Optimal Sampling Intensity in Biodiversity Prospecting and the Financing of Conservation

Formerly “Royalties, Subsidies and Biodiversity Prospecting”

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Abstract

Biodiversity prospecting, or the investigation of biological samples for potential new pharmaceutical products or biotechnology, has drawn considerable attention as a source of revenues for governments concerned with the preservation of biodiversity. Recent agreements designed to extract some of the surplus associated with the marketing of successful products by firms have employed royalties on the revenues from these products. However, taxes on revenues will tend to decrease the number of species sampled and thereby decrease the potential benefits to society and source governments. Further, the latest (or forthcoming) products provide information to other firms which is not accounted for in private decisions, implying that private sampling choice will be suboptimal even in the absence of distorting royalties. Subsidization of sampling and testing costs, combined with lump sum taxes, are shown to achieve both optimal sampling intensity and effective surplus expropriation. Using pharmaceutical industry and biodiversity protection estimates as well as data from existing international agreements, the extent of such surplus extraction to cover habitat protection costs is assessed.

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1 Introduction

Biodiversity preservation, or the protection of variety among species, is of a significant concern to many governments. While individuals may derive benefits (whether direct, indirect or other non-use in nature) from the species and their diversity, the public good aspect of these resources makes it difficult to finance the costs of conservation. One method of particular interest, gaining in popularity of use, is biodiversity prospecting, or the investigation of natural sources for commercially valuable pharmaceutical products or biotechnology. Recently, a number of governments have offered private firms the opportunity to sample species from within their borders in return for a share of the revenues (royalty) from any products resulting from the research and testing of the samples. A formal framework is developed to assess the effectiveness of royalties in extracting part of the surplus of firms and the influence of royalties on sampling practices.

Unlike other articles on biodiversity prospecting, such as Simpson et al. (1996) and Polasky and Solow (1995), the concern here is not directly the value of a particular species or collection thereof, but on the private and social decisions regarding sampling intensity and the potential for prospecting to finance biodiversity conservation. Further, individual species are not assumed to have a single potential use, but a myriad of possible uses, which may result in several products, a single product, or none at all. In a related article, Barbier and Aylward (1996) consider a firm which chooses “information-generating effort” and “protection effort,” but to assume that firms have a significant incentive to protect biodiversity (especially under the additional assumption of a potentially limitless supply of biochemical raw material) is quite suspect.\(^1\) While correctly noting that the government must invest (or encourage firms to invest) in species information generation, the claim that the returns

\(^1\)In their article, Barbier and Aylward assume that the supply of species available to be sampled depends on the amount of protected habitat, or protection effort, by the firm. More realistically, here it is assumed that governments protect habitat but must finance conservation by extracting part of the surplus of the prospecting firms.
from biodiversity prospecting will be insufficient to cover protection costs may be correct when royalties are involved but is less likely to be when more efficient surplus extraction is employed. As will be shown below, the introduction of a royalty on revenues will necessarily reduce the total extractable surplus by decreasing the expected number of successful products.

2 Background

The obvious reason for sampling and testing species is to gain information. This information may be directly useful, such as natural chemicals which inhibit or cure human diseases or genes which can be used to enhance agricultural products, or may simply provide insights into the likelihood of other species containing useful information. For an example of the latter, one may think of the rosy periwinkle of Madagascar, from which two important anti-cancer drugs (vincristine and vinblastine) have been derived, thus suggesting that the close relatives of this tropical plant are more likely to contain anti-cancer agents than other species. Even tested species with no successful applications provide information, given that their close relatives are similarly likely to be useless as sources of new products. In table 1, a number of pharmaceutical companies and agencies which have explored or are currently examining species for potential new products, including some of the world’s largest, as well as the biological species being tested by each, are listed.

A significant issue in biodiversity prospecting is property rights, given the public good nature of biological or genetic resources (genotypes). While rights for developed products are well-defined by patent law in the developed world, international ownership of genetic material and species is much more problematic. For the purposes of this study, it is assumed that nations have sovereignty over their genetic resources, as provided for in the Rio Convention of the 1992 United Nations Conference on Environment and Development. Under the conditions of the Convention, countries also have the responsibility for conserving their biological resources and for using them
in a sustainable manner. “In situ” conservation of ecosystems and natural habitats is expensive in terms of both preservation costs and the lost alternative use of land, and if biodiversity prospecting were a substantial and continual revenue generator for governments, the pressures against the conservation of biodiversity in developing countries could be lessened or even eliminated through compensation for lost opportunity costs. This is particularly important for “biodiversity rich” developing countries, as illustrated by the fact that 70 percent of the 3,000 species known to have anti-cancer properties are found in tropical forests (Sedjo, 1992).

