Biodiversity Prospecting, R&D, and the Financing of Conservation*

(Preliminary Draft)

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Abstract

Biodiversity prospecting has drawn considerable attention as a potential source of revenues for governments concerned with the preservation of biodiversity. Recent agreements designed to extract some of the surplus associated with successful products by firms have employed royalties on the revenues from these products. This paper examines the impacts of such government intervention into a two-firm research and development (R&D) market with uncertainty and information spillovers. Royalties are shown to reduce the research output of the taxed firm, which results in much lower expected government revenues when the research output of a competing firm is a strategic subsitute relative to when it is a strategic complement. Further, taxation alone is generally inferior to a combination of taxation/subsidization of successful products and research costs. It is shown that subsidization rather than taxation of successful products may even be optimal under particular types of uncertainty.

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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 from the species and their diversity, the public good aspects of these resources make it difficult to finance the costs of conservation. One method of particular interest, gaining in popularity of use, is extracting rents from 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. 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 relative to other methods of rent extraction.

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 more problematic. The Rio Convention of the 1992 United Nations Conference on Environment and Development nonetheless provides that nations have sovereignty over their genetic resources, but 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 in developing countries could be lessened through compensation for lost opportunity costs. This is particularly important for 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). A number of pharmaceutical companies (including some of the world's largest) and agencies have explored or are currently examining species for potential new products, as seed firms in agriculture have been doing for many years.

Several authors have previously 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. (1995) and Barbier and Aylward (1996) have questioned the effectiveness of such a tool, citing either low private values of the "marginal" species (Simpson et al., 1996) or low royalty revenues to source governments (Barbier and Aylward, 1996).[1] As shown here, the effectiveness of taxes/royalties depends on the nature of the uncertainty in the research and development process, which manifests itself through the strategic complementarity or substitutability of the firms' research expenditure. We examine the relationship between royalties and other surplus extraction methods in a model where two prospecting firms compete through R&D for the same product (prize). One firm uses samples from a country with the government planning the surplus extraction, while the other is not subject to any intervention. The R&D output of both firms is subject to outcome uncertainty and information spillovers.

2 The Model

Biodiversity prospecting is an example of R&D and is subject to competition from other firms, and accordingly, the model presented here is related to the literatures on strategic R&D and trade theory.[2] More specific to this paper, Brander and Spencer (1983), Dixit (1984), Spencer and Brander (1994), and Eaton and Grossman (1986), each considered international R&D competition under certainty, examining price and quantity competition by two or more firms. Uncertainty in production costs was added by Bagwell and Staiger (1992, 1994), while Muniagurria and Singh (1997) and Leahy and Neary (1999) introduced spillovers. Coe and Helpman (1995) show international R&D spillovers are quite significant. In a paper most closely related to this one, Zhou (2002) combines both uncertainty and spillovers in R&D. While incorporating both uncertainty and spillovers, the key difference in this paper (beyond the application) is the nature of the government objective function. In each of the studies above, the concern was to promote the welfare of the firm, compared to the rent extraction objective employed here. Governments in the noted literature could run deficits in order to encourage R&D spending, which a government concerned with raising funds for biodiversity protection would clearly not do.

Two risk-neutral firms are assumed to be selecting their respective levels of R&D input in

[1] Private values typically ignore non-use values or non-excludable use values. Contingent 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.

[2] Brander (1995) provides a survey of this literature.

the hope of creating a new pharmaceutical or biotechnology product. One firm purchases its R&D input (also referred to as sampling intensity) from outside the country in question and is not subject to any rent extraction policy. The other firm purchases its input from the country concerned with profiting from its biodiversity and applying such profits to conservation. The value (net of production costs) of a successful product is constant at $\bar{v}$, but the outcome depends on the rank order and not on the absolute difference between expenditures. In this way, only the firm with the higher R&D level receives this amount, while the losing firm receives no return (this value arises from the exclusive monopoly profits gained from prefect patent protection on the product for a finite period). Sampling and testing for viable products has a cost to the firms which depends on the number of species sampled, $c(s)$, with $c' > 0$ and $c'' > 0$. For simplicity, the probability of finding multiple successful products is assumed to be zero.

