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Bioprospecting and biodiversity contracts

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ABSTRACT. A dynamic economic model for a biodiversity prospecting contract, between a host country and a pharmaceutical company, is developed and used to explain the structure of existing contracts. The host country's stocks of biodiversity and genetic information are crucial inputs to the production of high-quality samples. Even with compete property rights contracts will be second best; it is not possible to perfectly monitor host-country inputs to the drug discovery process. Contracts vary due to the different degrees of observability of host-country inputs, and incomplete or ineffective property rights.

1. Introduction

Bioprospecting refers to the search for new *in situ* sources of chemical compounds, genes, proteins, micro-organisms for pharmaceutical and other products of potential economic value. Much of the biodiversity on our planet is found *in situ* in locations that lack effective property rights. Establishing control over access to *in situ* biodiversity does not guarantee a return (Barbier and Aylward, 1996). Some researchers have argued that, given uncertainty, a large collection from which to sample, and redundancy, the value of *in situ* biodiversity will be too small to support conserving it (Simpson, Sedjo, and Reid, 1996). However, recent research by Rausser and Small (2000) has shown that scientific information allows the partitioning of the collection according to expected quality, and that leads of high expected quality will generate information rents great enough to provide an incentive for conservation.

It should also be recognized that any return that can be generated by bioprospecting constitutes only a portion of the value of biodiversity. Policies to preserve biodiversity should not focus narrowly on bioprospecting. Nevertheless, *in situ* biodiversity provides a reservoir of robustness, which will continue to be drawn upon in the search for new pharmaceutical and other products. With the potential for high-quality *in situ* collections to generate significant conservation values, it is important that there be an institutional framework to channel these values into incentives, and to ensure returns for both the pharmaceutical company and the

host country. Bioprospecting contracts are likely to be a key feature, and it is useful to consider their structure in theory and application.

The purpose of this paper is to develop a dynamic economic model for a biodiversity-prospecting contract between a host country and a pharmaceutical company. The economic model is used to explain and critique the structure of the existing and proposed contracts. The host country's stocks of biodiversity and genetic information are crucial inputs to the production of high-quality samples. Even with complete property rights, contracts will be second best; it is not possible to perfectly monitor host-country inputs to the drug discovery process. Contracts vary due to different degrees of observability of host-country inputs, and incomplete or ineffective property rights. After some background in the next section, the economic theory of a contract (with a risk-averse agent) will be discussed in section 3. In section 4 five existing or proposed contracts will be presented and analyzed from the perspective of the economic model. Conclusions and recommendations for improved contracts are presented in section 5.

2. Background

Biodiversity has historically been treated as a global common property resource. While common property resources can often be effectively managed at the local level, it is difficult to carry out effective management at the global level. Without an effective property rights system, it is possible for foreign bioprospectors to take as much as they would like from the 'unowned' biodiversity, and potentially develop that material into pharmaceutical products that yield large profits for them, while returning little gain to the source country. Nor is there an incentive for the developing country to conserve or manage these natural resources. Without enforced property rights, indigenous people are unlikely to see any gain from preserving the biodiversity surrounding them.[1]

The United Nations Convention on Biological Diversity (CBD), Article 1 (1992) formally recognizes that the preservation of environmental resources is intimately linked to the provision of economic incentives for individuals, groups, and nations. It provides support for rights over these resources. But, biodiversity contracts can only be effective in combination with internal legislation exercising the host countries' property rights over

[1] The Madagascar Rosey Periwinkle provides an example of what can happen if the country is not able to exert property rights. In 1958 the Eli Lilly Pharmaceutical Company, tested an extract of the rosey periwinkle plant that had been found in the tropical forests of Madagascar. The screening found genetic activity, which implied that this plant possessed the characteristics desirable for successful drug development. Further research resulted in the development and patenting of two extremely effective anti-cancer drugs. Eli Lilly marketed the drugs and earned millions of dollars in sales long before the patent expired (Farnsworth, 1996). As of 1992, Eli Lilly had made no payments to Madagascar (Khalil, 1995). More recently some countries, such as India, have begun to take a much more aggressive approach to defending their property rights ('When rhetoric hits reality in debate on bioprospecting', 1998).

biodiversity, appropriate intellectual property rights (IPR), and the resolution of the status of *ex situ* collections.

Contracts exist when there are reasons that arms-length transactions will not work. The reasons can be related to the inter-temporal nature of the transaction, market imperfections in the production process, or the need for insurance (Eswaran and Kotwal, 1975). These elements are present in the case of the biodiversity contract. Host-country agents, are typically poor developing countries and risk averse. Random elements are inherent in the development of a successful pharmaceutical product, the outcome is only known after some passage of time, and contracts are often expected to provide insurance. A pharmaceutical company needs the services provided by collectors with access to information and biodiversity resources. But, there is not a well-functioning market for access to the information and biodiversity inputs.

The bioprospecting contract is modeled as a principal–agent relationship with the pharmaceutical company as a risk-neutral principal. This is a one-sided moral hazard model. A number of results flow from this model. With a risk-neutral host-country agent, the cooperative outcome will prevail. However, if the host-country agent is risk averse and the agent's production process includes random and unobservable elements, there will be trade-off between providing full insurance and full incentive compatibility. The particular payment pattern will depend upon the degree to which the biodiversity stock and the information stock can be monitored. Incomplete property rights will also affect the structure of payments.

