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BIOPROSPECTING AND BIODIVERSITY CONTRACTS

by

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Bioprospecting and Biodiversity Contracts*

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Bioprospecting and Biodiversity Contracts

An economic model for a biodiversity prospecting contract, between a developing country and a pharmaceutical company is developed. The theoretical model is compared with observed contracts and those being developed by biodiversity expects. It is found that these contracts roughly reflect the character of the economic model, although due to asymmetric information and risk aversion, the contracts are often second-best.

I. INTRODUCTION

Bioprospecting refers to the search for new *in situ* sources of chemical compounds, genes, proteins, microorganisms 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. Only recently have the countries containing large amount of biodiversity come to recognize the potential returns that may be lost to them without an institutional mechanism to control access to this resource.

Establishing control over access to *in situ* biodiversity does not guarantee a return. Due to the uncertainties associated with open access *in situ* storage, much material and information has already been extracted, and is now stored *ex situ* in gene banks, laboratories and botanical gardens outside the source countries. There is currently debate over the ownership of the materials in *ex situ* storage (Frisvold and Condon, 1998).[i] The return that can be generated by bioprospecting depends upon the rarity of the particular material or information, including both *in situ* and *ex situ* storage. It also depends upon the relative cost of a bioprospecting discovery. If bioprospecting is to yield a return for a host country, it must be competitive in a world in which combinatorial chemistry and genetic modification can both alter and substitute for the natural source material. [ii] Simpson (1997) has argued that conservationists have overstated the value of biodiversity-prospecting. Either because useful products are very common, or so rare as to be excessively costly to discover, the values are not so large as conservationists had supposed. The implication is that a sensible approach to bioprospecting would be a

systematic one, which uses biological, chemical, medical and indigenous knowledge, to direct bioprospecting activity to the locations where it will generate the greatest value. 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 has been, and will continue to be, drawn upon in the search for new pharmaceutical and other products. It is useful to consider institutional mechanisms to ensure that biodiversity-prospecting rents are not dissipated, and provide incentives for the preservation of biodiversity. Such mechanisms can also be useful for preserving other biodiversity values.

The purpose of this paper is to develop an economic model for a biodiversity-prospecting contract between a host country and a pharmaceutical company. The economic model will be compared with a legal model and contracts that are being observed in this area of emerging property rights. After some background in the next section, the economic theory of a contract (with a risk averse collector) will be discussed in section III. Ecologists, environmentalists and attorneys have been working together to design their own ideal. The contracts observed today are based upon their theory of what a contract should do. Their theory will be presented and compared with economic theory in section IV. This section will discuss any divergences between the two theories.

II 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 are able 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.[iii]

The United Nations Convention on Biological Diversity (CBD), Article 1 (1992) has formalized the recognition that the preservation of environmental resources is intimately linked to the provision of economic incentives for individuals, groups and nations. It has provided support for both the fair and equitable sharing of benefits derived from genetic resources and the recognition of rights over these resources. Combined with internal legislation exercising the host counties property rights, appropriate intellectual property rights (IPR) laws in both the host country and the demand country, and resolution of the status of *ex situ* collections acquired prior to the CBD's entry into force, the biodiversity contract provides a mechanism within which appropriate incentives and an equitable distribution of benefits can occur.[iv] While the details of the contract can vary from country to country, the basic framework will remain.

A related benefit of contract development is reduced transaction costs for future contractual relationships. Significant transaction costs are involved in negotiating contracts between developing country suppliers and corporate demanders. Nongovernmental and governmental organizations have taken on the role of intermediaries in bioprospecting. The intermediary may develop and assess projects, work in collaboration with the indigenous population to extract and export the samples, and/or be responsible for any permits or fees that must be paid to the host country. The intermediary has an increasing expertise that reduces transaction costs, and can be carried over to other types of biodiversity contracts (Biglaiser, 1993).

III. THE ECONOMIC MODEL OF THE CONTRACT

A typical example of a contract is a written agreement between a buyer and a seller. The seller agrees to supply a specific number of goods to the buyer, at an agreed upon date, in exchange for a specific amount of compensation. The quantity of goods, date of exchange, and amount of compensation are legally enforceable aspects of a contract. They are the observable events stated in the contract. If either party reneges on those aspects of the arrangement, the other party may seek legal retribution.

However, there are contracts or aspects thereof that are not enforceable in a court of law. This can occur for two reasons. Either a court of law does not exist or the actions of either party are not verifiable in a court of law. Currently, there is no international environmental court to uphold biodiversity contracts. Either party can renege on the

contract without legal retribution in an international environmental court system. Even if a court did exist, certain aspects of a contract are not enforceable due to asymmetric information. Effort levels of the collector are not legally verifiable, it they are not observable.

Problems that necessitate principal-agent contracts arise when there is imperfect information regarding the actions of one of the parties. Frequently there is an intertemporal aspect to the uncertainty. Payment may be contingent upon the occurrence some future event. That occurrence may be partly affected by one party's imperfectly observable characteristics or actions. If one party has access to information unavailable to the other party, the informed party has the ability to act opportunistically either prior to the signing of the contract (adverse selection) or after (moral hazard). For example, the collector may have access to valuable information regarding its resource supply that it does not reveal to the pharmaceutical company prior to signing the contract. The collector then has information relevant to the outcome that the pharmaceutical company does not, and may use that information strategically. Alternatively, the pharmaceutical company cannot verify the amount of effort exerted by the collector in obtaining the samples. The collector can choose to be lazy after the contract is signed.

Contract theory examines the principal-agent problem that arises when information is asymmetric. This theory defines a principal as "an employer that sets a compensation rule to motivate an agent to choose activities advantageous to the principal" (Parkin and Bade, 1991, p. 423). The agent is the "person hired by a principal

to perform various activities" (Parkin and Bade,1991, p. 423). The principal is affected by the agent's behavior, and must either monitor that behavior, or choose a compensation rule to induce the agent to behave in a particular manner. Since monitoring is often costly, choosing incentive compatible compensation rules is important. The duration of the contract and the likelihood for contract renewal can affect the optimal design of a contract. Short-term contracts that relate to onetime transactions are less likely to encourage high effort levels from the agent than longer-term arrangements. Even in longer-term arrangements, the expectation of contract renewal, or lack thereof, can affect an agent's behavior. If an agent does not expect the terms of the contract to be renewed and/ or renegotiated upon expiration, the agent may exert less effort than he would have if he expected his current performance to affect future arrangements. The risk preferences of the principal and the agent must also be take into consideration in the design of the contract. (Pindyck and Rubinfeld, 1989).