Although the foreign firm is not subject to government intervention, we consider two different ways the domestic firm can be taxed. The first is to place a royalty on the value of a successful product, if found, which has been the common method used in recent biodiversity prospecting contracts of Costa Rica and other nations. When this is the only instrument employed, the royalty (t) will be shown to always be positive (tax) and never negative (subsidy), as the tax serves to reduce the reward earned from R&D. A second instrument considered here is a tax or subsidy on each unit of the input (p). Again, if this is the only method, this per unit charge will always be a tax. However, when both instruments are employed, it will be shown that the government may employ a tax on a successful product and a subsidy on sampling, a subsidy on successful products and a tax on sampling, or a tax on both. Factors determining which combination is selected include the nature of the uncertainty (which has implications for strategic competition), the extent of information spillovers between the two firms, the value of the final product, and costs to both the firm (for sampling) or the government (for conservation).

The equilibrium examined here is subgame perfect. The following section describes the (simultaneous) competition between the firms in the second stage of the game, given the government tax instruments. This is followed by the selection of the instruments to maximize rent extraction by the government.

3 Uncertainty, spillovers, and the sampling intensity of the two firms

Each firm selects it desired sampling intensity s, but its overall R&D level depends on the degree of spillovers from the foreign firm, as well as a random component. If the exogenous percentage of information lost to the other firm and gained from the other firm is denoted by γ $(0 \leq \gamma \leq 1)$, and the random variable is denoted by ε, then the realized sampling intensity of firm i is given by

$$S_i = s_i + \gamma s_j + \varepsilon_i \tag{1}$$

and the realized sampling intensity of the foreign firm j would be given by

$$S_j = s_j + \gamma s_i + \varepsilon_j \tag{2}$$

where ε_i and ε_j are identically and independently distributed. The distribution function of ε is given by $F(\varepsilon)$ which is twice differentiable (the first derivative is the density function, denoted by f). As in Zhou, the R&D choice shifts the density function without changing its other properties.[3] The winner of the R&D competition is the firm with the higher realized sampling intensity, in the same manner of a labor tournament such as Lazear and Rosen (1981).

For the firm i to win, its realized sampling intensity S_i must be larger than that of the competing firm S_j, or equivalently

$$(1-\gamma)(s_i - s_j) + \varepsilon_i > \varepsilon_j \tag{3}$$

so that the probability of developing the successful product is $F((1-\gamma)(s_i - s_j) + \varepsilon_i)$ for a given ε_i. Over all possible values of ε_i,the expected probability of developing the successful product is $\int_{\tilde{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon$, where $\bar{\varepsilon}$ and $\tilde{\varepsilon}$ are the upper and lower bounds of the distribution function. Given the government instruments t and p, firm i's expected profits are

$$\pi_i = (1-t)\bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon - c(s_i) - p s_i \tag{4}$$

or the expected value of successful products (net of any royalties) less sampling costs and per unit

[3] The uncertainty in Bagwell and Staiger alters the density function of production costs, while that in Miyagiwa and Ohno (1997) alters the density function of the innovation date. For more detail on the specification chosen here, see Zhou.

charges. Maximizing this expected profit yields the first-order condition for firm i[4]

$$(1-t)(1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i-s_j)+\varepsilon_i)f(\varepsilon)d\varepsilon - c'(s_i) - p = 0 \quad (5)$$

whereby the firm samples up to the point in which the additional expected value of a successful product, net of taxes (or subsidies) and spillovers, from the greater likelihood of winning the competition, equals the sum of the marginal sampling cost and per unit charge. The reaction function for firm i is then

$$\frac{\partial s_i}{\partial s_j} = -\frac{\frac{\partial^2 \pi_i}{\partial s_i s_j}}{\frac{\partial^2 \pi_i}{\partial s_i^2}} = -\frac{-(1-t)(1-\gamma)^2\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'((1-\gamma)(s_i-s_j)+\varepsilon_i)f(\varepsilon)d\varepsilon}{(1-t)(1-\gamma)^2\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'((1-\gamma)(s_i-s_j)+\varepsilon_i)f(\varepsilon)d\varepsilon - c''(s_i)} \quad (6)$$