3. Economic model of the contract

Complete property rights

In a principal–agent contract, a first-best compensation rule must satisfy two conditions. First, it must maximize the expected profit of the principal. Since the principal is not directly able to force the agent to maximize the expected profit of the principal, the principal must indirectly induce the agent to behave as desired through the appropriate choice of the incentive payment. This is the incentive-compatibility constraint. The second condition requires that the agent be no worse off than he would have been had he chosen an alternative arrangement with another principal, or had he chosen not to participate at all. This requirement is the agent's participation constraint. As the principal, too, must receive at least her reservation utility, the incentive scheme must ensure that both the principal and the agent attain a certain level of utility in order for the scheme to be effective (Parkin and Bade, 1991).

Consider a relationship between a principal and an agent. The principal, in this case, shall be the pharmaceutical company. The agent is the host country. Assume risk neutrality for the principal and risk aversion for the agent. Given that the host country controls access to biodiversity resources and information relating to the pharmaceutical potential of these resources, the principal is trying to design a contract to offer the agent. Ignoring random elements, the principal wants to induce the agent to produce the amount of bioprospecting output, Q, which maximizes her

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discounted profits. The bioprospecting output is a function of both the stock of the biodiversity, Z, and the stock of the information related to the pharmaceutical potential of the biodiversity, G. The equations of motions for Z and G are

$$\dot{G} = e - \epsilon G$$

and

$$\dot{Z} = I - \delta Z$$

The biological stock, Z, is built up or maintained as the agent undertakes conservation measures, I, in order to ensure that a potential disease-curing sample is not lost due to the ongoing destruction or degradation of the biological stock, which occurs at a rate δ. The simple view of the information stock, G, is that it represents species information that is built up as the agent undertakes to collect, do initial screenings, and identify samples. Sample collection efforts are designated, e. However, there is a view of the drug discovery process that characterizes G as being more complex, including ecological data and ethno-botanical information. The complex view of G implies greater monitoring difficulties than the simple view. The information stock has a degradation rate, ϵ.

The production function for the bioprospecting revenue is $R(G, Z) = \pi Q(G,Z)$, with π as the competitive price for Q, $Q_g > 0$, $Q_z > 0$, $Q_{gg} < 0$, $Q_{zz} < 0$, $Q_{gz} > 0$ and $Q_{zg} > 0$.[2] The principal's objective may also be characterized as inducing the agent to provide the optimal biological and information stocks.

With a random element bioprospecting revenue becomes $W(\omega, G, Z) = \omega R(G, Z)$, where ω is a random variable whose distribution is $\omega = 1$ with a probability V, and $\omega = 0$ with a probability $1 - V$. As in Spence and Zeckhauser (1971), ω is assumed to be a state of nature, not subject to influence by either the principal or the agent. Complicating the problem is the fact that the production process for W is not fully observable. Unless W, G, e, Z, and I can be observed, the principal will not provide full insurance because it will not have full information on the distribution of W. The lack of observability creates a moral hazard problem. From the agent's perspective, insurance, in the presence of an incompletely unobserved production process, provides an incentive to shirk in the provision of inputs e, G, I, and Z.

The simple multiplicative form used for the stochastic specification of revenue, $\omega R(G,Z)$, and the production complementarity of G and Z ($Q_{gz} > 0$), ensure that G and Z (or e and I) are both risk increasing. This will mean less G and Z (or e and I) will be used by a risk-averse agent than by a risk-neutral agent (Batra and Ullah, 1974; Hartman, 1995).

Assume that each time t is a contract period in which the principal can pay the agent in three forms: an advanced payment, $a + \Phi(G, Z)$, a price per sample, P, and/or a royalty rate, α. The contract itself extends over a

[2] Barbier and Aylward (1996, p. 167) use a similar combination of input stocks to produce a pharmaceutical output. They define G as 'the accumulated knowledge … generated by taxonomic R&D effort.'

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large number of time periods (in the formal model an infinite number), with the same payment structure used in all t. The principal has the ability to choose the levels of any of these payments. Let $\Phi(G, Z)$ be the portion of the advance payment which is a function of G and Z, such that $\Phi_g > 0$, $\Phi_z > 0$, $\Phi_{gg} < 0$, $\Phi_{zz} < 0$, $\Phi_{gz} > 0$, and $\Phi_{zg} > 0$, and a be the portion that provides the flexibility to ensure that the agent receives exactly his reservation utility. Price, P, is a flat, per sample fee, and α is the royalty rate chosen by the principal and paid to the agent out of the profits from any products developed. Whereas the royalty payment is always based on an observed successful outcome, $\Phi(G, Z)$ and Pe are based on variables G, e, Z, and I that may not be perfectly observable.

The agent incurs the costs of extracting and processing each sample, $C(e)$. Assume that for each sample extracted and processed by the agent, one unit of effort is exerted, such that effort levels and sample quantities are interchangeable. The principal incurs a cost $L(e)$ of further screening of samples provided to her by the agent. The agent also incurs the costs of investing his resources to conserve the stock of biodiversity. These costs are denoted $K(I)$. It is assumed that $Ce > 0$, $Cee > 0$, $L_e > 0$, $L_{ee} > 0$, $K_i > 0$, and $K_{ii} > 0$.

The risk-averse agent

The problems of the agent and the principal are cast in the dynamic framework of a renewable contract through the use of the Hamiltonian. The Hamiltonian function can be interpreted as a performance indicator at time t. It is the sum of two terms of current profits and the value of net investments. First, consider the agent's problem, which is to maximize its Hamiltonian, A.[3] The agent is assumed to have a utility function $U(x)$, where $x > 0$ is net income, such that $U_x > 0$, and $-U_{xx} > 0$. With $-U_{xx}/Ux > 0$ *and* $-xU_{xx}/U_x > 0$ risk aversion is exhibited by Arrow–Pratt measures of absolute and relative risk aversion (Hey, 1979, pp. 48–49). Let the superscripts h, and l denote the marginal utility associated with high, and low payoff levels respectively.