Table 1. Natural Item Collection and Screening by Company and Treatment Sought, 1950 to the present. M=microbes, P=plants, F=fungi, MP=marine plants, A=algae, MF=marine fungi, I=Insects, IV=Invertebrates, SV=spider venom, TM=traditional Asian medicines, MM=marine microbes, Inf.=Inflammation,
C-V=cardio-vascular problems, G-I=Gastro-intestinal problems, O=Other.

Several authors have suggested that biodiversity prospecting can be used as a potential tool for conservation, such as Farnsworth and Soejarto (1985), Principe (1989), Wilson (1992), Reid et al. (1993), and Rubin and Fish (1994). Another subsequent branch of the literature, including Simpson et al. and Barbier and Aylward have questioned the effectiveness of such a tool, citing either low values of the “marginal” species or low royalty revenues to source governments. Regarding the latter, Hyde and Sedjo (1992) have graphically shown royalties to be both inefficient in extracting rents from logging firms and ineffective in inducing optimal deforestation rates, in addition to subjecting the country to significant risk. Similarly, lump sum charges will be shown here to dominate royalties in each of these respects.

Low marginal values of some species in the wild, due to the sheer numbers of species existing on the planet, are indeed the appropriate concern for normative questions such as “how many species we should protect” (although only if social values were added to private prospecting values), but cannot be employed in positive questions such as “can rent extraction from pharmaceutical prospecting cover the costs of biodiversity preservation?” or “what proportion of existing biodiversity can be protected using rent extraction from prospecting firms?” As an example, suppose the millionth species in a collection has a negligible marginal value (as shown by Simpson et al. for reasonable assumptions) which is slightly less than its marginal protection cost, implying that efficient resource use would dictate that this species should be allowed to disappear. Even at the private level, such a species would not be sampled for potential pharmaceutical use. However, if one considers the first species in a collection, the same calculations suggest that marginal value will not be negligible (as would be expected), and clearly will exceed its marginal protection cost. Thus, pharmaceutical firms will have a significant expected surplus on species sampled earlier, which may be used to offset the losses incurred on later unsampled species, if such a surplus can be extracted by source governments and applied to conservation. In sit-
uations of uncertainty regarding future values and given the irreversibility of current decisions, it is quite plausible that some species be protected despite marginal costs below their currently known marginal benefits (see Pindyck, 1991).

A logical question to ask is why a country would want to protect species in such a situation. While prospecting marginal costs and benefits may be relevant in an analysis of private incentives and decisions, there exists substantial work on social values that would suggest that biological species provide significant values to society beyond simple prospecting profits.² Low private values from prospecting may suggest that there is no incentive for firms to protect a large proportion of existing biodiversity but that is not to say that a social decision maker would not. To recapitulate, it is not the intention here to disprove prior studies which find low private marginal values, but to suggest that effective rent extraction may not be the poor conservation tool that it has recently been portrayed to be.

3 The Model

Consider a risk-neutral firm choosing the number of species to be sampled at each point in time $t$, $s_t$, in the search for new pharmaceuticals or biotechnology. Sampling and testing for viable products has a cost which depends on the number of species sampled, $c(s_t)$, with $c_s > 0$ and $c_{ss} \geq 0$. Other previous articles on biodiversity prospecting assume that the probability of finding a successful product is constant, but another possibility, to be described here, is that firms accumulate information, or knowledge, over time, which allows them to increase the likelihood of finding a successful product, in the manner of capital theory.

Denote the knowledge or information accumulated by a firm in question up to time $t$ as $k_t$. The probability of any given species yielding a successful product is a priori constant, but knowledge allows the firm to better choose the species to be tested,

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²Contingent valuation and travel cost studies of estimating existence and option values for different environmental amenities, such as Pearce (1990), Barbier et al. (1994) or Brown and Henry (1993), suggest that social values not included in private decisions may be significant.
so that the probability of finding a successful product at time \( t \) is higher as both knowledge and the number of species sampled increase, or \( \pi(k_t, s_t) \), where \( \pi_k > 0 \), \( \pi_{kk} \leq 0 \), \( \pi_s > 0 \), \( \pi_{ss} < 0 \) and \( \pi_{sk} = 0 \). For simplicity, the probability of finding multiple successful products at any particular point in time \( t \) is zero. The value (net of production and development costs) of a successful product is constant at \( \bar{v} \), and all products yield the same amount of profit (this value arises from the monopoly profits gained from a patent on the product for a finite period). One may think of more complex models in which the value of a successful product declines as the number of successes increases or increases as the total stock of biodiversity decreases. However, it is not clear whether the added value of such modifications will outweigh the costs of additional complexity.