The denominator of (6) is the second-order condition, which is negative. The reaction function therefore has a negative slope when $f' > 0$, is independent when $f' = 0$, and is positively sloped when $f' < 0$. When the two firms' sampling intensities move in the same direction (here when $f' < 0$), the two inputs are strategic complements, while they are strategic substitutes when the sampling intensities move in opposite directions ($f' > 0$).[5] Globally monotonic density functions include the distributions of the exponential ($f' < 0$), the uniform ($f' = 0$) and the power ($f' > 0$). The sign of f' can be interpreted as an indication of the prevalence of opportunities available in the market (Zhou, 2002), with higher values suggesting greater opportunities.

The other firm has the same cost function but no taxes or per-unit charges, so expected profits are

$$\pi_i = \bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_j-s_i)+\varepsilon_j)f(\varepsilon)d\varepsilon - c(s_j) \quad (7)$$

so that s_j is chosen according to

$$(1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_j-s_i)+\varepsilon_j)f(\varepsilon)d\varepsilon - c'(s_j) = 0 \quad (8)$$

which is equivalent to (5) without taxes or per unit charges.

Conditions (5) and (8) describe the outcome of the second stage of the game, given the government taxes set in the first stage (examined below). The sensitivity of the second stage equilibrium

[4]The second-order condition depends on the sign of f' and is therefore not automatically satisfied. The assumption made here is that γ is sufficiently large and/or marginal costs are increasing at a sufficient rate to satisfy the second-order condition for a maximum.

[5]Bulow et al. (1985) describe in detail strategic complementarity and substitutability in R&D competition. In summary, a strategic substitute is defined as the situation where, when faced with a firm spending more on R&D, profits are higher from decreasing R&D spending, and a strategic complement where, in the same increase in a competitor's spending, profits are higher from increasing R&D spending.

can be found from the total derivatives of these conditions, which can be written as follows

$$\begin{bmatrix} \delta_{11} & \delta_{12} \\ \delta_{21} & \delta_{22} \end{bmatrix} \begin{bmatrix} ds_i \\ ds_j \end{bmatrix} = \begin{bmatrix} (1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_j - s_i) + \varepsilon_j) f(\varepsilon) d\varepsilon & 1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} dt \\ dp \end{bmatrix} \tag{9}$$

where

$$\delta_{11} = (1-t)(1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon - c''(s_i) < 0 \tag{10}$$

$$\delta_{12} = -(1-t)(1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon \tag{11}$$

$$\delta_{21} = -(1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'((1-\gamma)(s_j - s_i) + \varepsilon_j) f(\varepsilon) d\varepsilon < 0 \tag{12}$$

and

$$\delta_{11} = (1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'((1-\gamma)(s_j - s_i) + \varepsilon_j) f(\varepsilon) d\varepsilon - c''(s_j) < 0 \tag{13}$$

Equations (10) and (13) are negative by second-order conditions. The sign of the off-diagonal elements of the Jacobian depend on whether the two inputs are strategic substitutes or strategic complements. When the sampling intensities of the two firms are substitutes, the off-diagonals are both positive; when the sampling intensities of the two firms are complements, the off-diagonals are both negative. The determinant of the Jacobian (denote by $|\Delta|$) is strictly positive.