The agent maximizes

$$\begin{aligned} \text{Max}A = {} & VU[a + \Phi(G, Z) + \alpha R(G, Z) + Pe - C(e) - K(I)] \\ & + (1 - V)U[a + \Phi(G, Z) + Pe - C(e) - K(I)] \\ & + z[-\delta Z + I] + g[-\epsilon G + e] \end{aligned} \tag{1}$$

such that

$$\begin{aligned} & VU[a + \Phi(G, Z) + \alpha R(G, Z) + Pe - C(e) - K(I)] \\ & + (1 - V)U[\alpha + \Phi(G, Z) + Pe - C(e) - K(I)] \geq U_0 \end{aligned}$$

[3] The convexity of the cost curves ensures the concavity of the agent's Hamiltonian in the control arguments. Schattler and Sung (1993) have shown that for the continuous time problem concavity of the Hamiltonian in the control arguments is required for the first-order approach to be used for the principal-agent problem.

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Setting the partial derivatives of A with respect to I and e equal to zero, the first-order conditions for a maximum are

$$\frac{\partial A}{\partial I} = -VU_x^h K_i - (1 - V)U_x^l K_i + z = 0 \tag{2}$$

$$\frac{\partial A}{\partial e} = -VU_x^h(P - C_e) - (1 - V)U_x^l(P - C_e) + g = 0 \tag{3}$$

The co-state variables z and g give the marginal values of the last unit of the stock Z and G respectively. Rearranging (2) equation (4) is obtained. It says that for the last unit of I, the marginal benefit equals the marginal cost in equilibrium

$$\left[Vu_x^h + (1 - V)U_x^l\right]K_i = z \tag{4}$$

Rearranging (3), equation (5) can be obtained

$$\left[C_e - P\right]\left[VU_x^h + (1 - V)U_x^l\right] = g \tag{5}$$

The adjoint equations of the risk-averse agent can be derived as:

$$\partial A \backslash \partial G = [Vu_x^h + (1 - V)U_x^l]\Phi_g + VU_x^h \alpha R_g - \epsilon g = -\dot{g} + rg \tag{6}$$

$$\partial A \backslash \partial Z = [Vu_x^h + (1 - V)U_x^l]\Phi_z + VU_x^h \alpha R_z - \delta z = -\dot{z} + rz \tag{7}$$

The left-hand side of (6) represents the marginal benefit of investing in G, while the right-hand side represents the marginal cost. Condition (7) gives the equivalent marginal benefit equals marginal cost condition (MC = MB) for the level of investment in Z.

Assuming the steady state, $\dot{g} = \dot{z} = \dot{G} = \dot{Z} = 0$. The agent's steady state MC = MB condition for I can be written as (8). Solving (4) for z and substituting into (7) gives

$$K_I(r + \delta) = \Phi_z + \frac{VU_x^h \alpha R_z}{VU_x^h + (1 - V)U_x^l} \tag{8}$$

Funds invested to generate an extra unit of G, if invested in the market, would yield a stream of returns $K_I(r + \delta)$, from time t to infinity. At the margin this must equal the return on the right-hand side, which also represents a stream of returns from t to infinity. Dividing both sides by $(r + \delta)$, would yield the interpretation that the marginal cost of investing in Z at time t must equal the present value of the time stream from t to infinity of marginal benefits. For the risk-neutral agent (8) would have been

$$K_I(r + \delta) = \Phi_z + V\alpha R_z \tag{9}$$

Similarly, the agent's steady state MC = MB condition for e can be derived. From the agent's model, substitute (3) into (6) to obtain

$$C_e(r + \epsilon) = \Phi_g + \frac{VU_x^h \alpha R_g}{VU_x^h + (1 - V)U_x^L} + (r + \epsilon)P \tag{10}$$

With a risk-neutral agent (10) would have been reduced to

$$C_e(r + \epsilon) = \Phi_g + V\alpha R_g + (r + \epsilon)\, P \tag{11}$$

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For the case of the risk-averse agent, (8) and (10), together with the steady state conditions $G = \epsilon e$ and $Z = \delta I$, constitute the system of equations that can be solved for e, I, G, and Z. With a risk-neutral agent (9) and (11) are used instead of (8) and (10).

From $U_x > 0$ and $-U_{xx} > 0$, it follows that $U^l_x > U^h_x$ and that $U^l_x / U^h_x > 1$. Hence, $U^h_x / [V\,U^h_x + (1 - V)U^l_x] = 1/[V + (1 - V)(U^l_x / U^h_x)]$ in (8) and (10) must be less than 1. To the extent that royalties are used as a payment mechanism, the marginal benefits for both I and e will be less in the risk-averse case than in the risk-neutral case. This implies that the risk-averse agent will use less of the risk-increasing inputs I and e (or Z and G).

The risk-neutral principal

For the principal, the profit function must include the participation constraint of the agent, and the incentive compatibility constraints. The latter are derived from the maximum and adjoint conditions for the agent.