### 3.1 The Private Solution

A representative firm’s expected profits at each point in time \( t \) are given by

\[
\Pi_t = \pi(k_t, s_t)\bar{v} - c(s_t),
\]

or the expected net value of successful products less sampling costs. If the number of firms is normalized to one, total industry knowledge is

\[
K_t = \int_0^1 k_t^i = k_t,
\]

At time \( t \), the firm’s knowledge set includes the information accumulated in the past, net of depreciation, information generated from newly sampled species, and information derived from the past products of other firms in the industry. Knowledge thus accumulates according to

\[
\frac{\partial k}{\partial t} \equiv \dot{k} = \rho K_t + \phi(s_t) - \theta k_t = \rho k_t + \phi(s_t) - \theta k_t,
\]

where \( \rho K_t \) is the amount of the knowledge which the firm observes from the past products of other firms (\( \rho \) is constant and \( 0 < \rho < 1 \)), \( \phi(s_t) \) is the knowledge generated
by the sampling of species, and $\theta$ is the “obsolescence rate” of information: as time progresses, some proportion of the knowledge accumulated becomes obsolete and worthless, with $0 < \theta < 1$. For there to exist a steady state equilibrium, it must be that $\theta > \rho$, or that a firm observes less information from the products of other firms than is made obsolete by time.\footnote{This assumption is clearly only necessary for the existence of a steady state and is not necessary for the private optimum in general.} Typical in the biodiversity prospecting literature is the assumption that the number of potential samples is infinite (see Barbier and Aylward, for example) as there are millions of known species and countless products which may be derived from each species. This assumption, made for consistency and comparability across articles, is strengthened by the increasing resistance of virus strains to current products and new infectious diseases that are “discovered” regularly.

Over an infinite horizon, the firm maximizes the discounted stream of profits, or

$$\int_{0}^{\infty} e^{-\delta t} [\pi(k_t, s_t)\bar{v} - c(s_t)] \, dt,$$

where $\delta$ is the private discount rate. The corresponding Hamiltonian is

$$H = \pi(k_t, s_t)\bar{v} - c(s_t) + \mu[p k_t + \phi(s_t) - \theta k_t],$$

where $\mu$ is the co-state variable, in this case the shadow price of information. Direct application of the Maximum Principle yields the optimality conditions

$$\pi_s \bar{v} - c_s + \mu \phi_s = 0,$$

$$\dot{\mu} = \mu(\delta - \rho + \theta) - \pi_k \bar{v},$$

and the transversality condition,

$$\lim_{T \to \infty} \mu_T k_T e^{-\delta T} = 0.$$
equal the marginal cost of sampling, while (7) describes the movement of the shadow price of biodiversity. In the steady state, \( \hat{\mu} = \hat{k} = 0 \), implying

\[
\mu = \frac{\pi_k \bar{v}}{\delta - \rho + \theta} > 0, \tag{9}
\]

and

\[
\phi(s) = (\theta - \rho)k_t. \tag{10}
\]

Using these conditions, the slope of the \( \hat{k} = 0 \) locus is positive and given by

\[
\left. \frac{ds}{dk} \right|_{\dot{k}=0} = \frac{\theta - \rho}{\phi_s} > 0, \tag{11}
\]

as \( \theta > \rho \). From the time derivative of (6), \( \dot{s} = 0 \) in the steady state as well. Using (6) and \( \hat{\mu} = \hat{s} = 0 \),

\[
\left. \frac{ds}{dk} \right|_{s=0} = \frac{\pi_{kk} \bar{v} \phi_s}{\bar{v} - \pi_{ss} \bar{v} - \frac{\pi_{kk} \phi_{ss}}{(\delta - \rho + \theta)}} < 0, \tag{12}
\]

so that the \( \dot{s} = 0 \) locus is downward-sloping. These loci result in a unique saddle-point equilibrium and a negatively sloped optimal trajectory (or stable path).

### 3.2 The Social Optimum

The social planner or government must take into account the knowledge accumulated by other firms but not yet observed by the individual firm under consideration, net of any overlap in the knowledge accumulated.\(^4\) As in Simpson et al., the social ecological, moral or aesthetic values of biodiversity are ignored, as are the benefits of habitat protection (including ecotourism and recreation), so that the focus here is strictly on prospecting incentives. The social knowledge dynamics are

\[
\dot{k} = \rho k_t + \phi(s_t) - \theta k_t + \gamma \dot{k}, \tag{13}
\]

or

\[
\dot{k} = \frac{\rho k_t + \phi(s_t) - \theta k_t}{1 - \gamma}, \tag{14}
\]