Whether the problem is one of moral hazard, adverse selection, monitoring costs, expectations of contract renewal, aversion to risk, or a combination thereof, an efficient compensation scheme must be designed to induce the desired behavior. An optimal 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. The second condition that must be satisfied is that the agent must agree to the terms of the compensation rule. The agent must 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). In some cases it is not possible to attain the first-best compensation rule because of the constraints of a particular problem. In these cases, the second-best rules must be used.[v]

Consider a relationship between a principal and an agent. The principal, in this case, shall be the pharmaceutical company. The agent is the collector country. Assume risk neutrality for the principal and risk aversion for the agent. The principal is trying to design a contract to offer the agent. The principal has several objectives that she would like to induce the agent to accomplish in order to maximize her discounted profits. First, she wants the agent to supply a specific number and type of samples, *e*, to the principal at price *P*. The principal realizes that the quantity and quality of current and future samples depend upon both the stock of the biological resources (the rainforest ecosystem), and the stock of the genetic information that is available. For this reason, her second objective is to induce the agent to increase the stock of genetic information in the samples he screens. This stock, *G*, is built up as the agent screens and identifies samples. The third objective is to induce the agent to undertake conservation measures, I, in order to ensure that a potential disease-curing sample is not lost due to destruction of the biological stock. This is to say that the principal wants to ensure that a certain level of natural biological stock, *Z*, is maintained.

Assume that 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 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, whereas a is 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.

Let V be the exogenous probability that a product will be developed from a given sample. Experts estimate that the probability of successfully developing a pharmaceutical product from each sample is one in ten thousand (Roberts, 1992). The principal's profits, $R(G,Z)$, are conditional on the development of a product.[vi] The assumption is that the stocks G and Z affect the quality of the product developed and, therefore, the profit.[vii] The agent is risk neutral and therefore is indifferent between payment schemes. He merely wants to maximize his own utility.

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 agent also incurs the costs of investing his resources to conserve the physical stock of samples, the tropical forest. These costs are denoted $K(I)$. It is assumed that $Ce>0$, $K_I>0$,[viii]

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*. 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*, *L* and *E* denote the income level associated with high, low, and expected payoff levels respectively. Let $U_x^E=1$ be the marginal utility from the expected income, Then the marginal utility associated with the income received when the agent receives a higher payoff is $U_x^H<1$, and the marginal utility associated with the income received when the agent receives a low payoff is $U_x^L>1$.

The agent maximizes:

$$\begin{aligned} MaxA = {} & VU^H\left[a+\Phi(G,Z)+e\alpha R(G,Z)+Pe-C(e)-K(I)\right] \\ & +(1-V)U^L\left[a+\Phi(G,Z)+Pe-C(e)-K(I)\right] \\ & +z\left[-\delta Z+I\right]+g\left[-\varepsilon G+e\right] \end{aligned} \tag{1}$$

such that :

$$\begin{aligned} & \mathrm{VU}U^H\left[a+\Phi(G,Z)+e\alpha R(G,Z)+Pe-C(e)-K(I)\right] \\ & +(1-V)U^L\left[a+\Phi(G,Z)+Pe-C(e)-K(I)\right]\geq U_o \end{aligned}$$

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

$$\frac{\partial A}{\partial I} = -VU_x^H K_I - (1-V)U_x^L K_I + z = 0 \quad (2)$$

$$\frac{\partial A}{\partial e} = VU_x^H \left[\alpha R(G,Z) + P - C_e\right] - (1-V)U_x^L (P - C_e) + g = 0 \quad (3)$$

Rearranging (2) equation (4) is obtained. It says that for the last unit of I, the marginal benefit equals the marginal cost in equilibrium.

$$z = \left[VU_x^H + (1-V)U_x^L\right]K_I \quad (4)$$

For a risk neutral agent (4) would have been $z = K_I$.

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

$$\left[C_e - P\right]\left[VU_x^H + (1-V)U_x^L\right] - VU_x^H\left[\alpha R(G,Z)\right] = g \quad (5)$$

With a risk neutral agent (5) would reduce to C_e –P- $V\alpha R$ (G, Z) = g.

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

$$\frac{\partial A}{\partial G} = \left[VU_x^H + (1-V)U_x^H\right]\Phi_G + VU_x^H e\alpha R_G - \varepsilon g = -\dot{g} + rg \quad (6)$$

$$\frac{\partial A}{\partial Z} = \left[VU_x^H + (1-V)U_x^H\right]\Phi_Z + VU_x^H e\alpha R_Z - \delta z = -\dot{z} + rz \quad (7)$$

The comparable conditions for a risk neutral agent are:

$$\Phi_G + VU_x^H e\alpha R_G - \varepsilon g = -\dot{g} + rg \quad (8)$$

$$\Phi_Z + VU_x^H e\alpha RZ - \delta z = -\dot{z} + rz \quad (9)$$

Assuming the steady state, one can solve for the agent's choice of I. From the agent's model, solving (4) for z and substituting this value into (7) gives:

$$K_I(r+\delta) = \Phi_Z + \frac{VU_x^H e\alpha R_Z}{VU_x^H + (1-V)U_x^L} \quad (10)$$

For the risk neutral agent (10) would have been:

$$K_I(r+\delta) = \Phi_Z + Ve\alpha R_Z \tag{11}$$

From $U_x>0$ and $-U_{xx}>0$, it follows that $U_x^L>U_x^H$ and that $U_x^L/U_x^H>1$. Hence, $U_x^H/[V\,U_x^{H\,H}/[V\,U_x^H+(1-V)U_x^L=1/[V+(1-V)(U_x^L/U_x^H)]$ in (10), must be less than 1 implying that the risk averse agent will invest less than the risk neutral agent.