The principal's problem, given a risk-averse agent, becomes

$$\begin{aligned}\text{MaxS} = {} & V(1 - \alpha)R(G, Z) - a - \Phi(G, Z) - Pe - L(e) \\ & + \theta\Big\{VU^h[a + \Phi\,(G< Z) + Pe + aR(G, Z) - C(e) - K(I)]\Big\} \\ & + \theta\Big\{(1 - V)\,U^l[a + \Phi\,(G, Z) + Pe - C(e) - K(\mathrm{I})] - U_0\Big\} \\ & + \gamma_i\Big[VU^h_xK_i + (1 - V)U^l_xK_i - z\Big] \\ & + \gamma_e\Big\{VU^h_x[-(P - C_e)] - (1 - V)U^l_x(P - C_e) - g\Big\} \\ & + \gamma_g\Big[VU^h_x(\Phi_g + \alpha R_g) + (1 - V)U^l_x\Phi_g - (r + \epsilon)g + \dot{g}\Big] \\ & + \gamma_z\Big[VU^h_x(\Phi_z + \alpha R_z) + (1 - V)U^l_x\Phi_z - (r + \delta)z + \dot{z}\Big] + \eta[-\epsilon G + e] \\ & + \psi[-\delta Z + I]\end{aligned} \tag{12}$$

In the case of the principal the participation constraint of the agent is binding. The principal must provide a payment scheme to the agent such that his reservation level of utility, U_0, is attained. Since risk has been introduced into this model, the participation constraint compares the agent's expected utility with the reservation utility, U_0. Initially assume the incentive compatibility constraints are not binding, in order to consider the principal's first-best insurance option. With γ_i, γ_e, γ_g, and γ_z equal to zero, the principal's first-order conditions are

$$\frac{\partial S}{\partial a} = -1 + \theta\Big[VU^h_x + (1 - V)U^l_x\Big] = 0 \tag{13}$$

$$\frac{\partial S}{\partial I} = -\theta\Big[VU^h_x + (1 - V)U^l_x\Big]K_i + \psi = 0 \tag{14}$$

$$\frac{\partial S}{\partial e} = -P - L_e + \theta\Big[VU^h_x + (1 - V)U^l_x\Big](P - C_e + \eta = 0 \tag{15}$$

In the agent's problem the multiplier of the participation constraint

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equaled zero, whereas for the principal the multiplier, $\theta = 1/[VU_x^h + (1 - V)U_x^l]$, is greater than zero.

Substituting (13) into (14) and (15) simplifies them to (16) and (17) respectively.

$$K_i = \upsilon \tag{16}$$

$$C_e + L_e = \eta \tag{17}$$

The adjoint equations are

$$V(1 - \alpha)R_g + \frac{VU_x^h \alpha R_g}{VU_x^h + (1 - V)U_x^l} - \epsilon\eta = -\dot{\eta} + r\eta \tag{18}$$

$$V(1 - \alpha)R_z + \frac{VU_x^h \alpha R_z}{VU_x^h + (1 - V)U_x^l} - \delta\psi = -\dot{\psi} + r\psi \tag{19}$$

Assuming the steady state, $\dot{\eta} = \dot{\varphi} = \dot{G} = \dot{Z} = 0$, and one can solve for the MC = MB conditions for the principal's steady state choices of I and e. From (16) and (19), (20) can be derived. This is the marginal condition for the principal's choice of I

$$K_i(r + \delta) = V(1 - \alpha)R_z + \frac{VU_x^h \alpha R_z}{VU_x^h + (1 - V)U_x^l} \tag{20}$$

With a risk-neutral agent this would reduce to (21)

$$K_i(r + \delta) = VR_z \tag{21}$$

From (17) and (18) the principal's choice of e is determined by

$$(C_e + L_e)(r + \epsilon) = V(1 - \alpha)R_g + \frac{VU_x^h \alpha R_g}{VU_x^h + (1 - V)U_x^l} \tag{22}$$

With a risk-neutral agent (22) becomes (23)

$$(C_e + L_e)(r + \epsilon) = VR_g \tag{23}$$

If the principal uses royalties in the payment schedule for a risk-averse agent, the marginal benefits are reduced, and lower levels of I, e, G, and Z will result. Viewed in terms of the agent's participation constraint, a royalty payment's contribution to the agent's expected utility is reduced by the agent's risk aversion. As a result it will be more costly to the principal to meet the agent's participation constraint through the use of royalties than through other means. If there are no binding incentive compatibility constraints, the principal will make herself better off by fully insuring the agent.

The optimal levels investment and effort

Now reconsider the incentive compatibility constraints. If these constraints are truly non-binding, the agent must have the same marginal benefits from investment and effort as does the principal, and therefore make the same choices. First consider investment in natural biodiversity. Begin by setting the right-hand sides of (8) and (20) equal

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$$K_i(r+\delta) = \Phi_z + \frac{VU_x^h \alpha R_z}{VU_x^h + (1-V)U_x^l}$$
$$= V(1-\alpha)R_z + \frac{VU_x^h \alpha R_z}{VU_x^h + (1-V)U_x^l} \tag{24}$$

If the agent is risk neutral, (24) will become

$$K_i(r+\delta) = \Phi_z + V\alpha R_z = V(1-\alpha)R_z + V\alpha R_z \tag{25}$$

For the optimal level of effort, set the right-hand sides of (10) and (22) equal. This gives

$$C_e(r+\epsilon) = \Phi_g + \frac{VU_x^h \alpha R_g}{VU_x^h + (1-V)U_x^l} + (r+\epsilon)P$$
$$= V(1-\alpha)R_g + \frac{VU_x^h \alpha R_g}{VU_x^h + (1-V)U_x^l} - L_e(r+\epsilon) \tag{26}$$

With a risk-neutral agent this reduces to

$$C_e(r+\epsilon) = \Phi_g + VaR_{g+}(r+\epsilon)P = V(1-\alpha)R_g + V\alpha R_g - L_e(r+\epsilon) \tag{27}$$

The case of the risk-neutral agent poses no problem. It is possible to ignore Φ and P and simply rely on royalty payments to provide incentives for the optimal levels of G, Z, e, and I. If agent countries are risk neutral and observing G, Z, e, and I is difficult, then only royalty payments will be observed

$$C_e(r+\epsilon) = \Phi_g + \frac{VU_x^h \alpha R_g}{VU_x^h + (1-V)U_x^l} + (r+\epsilon)P$$
$$= V(1-\alpha)R_g + \frac{VU_x^h \alpha R_g}{VU_x^h + (1-V)U_x^l} - L_e(r+\epsilon) \tag{26}$$

