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Bioprospecting as a Conservation and Development Policy: Overview and Insights from Three Cases

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Introduction

Biodiversity prospecting, or bioprospecting, is the search among natural organisms for products of commercial value in agricultural, industrial, or, particularly, pharmaceutical applications. Virtually everything we eat is of organic origin, as are many industrial products. Eighty-six of the 150 most-prescribed drugs in the United States are derived from, or patterned after natural sources (Grifo, et al., 1996). The total benefits human society receives from these varied products is immeasurable.

It is not surprising, then, that bioprospecting is among the most frequently cited reasons for saving biodiversity. In addition to being cited as a *motivation* for saving biodiversity, it has also been proposed as a *means* for doing so (see, e. g., Wilson, 1992; Reid, *et al*., 1993; Rubin and Fish, 1994; Rosenthal, *et al*., 1999). Many have argued that payments for rights of access to, or use of, indigenous genetic resources could provide incentives to maintain biologically rich habitats in their unspoiled state.

These speculations have been the subject of considerable controversy. A number of economists have derived a wide range of estimates of bioprospecting values using an equally wide array of approaches (Principe, 1989; Pearce and Puroshothamon, 1992; Aylward, 1993; Artuso, 1994; 1997; Mendelsohn and Balick, 1995; Polasky and Solow, 1994; Simpson, Sedjo and Reid, 1996; Simpson and Sedjo, 1996; Missios, 1998; Göschl and Swanson, 1999; Rausser and Small, 2000; Craft and Simpson, 2001). These exercises have been based largely on theoretical models, and as such illustrate possibilities without necessarily providing much insight as to empirical realities.

Experience is accumulating with bioprospecting ventures, however. The pioneering venture between Merck and Company, the world's largest pharmaceutical

firm, and Costa Rica's *Instituto National de Biodiversidad* (INBio) has received considerable publicity. After entering into its initial agreement with Merck in 1991, INBio also entered into contracts for the supply of genetic resources to Bristol-Myers Squibb, other companies, and other non-profit research organizations (INBio, 2001). In 1993 three U. S. government agencies initiated an International Cooperative Biodiversity Group (ICBG) program. This program continues, and has sponsored research teams in eight countries (Rosenthal, *et al*., 1999). In 1997 Diversa, a San Diego-based company, entered into an agreement with the U. S. National Park Service to conduct research on microorganisms found in the hot springs of Yellowstone National Park. Extracta, a Brazilian company, recently entered into a US$3.2 million agreement with Glaxo Wellcome, the world's second-largest pharmaceutical company, to screen 30,000 samples from Brazil's biota (Bonalume Neto and Dixon, 1999). In what may be a first, a research institutute in India and a tribe of indigenous people in the State of Kerala received a $21,000 payment for use a compound whose source they provided to an ayurvedic[1] drug company (Bagla, 1999). So far as I know, this is the first instance in which payments have been made for a successfully developed product. Many other organizations have engaged in bioprospecting activities.

Despite these developments—or, perhaps, because success stories have proved less frequent than some enthusiasts predicted ten years ago—some commentators have been pessimistic. A cover article in the British science journal *Nature* reported on "When Rhetoric Hits Reality in Debate on Bioprospecting" (MacIlwain, 1998), suggesting that developments to date have been disappointing. The financial misfortunes of Shaman

[1] Traditional herbal medicine.

Pharmaceuticals, which used indigenous knowledge in structuring its search for new products, occasioned a derisory report in the *Economist* (1999).

A troubling development of recent years has been the growing controversy concerning fairness in the conduct of bioprospecting operations. The United Nations Convention of Biological Diversity (1992) has certainly not resolved all issues concerning the interactions between providers of biological source materials and those who would use them for research. Costa Rica, the Philippines, India, Brazil, the nations of the Andean Community, and others have enacted legislation governing trade in genetic resources (ten Kate and Laird; ___; ___). Indigenous rights groups and NGOs have been harshly critical of the "biopiracy" they allege in some existing agreements (see, e. g., RAFI, 2001). Even the U. S. government has been sued to enjoin it from providing samples to a private research entity (199x). In this atmosphere of suspicion and hostility, many have expressed concern that even mutually beneficial transactions in genetic resources cannot be undertaken ( ).

