for conservation with only one landowner there are still parcels which host biological species that cannot be found in the contracted parcel. The firm may thus have an incentive to contract for more parcels as long as the gain in her expected payoff due to more

conserved species is greater than the marginal cost of compensating additional landowners¹³. In this sense, heterogeneity of parcels may lead to comparatively higher levels of conservation respectively the simplifying assumption of ecologically identical parcels effects that the impact of trade with genetic resources on the overall extent of conservation is relatively underestimated¹⁴.

After all, the discussed issues only consider ecological heterogeneity with respect to the hosting of biological species. Another facet of ecological heterogeneity relates to biomass productivity which has direct economic implication: if parcels vary with regard to the agricultural productivity, also the payoff from cultivation and thus opportunity costs of conservation are differentiated. In the extreme case, some parcels may stay unconverted and unmanaged due to the lack of land productivity. If at the same time the genetic resources that are of interest to the R&D firm can be found in these parcels, trade with genetic resources does not generate any additional impact to area conservation¹⁵.

¹³ When the firm has complete information concerning the ecological parameters, the parcels can be ordered with respect to species richness. Suppose the firm has contracted the landowner whose parcel hosts the highest diversity which thus enables the firm to extract all genetic resources in this parcel, the remaining parcels have to be newly ordered with respect to richness of the remaining species that are not contained in the already contracted parcel. This proceeding has to be repeated until the marginal benefit due to a gain in newly collected genetic resources for R&D is below the cost for compensating an additional landowner.

Note that there is a path dependence in the choice of parcels. In this context, it might not be payoff maximizing for the firm to contract the parcels with the highest species diversity: for example, let there be three parcels which differ with respect to the set of hosted species and assume that it is optimal for the firm to contract only with two landowners. If now the parcel with the highest diversity is characterized by a high overlap with respect to the set of species relative to the other two parcels while these parcels are very different, the appropriable set of genetic resources for a given constraint on access payment may be maximized by leaving out the parcels with the highest species richness.

¹⁴ For the case of weak ecological stability with heterogeneous parcels, the firm would have optimized in a similar way as described in preceding footnote. Here, clusters of parcels consisting of areas with high species diversity and necessary buffer zones as well as overlaps between different clusters have to be considered to maximize the obtainable collection of genetic resources subject to the condition that the benefit of a marginal cluster is not smaller than the cost for compensating the landowners.

¹⁵ Note, however, that this argument implies that ecosystems which serve as viable habitat for certain biological species do not have any potential as habitat for cultural plants or livestock which generate agricultural payoffs.

6 Concluding remarks

Recently, it is debated whether trading genetic resources in a market framework can effectively contribute to the conservation of biodiversity. Current economic research in this context has been focused on whether the value of genetic resources that is appropriable on the demand side is sufficiently high to make the supply of these goods profitable and hence create an incentive for the set-aside of biodiversity-rich natural areas.

Due to the lack of empirical data, existing studies have approached the question on a theoretical basis. This paper has attempted to extend the current research by investigating the impact of ecological sensitivity (in terms of externalities among parcels that come into question for bioprospecting) on the market-induced extent of conservation.

Having first considered a benchmark where no externalities prevail, the model results show that conservation in the market outcome is only of a marginal extent – only one land parcel is conserved. The reason for this is on the one hand non-rivalry in the use of genetic information which effects that there is only limited material demands and hence only few in-situ habitats need to be preserved for trade with genetic resources. This effect is actually reinforced when biological species at the local scale are rather evenly dispersed so that only a small area is needed to extract all relevant species. Given these characteristics of genetic resources and their in-situ habitats the extent of conservation in market equilibrium does not increase with an increasing relative value of genetic information.