Firm i performs less sampling when the royalty on successful products increases, as given by

$$\frac{\partial s_i}{\partial t} = \frac{(1-\gamma)^3 \bar{v}^2 \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f(\cdot_i) f(\varepsilon) d\varepsilon \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'(\cdot_j) f(\varepsilon) d\varepsilon - c''(s_j) \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f(\cdot_i) f(\varepsilon) d\varepsilon}{|\Delta|} \tag{14}$$

which is negative regardless of the sign of f'. The change in the sampling performed by firm j depends on the relation between s_i and s_j:

$$\frac{\partial s_j}{\partial t} = \frac{(1-\gamma)^3 \bar{v}^2 \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f(\cdot_i) f(\varepsilon) d\varepsilon \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'(\cdot_j) f(\varepsilon) d\varepsilon}{|\Delta|} \tag{15}$$

the sign of which depends on the sign of f'. If the reaction function is negatively sloped (strategic substitutes), a higher royalty on firm i results in more sampling by firm j. This would have the effect of significantly reducing the probability that firm i wins the competition. If the reaction function, however, is positively sloped (strategic complements), then the higher royalty reduces the sampling done by both firms (and thus having a lesser impact on the probability that firm i wins). For the same royalty rate, government revenues would be smaller when the two goods are strategic substitutes. Similar sensitivities can be found with respect to the per-unit charge p:

$$\frac{\partial s_i}{\partial p} = \frac{(1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'(\cdot_j) f(\varepsilon) d\varepsilon - c''(s_j)}{|\Delta|} \tag{16}$$

which is always negative, and

$$\frac{\partial s_j}{\partial p} = \frac{(1-\gamma)^2 \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f'(\cdot_j) f(\varepsilon) d\varepsilon}{|\Delta|} \tag{17}$$

which, like the royalty, is positive when $f' > 0$ and is negative when $f' < 0$.In the following section, these sensitivities will be used to determine the optimal government choices of t and p.

4 Rent extraction and the choice of taxes and subsidies

According to the UN Conference on Environment and Development, governments must protect their biological resources. The commonly cited difficulty in achieving such an objective is finding a source of funding. In addition to the recovery of biodiversity protection financing costs from bioprospecting, the government must take into account the impacts that its policies will have on the likelihood the prospecting firm will actually achieve a successful product. In another way, the government must recognize the reactions of the sampling intensities of both firms from the second stage of the game in setting its own policies. The objective of the government is then to maximize the total revenues extracted from the firms, either through royalties or per-unit charges, subject to the constraint that firms will act in accordance with the above detailed second stage results. 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.

Providing the samples to firm i has a cost $e(s_i)$ with $e' > 0$ and $e'' \geq 0$.This cost could relate to the actual provision of the samples, or to the cost of preserving an area large enough to encompass enough species to meet the demand. The government thus maximizes its net revenues

$$R = t\bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon - e(s_i) + p s_i \tag{18}$$

with respect to both t and p. This yields the first-order conditions

$$\frac{\partial R}{\partial t} = \bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon + t(1-\gamma)\bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon \left[\frac{\partial s_i}{\partial t} - \frac{\partial s_j}{\partial t}\right]$$

$$-e'(s_i)\frac{\partial s_i}{\partial t} + p\frac{\partial s_i}{\partial t} = 0 \tag{19}$$

and

$$\frac{\partial R}{\partial p} = t(1-\gamma)\bar{v} \int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i) f(\varepsilon) d\varepsilon \left[\frac{\partial s_i}{\partial p} - \frac{\partial s_j}{\partial p}\right]$$

$$-e'(s_i)\frac{\partial s_i}{\partial p} + p\frac{\partial s_i}{\partial p} + s_i = 0 \tag{20}$$

Using the first-order condition of firm i from (5) solved for p, and re-arranging

$$t = \frac{\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_i - s_j) + \varepsilon_i)f(\varepsilon)d\varepsilon + (1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i)f(\varepsilon)d\varepsilon\frac{\partial s_i}{\partial t} - (c' + e')\frac{\partial s_j}{\partial t}}{\frac{\partial s_j}{\partial t}} \tag{21}$$

and

$$p = \frac{-t(1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i)f(\varepsilon)d\varepsilon\left[\frac{\partial s_i}{\partial p} - \frac{\partial s_j}{\partial p}\right] - s_i + c'\frac{\partial s_i}{\partial p}}{\frac{\partial s_i}{\partial p}} \tag{22}$$