For the risk-averse agent, full insurance and incentive compatibility are both possible only if it is possible to observe G, Z, e, and I, and set $\alpha = 0$, $\Phi_z = V(1-\alpha)R_z$ and $\Phi_g + P(r+\epsilon) = V(1-\alpha)R_g - L_e(r+\epsilon)$. Otherwise the principal faces a trade-off between absorbing the agent's risk and providing an incentive compatible payment mechanism. The simple view of G makes it more observable and makes use of sample fees more likely, and $\Phi(Z)$ rather than $\Phi(G, Z)$ may be observed. Alternatively, one might observe advance payments that are earmarked for investments in G and Z, or in-kind transfers that are inputs into the agent's production process and complementary to his efforts to maintain G and Z (Deere, 1989).

Incomplete property rights

Property rights may be incomplete in a number of ways. If *ex situ* collections, and/or other countries' *in situ* collections of biodiversity and information, are open access, and substitutes for those of the host country, then the marginal values of the host country's stocks, z and g, will be very

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small because the principal's R_z and R_g are very small. There will be little incentive to invest in these stocks. Only endemic stocks of biodiversity and information will be valuable.

Even with endemic biodiversity and information resources, if the host country does not exercise property rights, outside collectors will use the host country's biodiversity as open access, and build up their own information stocks while free-riding on host-country information. With open access biodiversity $\psi = 0$ for the principal, which translates into $z = 0$ for the agent, no investment in biodiversity will be made.

With an open-access information stock the principal will view investments in the agent's information stock as worthless, but will invest in sampling the agent's biodiversity to build up its own stock of information. This will result in $g = 0$ and $C_e = P$ for the agent. With no reason to provide incentives for the agent to build up its G, the principal will set $\Phi_g = 0$, $\alpha = 0$ and $P(r+\epsilon) = VR_g - Le(r+\epsilon)$, regardless of the agent's risk preferences.

Open access means multiple principals, with no one principal having exclusivity with respect to the generation of an information stock. Lack of exclusivity will result in an externality. For example, suppose that there are two principals, x and y, building up their own private stocks of information G^x and G^y, and that neither has any influence on the production process of the other. Then the maximization problem is as stated in (12) and conditions (17), (18), (22) and (23) would apply for each of them. However, if they are forced into open-access competition for information, there may well be some samples collected by both parties, but productive only for the first collector. If there is some pre-ordering of the principals/collectors, the first will impose an externality on the second. In computing its marginal product of sample collection the first principal will ignore the negative externality it imposes; Q_{gx} and VR_{gx} will be too large. The principal will set P too high and sampling efforts will be too large. The second principal will have its marginal product reduced by the externality, it will be willing to pay too little per sample, and sampling efforts will be too small. If there is no pre-ordering, P will be set too high as both principals race to be first. As they impose externalities on each other each principal's maximization problem changes. P will be reduced, eventually to zero.[4]

Under open access, the overall result is that principals have no interest in maintaining the host country's biodiversity, and will race to build up their own information stocks. The only payments they are interested in making are sample fees. They will pay high sample fees initially, but lower samples fee later due to the reduced productivity of samples. The host country receives no return on its biodiversity resource, and the return that it receives for building up the principal's biodiversity will be reduced to zero in the long run.

Patent laws in developed countries exacerbate the problem of inappropriate IPR laws in host counties. Developed countries typically have patent laws that do not protect unmodified genetic sequences or information about them. This reduces the marginal value of host countries' information

[4] See the Appendix for further details.

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and biodiversity stocks, and reduces incentives to invest in these stocks. Host countries not only need legislation to protect their biological resources, but laws that protect the intellectual property contained in these resources, and these laws must be recognized in developed countries and enforced (Lerch, 1998; Walden, 1995).

4. Real contracts

Five types of contracts found to be in current use or proposed for use. These are the INBio-Merck contract, Biotics contracts, Shaman Pharmaceuticals (now Shaman Botanicals) International Cooperative Biodiversity Groups (ICBG) Program agreements, and the Iwokrama International Centre for Rainforest Conservation and Development (Iwokrama) proposed contracts. To some degree, each of the contracts faces incomplete markets and incomplete obervability with respect to the bioprospecting process.

The INBio-Merck contract most closely resembles the model developed in section 3. The National Biodiversity Institute of Costa Rica (INBio) serves as the agent for the country. INBio is a private, non-profit institution, closely tied to the Costa Rican government's Ministry of Environment and Energy (MINAE). MINAE has created and administers a system of conservation areas, containing about 25 per cent of Costa Rica's land area as protected wild-lands. INBio is in the process of making an inventory of Costa Rica's biodiversity and involves local communities in that process. INBio has also entered into a bioprospecting contract with pharmaceutical firm Merck & Co. In this contract INBio agreed to supply samples for pharmaceutical screening over a two-year period in return for one million dollars, technology transfer to develop local sample preparation and screening capabilities, and a share of potential royalties. INBio invests 10 per cent of any payments and half of any royalties into the conservation areas.

Biotics is a private company which plays and intermediary role between pharmaceutical companies and the suppliers of plant samples from developing countries (Laird, 1993; Aylward, 1995). Biotics is an outside collector with a network of in-country suppliers across a range of countries. Some pharmaceutical companies prefer to contract for samples through a collector like Biotics because they can obtain geographically diverse samples. Biotics' contracts with in-country suppliers provide for an initial sample payment of 25 pounds per sample and 50 per cent of any royalties obtained by Biotics. Biotics includes in its contract with the supplier a requirement that a share of the royalties paid to the collector be contributed to development of biodiversity projects in the country. However, there is no mechanism for enforcement of this provision.