When introducing spatial externalities this result changes: The higher the relative value of genetic information the more natural areas are allocated to conservation. If in addition biological thresholds with respect to the habitat size necessary for species' survival are introduced, it can be shown that on the one hand that the market allocation can lead to complete conservation of the considered area at comparatively lower relative values for genetic information, on the other hand, however, the minimum level the relative value has to exceed for bioprospecting to become profitable is relatively higher.

Nevertheless, the relative value of genetic information for a break even in bioprospecting which represents the requirement for a minimum contribution of trade with genetic resource to biodiversity conservation is the lowest in the benchmark with high ecological stability. This implies that it is easiest to induce conservation if the ecological characteristics of the benchmark prevail.

Considering these results, it has to be emphasized, that they rely on a stylized ecological modeling and are derived for the monopsony case only. If there is also competition on the demand side of a market for genetic resources, more than one firm may emerge asking for bioprospecting sites and thus introduce a relatively higher level of conservation. Otherwise competition in research with the same or similar set of genetic resources may decrease the expected payoffs from bioprospecting from

the view of a single firm and thereby reduce the willingness to pay for accessing them. In this context, it has to be investigated whether the offer price can fall below the cost of conservation and hence limit conservation in the market equilibrium.

Furthermore it has been assumed that the costs of supplying conservation are zero. Landowners who do not get into contract convert their parcels for cultivation and they do not experience any noticeable output losses relative to a situation where they decide to convert their land regardless of any potential demand for genetic resources. Alternatively, conservation may require an up-front investment which is connected with sunk costs. Do landowners in this context have the same incentive to conserve genetic resources when keeping the land in its initial natural state comes at a cost and there is a risk that the landowner may not be compensated for these costs as he may not get into contract after he had decided to conserve. Given that species endowments are identical, the outcome in this setting would apparently resemble the patent race in R&D competition where multiple agents invest but only one gets a positive payoff out of that investment (Bergeron and Polasky 2000, Tirole 1995).

Further remaining questions concern the interactions in a dynamic setting like potential incentives of landowners to conserve in the future when they have not got into contract for conservation in present periods or any incentives of firms to contract for long-term conservation even when the discovered genetic information can be replicated outside the in-situ area. These two aspects refer to any sustainable impact from a commercialization of genetic resources to biodiversity conservation.

Appendix

A positive but decreasing value of marginal species

Using the definition of a value of a collection of species, $V(x)$, in (4), it can be shown that the value of a marginal species $v(x)$ is positive since it adds an additional research option with a positive hit probability to the collection.

$$\begin{aligned} v(x) &= V(x+1) - V(x) = \\ &= \frac{\eta * V - r}{\eta} * \left[\left(1 - (1 - \eta)^{x+1}\right) - \left(1 - (1 - \eta)^x\right) \right] = \\ &= \frac{\eta * V - r}{\eta} * \left[(1 - \eta)^x - (1 - \eta)^{x+1} \right] = \\ &= \frac{\eta * V - r}{\eta} * (1 - \eta)^x [1 - (1 - \eta)] = \\ &= \eta * V - r * (1 - \eta)^x \end{aligned}$$

with $0 < \eta < 1$, $V > 0$, $r > 0$.

The value of a marginal species is however decreasing the more species are already contained in the collection.

$$\begin{aligned} (4.2) \quad dv(x) &= v(x+1) - v(x) = \\ &= (\eta * V - r) * \left[(1 - \eta)^{x+1} - (1 - \eta)^x \right] < 0. \end{aligned}$$

This is because it is assumed that only one new product can be derived from the available genetic material: if species are tested sequentially and once a discovery has been made, all remaining species can at maximum contain redundant information. Hence, the potential value of a marginal species ($\eta * V$) has to be discounted by the probability that none of the species which were potentially tested before has yielded a hit in R&D. This is essentially the model shown in Simpson et al. (1996) in the notation of the model in our paper.

Market equilibrium when strong ecological stability prevails

The proposition is that if strong ecological stability prevails, the firm at maximum contracts with one landowner and thus, not more than one parcel will be conserved in equilibrium. The proof is as follows:

If strong ecological stability prevails, species richness in the single parcels as well as in the total conserved area is $x=X=0*N^{\delta}$.