Simiarily, assuming a steady state, the agent's choice of *e* can be derived. From the agent's model, substitute (3) into (6) to obtain:

$$C_e(r+\varepsilon) = \Phi_G + \frac{VU_x^H e\alpha R_G}{VU_x^H + (1-V)U_x^L} + (r+\varepsilon)\left[P + \frac{VU_x^H \alpha R(G,Z)}{VU_x^H + (1-V)U_x^L}\right] \tag{12}$$

With a risk neutral agent (12) would have been reduced to:

$$C_e(r+\varepsilon) = \Phi_G + Ve\alpha R_G + (r+\varepsilon)\left[P + V\alpha R(G,Z)\right] \tag{13}$$

As the right hand side of (13) is smaller than the right hand side of (12), the risk averse agent exerts less effort than the risk neutral agent.

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 must choose the incentive scheme such that those conditions are satisfied. However, the incentive compatibility constraint need not be binding. Assuming these constraints are non-binding, their

multipliers are zero, and they can be ignored in the principal's first order conditions.

In the case of the principal it is the participation constraint of the agent that 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. The principal must provide a payment scheme such that the reservation level of utility is achieved. In order to do this, she must take into account the agent's preferences for risk. The principal's problem, given a risk averse agent, becomes:

$$\begin{aligned} MaxQ = {} & Ve(1-\alpha)R(G,Z) - a - \Phi(G,Z) - Pe \\ & \theta\left\{\begin{array}{l} \mathrm{VU^H}\left[\mathrm{a} + \Phi(\mathrm{G},\mathrm{Z}) + \mathrm{Pe} + \mathrm{e}\alpha\mathrm{R}(\mathrm{G},\mathrm{Z}) - \mathrm{C(e)} - \mathrm{K(I)}\right] \\ + (1-\mathrm{V})\mathrm{U^L}\left[\mathrm{a} + \Phi(\mathrm{G},\mathrm{Z}) + \mathrm{Pe} - \mathrm{C(e)} - \mathrm{K(I)}\right] - \mathrm{U_o} \end{array}\right\} \\ & + \gamma_I\left[VU_x^H K_I + (1-V)U_x^L K_I - z\right] \\ & + \gamma_e\left\{VU_x^H\left[\alpha R(G,Z) - (P - C_e)\right] - (1-V)U_x^H(P - C_e) - g\right\} \\ & + \gamma_{\mathrm{G}}\left[VU_x^H(\Phi_G + e\alpha R_G) + (1-V)U_x^L\Phi_G - (r+\varepsilon)g + \dot{g}\right] \\ & + \gamma_Z\left[VU_x^H(\Phi_Z + e\alpha R_Z) + (1-V)U_x^L\Phi_Z - (r+\delta)z + \dot{z}\right] \\ & + \eta\left[-\varepsilon G + e\right] + \psi\left[-\delta Z + I\right] \end{aligned} \tag{14}$$

With γ_I, γ_e, γ_G, and γ_Z equal to zero, the principal's first order conditions are:

$$\frac{\partial Q}{\partial a} = -1 + \theta\left[VU_x^H + (1-V)U_x^L\right] = 0 \tag{15}$$

$$\frac{\partial Q}{\partial I} = -\theta\left[VU_z^H + (1-V)U_z^L\right]K_I + \psi = 0 \tag{16}$$

$$\begin{aligned} \frac{\partial Q}{\partial e} = {} & V(1-\alpha)R(G,Z) - P \\ & + \theta\left\{\left[VU_z^H + (1-V)U_z^L\right](P - C_e) + VU_z^H\alpha R(G,Z))\right\} + \eta = 0 \end{aligned} \tag{17}$$

In the agent's problem the multiplier of the participation constraint equaled zero, whereas for the principal the multiplier, $\theta=1/[VU_x^H+(1- V)U_x^L]$, is greater than zero. Substituting (15) into (16) and (17) simplifies them to (18) and (19) respectively.

$$K_I = \psi \tag{18}$$

$$C_e - V(1-\alpha)R(G,Z) - \frac{VU_x^H \alpha R(G,Z)}{VU_x^H + (1-V)U_x^L} = \eta \tag{19}$$

The adjoint equations are:

$$Ve(1-\alpha)R_G + \frac{VU_x^H e\alpha R_G}{VU_x^H + (1-V)U_x^L} - \varepsilon g = \dot{\eta} + r\eta \tag{20}$$

$$Ve(1-\alpha)R_Z + \frac{VU_x^H e\alpha R_Z}{VU_x^H + (1-V)U_x^L} - \delta z = \dot{\psi} + r\psi \tag{21}$$

Assuming the steady state, one can solve for the conditions that determine the principal's choices of *I* and *e*. From (18) and (21), (22) can be derived.

$$K_I(r+\delta) = Ve(1-\alpha)R_Z + \frac{VU_x^H e\alpha R_z}{VU_x^H + (1-V)U_x^L} \tag{22}$$

With a risk neutral agent this would reduce to (23)

$$K_I(r+\delta) = Ve(1-\alpha)R_Z + Ve\alpha R_Z \tag{23}$$

Equation (22) implies a lower investment level than does (23).

From (19) and (20) the principal's choice of *e* is determined by:

$$C_e(r+\varepsilon) = Ve(1-\alpha)R_G + \frac{VU_x^H e\alpha R_G}{VU_x^H + (1-V)U_x^L} + (r+\varepsilon)\left[V(1-\alpha)R(G,Z) + \frac{VU_x^H \alpha R(G,Z)}{VU_x^H + (1-V)U_x^L}\right] \quad (24)$$

With a risk neutral agent (24) becomes (25).

$$C_e(r+\varepsilon) = VeR_G + (r+\varepsilon)VR(G,Z) \quad (25)$$

With a smaller right hand side, equation (24 implies a lower effort than does (25).

The Optimal Levels Investment and Effort

Now consider the optimal levels for investment and effort. In order to obtain the optimal level of investment, the principal must ensure that, at the principal's optimal effort level, the agent sees the same marginal benefit from his effort as does the principal. In addition any risk must be efficiently allocated. Begin by setting the right hand sides of (10) and (22) equal.

$$K_I(r+\delta) = \Phi_Z + \frac{VU_x^H e\alpha R_Z}{VU_x^H + (1-V)U_x^L} = \mathrm{Ve}(1-\alpha)\mathrm{R}_Z + \frac{VU_x^H e\alpha R_Z}{VU_x^H + (1-V)U_x^L} \quad (26)$$

If the agent is risk neutral (26) will become:

$$K_I(r+\delta) = \Phi_z + Ve\alpha R_Z = Ve(1-\alpha)R_Z + Ve\alpha R_z \quad (27)$$

If the agent is risk neutral, and it is possible to set $\Phi(G, Z)$ such that $\Phi_z = VeR_z$ then the principal has many payment options which would yield the optimal level of investment. Even if it is not possible to set $\Phi(G, Z)$ such that $\Phi_z = VeR_z$, it is still possible to obtain the optimal level of effort by setting $\alpha = 1$.