Shaman takes the strategy of actively using indigenous ethno-botanical knowledge. It not only collects samples, but also extensive ethno-botanical information regarding their traditional medicinal use. This makes e very difficult to standardize, and Shaman does not pay sample fees. However, it does direct 20 per cent of its field research budget to advance payments, which fund local projects proposed by the local people who are the source of the ethno-botanical knowledge (e.g. clean water systems). Shaman also

invests in building up the local infrastructure for supplying plants. A percentage of royalties was to be distributed among the indigenous people. In addition the Healing Forest Conservancy has been established to conserve *in situ* biological diversity and its indigenous caretakers. Shaman set up the Conservancy because there was no governmental organization through which funds could be directed toward the desired beneficiary group. Governments, it was argued, typically have other priorities for such funds (Moran, 1996).

The ICBG Program was established by four US agencies, the National Institutes of Health (NIH), the National Science Foundation and the US Agency for International Development (USAID). The idea was to build a partnership between science and industry in the United States and the host country. There are currently five projects which cost about $500,000 (Report of a Panel, 1997).

An example of an ICBG project is the Suriname Project. Suriname has no formal institution like INBio. However, it has a formal agreement in which the Conservation International and the Missouri Botanical Garden are to conduct a national biodiversity inventory. A local pharmaceutical company conducts extraction, and initial screening of samples. Bristol Myers Squibb (BMS) Pharmaceuticals has agreed to provide training and equipment to the local pharmaceutical company. Samples are provided to BMS. An agreed upon share of the royalties are to be returned to Suriname. Half of the returned royalties are to go to Suriname University, the Suriname Government, and the local pharmaceutical company. The rest go into the 'Forest People's Fund' for the indigenous people of Suriname. Shamans and other sources of traditional knowledge are eligible to hold joint patent rights with a pharmaceutical partner (Supriatna and Guérin-McManus, 1997).[5]

Suriname is a country that, unlike Costa Rica, does not have the institutional or financial capability to negotiate, honour and enforce contracts on its own behalf. Without the ICBG Program, bioprospecting in Suriname is likely to have followed the Biotics model, with provisions for royalties honoured only when in-country suppliers chose. The ICBG contract has the ethno-botanical aspects of Shaman contracts. Its advance payments and royalty sharing focus primarily on information stocks. A portion of the royalty share is directed specifically toward indigenous people. There are no funds specifically earmarked for the biodiversity protection. This is a reaction to a criticism of INBio's biodiversity protection activities in Costa Rica. INBio's activities occur mainly within conservation areas, while biodiversity loss is occurring elsewhere due to rural poverty (Supriatna and Guérin-McManus, 1997). Providing alternatives to the slash and burn agriculture of the rural poor is seen as a more effective way of reducing biodiversity loss.

Iwokrama was legally extablished in 1996 by the Parliament of Guyana.

[5] Other ICBG projects are located in Peru, Costa Rica, Argentina, Chile, Mexico, Cameroon and Nigeria. Corporate involvement includes the Montsano Company, BMS, Shaman, and American Cyanamid (Report of a Panel of Experts on the International Cooperative Diversity Groups, 1997).

Three hundred and sixty hectares of rainforest were set aside for the purpose of demonstrating the benefits that can be provided by tropical rainforests, without destroying biodiversity (Iwokrama International Centre for Rain Forest Conservation and Development Operational Plan, 1997). The United Nations Development Program, and international development agencies in several countries have contributed funds and technical assistance to support the Iwokrama institutional framework. The most urgent current need of the Iwokrama Centre is to attain further donations to set up the basic infrastructure and to staff the program. It is expected that bioprospecting will become one of a set of income generation activities for Iwokrama.

It is recognized in the Operation Plan that building up an information stock on the pharmaceutical or other commercial potential of its natural biodiversity stock is extremely important for the host institution/country, if it is to obtain a significant share of the benefits from the development of commercial products. Although there are other commercial products (e.g. timber and ecotourism) that will provide some income, Iwokrama is relying on bioprospecting as a source of 'large payments and substantial royalties' to sustain it financially (Iwokrama International Centre for Rain Forest Conservation and Development Business Plan, 1997, 6.24). Iwokrama accepts the ethno-botanical view of the informational stock, and includes in its goals the documentation of ethno-botanical knowledge, and the acknowledgement of the intellectual property rights associated with that knowledge.

The role of Iwokrama as a demonstration project, not only implies that Iwokrama can sustain itself financially and its biodiversity, it also implies that the way in which it does this provides a model for Guyana and other developing, host countries. Iwokrama is considering a plan which involves two contract regimes. In the initial regime Iwokrama would sell licences for prospecting rights, with an advance payment and a small royalty share on discoveries. This would be used while Iwokrama gears up for the second contract regime. Under the second regime Iwokrama would sell samples, with a royalty on discoveries (Business Plan, 1997). While the second regime involves a contract that has similarities with Biotics and the INBio-Merck contracts, the two regime plan is unique. The reason for the two regimes is that Iwokrama needs income quickly, but has not developed the capacity to provide samples. Hence, it cannot immediately obtain income from sample fees. However, as part of a demonstration project the two-regime plan is flawed.

In the economic model presented in section 3, the contract is long-term with services provided and payments made every time period. It is the expectation of future returns, which motivates the principal to provide incentives for the host-country agent to invest in information and natural biodiversity preservation. In Iwokrama's two-regime plan, the proposed first contract is not long term. It ends when the regime changes. The change in regime destroys the exclusivity that one principal in a long-term contract would have. The principal (licensee) in the first contract will not benefit from investments in Z after the expiration of the contact, and will have little incentive to encourage the agent to invest in protecting the

natural biodiversity stock. On the other hand the principal will benefit from whatever information stock it is able to build up during the period of the first contract, but it will over invest in building up its information stock because it will ignore the fact that it will impose externalities on future principals. Their information stocks will be less productive because of the information held by the first principal.