($n=1$) is a unique equilibrium if for the firm's payoff $Z_j(n,p)$ in (6.1) holds that

$$Z_j(1,\pi) > Z_j(0,0) = 0 \text{ and } Z_j(1,\pi) > Z_j(m,\pi) \text{ for } \forall (m) \in \{2,\dots,N\} \subset \mathbb{N}$$

The two inequalities imply that it is profitable to contract with one landowner but that the payoff decreases if the firm concludes a contract with any further landowner.

Considering firstly the second inequality, it can be shown that the firm's payoff decreases by (π) with every additional contract when already one parcel has been contracted. Using (6.1) and the species-area-relationship for strong ecological stability

$$Z_j(1,\pi) - Z_j(m,\pi) = -(m-1) * \pi < 0$$

Since in this setting, species diversity within a parcel does not decrease if adjacent parcels are converted, it also cannot be increased by conserving more than one parcel. Thus, the benefit of any additional conserved parcel when ($n=1$) is zero. This second condition for a unique equilibrium is always fulfilled. The proposition is shown.

Rearranging the first inequality

$$Z_j(1,\pi) = \frac{\eta V - r}{\eta} * (1 - (1 - \eta)^x) - \pi > 0.$$

yields

$$\frac{\eta V - r}{\eta} * \frac{1}{(1 - (1 - \eta)^x)} = \frac{\eta V - r}{\eta} * H > \pi$$

$$\Leftrightarrow \eta V > r + \frac{\eta}{H} * \pi \text{ with } H = \frac{1}{(1 - (1 - \eta)^x)}$$

which implies that it is profitable for the firm to conclude a contract with one landowner whenever the expected gross value of a single species covers the costs of its testing (r) in R&D and a share of the land price which is (π) times the hit probability weighted by the probability that any of the available species will lead to a hit.

Furthermore, the presented equations also indicate that if the condition for $n=1$ is fulfilled the number of conserved parcels in equilibrium does not increase with an increasing relative value of the genetic information.

Market equilibrium when weak ecological stability prevails

When weak ecological stability prevails further equilibria besides $(n=0)$ and $(n=1)$ may exist. Actually, there are two possible border solutions. Using again (6.1) but this time in combination with (3) the intuitive conditions for the border solutions are

$$\text{if } Z_j(1, \pi) < Z_j(0, 0) = 0 \quad \Leftrightarrow \quad \eta V < r + \frac{\eta}{(1 - (1 - \eta)^v)} * \pi,$$

$n=0$ (zero conservation)¹⁶ and

$$\text{if } Z_j(N, \pi) > Z_j(N - 1, \pi) \quad \Leftrightarrow \quad \eta V > r + \frac{\eta}{\left((1 - \eta)^{v*(N-1)^\delta} - (1 - \eta)^{v*N^\delta} \right)} * \pi$$

$n=N$ (complete conservation).

Consequently, for an interior solution, it must hold that

$$Z_j(1, \pi) > 0 \text{ and } Z_j(N - 1, \pi) > Z_j(N, \pi).$$

There are two conditions for (n) to be a *unique* interior solution. Firstly, the firm's benefit of an additional conserved parcel when already (n) parcels will be conserved is below marginal cost, i.e. in equilibrium, it is not profitable to contract for further parcels,

$$\frac{\eta V - r}{\eta} * \left(1 - (1 - \eta)^{v*(n+1)^\delta} \right) - \frac{\eta V - r}{\eta} * \left(1 - (1 - \eta)^{v*n^\delta} \right) < \pi.$$

Secondly, given the constraint from the first inequality, total benefit to the firm is greater if exactly (n) parcels are conserved than when only $(n-1)$ parcels are conserved,