The first conclusion we can draw from these conditions is if there is only to be one instrument (either a tax on successful products or a tax on sampling but not both), then that tax would certainly be positive. This follows directly from the objective of revenue extraction of the government. Related to this, if one instrument is a subsidy the other must be a tax. Again, this simply ensures that the government has a positive revenue flow. In general, however, a tax on successful products can be combined with either a tax or subsidy on sampling, and a tax on sampling can be combined with either a tax or subsidy on successful products.[6] When the tax on successful products is positive, then a subsidy on sampling will only be used if

$$-t(1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i)f(\varepsilon)d\varepsilon\left[\frac{\partial s_i}{\partial p} - \frac{\partial s_j}{\partial p}\right] - s_i + c'\frac{\partial s_i}{\partial p} > 0 \tag{23}$$

which is more likely when: (a) the degree of spillovers between firms (γ) is low, (b) the marginal cost of sampling is low, (c) the value of a successful product is high, and (d) the two goods are stronger strategic substitutes (that is, a higher value of f').

When the government applies a tax on sampling, the conditions under which the optimal royalty would be negative depend on the sign of f', or whether the R&D expenditures are strategic complements or substitutes. When the two expenditures are strategic complements or $f' < 0$, so that the foreign firm reduces its own R&D when the domestic tax increases, a subsidy (rather than a royalty) on successful products would be the desired choice of the government when

$$\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} F((1-\gamma)(s_i - s_j) + \varepsilon_i)f(\varepsilon)d\varepsilon + (1-\gamma)\bar{v}\int_{\underline{\varepsilon}}^{\bar{\varepsilon}} f((1-\gamma)(s_i - s_j) + \varepsilon_i)f(\varepsilon)d\varepsilon\frac{\partial s_i}{\partial t} - (c' + e')\frac{\partial s_j}{\partial t} > 0 \tag{24}$$

which is more likely if (a) marginal sampling costs (c') are high, (b) marginal protection costs (e') are high, or (c) the degree of spillovers of information across the two firms is high. However, the

[6] In another way, there are three classes of possible outcomes with two non-zero instruments: $t > 0$ and $p > 0$, $t > 0$ and $p < 0$, and $p > 0$ and $t < 0$.

opposite is true if the two R&D expenditures are strategic substitutes ($f' > 0$). In this case, a subsidy on successful products would be chosen if (24) is negative, which is more likely if marginal sampling or protection costs are low, or if spillovers are low.

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.

We have shown here that although a positive tax (royalty) on successful finds forces firms to sample fewer species than they would with no regulation, this does not necessarily imply that the firm will be less likely to win the R&D game presented here. The nature of the uncertainty may result in the two R&D expenditures being strategic complements, so that foreign competitors reduce their own expenditure when a domestic royalty is applied. In general, however, it is suboptimal for domestic governments to only tax successful products, as a combination of tax (or subsidies) on successful products and sampling costs would produce larger revenues than a single tax alone. It is not impossible that the appropriate tax on successful products be negative.

What are the implications of this model for the viability of biodiversity prospecting as a source of revenues for conservation? The limited data from existing agreements makes it difficult to determine, particularly since no existing contracts use the instruments prescribed here. Further, the type of uncertainty faced by research firms needs greater attention. Nonetheless, it is not unreasonable to expect that a greater share of revenues could be extracted if the taxes were chosen optimally. A number of studies, 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), the present value is almost $228 million, of which only $4.6 million is extracted by the government in royalties. However, there is no reason to believe that the chosen royalty is necessarily optimal. If the inputs of competing firms are strategic complements, significantly raising the royalty rate will yield greater expected revenues to the government. Per unit charges, or a combination of per unit charges and royalties, may be also be more attractive revenue generator for governments. 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.

5 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 the effectiveness of this method will has been shown to be highly dependent on the nature of the uncertainty in the R&D process and the spillovers that occur between firms. In general it is appropriate to combine royalties and per unit charges (either of which, but not both, could in fact be subsidies instead of taxes), which has the additional benefit of shifting some of the risk associated with exploration onto those firms performing the search.

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 transactions. However, pharmaceutical patents often provide firms with substantial 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.

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