\(^4\)It is assumed that firms are not competing for identical products to ensure there are no problems of “first discovery” or information-masking.
where the parameter \( \gamma \) is the proportion of industry knowledge that does not overlap with the firm in question’s information set. Here, the social planner takes into account not only the information available to the firm from past products of other firms, but also the knowledge accumulated by other firms at the current instant in time, which is not observed the firms when its decisions are made. As the constant \( \gamma \) lies between zero and one, there is positive but not perfect overlap between the knowledge accumulated by all other firms and the representative firm. For simplicity, the social rate of time preferences is assumed to be equal to the private discount rate, so that the planner’s Hamiltonian is then

\[
H = \pi(k, s)\bar{v} - c(s) + q\left[\frac{\rho k_t + \phi(s_t) - \theta k_t}{1 - \gamma}\right],
\]

where \( q \) is the co-state variable, or the social shadow price of knowledge, and the resulting optimality conditions are given by

\[
\pi_s\bar{v} - c_s + \frac{q}{1 - \gamma}\phi_s = 0,
\]

\[
\dot{q} = (\delta + \theta - \rho)q - \pi_k\bar{v},
\]

and

\[
\lim_{T\to\infty} qT^kT e^{-\delta T} = 0.
\]

When \( \dot{q} = 0 \) (as in the steady state),

\[
q = \frac{(1 - \gamma)\pi_k\bar{v}}{(1 - \gamma)\delta + \theta - \rho}.
\]

Comparing the social and private optimality conditions, the number of species sampled \((s)\) is certainly larger in the social case, as

\[
\frac{q}{1 - \gamma} > \mu
\]

and \( \pi_{ss} < 0 \). In the social steady state,

\[
\pi_s\bar{v} - c_s + \frac{\pi_k\bar{v}}{(1 - \gamma)\delta + \theta - \rho}\phi_s = 0,
\]
and
\[ \phi(s) = (\theta - \rho)k, \] (22)
given that \((1 - \gamma) > 0\). Accordingly, the slope of the zero-\(s\) locus is negative,
\[ \frac{ds}{dk}\bigg|_{\dot{s}=0} = \frac{\pi_{kk} \bar{v} \phi_s}{c_{ss} - \pi_{ss} \bar{v} - \frac{\pi_{kk} \bar{v} \phi_{ss}}{(1-\gamma)(\delta - \rho + \theta)}} < 0 \] (23)
and the slope of the zero-\(k\) locus is positive,
\[ \frac{ds}{dk}\bigg|_{\dot{k}=0} = \frac{\theta - \rho}{\phi_s} > 0. \] (24)

From the last equation and the steady state condition for knowledge, the \(\dot{k} = 0\) locus has the same position (and slope) as in the private case. However, the social \(\dot{s} = 0\) locus has a steeper slope and lies above the private locus. Dynamics off of these loci are given by
\[ \frac{d\dot{k}}{ds} = \frac{\phi_s}{1 - \gamma} > 0 \] (25)
and
\[ \frac{d\dot{s}}{dk} = \frac{\pi_{kk} \bar{v} \phi_s}{(1 - \gamma) \pi_{ss} \bar{v} - (1 - \gamma) c_{ss} + q \phi_{ss}} > 0, \] (26)
as illustrated by the arrows in the phase diagram of Figure 1. In the following section, a method for inducing a private firm to make its decisions correspond to the social optimum is presented.

4 Achieving Optimality through Subsidization

The previous section has shown that the private firm will undersample species (or biodiversity) relative to the social optimum. In order to induce the private firm to take into account the fact that the knowledge it accumulates also benefits other firms, the government can implement a subsidy for sampling costs, financed by a lump-sum tax to balance the government budget. The subsidy is of the form \(\lambda c(s)\), where \(\lambda\) is the subsidy per dollar of exploration cost. This modifies the private firm’s profit function to
\[ \Pi = \pi(k, s) \bar{v} - (1 - \lambda) c(s). \] (27)
The resulting optimality conditions are

$$\pi_s \bar{v} - (1 - \lambda)c_s + \mu \phi_s = 0 \quad (28)$$

and (7). The optimal subsidy to achieve the first-best is then

$$\lambda = \frac{\pi_k \bar{v} \phi_s}{c_s} \left[ \frac{\gamma \delta}{(\delta(1 - \gamma) + \theta - \rho)(\delta + \theta - \rho)} \right] > 0, \quad (29)$$

evaluated at the socially optimal level of $s$, $s^*$, at each point in time. Therefore, the source government must provide a subsidy on exploration costs which depends on the expected number of successful products, the marginal sampling cost, the rate of time preference, the marginal information gained by sampling the last species, and the rates of knowledge obsolescence, observation and overlap across firms. Specifically, and intuitively, the subsidy must be higher if the expected number of successful finds is higher, the information gained from another sample is larger, or the marginal sampling cost is lower.