¹⁶ Technically, an equilibrium with no parcels conserved would not be possible if parcels were divisible in any desired unit. The optimal value of (n) would be positive but close to zero if (π) relative to (V) converges to infinity. However, since parcels are indivisible and accordingly the number of contracts can only be varied in integer numbers, zero conservation is an equilibrium whenever the firm's net payoff from contracting one parcel is negative.

$$\frac{\eta V - r}{\eta} * \left(1 - (1 - \eta)^{v * n^\delta}\right) - \pi * n > \frac{\eta V - r}{\eta} * \left(1 - (1 - \eta)^{v * (n-1)^\delta}\right) - \pi * (n - 1).$$

Rearranging the second condition yields

$$\frac{\eta V - r}{\eta} * \left(1 - (1 - \eta)^{v * n^\delta}\right) - \frac{\eta V - r}{\eta} * \left(1 - (1 - \eta)^{v * (n-1)^\delta}\right) > \pi$$

If now the two conditions are combined,

$$\begin{aligned} & \frac{\eta V - r}{\eta} * \left(1 - (1 - \eta)^{v * (n+1)^\delta}\right) - \frac{\eta V - r}{\eta} * \left(1 - (1 - \eta)^{v * n^\delta}\right) < \frac{\eta V - r}{\eta} * \left(1 - (1 - \eta)^{v * n^\delta}\right) - \frac{\eta V - r}{\eta} * \left(1 - (1 - \eta)^{v * (n-1)^\delta}\right) \\ \Leftrightarrow & \frac{\eta V - r}{\eta} * \left(1 - (1 - \eta)^{v * (n-1)^\delta}\right) + \frac{\eta V - r}{\eta} * \left(1 - (1 - \eta)^{v * (n+1)^\delta}\right) < 2 \frac{\eta V - r}{\eta} * \left(1 - (1 - \eta)^{v * n^\delta}\right). \end{aligned}$$

This last inequality states concavity for the function of the firm's benefits of conserved parcels, i.e. the payoff function (Z_j) without payments to landowners. Furthermore, the rearranged second condition also implies that the firm's benefit of a marginal conserved parcel (BMCP) is positive, since ($\pi > 0$). Due to concavity, BMCP must be decreasing.

Thus, whenever BMCP is positive but decreasing any interior solution that can be found is unique. As it will be shown in the following, this condition is fulfilled for the assumed range of parameters.

A positive but decreasing benefit of marginal conserved parcel

Let us define BMCP according to the LHS of (7).

$$\text{BMCP} = \frac{\eta * V - r}{\eta} * \left[(1 - \eta)^{v * n^\delta} - (1 - \eta)^{v * (n+1)^\delta} \right]$$

Since $\eta V > r + \frac{\eta}{(1 - (1 - \eta)^v)} * \pi$, which is the condition for an interior solution, $\frac{\eta * V - r}{\eta} > 0$

whenever ($\pi > 0$). Thus, BMCP is positive if

$$\left[(1 - \eta)^{v * n^\delta} - (1 - \eta)^{v * (n+1)^\delta} \right] > 0$$

$$\Leftrightarrow (1 - \eta)^{v * n^\delta} > (1 - \eta)^{v * (n+1)^\delta}$$

$$\Leftrightarrow (1 - \eta)^{v * (n^\delta - (n+1)^\delta)} > 1$$

Let us define $q = -(n^\delta - (n+1)^\delta)$, then

$$(1-\eta)^{v*(n^\delta - (n+1)^\delta)} = (1-\eta)^{-vq} = \frac{1}{(1-\eta)^{vq}} > 1$$

$$\Leftrightarrow 1 > (1-\eta)^{vq}$$

$$\Leftrightarrow 0 > v * q * \ln(1-\eta)$$

Since $q > 0$, this inequality is fulfilled. Hence, it has been shown that BMCP is positive.