The focus of this paper will largely be on bioprospecting for the pharmaceutical industry, although the issues arising in other contexts are often similar. In the next section I discuss some basic economic principles relevant to the analysis of bioprospecting, and review the economic literature on the subject. In the second section following I discuss some general considerations regarding pharmaceutical companies' demand for natural products to test. The third section following presents some illustrative examples concerning unresolved issues in bioprospecting. The final section contains conclusions.

The Economic Value of Biodiversity for Use in New Product Development

There are a number of reasons for which it may be important to have some estimate of the economic value of biodiversity for use in developing new products. First, bioprospecting will only provide effective conservation incentives to the extent that the values landowners receive from bioprospecting ventures exceed their opportunity costs of conservation.[2] It would be interesting to now the extent to which bioprospecting can be relied upon as a conservation strategy.

Second, it is important to think clearly about the basis of economic value. Some bioprospecting ventures are advanced as a form of "Integrated Conservation and Development Program" (Rosenthal, *et al*., 1999). In an ICDP, as they have come to be abbreviated, a donor with conservation and/or economic development interests provides financial assistance to a venture intended to exploit the economic values of natural resources. Such programs have been evaluated, and in many instances criticized, by a number of authors (Wells and Brandon, 1992; Simpson and Sedjo, 1996; Southgate, 1997; Wells, 1998; Terborgh, 1999; Ferraro and Simpson, 2000; Ferraro, in press), and in some instances have given rise to second thoughts even among those who initiated them (BSP, 2000). Economic value arises when a commodity is scarce. Biodiversity is only valuable in new product research to the extent that it is scarce. Bioprospecting ICDPs will only generate economic returns sufficient to induce conservation to the extent that the combination of genetic resources, information, research expertise, and infrastructure they embody are not widely available elsewhere in the world. It is worth noting in this

[2] This statement should be elaborated. The "opportunity costs of conservation" ought be calculated net of earnings derived from ecotourism, sustainable use of nontimber forest products, local payments for ecosystem services, and other activities consistent with the maintenance of natural habitats. Bioprospecting

regard that having exceptional research capabilities is not, by itself, sufficient to generate powerful conservation incentives. Major pharmaceutical laboratories have already invested heavily in such capabilities. A region's biodiversity is only valuable to such laboratories if it is unique.

A third reason for which knowing something about the value of biodiversity is useful is that it may help in determining the efficacy of institutional changes in promoting conservation. Interest in structuring legal arrangements for access to, and sharing the benefits derived from, indigenous genetic resources is a relatively recent development. Colonial history is replete with examples in which foreign conquerors appropriated genetic resources from local peoples without compensation. Rubber, quinine, maize, and potatoes are all examples. These experiences may explain the suspicion and hostility with which bioprospecting is viewed by many. Contractual arrangements for the formal transfer of rights in unimproved genetic resources have only come into existence in the past decade (although there is a somewhat longer history of transactions in "improved" organisms under, for example, the United States Plant Varieties Protection Act first enacted in 1933 [CHECK THIS]).

Considerable effort has gone into the structuring of legal instruments for transfer of genetic resources (see, e. g., Gollin, 1993; Environmental Law Institute, 1996; Downes, 1997; ten Kate and Laird, 1999). There will be no incentive to conserve biodiversity, regardless of its value to private researchers or society at large, if the owners of habitats sheltering biodiversity do not stand to gain from conservation. By the same

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need not cover *all* the costs of conservation, but it could be useful to know what proportion of such costs it will cover.

token, however, the definition and enforcement of property rights in genetic resources will have little effect if potential purchasers of such rights assign them little value.

Let us consider first how economic value is calculated, and second, what implications there may be for the valuation of bioprospecting opportunities. Economic value is determined on the margin. The relevant consideration is not "how much is it worth to have biodiversity," but rather, "How much is it worth not to have a little less biodiversity?" As has already been said, products derived from natural sources are of astronomical value *in total*, but this does not necessarily reveal anything about their value on the margin.

Biodiversity is used in the search for new products. Thus its marginal value is determined by its incremental contribution to the success of such searches. If there are a number of potential sources of new products, and each such potential source affords approximately the same prospect of success and can be pursued at approximately the same cost, none will be of very great value. Under such circumstances, each is a substitute for the others, and when numerous substitutes exist, the price of each will be low. When there are large numbers of such research leads available, the conclusion that none can command a high price follows *regardless* of the probability with which any particular lead may give rise to a success. If the probability of success in testing any one lead is low, the expected payoff from pursuing an additional lead is low. If the probability of success in any testing any one lead is high, additional leads are likely to prove redundant, and hence, of low value. An upper bound on marginal value can be calculated under these simple assumptions, and it can be shown that the maximum possible price the "marginal species" (or "marginal hectare of habitat" providing the

"marginal species") declines to zero as the number of species (or hectares) grows large (Simpson, Sedjo, and Reid, 1996).