5 Comparative Statics

To this point, the model parameters have been considered constant, but it is often interesting to examine how the steady state levels of knowledge and sampling are affected by changes in the values of the parameters, particularly by the rate of time preference, value of successful products (possibly from changes in patent life or imposed royalties) or the rates of information obsolescence, overlap and observation. With this goal, the total derivatives of the steady-state conditions can be written as

$$\begin{bmatrix}
\phi_s \\
\pi_{ss} \bar{v} - c_{ss} + \frac{\pi_k \bar{v} \phi_{ss}}{(1 - \gamma)(\delta - \rho + \theta)} \\
\pi_{ss} \bar{v} - c_{ss} + \frac{\pi_k \bar{v} \phi_{ss}}{(1 - \gamma)(\delta - \rho + \theta)}
\end{bmatrix} \begin{bmatrix}
dn \\
dk
\end{bmatrix} = 0$$
or

$$Ax = Zb,$$

where

$$z_{11} = k,$$

$$z_{12} = z_{14} = z_{15} = 0,$$

$$z_{13} = -k,$$

$$z_{21} = \frac{\pi_k \bar{v} \phi_s}{[(1 - \gamma)(\delta - \rho + \theta)]^2},$$

$$z_{22} = -\delta \pi_k \bar{v} \phi_s,$$

$$z_{23} = \frac{-\pi_k \bar{v} \phi_s}{[(1 - \gamma)(\delta - \rho + \theta)]^2},$$

$$z_{24} = \frac{(1 - \gamma) \pi_k \bar{v} \phi_s}{[(1 - \gamma)(\delta - \rho + \theta)]^2},$$

and

$$z_{25} = -\pi_n - \frac{\pi_k \phi_s}{(1 - \gamma)(\delta - \rho + \theta)}.$$

The determinant of the matrix $A$ is thus

$$|A| = \frac{\pi_k \bar{v} (\phi_s)^2}{(1 - \gamma)(\delta - \rho + \theta)} + (\theta - \rho) \left[ \pi_s \bar{v} - c_{ss} + \frac{\pi_k \bar{v} \phi_{ss}}{(1 - \gamma)(\delta - \rho + \theta)} \right] < 0. \quad (31)$$

One of the most significant parameters, and one of the most important features of biodiversity prospecting itself, is the value of a successful product, $\bar{v}$. Using Cramer’s rule, (30) and (31),

$$\frac{ds}{d\bar{v}} = \frac{\rho - \theta}{|A|} \left\{ \pi_s + \frac{\pi_k \phi_s}{(1 - \gamma)(\delta - \rho + \theta)} \right\} > 0, \quad (32)$$
As would be expected, when the value of a successful find increases, the number of species sampled and the knowledge accumulated in the steady state increase. A higher value, other things constant, increases expected revenue, and thus increases marginal revenue above the marginal cost of sampling. Sampling intensity increases as a result, until equality between marginal cost and marginal benefit is restored. A royalty, which reduces the value of a successful product to the firm by the amount of the tax, would then decrease the number of species sampled, contributing to enhance the undersampling problem associated with unregulated firms (see the following section). In the steady state, any increase in the number of species sampled must be accompanied by an increase in knowledge (from (10)), given that the newly acquired information (from sampling and observation) and the depreciated knowledge are the same and that depreciated knowledge necessarily exceeds the knowledge observed from other firms ($\rho < \theta$).

With respect to the rate of time preference,

$$\frac{ds}{d\delta} = \frac{\rho - \theta}{|A|} \left\{ \frac{(1 - \gamma) \pi_k \bar{v} \phi_s}{[(1 - \gamma)(\delta - \rho + \theta)]^2} \right\} < 0, \tag{34}$$

and

$$\frac{dk}{d\delta} = \frac{\phi_s}{|A|} \left\{ \frac{(1 - \gamma) \pi_k \bar{v} \phi_s}{[(1 - \gamma)(\delta - \rho + \theta)]^2} \right\} < 0. \tag{35}$$

As firms (and society) become less future oriented (that is, have a higher discount rate), accumulated knowledge becomes less important, as the use of that knowledge in later periods generates revenues which are of lower consequence to the firm. In other words, the shadow price of knowledge is lowered, which in turn decreases the knowledge accumulated. As above, any decrease in the steady state level of knowledge necessarily decreases the number of species sampled as well.

As mentioned previously, there undoubtedly is some degree of overlap between the information set of the firm under consideration and the newly accumulated knowledge.
of other firms, described above by $1 - \gamma$:

$$\frac{ds}{d\gamma} = \frac{\theta - \rho}{|A|} \left\{ \frac{\delta \pi_k \bar{v} \phi_s}{[(1 - \gamma)(\delta - \rho + \theta)]^2} \right\} > 0,$$

(36)

and

$$\frac{dk}{d\gamma} = \frac{-\phi_s}{|A|} \left\{ \frac{\delta \pi_k \bar{v} \phi_s}{[(1 - \gamma)(\delta - \rho + \theta)]^2} \right\} > 0.$$

(37)

As $\gamma$ increases, the overlap of the two sets of information decreases, which makes the knowledge acquired in the current period by other firms in the industry more valuable. Essentially, the (positive) externality imposed on other firms becomes greater, which obviously affects only the socially optimal steady state. When the knowledge of the industry is more valuable, knowledge increases, which consequently increases the number of species sampled (to maintain the higher knowledge level).