For studying the incremental changes of BMCP, we define $b(n) = BMCP(n+1) - BMCP(n)$.

$$\begin{aligned} b(n) &= \frac{\eta * V - r}{\eta} * \left[(1-\eta)^{v*(n+1)^\delta} - (1-\eta)^{v*(n+2)^\delta} \right] - \frac{\eta * V - r}{\eta} * \left[(1-\eta)^{v*n^\delta} - (1-\eta)^{v*(n+1)^\delta} \right] \\ &= \frac{\eta * V - r}{\eta} * \left[2 * (1-\eta)^{v*(n+1)^\delta} - (1-\eta)^{v*(n+2)^\delta} - (1-\eta)^{v*n^\delta} \right] \end{aligned}$$

Since $\eta * V > r$, we focus on the term in brackets. Actually $b(n) < 0$ if

$$2 * (1-\eta)^{v*(n+1)^\delta} < (1-\eta)^{v*(n+2)^\delta} + (1-\eta)^{v*n^\delta}$$

This condition can be reformulated in the way that a function $f(n) = (1-\eta)^{v*n^\delta}$ is strictly convex.

$$\frac{df}{dn} = (1-\eta)^{v*n^\delta} * \ln(1-\eta) * \delta * v * n^{\delta-1} < 0,$$

$$\frac{d^2f}{dn^2} = (1-\eta)^{v*n^\delta} * \ln(1-\eta) * \delta * v * n^\delta * \left[\ln(1-\eta) * \delta * v * n^{\delta-2} + (\delta-1) \right] > 0.$$

Therefore, $f(n+1) < \frac{f(n+2) + f(n)}{2}$

and consequently, $b(n) < 0$. Hence, it has been shown that BMCP is decreasing.

To resume, when the conditions for an interior solution of the market equilibrium are fulfilled this equilibrium is unique.

Note that since parcels are assumed to be indivisible, BMCP is represented by discrete numbers. To reduce complexity, we neglect a situation where BMCP and marginal cost do not coincide for any $(n) \in \{1, \dots, N\} \subset \mathbb{N}$ and define the interior market equilibrium by the condition presented in (7), i.e. BMCP is equal to (π) .

Market equilibrium when biological thresholds prevail

The proposition is that if biological thresholds prevail in addition to weak ecological stability and the threshold value is uniformly distributed then the firm's benefit of a marginal conserved parcel (BMCP) is increasing.

Let us first define BMCP in the threshold case - henceforth (BMCP_T) - according to the LHS of (7.1).

$$BMCP_T = \frac{\eta * V - r}{\eta} * \left[(1 - \eta)^{U * N^{-1} * n^{\delta+1}} - (1 - \eta)^{U * N^{-1} * (n+1)^{\delta+1}} \right].$$

It then has to be shown that BMCP_T is positive. Since $\eta V > r$, this holds the difference in brackets is positive,

$$\begin{aligned} (1 - \eta)^{U * N^{-1} * n^{\delta+1}} - (1 - \eta)^{U * N^{-1} * (n+1)^{\delta+1}} &> 0 \\ \Leftrightarrow (1 - \eta)^{n^{\delta+1}} &> (1 - \eta)^{(n+1)^{\delta+1}} \\ \Leftrightarrow (1 - \eta)^{n^{\delta+1} - (n+1)^{\delta+1}} &> 1 \\ \Leftrightarrow \ln(1 - \eta) * (n^{\delta+1} - (n+1)^{\delta+1}) &> 0 \end{aligned}$$

Since both factors are negative, the condition is fulfilled. Hence, it has been shown that BMCP_T is positive.