Sample fees, other advance payments and royalties

Biotics and Merck pay sample fees, and there is provision for them in Iwokrama's second contract regime. The use of the sample fee reflects the simpler view of G and e in both the Biotics and Merck contracts. Merck's one millions dollar payment is actually a two part payment. The first part contains an advance on sample fees. The second part can be prorated if the agreed upon samples are not forthcoming. Biotics' sample fee is a straightforward 25 pounds per sample. For Iwokrama the reason for the sample fee in its second contract regime is the continuing need for secure funding. However, the sample fee works best when ethno-botanical information is not a component of Z. In the Iwokrama case ethno-botanical information is important, but it is not clear how the sample fee will provide a return to such information and an incentive for providing it.

Four of the contract types include some form of advance payment. Biotics, the outside collector, is the exception. Merck's advance on sample fees amounts to an advance payment. Shaman's approach of financing locally recommended projects and investing in the local infrastructure for the supply of raw plant material are effectively up-front payments, and the Healing Forest Conservancy is an attempt to invest in biodiversity resources. ICBG's initial investments in the establishment of biodiversity inventories, and shaman apprentice programs for local indigenous groups, are similar examples. Iwokrama has an advance payment in the form of a licence fee in its first contract regime. Since the reason for the first contract is to allow Iwokrama to gear up to sell samples during the second contract regime, it may be expected that that the funds from the licence fee will go toward building up Iwokrama's information stock. However, the first contract regime is of limited duration and the second contract regime includes no advance payment.

All of the contracts examined include payment of royalties. Estimates put the royalty rate that Merck has promised to INBio at about 5 per cent (Laird, 1993, p. 111). In its contracts, Biotics promises to pay the in-country supplier 50 per cent of any royalties it receives (Aylward, 1995). The ICBG and Shaman contracts also include royalties to contributors of any ethno-botanical information that leads to product development.[6] Iwokrama includes a royalty share, and plans to document ethno-botanical information with a view to establishing IPR protection for the suppliers of this information.

[6] Industry averages for royalty rates to collectors range from 1 to 3 of the pharmaceutical company's profits from the drugs developed, although some royalty rates have been much larger than this average (Laird, 1993, p. 112). The range is from zero to 50 per cent.

In general, the supplies of ethno-botanical information have neither been able to prevent pharmaceutical companies from patenting 'innovations' based largely on ethno-botanical knowledge, nor have they been included as patent holders. Even Shaman, which has been praised for its recognition of the ethno-botanical contributions in the drug discovery process, did not attempt to include the providers of this information in its patent applications. The ethno-botanic origins of the drugs patented by Shaman are not ascribed to any named community (RAFI, 1994). This leaves the providers with a weak *ex poste* case for a share of the royalties.[7] IPR protection for the ethno-botanical information will help. One option is a more inclusive patenting process, with ethnobotanic providers included as patent holders. Whether the drug discovery process can be specified clearly enough to allow this is debatable. Alternatively, the host country must exert its property rights prior to the access to bioprospecting information and resources. Advance-payments and sample fees can be used. If a share of royalties is to be part of the package in absence of recognition in the patent, the contract must clearly identify the conditions under which the royalty share will be paid.

Earmarking and in-kind transfers

With the exception of Iwokrama, all contracts with advance payments include in-kind transfers of technology or earmarking provisions for investment in building up the information stock or conserving natural biodiversity. Even Iwokrama's licence fee is likely to be used to develop the host's capacity to provide effective bioprospecting. Technology transfers can be of general benefit to the host or specifically directed toward building up the information stock that contributes to effective bioprospecting. Transfer of technology that is not directly related to an effective biodiversity-prospecting infrastructure includes Shaman's financing of locally recommended projects. Technology transfers, directly related to the effectiveness of bioprospecting include the provision of technical equipment and trained researchers to facilitate the screening process.

Part of Merck's up-front payment is to be used to finance the training of scientists, salaries, and collector expenses, office supplies, computers, administration and overhead costs (Laird, 1993). Merck provided has also provided 'laboratory equipment worth an additional US$130,000' to (Merck, 1993, p. 1). Shaman has also made a commitment to technology transfer programs, such as bringing host country scientists to Shaman's California laboratories, and providing equipment and financial support for research in the host country. ICBG projects have a similar commitment to technology transfer. ICBG training includes long-term education programs, as well as short technical courses and workshops related to biodiversity inventories and science. Equipment for the host country is

[7] Due to prohibitive costs, Shaman Pharmaceuticals has given up its attempt to have its discoveries approved as medicinal drugs. The patents might have been challenged had this not occurred. Shaman continues to pursuing the development of products for the less rigorously regulated herbal dietary supplements market ('Shaman Loses its Magic', 1999).

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provided both by the corporate partner and through government funding. Merck has specifically required in its contractual agreement that 10 per cent of the advanced payment and 50 per cent of all royalties received must be contributed towards conservation efforts. These funds are 'earmarked for support of biological diversity' (Merck, 1993, p. 3).

Shaman and ICGB projects, with their more complex view of information, tend not to distinguish between support for indigenous people and their knowledge and support for conservation. Indigenous people are seen as the stewards of biodiversity, and supporting them is supporting conservation. A panel of experts reviewing ICBG projects has reports that in some host countries, the ICGB pograms have stimulated biodiversity conservation and reduced reliance on deforestation and mining activities (Report of a Panel, 1997).