As the optimal subsidy also depends on the rate of obsolescence of knowledge, it may also be worthwhile to examine the effect of a change in this rate on the steady state values. In this particular case, the effect is given by

$$\frac{ds}{d\theta} = \frac{1}{|A|} \left\{ \frac{k\pi_k \bar{v} \phi_s}{(1 - \gamma)(\delta - \rho + \theta)} + (\theta - \rho) \frac{\pi_k \bar{v} \phi_s}{[(1 - \gamma)(\delta - \rho + \theta)]^2} \right\},$$

(38)

and is ambiguous. However, the relationship between the optimal number of species sampled and the proportion of other firms' knowledge observed by any firm,

$$\frac{ds}{d\rho} = \frac{1}{|A|} \left\{ \frac{-k\pi_k \bar{v} \phi_s}{(1 - \gamma)(\delta - \rho + \theta)} + (\rho - \theta) \frac{\pi_k \bar{v} \phi_s}{[(1 - \gamma)(\delta - \rho + \theta)]^2} \right\},$$

(39)

has the opposite sign of $\frac{\partial s}{\partial \theta}$. The relationship between optimal knowledge (or information) accumulation and these parameters are nonetheless unambiguous, given by

$$\frac{dk}{d\theta} = \frac{1}{|A|} \left\{ \frac{\pi_k \bar{v}(\phi_s)^2}{[(1 - \gamma)(\delta - \rho + \theta)]^2} - k \left[ \pi_{ss} \bar{v} - c_{ss} + \frac{\pi_k \bar{v} \phi_{ss}}{(1 - \gamma)(\delta - \rho + \theta)} \right] \right\} < 0,$$

(40)

and

$$\frac{dk}{d\rho} = \frac{1}{|A|} \left\{ \frac{-\pi_k \bar{v}(\phi_s)^2}{[(1 - \gamma)(\delta - \rho + \theta)]^2} + k \left[ \pi_{ss} \bar{v} - c_{ss} + \frac{\pi_k \bar{v} \phi_{ss}}{(1 - \gamma)(\delta - \rho + \theta)} \right] \right\} > 0.$$

(41)
The ambiguity of number of species sampled with respect to both the rate of obsolescence of knowledge and the proportion of industry knowledge that the firms observe from past industry products, can be explained using the strictly negative relationship between accumulated knowledge and the obsolescence rate, and the positive relationship with the proportion of observed industry knowledge. For example, if the obsolescence rate increases, steady state knowledge decreases, so that the change in the total amount of obsolete knowledge depends on whether the percentage increase in the obsolescence rate is greater than the percentage decrease in the knowledge stock. If the change in the rate is the larger, so that obsolete knowledge increases, the number of species sampled must increase to offset this and the less knowledge observed from other firms, and vice versa.

6 Expropriating the Surplus of Firms

In practice, royalty agreements have been employed to share profits between the firms and the source country, as intended by the Biodiversity Convention. Royalties are usually based on the expected value of the potential product, with royalty figures typically ranging from 1 to 5 percent. In probably the most publicized agreement, Costa Rica’s Instituto Nacional de Biodiversidad (INBio) signed a contract with US pharmaceutical multi-national Merck & Co. in 1991 to pay $1 million over two years for the opportunity to search for sources of new pharmaceuticals from 1000 samples from the diverse species of Costa Rica’s tropical forests, in return for royalties paid on the therapeutics developed. INBio, as a non-governmental organization, cannot sell the exclusive rights to any particular species, but its mission to integrate Costa Rica’s biodiversity into a sustainable development strategy is consistent with the Biodiversity Convention. The Merck-INBio agreement was renewed in 1994 (Zebich-Knos, 1997), under similar terms.

If the objective of the government is to expropriate the surplus gained by firms in addition to achieve the optimal sampling intensity, it only has to increase the
amount of the lump sum tax. When looking at the sampling intensity alone, the government sets the lump sum tax such that the subsidy paid out to firms is exactly offset. However, substantial profits are earned by the firm when a successful product is found, which may not accrue to the nation providing the samples, as in the case where pharmaceutical companies of the developed world purchase the samples from developing countries. Like the Costa Rica-Merck agreement, most contracting of this type has involved a royalty paid on successful products, and sometimes a up-front fee to cover costs. From the above analysis, we can see that such a policy results not only in the suboptimal sampling incurred due to the externality effect, but compounds this problem by reducing the value of the successful product by the amount of the tax/royalty. In other words, the positive tax (royalty) on successful finds forces firms to sample fewer products than they would with no regulation, which then reduces the expected number of successful products found and results in a lower extractable surplus.