However, if the agent is risk averse, the principal must insure the agent against the risk associated with the royalty payment and provide incentive compatible payment mechanisms for the agent. The principal can insure the agent by setting $\alpha=0$, and using the up-front payment option $\Phi(G, Z)$ to provide incentives by setting $\Phi_z = VeR_z$. However, this implies that $VeR(G, Z)$ and VeR_z must be estimable. It must be possible to observe how expected net revenue varies with Z and G.

Now consider the optimal level of effort. Set the right hand sides of (12) and (24) equal. This gives:

$$C_e(r+\varepsilon) = \Phi_G + \frac{VU_x^H e\alpha R_G}{VU_x^H + (1-V)U_x^L} + (r+\varepsilon)\left[P + \frac{VU_x^H \alpha R(G,Z)}{VU_x^H + (1-V)U_x^L}\right] \tag{28}$$

$$= Ve(1-\alpha)R_G + \frac{VU_x^H e\alpha R_G}{VU_x^H + (1-V)U_x^L}$$

$$+ (r+\varepsilon)\left[V(1-\alpha)R(G,Z) + \frac{VU_x^H \alpha R(G,Z)}{VU_x^H + (1-V)U_x^L}\right]$$

With a risk neutral agent this reduces to:

$$\Phi_G + Ve\alpha R_G + (r+\varepsilon)\left[P + V\alpha R(G,Z)\right] = \tag{29}$$
$$Ve(1-\alpha)R_G + Ve\alpha R_G + (r+\varepsilon)\left[V(1-\alpha)R(G,Z) + V\alpha R(G,Z)\right]$$

For a risk neutral agent, there are number of possible payment options the principal can. If $\alpha=0$, there is no royalty, the up-front payment, $\Phi(G, Z)$, and the sample price, P, must be chosen so that $\Phi_G+(r+\varepsilon)P= VeR_G+(r+\varepsilon)VR(G, Z)$. If $\alpha=1$, then $\Phi_G+(r+\varepsilon)P=0$. There is no up-front incentive payment or per sample payment. If $0<\alpha<1$, there will be an up-front incentive payment, a per sample payment, and a royalty. But, given the option of using only the royalty payment, it is straightforward to provide the incentive for the optimal level of effort.

As Figure 1 shows, this result is quite different if the agent is risk averse. Assuming $0<\alpha<1$, let the intercept of the risk neutral and risk averse agent's marginal benefit curves be A and A'. Let the slopes be B and B' respectively. Let the intercept and slope terms for the principal's marginal benefit curves be Γ and β with and risk neutral agent and Γ' and β' with a risk averse agent. Finally let A'' be the optimal marginal benefit level. When risk is introduced, both the principal and the agent's marginal benefit curves are affected in two ways. For both parties, the slope term and the intercept term are smaller in the risk averse case than in the risk neutral case. The reason for this change can be understood by examining the principal and the agent separately. For the risk averse agent, the marginal value of the conditional future payments will be smaller because the royalty payment is not guaranteed. The uncertainty associated with the royalty will reduce its marginal value to the agent.

[Figure 1 about here]

The marginal benefit of the principal is reduced by the risk averse agent. Her profit function is dependent upon the utility that the agent receives and the action that he chooses to take accordingly. A smaller exertion of effort will yield a smaller amount of genetic information learned, *G*. The principal's profits are dependent, by definition, upon the quantity of genetic information available. Since the level of *G* will be smaller in the risk averse case, the principal's profits will subsequently be smaller than they would be if the agent was risk neutral.

With a risk averse agent and a risk neutral principal, the principal can absorb the agent's risk by setting $\alpha = 0$, and putting all of the payment to the agent into a combination of the up-front incentive component, $\Phi(G, Z)$, and the per sample component, *P*, such that $\Phi_G+(r+e)P=VeR_G+(r+\varepsilon)VR(G, Z)$. If $R(G, Z)$ and its determinants are observed by the principal, this will be the most efficient method of payment. The fact that $\Phi(G, Z)$ is adjusted as Z and G vary gives the necessary incentives for the agent's effort, e^*, and investment, I^*. If *P* is not fixed through time, but varies according to expected revenue, additional flexibility in the payment structure is provided.

Past revenue and effort are likely observable. However, if the levels of *G* and *Z* are not observable, it will be more difficult to set $\Phi(G, Z)$ at the correct level. Recall that the optimal level of effort and the optimal level of investment must be achieved simultaneously. For this reason, the principal is not able to use the per sample payment alone, as this would not achieve the optimal level of investment. When $\alpha = 0$ in the

payment condition for the optimal level of investment for both a risk averse and a risk neutral agent, $\Phi_Z = VeR_Z$. VeR_Z is the marginal expected profit from the last unit of Z. V is a probability which may be estimated from past experience. However, the marginal profit, $e\ R_Z$, occurs only if a product is successfully developed. It may not be possible to estimate this correctly and provide the appropriate incentive effects. If this cannot be accomplished, and $\Phi(G, Z)$ is treated simply as a fixed, up-front payment (like *a),* then the principal faces a tradeoff between absorbing the agent's risk and providing an incentive compatible payment mechanism.[ix]

IV. THE LEGAL MODEL

Environmentalists and attorneys have established a general framework of the concessions that should be included in the agreement. This framework is referred to as the Legal Model. Table 1 compares the compensation forms provided for in the economic model and the legal model. Some differences can be attributed to variations in definitions, while some are real divergences between the two models. The legal model provides for several types of remuneration, both monetary and nonmonetary. These include advance fees, per sample fees, royalties, and technology transfers. According to the legal model, all types of compensation should be specified in the original contract. But, not all types of compensation need be paid in any particular case. This is also true for the economic model.

Table 2 shows four types of contracts found to be in current use. These are the INBio/Merck contract, Biotics contracts, Shaman Pharmaceuticals contracts, and agreements supported by the International Cooperative Biodiversity Groups (ICBG) Program.