We might consider some extensions of the simple approach outlined in the paragraph above. If all research leads are not approximately equally likely to generate a success, or cannot be evaluated at approximately the same cost, researchers will first concentrate their search on the most likely/least costly options. Thus species for which chemical, ecological, or ethnobotanical information is available are more valuable than those for which it is not (Rausser and Small, 2000).

The practical consequences of this observation depend on the identities of the species and locations for which information is available. The inevitable consequence of some research leads being more valuable is, of course, that others are less valuable. If the best prospects are to be found among specimens already contained in botanical gardens or research laboratory collections, the demand for further natural products to test will be negligible. If prior information is important in bioprospecting, the logical conclusion would seem to be that the *least* valuable leads would be those for which there is literally no information. Biologists estimate that ninety percent or more of the earth's species may not be identified yet [EB cite]. Thus there may be little incentive to preserve forests that are being felled before their biota is thoroughly studied.

There is, however, an argument that perhaps the incentives bioprospecting affords would be strongest in precisely the areas in which threats are greatest (Artuso, 1997). Areas far removed from roads and population centers may have great undiscovered biodiversity but few immediate threats. Conversely, areas under greater threat may also have been subject to more study, precisely because they are more accessible.

The focus thus far has been on *private* willingness to pay for bioprospecting opportunities. Not all the benefits of new product development accrue to the developer, however. Sellers of drugs typically cannot recoup the consumer's entire willingness to pay for the treatment. One drug may also create demand for others. By saving a patient's life, a drug used to treat one condition may generate demand for other drugs to treat the patient for other conditions. Moreover, considerable recent research in economics has addressed the "spillovers" generated by innovations. Pharmaceutical research is but one aspect of research and development, but such spillover considerations may be important in calculating social values (Göschl and Swanson, 1999; Craft and Simpson, 2001). It seems reasonable to conclude that the social values generated by the use of biodiversity in new product research exceed the private.[3] This may not comprise an argument to promote bioprospecting so much as one to save biodiversity for this among other purposes, however.

Regrettably, given the importance of knowing something about values, we lack the data with which to reach firm conclusions. It is probably accurate to say that *most* researchers would agree that biodiversity provides few incentives for conservation in *most* places. Substantial disagreements exist as to the incentives afforded in particular instances.[4] These disagreements will not be resolved until more evidence becomes available. Let us now turn to such evidence as can be cited.

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[3] It is also theoretically possible that the social value of incremental biodiversity for use in new product research would be negative. Private researchers, left to their own devices, may engage in too much product differentiation through R&D (Salop, 1980; Brander and Spencer, 1984; Craft and Simpson, 2001).

[4] Such evidence as I have reviewed leads me to believe that the incentives are negligible everywhere, but reasonable people might intepret the evidence differently.

The Demand for Biodiversity in New Pharmaceutical Product Research

The data are sparse. Of the world's ten largest pharmaceutical companies (ranked by sales), eight conduct their own natural products discovery programs and the other two have wholly-owned subsidiaries doing such work (ten Kate and Laird, 1999). This does not, of course, address the importance such companies place on natural products. To make such an assessment would be difficult.[5] There is a distinction to be drawn between natural products research *per se*—that is, research on samples collected from *in situ* sources—and research on the derivatives of natural products. In addition, major pharmaceutical companies frequently contract with smaller research laboratories, so an absence of in-house research would not necessarily betoken a lack of interest in general.

Natural products may be substitutes or complements for other "leads" used in conducting pharmaceutical research. "Combinatorial chemistry," the combination and refinement of complex compounds, can proceed from synthetic sources. Natural molecules may provide novel starting points for such exercises, however. While it would appear that research trends in the pharmaceutical industry place greater emphasis on natural products at one point and combinatorial approaches at another (Rosenthal, *et al*., 1999), it would be too simplistic to suggest that one will replace the other. It is not clear even whether technological advances enhance or reduce the value of natural products. On one hand, improved technologies increase the number of synthetic and natural sources from which new products might be developed. The economic value of more numerous commodities is lower, other things being equal. But among the "other things" that are not necessarily equal are the rewards to developing improved products. In addition to a

[5] One perhaps relevant observation is that bioprospecting is not mentioned at all on the web sites of many of these companies.

growing demand for new medicines, technological advances reduce the costs of bringing new products to markets, hence increasing net rewards.