With a subsidy and lump sum tax, it is possible to induce firms to sample the socially optimal number of species while still expropriating some or all of the surplus earned from successful products. A lump sum tax has the benefit of not distorting the decision making of the firms, unlike a royalty, and allows the risk associated with uncertain search to be completely shifted onto the firms performing the exploration. Here it is assumed that there is no competition among countries - one can think only of endemic species, of a global context, or of other reasons why this would be the case. Nonetheless, competition would be as likely under a royalty-based system as with other rent extraction alternatives.

In order to evaluate the extent to which rent extraction can finance conservation,

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5 In addition to covering costs, ten percent of the up-front fee in the Costa Rica-Merck agreement is to go toward conservation efforts.

6 For a graphical exposition of the extraction of rents from firms in the overuse of land, see Hyde and Sedjo (1992).

7 These international conflicts are also ignored in Simpson, Sedjo and Reid, and in Barbier and Aylward.
it is necessary to know the value of biodiversity prospecting. A number of articles, including Farnsworth and Soejarto (1985), Principe (1989), McAllister (1991), Harvard Business School (1992), Pearce and Puroshothamon (1992), Aylward (1993), and Barbier and Aylward have attempted to place values on untested species in situ, with results ranging from US$44 to US$23.7 million. Barbier and Aylward estimate the expected royalty per sample to be US$233, which implies (given the assumed 2 percent royalty) that the expected net revenues per sample is $11650. Using their estimates (40 years, 2000 samples per year, 10 percent discount rate), full surplus extraction would yield a present value of almost $228 million, compared to just $4.6 million by royalties, to the government. The estimated costs (net of sampling fees and collection costs) of protecting all 500,000 species for the 40 year period (although only 40000 species are sampled with 2 samples per species) in Costa Rica is $244 million, which suggests that this country would lose $17 million by lump sum taxation compared to a loss of $240 million by royalties (see Table 2), or would cover 93.4 percent of conservation costs. However, this assumes that the number of species sampled is constant across the two alternatives. As can be seen from the above analysis, more species would be sampled in both the no intervention situation and the subsidization case. If the number of species sampled were to increase by 5 percent (column 4), the source country would lose just $6 million over costs, and if sampling were to increase by 10 percent as a result of the subsidization of costs (column 5), it would be possible for the government to break even even if the present value of the subsidies were not to exceed $5.12 million (or $238 dollars per sample). These figures, although based on pharmaceutical industry data and sampling history, are clearly for illustrative purposes only, but they do show the possibility of governments extracting enough of the surplus of prospecting pharmaceutical firms to cover the costs of biodiversity preservation. Further, as biodiversity has values other than new products (harvesting of species, ecosystem support, existence values to individuals, etc.), the burden of covering all the costs of conservation should not necessarily be placed upon prospecting.
Nonetheless, this straightforward exposition based on reasonable estimates suggests that covering costs is at least possible, if not probable.

<table>
<thead>
<tr>
<th>Number of Samples</th>
<th>Royalty</th>
<th>Lump-Sum</th>
<th>Lump-Sum</th>
<th>Lump-Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000</td>
<td>2000</td>
<td>2100</td>
<td>2200</td>
</tr>
<tr>
<td>Expropriated Surplus</td>
<td>4.56</td>
<td>227.85</td>
<td>239.24</td>
<td>250.64</td>
</tr>
<tr>
<td>Sample Fees</td>
<td>1.23</td>
<td>1.23</td>
<td>1.29</td>
<td>1.36</td>
</tr>
<tr>
<td>Total Government Revenues</td>
<td>5.79</td>
<td>229.08</td>
<td>240.53</td>
<td>251.76</td>
</tr>
<tr>
<td>Costs of Biodiversity Protection</td>
<td>244.48</td>
<td>244.48</td>
<td>244.48</td>
<td>244.48</td>
</tr>
<tr>
<td>Costs of Collection</td>
<td>0.98</td>
<td>0.98</td>
<td>1.03</td>
<td>1.08</td>
</tr>
<tr>
<td>Costs of Taxonomic Information</td>
<td>0.98</td>
<td>0.98</td>
<td>1.03</td>
<td>1.08</td>
</tr>
<tr>
<td>Total Government Costs</td>
<td>246.44</td>
<td>246.44</td>
<td>246.54</td>
<td>246.64</td>
</tr>
<tr>
<td>Government Profit (Loss)</td>
<td>(240.65)</td>
<td>(17.36)</td>
<td>(6.01)</td>
<td>5.12</td>
</tr>
</tbody>
</table>

**Table 2.** Present Values of Costs and Extracted Surplus, Royalties vs. Lump-Sum Taxes, in millions of US dollars, extrapolated Aylward and Barbier data.