To study the behavior of BMCP_T, we again define the incremental change as $b_T(n) = BMCP_T(n+1) - BMCP_T(n)$.

$$\begin{aligned} b_T(n) &= \frac{\eta * V - r}{\eta} * \left[(1 - \eta)^{U * N^{-1} * (n+1)^{\delta+1}} - (1 - \eta)^{U * N^{-1} * (n+2)^{\delta+1}} \right] - \frac{\eta * V - r}{\eta} * \left[(1 - \eta)^{U * N^{-1} * n^{\delta+1}} - (1 - \eta)^{U * N^{-1} * (n+1)^{\delta+1}} \right] \\ &= \frac{\eta * V - r}{\eta} * \left[2 * (1 - \eta)^{U * N^{-1} * (n+1)^{\delta+1}} - (1 - \eta)^{U * N^{-1} * (n+2)^{\delta+1}} - (1 - \eta)^{U * N^{-1} * n^{\delta+1}} \right] \end{aligned}$$

Since $\eta * V > r$, $b_T(n) > 0$ if

$$2 * (1 - \eta)^{U * N^{-1} * (n+1)^{\delta+1}} > (1 - \eta)^{U * N^{-1} * (n+2)^{\delta+1}} + (1 - \eta)^{U * N^{-1} * n^{\delta+1}}$$

This condition can also be reformulated in the way that a function $h(n) = (1 - \eta)^{U * N^{-1} * n^{\delta+1}}$ is strictly concave.

$$\frac{dh}{dn} = (1 - \eta) \frac{v}{N} n^{\delta+1} * \ln(1 - \eta) * (\delta + 1) * \frac{v}{N} * n^{\delta} < 0 ,$$

$$\frac{d^2h}{dn^2} = (1 - \eta) \frac{v}{N} n^{\delta+1} * \ln(1 - \eta) * (\delta + 1) * \frac{v}{N} * n^{\delta} * \left[\ln(1 - \eta) * (\delta + 1) * \frac{v}{N} * n^{\delta} + \frac{\delta}{n} \right] .$$

Considering the sign of the second derivative, the factor in front of the brackets is negative while the sign of the term in brackets is not unique but varies with the parameter assignments.

A reasonable parameter value for the species richness elasticity is ($\delta \approx 0.25$). The highest value for the hit probability that is assumed in existing studies is ($\eta \approx 10^{-5}$)(cf. section 4).

Using these numbers, the sign of the sum in the brackets is negative if

$$\ln(1 - \eta) * \frac{v}{N} * n^{\delta+1} < -\frac{\delta}{(\delta + 1)} , \text{ respectively } \frac{v}{N} * n^{1.25} < 20,0000$$

This inequality does hold if $\frac{v}{N}$ is relatively small. If otherwise $\frac{v}{N}$ would be very large this would imply that there is a very high species richness with in region of small extent. For the scenarios we consider in the numerical simulation we can rule out this case.

$$\text{Therefore, } \frac{d^2h}{dn^2} > 0 \text{ and } h(n + 1) > \frac{h(n + 2) + h(n)}{2} .$$

Consequently, $b_T(n) > 0$. Hence, it has been shown that $BMCP_T$ is increasing for a reasonable range of parameters.