[Table 1 about here]

[Table 2 about here]

In the case of the INBio/Merck contract, the National Biodiversity Institute of Costa Rica (INBio) serves as the agent for the country. INBio is a private, nonprofit 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 twenty-five percent of Costa Rica's land area as protected wild-lands. INBio is in the process of inventorying Costa Rica's biodiversity and involves local communities in that process. INBio as 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, a share of potential royalties, and technology transfer to develop local sample preparation and screening capabilities. INBio invests ten percent of any payments and half of any royalties into the Conservation Areas.

Biotics Ltd. is a private company which plays and intermediary role between pharmaceutical companies and the suppliers of plant samples from developing countries. Its bioprospecting activities with were initially funded through the European

Community's initiative on biotechnology (Aylward, 1995). Suppliers receive an initial payment of twenty-five pounds and fifty percent of any royalties obtained by Biotics. Biotics attempts to include in the contract a requirement that a share of the royalties paid to the collector be contributed to development or biodiversity projects in the country. Buyers are granted a six-month or longer periods of exclusivity, which sellers must honor.

With the aim of a more profitable discoveries, Shaman Pharmaceuticals has taken the strategy of actively using indigenous ethnobotanical knowledge. Shaman devotes twenty percent of its field research budget to financing local projects proposed by the local people (e.g. clean water systems). Shaman also invests in building up the local infrastructure for supplying plants. A percentage of royalties is to be distributed among the indigenous people.

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 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 other half 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 (Conservation International, 1997).[x]

Advance Payments

Both the legal and the economic models provide for advance payments. The legal model calls for an advanced payment "to initiate the agreed-upon work-plan"(Downes*, et. al.,* 1993, p. 260). It specifies that the advanced payment should be used to cover operation and conservation costs (Laird, 1993). This coincides with the economic model. A slight variation on the specification of the economic model would allow the up-front payment to include expected sample fees, with an adjustment after actual effort is observed. Let the up-front payment be $[a+Pe^*+\Phi(G, Z)]$, where $(a+ Pe^*)$, is the portion of the advanced payment that could be used to cover operation costs. This includes a fixed payment, a, plus the price for the expected level of effort, Pe^*. The second part of the advanced payment, $\Phi(G, Z)$, is the portion which could be used to cover conservation costs. If $\Phi(G, Z)$ is a function with $\Phi_Z > 0$, $\Phi_G > 0$, $\Phi_{ZZ} < 0$, and $\Phi_{GG} < 0$, the less

established the collector and the more threatened the natural resources, the smaller is $\Phi(G, Z)$ but the more it will increase with increases in G and Z. The payment for actual observed effort would be $P(e-e^*)$.

Advanced payments ensure collectors of reimbursement, regardless of whether a successful discovery results, removing the risk to the collecting country by providing income security to the collectors. According to Rubin and Fish (1994), this security will facilitate validation of the potential of the biodiversity industry to the source country's government, and provide an incentive to improve the regulation of its natural resources.

Three of the contract types include an up-front payment, with some provision for investment in conservation efforts. Biotics is the exception. Shaman's approach of financing locally recommended projects and investing in building up the local infrastructure for the supply of raw plant material are effectively up-front payments of this type. ICBG's initial investments in the establishment of biodiversity inventories, and shaman apprentice programs for local indigenous groups, are similar examples.

Merck & Co. Inc. has committed to a more than one million-dollar payment that provides for sample fees plus financial assistance to improve the collection facility and conservation measures. They describe it as a payment to "help to get the operation moving" (Albers-Schönberg, 1992, p.11). The remuneration is disbursed in two payments; the first is given at the beginning of the agreement, prior to any collection, and the second is given one year from the signing of the agreement. The structure of the first

payment is the same as the advance payment of both models, where $a = A - Pe^*$ is the portion to improve the collection facility, and $\Phi(G,Z)$ is to improve conservation measures.

It should be noted that the portion of the payment that is directed toward conservation is connected to inputs to build up G and Z, rather than being based on observation of G and Z. This may simply reflect the fact that G and Z are not accurately observable. The economic model acknowledged that $\Phi(G,Z)$ may be set equal to zero when G and Z are not observable. An alternative approach in that case is to designate a portion of the fixed payment to be earmarked for conservation programs in the host country. The payment is connected to the input, investment, since that can be observed. While this approach does not provide the same incentives as does $\Phi(G,Z)$, it may be useful in the absence of sufficient information to specify $\Phi(G,Z)$.

There is a view that nothing beyond expected sample fees would be included in the advance payment. According to researchers at BMS, it seems unlikely that many companies would even consider making a heavy financial investment beyond the sample fees (Laird, 1993). This is a natural reaction if little information is available about G and Z, and if there are no easy ways to direct the up-front payment toward investments in G and Z. However, intermediaries can assist in providing information about G and Z. INBio was created by a small group of entomologists who had discovered the wealth of information located in the tropical forests of Costa Rica. Initially, their goals were to conserve and catalogue all of the genetic resources located in the developing country. The

entomologists approached Merck to request a grant to fund their project. Merck had been unaware of the magnitude of genetic information located in Costa Rica's forests until the entomologists informed them of their findings. This may also explain the roll of the US Government funded ICBG Program. ICBG has taken the role of the intermediary in its projects, making the up-front payment, and investing in G and Z. This makes companies like BMS more willing to participate.

Sample Fees

Both the legal and economic models call for per sample fees to be paid to the agent by the principal. In the legal model, the payment of sample fees occurs via an annual payment. If the advance payment included the expected sample fees, *Pe**. then the sample fee payment is *P(e-e*)*. This payment is merely the balance due on the samples received. It reflects the difference between the actual and the expected effort levels. It will be positive if the agent exerted more effort than was expected, and it will be negative (a refund to the principal) if the agent's effort was inadequate.

Biotics and Merck pay sample fees. Biotics' sample is a straightforward twenty-five pounds per sample. As reported above, Merck & Co. Inc. has committed to a two-part payment includes sample fees. The second part of the payment is the same as the sample fee of both models. This is the payment P(e-e*), which is dependant upon the observed efforts of the collector.