It seems reasonable to conclude that pharmaceutical companies will continue to demand natural products. It is less clear whether this demand will be large enough to have an appreciable impact on biodiversity conservation.

Some Examples

In this section I will review some selected examples of bioprospecting agreements. A good place to start is with the first

Merck/INBio

In 1991 Merck and Company entered into an agreement with INBio under which the latter would supply samples to Merck for pharmaceutical evaluation. Merck could request approximately 2,000 samples from INBio. Merck paid Costa Rica approximately one million dollars at the initiation of the contract and agreed to pay royalties in the event that a commercial product were developed. While terms of the royalty were never disclosed, industry sources estimated it to be on the order of 1-3 percent.

Merck received no assurance that it would have exclusive rights to such samples (other researchers could collect samples for the payment of a much lower fee), but it was assured of confidentiality concerning the samples it had selected. INBio has subsequently entered into contracts with Bristol-Myers Squibb and several other companies (ten Kate and Laird, 1999; INBio, 2001). The terms of agreements vary across the companies involved, but may include up-front payments, payments for

services and equipment, and royalties in the event of new product development. No royalties have been paid to date. INBio's agreement with Merck has now expired after several two-year renewals. Arrangements with other companies continue.

It has been reported that INBio's contracts with various entities have contributed approximately US$1.2 million to the Ministry of Environment and Energy and national conservation areas, and over $700,000 to universities, as well as $700,000 to other programs at INBio (ten Kate and Laird, 1999). Despite this record, the conservation implications of the Merck/INBio agreement and subsequent arrangements remain uncertain. Of the initial payment of over $1 million from Merck to INBio, less than ten percent was for conservation-related activities directly. The remainder went for equipment acquisition, training, and other expenses (Sittenfeld and Gamez, 1993). To the extent that such purchases enhanced INBio's own demand for natural samples they may have encouraged conservation, but it would be difficult, if not impossible, to estimate such demand generating effects.

The Merck/INBio agreement was a trendsetter in a number of ways. Both organizations received considerable publicity as a result of their arrangements. Major media outlets reported the original contract, largely on favorable terms. INBio officials were invited to share their experiences with would-be emulators around the world. There was also, however, some less favorable publicity (RAFI, 2001)—and in this respect, the Merck/INBio agreement also set the trend for those that followed.

International Cooperative Biodiversity Groups

The International Cooperative Biodiversity Groups (ICBG) program is a collaborative venture of the United States National Institutes of Health, National Science Foundation, and Department of Agriculture (the USDA began funding the program after the United States Agency for International Development withdrew in 1995). Beginning in 1993, the ICBG program has funded researchers in Argentina, Cameroon, Chile, Costa Rica, Laos, Madagascar, Panama, Peru, and Vietnam, as well as the United States (Rosenthal, *et al*., 1999). Under terms of the grants, each ICBG must address the goals of new product discovery, scientific and economic development in the host country(ies), and conservation of biodiversity. Each group must also institute an agreement for benefit-sharing with the countries or groups that provide it with material. While a great many samples have been tested and a number of interesting compounds are being evaluated further, no commercial products have yet been developed (given the time scale on which pharmaceutical research is conducted, it would be virtually unprecedented if a new product were developed so quickly).

The ICBG program's 1999 budget was US$3.7 million (Rosenthal, *et al*., 1999). Funding at this level begs a number of questions. Six of the eight projects funded by the ICBG program include participation by private firms, including industry giants Bristol-Myers Squibb, Monsanto, and Glaxo Wellcome. While these firms make contributions in kind, it seems reasonable to ask on what basis public expenditures should be made to subsidize the research activities of private entities. Many large pharmaceutical companies spend well in excess of a billion dollars a year conducting their own research and development activities (ten Kate and Laird, 1999). From an economic standpoint,

one would want to identify the market failure that motivates subsidization of their involvement in ICBG research.

Answers are suggested by the objectives of the program. As noted above, these include in addition to the development of new products, spurring economic development and conserving biodiversity. The last of these objectives clearly involves the provision of a public good, and hence one of the classic arguments for public action. Economic development in poor countries is, with respect to the interests of U. S. citizens, probably also a public good: we feel a moral obligation to improve the plight of those less fortunate than ourselves.