References

- Artuso, A. (1996). Economic analysis of biodiversity as a source of pharmaceuticals. In: PAHO (Pan American Health Organization) Biodiversity, biotechnology, and sustainable development in health and agriculture pp.167-182.
- 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.
- Barrett, S. (1993). Optimal economic growth and the conservation of biological diversity. In: E.B. Barbier (ed.). *Economics and ecology. New frontiers and sustainable development*. London. 130-145.S
- Bergeron, N. and S. Polasky (2000). Species conservation with multiple Landowners. Department of Applied Economics. University of Minnesota. St.Paul. <<http://www.apec.umn.edu/faculty/spolasky/paper5%7E1.pdf>> 01-04-03.
- Cervigni, R. (2001). Biodiversity in the balance. Land use, national development and global welfare. Cheltenham, Northampton.
- Chapin, F. S. III, E. S. Zavaleta, V. T. Eviner, R. L. Naylor, P. M. Vitousek, H. L. Reynolds, D. U. Hooper, S. Lavorel, O. E. Sala, S. E. Hobbie, M. C. Mack and S. Diaz (2000). Consequences of changing biodiversity. *Nature* 405:234-242.
- Craft, A. B. and R. D. Simpson. (2001). The value of biodiversity in pharmaceutical research with differentiated products. In: *Environmental and Resource Economics* 18: 1-17.
- 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.
- Dutfield, G. (2002). Sharing the benefits of biodiversity: is there a role for the patent system? *The journal of world intellectual property* 5(6):899-931.
- Irwin, E. G. and N. E. Bockstael (2002). Interacting agents, spatial externalities and the evolution of residential land use patterns. *Journal of Economic Geography* 2:31-54.
- Goeschl, T and T. Swanson (2002). The social value of biodiversity for R&D. *Environmental and Resource Economics* 22:477-504.
- Gollin, D., M. Smale and B. Skovmand (2000). Searching an ex situ collection of wheat genetic resources. *American Journal of Agricultural Economics* 82:812-827.
- Li, C.-Z. and K.-G.Löfgren (1998): The dynamic model of biodiversity preservation. *Environment and Development Economics* 3:157-172.
- Mäler, K.-G. (2000). Development, ecological resources and their management: A study of complex dynamic systems. *European Economic Review* 44:645-665.
- 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.
- Parkhurst, G. M. and J. F. Shogren, C. Bastian, P. Kivi, J. Donner and R. B. W. Smith (2002). Agglomeration bonus: an incentive mechanism to reunite fragmented habitat for biodiversity conservation. *Ecological Economics* 41:305-328.
- Parks, P. J., E. B. Barbier and J. C. Burgess (1998). The Economics of Forest Land Use in Temperate and Tropical Areas. In: *Environmental and Resource Economics* 11(3-4):473-487.
- Perrings, C. and D. Pearce (1994). Threshold effects and incentives for conservation of biodiversity. *Environmental and Resource Economics* 4(1):13-28.
- 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.

- Polasky, S. and A. R. Solow (1995). On the value of a collection of species. *Journal of Environmental Economics and Management* 29:298-303.
- Rausser G. C., and A. A. Small (2000). Valuing research leads: biosprospecting and the conservation of genetic resources. *Journal of Political Economy* 108 (1):173-206.
- 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. Gomez, 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.
- Shiva, V. (1995). *Monocultures of the mind : perspectives on biodiversity and biotechnology*. Third World Network. Penang. 2. Printing.
- 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.
- Small, A. A. (1998). *The market for genetic resources: The role of research and development in the valuation and conservation of biological intellectual capital*. Berkeley, Univ. of California. Diss. Ann Arbor.
- Swanson, T. (1996). The reliance of northern economies on southern biodiversity: Biodiversity as information. In: *Ecological Economics* 17:1-8.
- Swanson, T. and T. Goeschl (2000). Property rights issues involving plant genetic resources: implications of ownership for economic efficiency. In: *Ecological Economics* 32:75-92.
- ten Kate, K., and S. A. Laird (1999). *The commercial use of biodiversity - access to genetic resources and benefit-sharing*. London.
- Tilman, D. (1999). The ecological consequences of changes of biodiversity: A search for general principles. *Ecology* 80:1455-1474.
- Tirole, J. (1995). *The theory of industrial organization*. 5th printing. Cambridge, Mass.
- 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.
- Wolfrum, R., G. Klepper, P.-T. Stoll and Stephanie L. Franck (2001). *Genetische Ressourcen, traditionelles Wissen und geistiges Eigentum im Rahmen des Übereinkommens über die biologische Vielfalt*. Schlussbericht des F+E Vorhabens „Rechtliche Analyse des Übereinkommens über die biologische Vielfalt unter besonderer Berücksichtigung der Fragen des geistigen Eigentum“. Bundesamt für Naturschutz. Bonn-Bad Godesberg.
- 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. Berlin.