Royalties to the Collector and/or the Royalties for the Information Provider

Both the economic and the legal model provide for royalty payments to be paid to the collecting group should a product be developed from one of the samples that the collector provided. The legal model suggests that the value of the royalty should be based upon the preferences of the parties involved and the degree of contribution to the final product. It also acknowledges that an inverse relationship typically exists between the royalty rate and the other payments (Laird, 1993). In the economic model, the royalty payment was denoted $Ve \alpha R(G,Z)$. The agent's level of effort, *e*, or degree of contribution to the final product, is included in this royalty payment. Lower levels of *e* will yield lower royalty payments, and conversely, higher levels of e will yield higher royalty payments.

According to the legal model, there is another type of royalty rate that should be included in the biodiversity-prospecting contract. This is a payment made to the contributors of any ethnobotanical information that may have led to the product development. In the economic model, the provider of botanical samples and ethnobotanical information are defined to be one agent performing both functions. This can be viewed as the effort variable being composed of two parts, the ethnobotanical information and the actual samples. Samples are not valuable unless there is ethnobotanical information. This is incorporated this by having effort contribute to the stock of information, G. If a payment per sample is used as part of the payment structure, that payment will be set according to the expected revenue generated from the sample, which is itself related to G.

All of the contracts examined include payment of royalties. Estimates put the royalty rate that Merck has promised to INBio between one and five percent (Roberts, 1992). In its contracts, Biotics promises to pay the collector fifty percent of any royalties it receives (Aylward, 1995). ICBG projects have an agreed upon share of royalties to the collector, as well as a provision for patents rights to be shared with sources of indigenous knowledge.[xi] Shaman Pharmaceuticals has committed to pay royalties to collectors as well as supplies of indigenous knowledge, making little distinction between the two. [xii]

Technology Transfer

The legal model provides for technology transfer. Such provisions serve to permanently enhance the knowledge base and advance the technological development of the developing country. The developing economy will benefit overall from a better educated, and potentially more productive, population. Technology transfer can also be focussed on the bioprospecting sector, with the aim of producing higher quality samples, better genetic information about the samples, and greater supply security.

While technology transfer is not directly addressed in the economic model, the advance payment, $a+\Phi(G, Z)$, could include a contribution toward technology transfer. Transfer of technology not related to an effective biodiversity-prospecting infrastructure would appear in a (e.g. Shaman's financing of locally recommended projects). Technology transfer directly related to the quality of the bioprospecting product would appear in $\Phi(G,Z)$. This could involve the provision of technical equipment and trained

researchers to facilitate the screening process. This type of technology transfer is a way of ensuring that investments in Z and G occur.

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 provided both by the corporate partner and through government funding. Biotics merely attempts negotiate contracts which have a share of the royalties going toward development in the source country (Aylward, 1995).

Conservation Measures

The final form of compensation prescribed by the legal model is the requirement the contribution to national or in-country conservation programs (Downes, *et. al.,* 1993, p. 268-270). All of the contracts examined have specifically referred to conservation measures in their agreements with the source countries. Biotics, attempts to include a provision in the contract with the collector which stipulates a share of the royalties go to

“development in the host country or its biodiversity related projects” (Aylward, 1995, p, 116). Shaman promises to contribute a percentage of all of their profits to the Healing Forest Conservancy (Blum, 1993, p. 42-43). Merck has specifically required in its contractual agreement that ten percent of the advanced payment and fifty percent of all royalties received must be contributed towards conservation efforts. These funds are "earmarked for support of biological diversity" (Merck Handout, 1993, p. 3). In the case of ICBG, a panel of experts reviewing ICBG projects has reports that in some host countries, the ICBG programs have stimulated biodiversity conservation and reduced reliance on deforestation and mining activities (Report of a Special Panel of Experts on the International Cooperative Biodiversity Groups, 1997).

With respect to the economic model, the designation of funds toward conservation is inherent in the payments $\Phi(G,Z)$, and $Ve\alpha R(G,Z)$. If the contract is a long term one, there is a built in incentive for both parties to ensure that the natural biological stock is not eliminated, and hence, secure the future supply of samples. However, most contracts, specify that portions of the royalties and the up-front payment are to be allocated to conservation. With the up-front payment, $\Phi(G, Z)$, this may simply reflect the fact that G and Z are not accurately observable Z are not observable. The payment is connected to the input, investment, since that can be observed.

Given that the net revenue from a successful discovery is directly related to the magnitude of G and Z, the economic model states that the royalty payment itself will provide an incentive to invest in G and Z. However, with a risk averse agent the level of

investment will be too low. Hence, there may be a reason for the principal to explicitly regulate the level of investment in G and Z.

Conclusions

Considerable work has gone into the development of biodiversity contracts. The contracts developed roughly reflect the character of the economic model developed in this paper. Although it is quite likely that host counties are risk averse, and most contracts acknowledge this by providing some form of up-front payment, the contracts all include some provision for royalties. This implies that the contracts are second-best approximations in which the principal faces a tradeoff between absorbing the agent's risk and providing an incentive compatible payment mechanism. Hence, the need for contract stipulations that earmark payments for conservation, or for the principal to make direct investments in training and technology development in the host country.

There are intermediaries involved in at lest some of these contracts. In some cases, such as those of INBio and the ICBG projects, the intermediary has played a large role in establishing the contract. Whether or not bioprospecting values constitute a large part of the value of biodiversity, the development of such contracts provides a model and reduces transaction costs for future contractual arrangements to conserve biodiversity.

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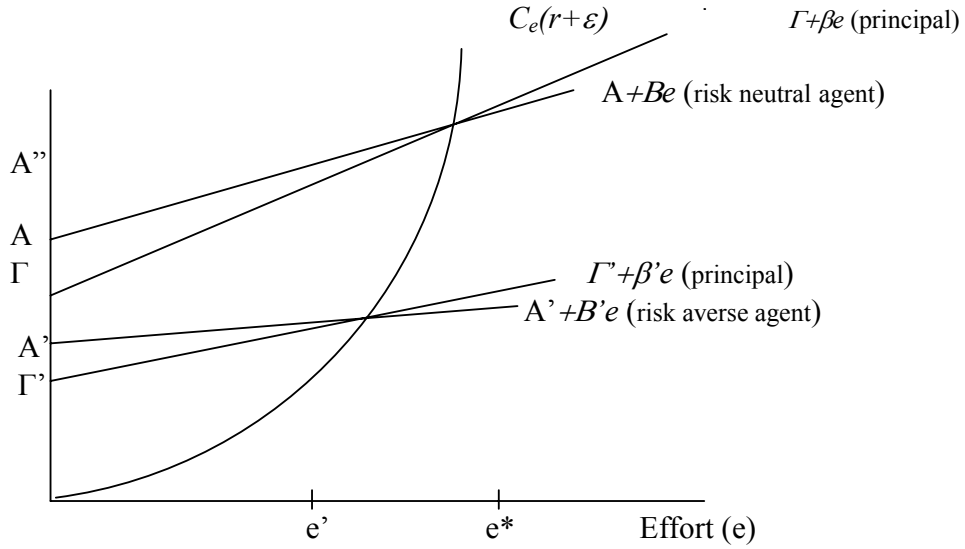
Figure 1: Level of Effort