These considerations also beg questions, however. "The ICBG is, in part, an integrated conservation and development program" (Rosenthal, *et* al., 1999).[6] Does an ICBG represent an efficient means of accomplishing its various goals? Financing pharmaceutical research and development is a round-about way of encouraging conservation. If the wisdom of the old adage "you get what you pay for" is to be credited, programs that provide more direct incentives for conservation should be more effective (Ferraro, in press; see also Ferraro and Simpson, 2000, for a formal demonstration). Other forms of ICDPs have been criticized for being ineffective, or worse, counterproductive in accomplishing their conservation objectives (Barrett and Arcese, 1995; Southgate, 1997; IPICD, 1998). At the same time, recent experiments and research have suggested that direct payments for biodiversity conservation may be more effective than one might expect in the institutional setting of a less developed country

[6] In addition to their primary activities, ICBGs have "support[ed] development of traditional woodcraft enterprises (Suriname), propagation of ornamental plants (Mayan Mexico), and propagation of plants for idely sold herbal remedies (West Africa, Vietnam, Mexico, Peru)" (Rosenthal, *et al*., 1999).

(Chomitz, *et al*., 1998; Brunner, *et al*., 2001). The donor community may also be losing patience with conservation programs that attempt to mask failure in their area of primary interest by pointing to peripheral accomplishments.[7] It can be difficult to evaluate a program that achieves varying levels of success in achieving a number of incommensurate objectives.

It might also be argued that the ICBGs provide another form of foreign aid by seeking cures for diseases that affect poorer people. The "ICBG program goals" include the discovery of " . . . agents . . . to treat or prevent cancer, infectious diseases including AIDS, cardiovascular diseases, mental disorders, and other diseases, as well as a variety of crop plant and veterinary concerns". Some groups also seek antimalarial and antiparisitical compounds, however (Rosenthal, *et al*., 1999). These targets do not receive as much attention from commercial researchers, yet they are endemic in some poorer countries. One might again ask whether a natural products research program is the best instrument with which to address such ends, however. If treatments for diseases of the Northern rich can be found in the rainforests of the South, might not treatments for the diseases of the Southern poor be found in the laboratories of the North?

The ICBG program may confirm the wisdom of another adage: "No good deed will go unpunished." It is perhaps unavoidable that any program financed by the United States Government will raise suspicions. ICBG Participants also receive mention in accounts of "biopiracy" (RAFI, 2001). Partly as a result of such allegations, and partly simply as a result of political uncertainties, two ICBGs operating in Mexico had to suspend their operations last year (Dalton, 2000).

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[7] A recent article in *Barron's*, the financial weekly, reports on efforts at the World Wildlife Fund to implement a business paradigm, emphasizing clear goals and financial accountability.

Yellowstone

An enzyme from the hotsprings microorganism *Thermus Aquaticus* (*Taq*) is used in the biotechnology industry. The polymerase chain reaction (PCR) is a process by which DNA is copied and amplified. This technique is used in, for example, medical diagnosis and "DNA fingerprinting." *Taq* was first isolated in Yellowstone National Park (Brock, 1994). In 1997 Diversa, a San Diego based biotechnology company, entered into an agreement with the U. S. National Park Service (NPS) under which Diversa would pay the NPS $100,000, plus another $75,000 in kind, for the right to conduct research on microorganisms drawn from the Yellowstone hot springs (Sonner, 1998). Royalties in an undisclosed amount were also specified in the event that a new product were developed. It was reported in 1998 that the NPS was considering over a dozen other such arrangements (ICTA, 1998).

The National Park Service was subsequently sued by the Edmonds Institute, a Seattle-based NGO, the International Center for Technology Assessment, and the Alliance for the Wild Rockies. This case illustrates a couple of troubling aspects. First, there appears to have been considerable disagreement among environmental advocates as to the deal's merits. Vice-President Al Gore had announced the deal himself on the occasion of the 125th anniversary of Yellowstone National Park. Vice-President Gore emphasized his pro-environment stance in the recent U. S. Presidential election, and apparently considered the Diversa/NPS deal as one in which industry could "do well by doing good." The court's initial decision in the case was, ironically, that the U. S

National Environmental Protection Act required an Environmental Impact Assessment be undertaken before Diversa could conduct its collection activity. While concern is occasionally expressed that bioprospecting collection could have an adverse impact on forest ecosystems, this seemed questionable in the Yellowstone case. Samples taken were described as being of "teaspoon" size. The cumulative impact of such extractions was, presumably, the subject of the environmental impact assessment. One has to wonder, however, if the impact would be appreciably greater after the Diversa agreement, as Thomas Brock reported in 1994 that

> The hyperthermophilic bacteria of Yellowstone hot springs are attracting biotechnology researchers from around the world. Dozens of microbiological research projects are underway, and virtually every week of the year some researcher is exploring Yellowstone's hidden resources.