Tables 3a and 3b extend this analysis, providing numerous estimates of potential surplus extraction and percentage of Costa Rican biodiversity protected under different assumptions of success probabilities, net revenues, and number of species sampled, and using protection-cost data from the Guanacaste National Park in Costa Rica, from Barbier and Aylward. While estimates of revenues net of production, marketing, distribution and research and development costs may seem high to some, ranging from $50 million to $300 million (or $6 million to $36.6 million per year over an 18 year patent life with a discount rate of 10 percent), one only has to look so far as net income from pharmaceutical companies such as Merck and Company, which made profits of almost US$4 billion in 1996, and Eli Lilly Pharmaceutical Co. which made net profits of almost $88 million from vincristine and vinblastine in 1985 alone (Farnsworth, 1988). From data from US Food and Drug Administration, reported in
Simpson et al., there were on average 23.8 new drugs approved from 1981 to 1993 (with no discernible trend). Approximately one-third of current pharmaceuticals are derived or synthesized from natural products, or roughly 8 products per year. One must be careful when comparing the costs of biodiversity preservation of a single country to revenues from biodiversity prospecting in general. However, as the expected numbers of successful products (hits) indicate, the chosen sampling intensities have low expected numbers of hits except when the probability of success is relatively very high. For Costa Rica, which contains or shares more than one quarter of the known species on earth, it is not unreasonable to assume that some positive proportion could be appropriated by its government, particularly when many species are endemic to Costa Rica. Using the most extreme assumptions, biodiversity prospecting may be expected to protect from 2 percent per year (present value net revenues of $50 million, 1000 samples per year, and a success probability of 1 in 200,000 samples) to 27,500 percent per year or 275 times the biodiversity that currently exists (present value net revenues of $275 million, 5000 samples per year, and a success probability of 1 in 200 samples). The latter would not be sustainable for long periods due to the large numbers of samples performed each year, but these assumptions are not as unreasonable as one may initially perceive, falling within the parameters from certain articles described above. Conservative estimates from the pharmaceutical industry and other literature would suggest that the present value of net revenues would be roughly $125 million ($15 million per year), the number of samples per year as 1,500 and a success probability of around 1 in 13,333 samples, suggesting that revenues from prospecting alone could finance the protection of over 56 percent of Costa Rican biodiversity. Lastly, more reasonable estimates of $150 million net revenues, 2,500 samples and a 0.001 probability would provide revenues exceeding the level necessary to protect all of the 500,000 species. The probability of finding a successful product may in fact be substantially higher, given the limited screening technology and effort that generated some 2,000 naturally-derived pharmaceuticals currently prescribed in
the developed world. The exact protection-financing ability of prospecting would of course require more accurate information than currently available, but it seems plausible that prospecting could in fact generate funds to protect a more significant proportion of biodiversity conservation than previously claimed.

7 Concluding Remarks

Many countries, particularly those at lesser stages of development, have recently become increasingly concerned with the ability of biodiversity contracts to finance conservation efforts. Initial agreement attempts have employed royalties, or a tax on net revenues, as a means to this end, but such methods will necessarily reduce the extractable surplus available for governments. Instead of taxing successful products via royalties, source governments must combine subsidies on sampling costs with up-front lump sum taxes. In this way, governments can achieve the targets of inducing the socially optimal level of sampling intensity and extracting the entire surplus earned by firms above normal profits, to be applied to biodiversity preservation, in addition to shifting the risk associated with exploration onto those firms performing the search. Royalties and low up-front fees, as seen in recent agreements, force developing countries to not only pay for biodiversity conservation themselves but also bear some of the risk associated with exploration. Zero royalties and high up-front fees, on the other hand, allow developing governments to finance some proportion of biodiversity, an attractive proposition given the limitations of other sources of funding. Even with respect to risk-sharing, smaller lump-sum charges would dominate royalties by increasing the total surplus earned (and divided).

Some recent studies have suggested that low values of the “marginal species” necessarily imply that biodiversity prospecting is a poor tool for conservation. Due to the extremely large numbers of species existing currently, it is virtually uncontestable that private values from these species is negligible and below their marginal protection cost, despite potentially high social values not captured in market trans-
actions. However, pharmaceutical patents provide firms with substantial monopoly profits which normally exceed research and development, production and distribution costs, so that rent extraction may indeed be a viable option for governments desiring to finance biodiversity conservation. Employing data from the pharmaceutical industry and Costa Rica, it has been shown that it is not unreasonable that a significant proportion of preservation costs could be paid through surplus extraction from biodiversity prospecting.
References


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