$$A = \Phi_G + (r+\varepsilon)\left[P + V\alpha R(G,Z)\right], \qquad B = V\alpha\alpha_G ,$$

$$\mathrm{A}' = \Phi_{\mathrm{G}} + (r+\varepsilon)\left[P + \frac{VU_x^H \alpha R(G,Z)}{VU_x^H + (1-V)_x^L}\right], \; B' = \frac{VU_x^H \alpha R_G}{VU_x^H + (1-V)_x^L} ,$$

$$\Gamma = (r+\varepsilon)VR(G,Z), \qquad \beta = VR_G ,$$

$$\Gamma' = (r+\varepsilon)\left[V(1-\alpha)R(G,Z) + \frac{VU_x^H \alpha R(G,Z)}{VU_x^H + (1-V)_x^L}\right] ,$$

$$\beta' = V(1-\alpha)R_G + \frac{VU_x^H \alpha R_G}{VU_x^H + (1-V)_x^L} ,$$

$$A'' = \Phi_G + (r+\varepsilon)P = VeR_G + (r+\varepsilon)VR(G,Z)$$

Table 1: Types of Compensation Payments

Compensation Form	Economic Model	Legal Model
Advanced Payment	Yes	Yes
Sample Fees	Yes	Yes
Royalties (for Collectors)	Yes	Yes
Royalties (for Shaman)#	No	Yes
Technology Transfer	Yes	Yes
Contributions for Conservation Measures	Yes	Yes

Table 2 : Four Contracts

Compensation	INBio/Merck	Biotics	Shaman	ICGB/ Suriname
Parties	INBio, MINAE, Merck	Various	Various	CI, MBG, BMS
Advance Payments	Monetary	No	Financing local projects	Inventory of Biodiversity
Sample Fees	Yes	Yes	No	No
Royalties to Collectors	Yes	Yes	Yes	Yes
Royalties for information	No	No	Yes	Yes
Technology Transfer	Yes	No	Yes	Yes
Funds for Conservation	Yes	Maybe	Yes	Yes

APPENDIX: A MODEL OF STOCHASTIC OPTIMAL CONTROL

The previous sections used essentially a Tobit model of expected revenue, with the conditional revenue being deterministic with deterministic stock variable arguments, *R(G, Z)*. This section models revenue as itself being a stock variable, but one which has a stochastic component. *R* is assumed to be related to the stock variables Z and G, and the decay rates of G and *Z*, in a very simple way *R*=*G*+*Z*. Formally, let the accumulation equation for *R* be:

$$\dot{R} = -(\varepsilon + r)R + I + e + \sigma(R)\dot{W} \qquad \text{(A1)}$$

Where W is Brownian motion, and the revenue increment has an expected mean of *[-(ε+δ)R+I +e]* and a standard deviation of *σ(R)*. The investor is assumed to have information on the past values of *R*, *[-(ε+δ)R+I +e]*, and *σ(R)*, knowing not only the expected revenue, but also the expected mean and standard deviation of revenue increments consecutive to any decision she makes. Following the approach of Bismut (1975), the agent maximizes:

$$MaxA = a + \Phi(R) + e\alpha R + Pe = C(e) - K(I) + He\alpha\sigma(R) + \rho\left[-(\varepsilon + \delta)R + I + e\right]$$
such that
$$a + \Phi(R) + e\alpha R + Pe - C(e) - K(I) + He\alpha\sigma(R) \geq U_o \qquad \text{(A2)}$$

H is negative representing risk aversion. The standard deviation *σ(R)* has positive first partial derivatives. With the shadow price for the participation constraint equal to zero, the maximum conditions are:

$$P - C_e - \alpha R + \rho + H\alpha\sigma(R) = 0 \quad \text{(A3)}$$

$$- K_I + \rho = 0 \quad \text{(A4)}$$

The adjoint equation is:

$$\Phi_R + \alpha e - \rho(\varepsilon + \delta) + H\alpha e\sigma_R - H\dot{W} = -\dot{\rho} + r\rho \quad \text{(A5)}$$

Assuming a steady state for *G* and *Z*, assumes a steady state for R. With a steady state, substituting (A4) into (A5) yields the agent's marginal cost equals marginal benefit condition for I:

$$K_I(r + \delta + \varepsilon) = \alpha e + \Phi_R + H\alpha e\sigma_R \quad \text{(A6)}$$

Similarly, substituting (A3) into (A5) yields the agent's marginal cost equals marginal benefit condition for e.

$$C_e(r + \delta + \varepsilon) = \left[P + \alpha R + H\alpha\sigma(R)\right]\left[r + \delta + \varepsilon\right] + \left[\alpha e + \Phi_R + H\alpha e\sigma_R\right] \quad \text{(A7)}$$

With the participation constraints not binding, the principal's problem is to maximize:

$$\begin{aligned} MaxQ = {} & e(1-\alpha)R - a - \Phi(R) - Pe \\ & + \omega\left[a + \Phi(R) + Pe + \alpha eR - C(e) - K(I) + H\alpha e\sigma(R) - U_o\right] \\ & + \vartheta\left[-(\varepsilon + \delta)\mathrm{R} + \mathrm{I} + \mathrm{e}\right] \end{aligned} \quad \text{(A8)}$$

The maximum conditions are:

$$R - C_e + H\alpha\sigma(R) + \vartheta = 0 \quad \text{(A9)}$$

$$- K_i + \vartheta = 0 \quad \text{(A10)}$$

The adjoint equation is:

$$e - \vartheta(\varepsilon + \delta) + H\alpha e\sigma_R = -\dot{\vartheta} + r\vartheta \qquad \text{(A11)}$$