Environmental impacts *per se* appear to have been only one concern of the plaintiffs in the suit. While the judge in the case did not grant the plaintiffs' request that the royalty rate agreed between the NPS and Diversa be made public,[8] the plaintiffs were concerned that the public was not being adequately compensated. Mike Bader, Executive Director of the Alliance for the Wild Rockies claimed " . . . the National Park Service and the Department of the Interior . . . did a deal without the knowledge and consent of the American people . . . " (quoted in ICTA, 1999). The matter was ultimately resolved in favor of Diversa and NPS. Judge Lamberth, ruling again in April of 2000, rejected all of the plaintiff's claims (YNP, 2000).

[8] The history of the legal action is interesting. The first action was a request from the Edmonds Institute, an NGO in the Seattle area, for information concerning the then-proposed agreement between Diversa and the NPS under the United States Freedom of Information Act. The NPS declined to release the royalty terms of the agreement under the argument that this was proprietary commercial information. The Edmonds Institute, joined by other plaintiffs, then sued (ICTA, 1998).

The Yellowstone example illustrates a couple of troubling points. First, the conservation incentives afforded by the deal were negligible. Yellowstone has been designated as a National Park for over a hundred years. It would be hard to argue that the Diversa agreement provided additional funds for conservation.[9] This is a case in which prior information in the sense of Rausser and Small's (2000) analysis was very important. *Taq* enzymes from Yellowstone were the known source of compounds patented by Hoffman-Larouche and earning annual revenues in excess of $100 million. There are hot springs around the world. In this case, bioprospecting funds may have been attracted to the area in which they were needed least.[10] In a sense, however, this is perhaps an "exception that proves the rule." Brock (1994) argues that researchers come to Yellowstone because the other hotsprings of the world (in Japan, New Zealand, and Iceland, for example) have been degraded by geothermal use, bathers, and other stressors.

Inasmuch as the use of bioprospecting as a conservation policy is more germane in developing countries, this discussion of events in the United States may seem out of place. The point, however, is that a deal could not be consummated without political controversy and judicial review even in a country where one might expect the conditions for successful transactions to be most favorable. While the court case was ultimately resolved in favor of Diversa and the NPS, this occurred only after a two-year delay and, one presumes, the accrual of significant litigation expenses. A cost that is more difficult

[9] While Judge Lambeth ruled, among other findings, that the Diversa agreement would "afford . . . monetary support for Park programs," (quoted in YNS, 2000), the NPS has been traditionally been precluded by law from appropriating monies received (for admissions and concessions for example), for its own budget. Thus the Diversa agreement would not have directly benefited Yellowstone, or the National Park System more generally.

[10] Diversa is, however, active in other parts of the world, and has contracts with INBio in Costa Rica as well (ten Kate and Laird, 1999).

to evaluate but probably at least as important is the negative publicity the parties received while the case was pending.

Conclusion

We have reviewed some basic economics relating to bioprospecting and considered evidence from three case studies. Two conclusions emerge from the economics. First, as with all commodities, value is related to scarcity. Second, there simply is not enough information available to determine if the bioprospecting opportunities presented by particular sites are scarce and, hence, valuable.

This latter consideration is something of an anomaly in a world in which almost everything has a price. We typically do not greatly concern ourselves with the economic value of wheat or coal: there are well established markets in these commodities, and their economic value is whatever the market will bear.[11] If left to its own devices the market will determine the value of bioprospecting opportunities as well.

It seems unlikely, however, that convergence to a consensus concerning such values will occur soon. There are a number of reasons for this conclusion. One is simply that transactions in genetic resources remain relatively novel. One of the reasons for which the prices of more common commodities are more easily determined is simply that they *are* more common. If coal had been discovered yesterday rather than millennia ago, uncertainty as to its properties and uses would probably be reflected in inchoate markets.