5. Conclusions

The contracts developed roughly reflect the character of the economic model developed in this paper. All contracts acknowledge risk by providing some form of up-front payment or sample fees. But all of them also have some provision for royalties. This implies that the production process is not fully observable: advance payments and sample fees do not provide sufficient incentives for investment in information and natural biodiversity. The contracts are all second-best approximations in which the principal faces a trade-off between absorbing the agent's risk and providing an incentive compatible payment mechanism. Hence, the contract stipulations, which earmark payments for conservation, or stipulate direct investments by the principal in training, technology development and biodiversity conservation in the host country. Demonstration contracts should recognize this trade-off and be wary of proposing contracts that do not adequately provide both insurance and incentive compatibility. Iwokrama's first contract provides insurance without appropriate incentives. The need for immediate funds can be better dealt with using an advance payment (earmarked for investment in biodiversity and information) within a long-term contract that can also include sample fees and royalties.

The completeness of property rights, and the degree to which the drug discovery process is viewed as ethno-botanical, explain differences among the contracts. Most outside collectors have suppliers in a number of host countries, but are not bound by effective property rights on information or biodiversity in those countries. Although the outside collector's contract with a host-country collaborator may contain a provision for the sharing of royalties, it is unlikely to be enforced.

Current developed country patent laws cannot be relied upon to substitute for effective host-country control over access to its own information and biodiversity stocks. In a world in which patents cover only pharmaceutical company 'innovations', vague royalty provisions are equivalent to incomplete property rights.

When the ethno-botanical view of the information stock is adopted, the difficulties in observing the drug discovery complicate the problem of providing both insurance and incentives. Iwokrams's plans to document

ethno-botanical information may help overcome this difficulty, as may the ICGB's inclusion of the sources of such information as eligible to hold patent rights. However, it will not be easy to link royalty or non-royalty payment mechanisms directly to this input. An alternative is to provide general support (financial or in-kind) that goes toward the preserving the way of life of indigenous groups. Whether such support will build up and sustain the information and biodiversity stocks that lead to successful bioprospecting outcomes is difficult to predict. If is does not, the principal will lack the incentive to continue the support.

The greatest needs are for host countries to build-up and sustain their stocks of information and biodiversity, and to develop the capability to control access to these stocks and negotiate, honour and enforce their own contracts. Costa Rica is the country that has the greatest capability in this area (Simpson and Sedjo, 1994). It has been criticized because there is no provision for participation of indigenous people who live within the biodiversity reserves (RAFI, 1994). While the ethno-botanical view may be the correct one, it makes observing the drug discovery process problematic. As a result it is difficult to structure contracts with the appropriate incentives. The Shaman contracts suffer from the absence of an effective host-country agent. While the Healing Forest Conservancy may have laudable goals, in the end it can only succeed if there is a good working relationship with the host country.

Intermediaries, such as those in the ICBG and Iwokrama demonstration projects, can assist host countries in developing the capability of acting as effective agent. However, it is important that such projects recognize the importance of incentives, as well as insurance in the contracts they propose. Overall, the greatest need is for a fuller understanding and recognition of the bioprospecting production process.

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Appendix

To simplify the analysis, the argument Z is suppressed in the production function for bioprospecting output. Consider G^x and G^y to be private goods in that if G^x is used by x it will not be available for y to use. Similarly, G^y will not be available for x to use. In addition, x's use of G^x does not affect y's productivity in its use of G^y, nor does y's use of G^y affect x's productivity in its use of G^x.

If the two principals x and y are separately producing Q^x and Q^x, then total output would

$$Q = Q^x(G^x) + Q^y(G^y) \tag{A1}$$

The marginal products of G^x and G^y are $Q^x_{gx} > 0$ and $Q^y_{gy} > 0$ respectively.

If there is open access to information, the assumptions change. The collection of a sample by x does not preclude its collection by y (Mendelsohn and Balick, 1995). But, if x is the first in developing and patenting a successful bioprospecting output, that sample becomes less productive for the second principal, y. Total output is not as given in (A1). Instead, the argument in y's production function becomes the productive information collected by y, given x's prior collecting. Let this effective information be $\Gamma^y = \dfrac{(G^y)^2}{G^x + G^y}$, with $\Gamma^y_{gx} < 0$ and $\Gamma^y < G^y$ for all $G^y > 0$. Only if x does no collecting of information will the effective information become G^y. Now total output is (A2).

$$Q = Q^x(G^x) + Q^y\left(\frac{(G^y)^2}{G^y + G^x}\right) \tag{A2}$$

The marginal product of x is now

$$Q_{gx} = Q^x_{gx} + Q^y_{\Gamma y}\left(\frac{-(G^y)^2}{(G^x + G^y)^2}\right) \tag{A3}$$

The first term on the right hand side is x's private marginal product. The second term on the right-hand side is the externality imposed on y by x. Since x ignores the second right-hand-side term, it will over invest in sample collection.

The marginal product of G^y is:

$$Q_{gy} = Q^y_{\Gamma y}\left(\frac{(G^y)^2 + 2G^xG^y}{(G^x + G^y)^2}\right) \tag{A3}$$

The right-hand-side of (A3) is less than Q^y_{gy}, as y's marginal product is reduced by x's collections efforts, and y will under invest in sample collection efforts.

The overall effect of open access to sample information is to speed up sample collection efforts. The first mover will over invest, ignoring the influence of its information collection efforts on the productivity of the second mover's information. The second mover will under-invest because its samples have made less productive. If both x and y are acting on the presumption of being the first mover, then they will each over-invest in sampling initially, but reduce investment in later time periods as each adjusts to the reduction in its marginal product caused by the other's sampling efforts. In the long run there will be no investment.

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