Assuming a steady state the principal's marginal cost equals marginal benefit equations for *I* and *e* are:

$$K_I(\varepsilon + \delta + r) = e + H\alpha e\sigma_R \qquad \text{(A12)}$$
$$C_e(\varepsilon + \delta + r) = [R + H\alpha\sigma(R)][\varepsilon + \delta + r] + e + H\alpha e\sigma_R \qquad \text{(A13)}$$

For the agent to invest optimally the right hand sides of (A6) and (A12) must be equal at the optimal level of investment.

$$\alpha E + \Phi_R + H\alpha e\sigma_R = E + H\alpha e\sigma_R \qquad \text{(A14)}$$

For the optimal level of effort, the right hand sides of (A7) and (A13) must be equal.

$$[P + \alpha R + H\alpha e\sigma(R)][r + \varepsilon + \delta] + [\alpha e + \Phi_R + H\alpha e\sigma_R] \qquad \text{(A15)}$$
$$= [R + H\alpha\sigma(R)][r + \varepsilon + \delta] + [e + H\alpha e\sigma_R]$$

If the agent was risk neutral, $H=0$ and (A14) reduces to $\alpha e + \Phi R = e$. The condition in (A15) reduces to: $[P+\alpha R][r+\delta+\varepsilon] + \alpha e + \Phi_R = R[r+\delta+\varepsilon] + e$. The optimal level of investment and effort could be obtained by setting $\alpha=1$, $\Phi_R=0$, and $P=0$. Alternatively, α could be set equal to zero, with $P=R$ and $\Phi_R=e$. More generally, setting a between zero and one, $\Phi_R = (1-\alpha)e$ and $P = (1-\alpha)R$ would allow the risk neutral version of (A15) to hold.

If the agent is risk averse, then the $\alpha=0$ option must be chosen if the first-best solution is to hold. *With* $\alpha=0$, $P[r+\delta+\varepsilon]+\Phi_R=R[r+\delta+\varepsilon]+e$. So the principal can absorb all of the risk, P must be set equal to R, and the up front payment $\Phi(R, Z)$ must be set such that $\Phi_R=e$. This is exactly the same result as was derived for the previous model as e is the equivalent of VeR_G in the previous model, and R is the equivalent of VR(G, Z). Again it is implied that expected effort and expected revenue be observable. In this model it is assumed that $R_G= R_Z=1$, but Z and G will have to be observed in order to predict expected revenue, R.

[i] *Ex situ* conservation can only conserve known materials, and some of these are unsuited to currently available techniques for *ex situ* storage. As *ex situ* storage stores materials outside their natural habitats and isolates them from the natural evolutionary process, there is a potential problem of genetic drift (Frisvold and Condon, 1998)

[ii] Although bioprospecting for materials of pharmaceutical value is the focus of this paper, biodiversity is also an important reservoir of robustness for agriculture. However, for crops, the supplies of *ex situ* resources tend to be larger, and establishment of effective property rights more problematic. There is a large supply of *ex situ* germplasm already available in existing gene banks (e.g. the Consultative Group for International Agricultural Research (CGIAR)). While developing countries would like to have greater control over the germplasm they have supplied, for the most part it has been freely exchanged Frisvold and Condon, 1998). Biotechnology is poised to produce products that substitute for natural ones. Already, the *Bacillus thuringiennsis gene has been used to create* pest resistance in crops such as maize (Brush , 1998).

[iii] The Madagascar Rosey Periwinkle provides an example of what can happen if the country is not able to exert any property rights. In 1958, Gordon H. Svoboda, of 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 was conducted which resulted in the development and patenting of two extremely effective anti-cancer drugs. Within a few years, Eli Lilly began marketing the drugs and earned millions of dollars in sales long before the patent expired. In 1985 alone, sales were estimated at $100 million, "88% of which was profit for the company" (Farnsworth, 1988). 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. See “When Rhetoric Hits Reality in Debate on Bioprospecting” in *Nature*, Vol. 392, 1998.

[iv] The Trade-related Intellectual Property Section (TRIPS) of the GATT agreement requires all signatories to implement IPR systems for microorganisms, microbiological processes and plant varieties. The problem is how to recognition of indigenous, community-based forms of indigenous innovation in an IPR system which been developed to reward individual and corporate innovation (Brush, 1998).

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[v] In a second-best solution, efficiency gains always exist but may not be fully attainable because of asymmetric information. If information was symmetric, and actions were observable, the first-best solution would be attainable. See Rees, 1987, p. 65.

[vi] The opportunity cost of all of the principal's inputs, including a return to entrepreneurial talent, is netted out of $R(G,Z)$. An unsuccessful outcome is assumed to yield $R(G, Z) = 0$, while a successful outcome will yield $R(G,Z) > 0$.

[vii] This assumption says that the stock of biological resources (Z) and the stock of genetic information (G) don't have any influence on the probability of a successful discovery, but they do influence the quality of the product discovered and therefore the profitability of the discovery. Successful discoveries will still take place at lower levels of Z and G, but they will be less profitable. In the case of the rosey periwinkle, lower values of Z and G would mean that something less profitable would have been discovered. High quality genetic stocks mean more knowledge and better products can be found. High quality biological stocks mean more diversity and materials that have potential for greater returns can be selected.

[viii] The convexity of the cost curves ensures the concavity of the agent's Hamiltonian in the control arguments. Sattler 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

[ix] This section used a Tobit model of expected revenue, with conditional revenue being deterministic, with deterministic arguments, R(G,Z). In the appendix a stochastic optimal control model is used. Revenue is

modeled as itself being a stock variable, but one that has a stochastic component. However, the results of the stochastic control model are the same as those derived in Section III.

[x] 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 (Department of Health and Human Services, 1994).

[xi] In previous contractual arrangements, Biotics and the National Cancer Institute (NCI) had merely agreed to negotiate royalties at the time of product development. They did not guarantee that royalties would be paid in the event of product development. Their contractual design has evolved due to the opportunity for post contractual opportunistic behavior by either party in the earlier agreements. They have found that by specifying the rates in advance, neither party has the ability to exercise leverage over the other at a future time (Sedjo and Simpson, 1994).

[xii] Industry averages for royalty rates to collectors range from one to three percent of the pharmaceutical company's profits from the drugs developed, although some royalty rates have been much larger than this average (Laird, 1993). The range is from zero to fifty percent.