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[11] Environmental economists do on occasion concern themselves with the externalities associated with the production or consumption of such commodities, but the market prices of the commodities themselves are well established.

In addition, natural areas rich in genetic resources are not "commodities" in the sense that word is applied to fungible, and often even indistinguishable, goods. No two areas of the world could be said to be identical in their bioprospecting potential. Different regions differ in the extent and diversity of their biota, in the physical impediments to gaining access to them, and in the political, legal, economic, and social circumstances surrounding their collection.

Transactions in genetic resources also raise complex contracting issues. Sellers may know more about the potential of the products they offer than do would-be buyers. In such circumstances a buyer may want the seller to "put her money where her mouth is" by maintaining an equity interest in the outcome of product development (i. e., structuring a contract calling for royalties instead of, or in addition to, upfront payments). Buyers may also want sellers to assure that future sources of supply will be available for leads found to be promising and to maintain confidentiality concerning promising leads. All of these considerations call for the structuring of sophisticated contracts and ongoing efforts to assure that their provisions are being observed.

While these factors are unusual, arrangements reflecting such complexities are not unprecedented. In fact, there is a ready example after which bioprospecting contracts are modeled. Major pharmaceutical companies routinely enter into licensing agreements with independent research organizations for the commercialization of promising compounds (see extended discussion in ten Kate and Laird, 1999, pp. 64-68). The terms of existing bioprospecting contracts appear to be roughly consistent with those for the transfer of potentially promising leads from other sources.

It is here where problems often arise, however. The terms of a "standard" contract seem unfair to some observers. A common theme encountered in the writings of organizations opposed to bioprospecting agreements concerns the disparities between the vast sums the developers of successful new commercial products can receive and royalties often measured in fractions of a percentage point. Much of this is due simply to economic misunderstandings. An explanation many economists find plausible for the extremely high prices and profits pharmaceutical firms receive for successful products is that they amortize their equally astronomical costs of research and development. Research and development is often a matter of trial and error, and as success rates are generally extremely low, the costs of failure accumulate to large sums.

Historical grievances can also be complicating factors. Brazilian attitudes, it has been said, reflect " . . . still-smoldering anger over the collapse of Brazil's rubber industry . . . after Brazilian seeds were transplanted to Southeast Asia and used to start the region's booming rubber plantations" (Pennisi, 1998). There have been any number of other instances in which biological resources from one area have been transplanted to another with great benefit to the recipient and no compensation to the originator. More generally, one can easily understand the desire of people in the nations of the developing world to share in the much greater wealth of the industrial countries. A would-be seller of genetic resources cannot squeeze more out of buyers than they are willing to pay, however. Unrealistic expectations result in missed opportunities.

Unrealistic expectations may also motivate unwise public spending. We touched briefly on arguments for public subsidization of bioprospecting efforts in discussing the ICBG program above. There I concluded that "public goods" arguments are not very

compelling. Conservation and economic development objectives would be better achieved by alternative instruments.

Another argument for public investment in bioprospecting is also made. By investing in "value added" processing, it is felt, a source country can increase its returns from its biodiversity (Reid, *et al*., 1993; INBio, 2001). This view is based in part on a semantic confusion. "Value added" can be defined as the excess of revenues received over variable costs incurred. As such, however, it does not necessarily represent true earnings in an economic sense. Value added is, rather, related to return on investment in fixed assets, both tangible (plant and equipment) and intangible (expertise in processing samples, for example).

It is possible that such investments are justified, but one must remember again that economic value is inversely related to scarcity. A country contemplating investment in bioprospecting—or a donor contemplating subsidizing such investment—should be prepared to identify the scarce asset that will be exploited as a result. International donors in particular need to bear in mind that not every region can be uniquely situated to generate substantial earnings from its indigenous biodiversity.

Conservation advocates, international donors, and policy makers in developing countries now find themselves in a dangerous position. Markets in genetic resources are not well established, whereas markets in pharmaceutical products, or at least compounds with demonstrated pharmaceutical potential, to exist. It is an expensive and risky proposition to invest in the capacity to develop products of demonstrated potential. At the same time, entering into agreements by which relatively unprocessed materials are sold for modest compensation may be politically impossible. These issues will not be

resolved until greater experience is accumulated. Perhaps the best advice an economist can offer at this point is simply that groups interested in conservation and/or development would be wiser to address these ends more directly, and wait for private actors to resolve the issues of bioprospecting.

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