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THE APPROPRIATION OF THE BENEFITS OF PLANT GENETIC RESOURCES FOR AGRICULTURE: AN ECONOMIC ANALYSIS OF THE ALTERNATIVE MECHANISMS FOR BIODIVERSITY CONSERVATION

by

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THE APPROPRIATION OF THE BENEFITS OF PLANT GENETIC RESOURCES FOR AGRICULTURE:

AN ECONOMIC ANALYSIS OF THE ALTERNATIVE MECHANISMS FOR BIODIVERSITY CONSERVATION

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The Valuation and Appropriation of The Global Benefits of Plant Genetic Resources for Agriculture

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Abstract

This report presents an economic analysis of the need for and the nature of "Farmers' Rights", the concept developed within the International Undertaking on Plant Genetic Resources. It shows that the need for Farmers' Rights derives from bias within the socio-economic process that is driving the depletion of plant genetic resources for agriculture. It identifies the nature of Farmers' Rights as being in the first instance the creation of internationally-recognised rights to the appropriable values (discoveries, contributions to enhanced yields) generated by these resources as a factor of production. There are also other values of plant genetic resources (systemic stability, reduced yield variability) which are incapable of appropriation; for these, a cost-effective international compensation mechanism is required.

Executive Summary

The loss of biodiversity in plant genetic resources for agriculture derives from the relative appropriability of the values that emanate from diverse and nondiverse agricultural resources. Since many of the values from diverse resources are either global or nonappropriable (under existing institutions), there is a bias towards conversion to modern high yielding varieties.

> Conversion to high yielding varieties usually substitutes a high mean yield system for a lower yield but more diverse system.
>
> Planting a diversity of varieties provides insurance through a portfolio effect, but the individual farmer perceives less need for diversity-supplied insurance now that other forms of risk-spreading and insurance are available.
>
> In the absence of individual incentives to supply diversity, governments must now determine and supply the optimal amount of diversity-supplied insurance. There is no substitute for this form of insurance, as financial markets are unable to reduce highly correlated risks such as this one.

Individual governments will undersupply diversity-insurance because most of the values are global in nature. These values derive from the reduced variability in world food yields (and hence prices) that results from the correct quantity of diversity.

Diversity does generate some appropriable values but these are not appropriated under existing property rights systems by those best able to invest in the resource. Poor property rights systems generate poor investment incentives, and are partially responsible for the underinvestment in diverse resources.

The appropriable benefits of plant genetic resources are derived from its value for exploration, and contribute to enhanced mean yields as well as reduced variability in agriculture. This value is currently being captured as a composite value (in combination with rewards to other factors of production) at other levels within the plant breeding/seed industries.

The implementation of Farmers' Rights concept should correct this inefficient bias towards conversion of land to high yielding varieties. The optimal institution is one that will compensate host states for supplying global values, and appropriate to host states the factor share of plant genetic resources within the plant breeding/seed industries. This will require an international agreement (or protocol) to generate and assure these flows of value into the future, in order to institute the correct incentives for conservation.

To alter host states'investment decisions regarding their portfolio of agricultural resources will require an institution that will create and direct values from diverse resources into the indeterminate future. Investment depends upon expectations about the future, not payments in the present.

An optimal compensation mechanism is required for the channelling of global values to host states. This would take the form of an international agreement that assures the global community that additional diverse resources will be conserved for each additional dollar spent. It is the creation of this direct and dynamic link between payment and provision that generates the willingness to pay for diverse resource conservation.

Another possibility for the elicitation of willingness to pay is the estimation of the value contributed by plant genetic resources for agriculture. This is not a practicable option for the global values, although it is possible to estimate the contribution of plant genetic resources within the plant breeding and seed industries. A study of this sort has not previously been accomplished.

The contribution of plant genetic resources to plant breeding/seed industries is appropriable as well as estimable. At present the contribution of plant genetic resources is being consolidated with the other factors of production in these industries, rather than being separately rewarded.

Farmers are paying for the use of this factor, but the reward to this factor is not being returned to those making decisions regarding its conservation.

The creation of an internationally-recognised genetic resource right would allow for the separation of this composite value between the various factors of production in these industries, and create a system of incentives for conservation of plant genetic resources. This requires the creation of a registration office or exchange where rights to plant genetic resources may be claimed via first registration.

1. Introduction to the Biodiversity Problem in the Context of PGRFA

The "green revolution" has generated large increases in average yields in most countries adopting the methods of modern agriculture. Between 1960 and 1983, world food production increased by almost three per cent per annum largely attributable to the adoption of such methods.

One of the linked inputs in modern agricultural production is the specialised high yielding variety developed for use in intensive agriculture. These varieties are developed by plant breeding industries by selective breeding techniques making use of the entire gene pool available through the gene bank networks and through screening the various landraces still in use. Therefore, in recent history, one of the fundamental inputs into the modern agricultural process has been the range of varieties still being used by the non-modern (traditional) sector of agriculture.

However, despite the need for the inputs from the traditional sector (either directly or indirectly via gene bank accessions), there was no return from modern agriculture invested in the traditional sector in order to maintain it for this purpose. Therefore, the very success of the modern sector has resulted in the erosion of the traditional sector upon which it had depended for raw material.

Now, in addition to the role of plant germplasm as an input in plant breeding for yield enhancement, it is also recognised that it plays a role in reducing variability in yields as well. It does so in several ways both now and in the future, e.g. by reducing reliance upon too few productive varieties at any one time and place and by providing a basic resource to turn to in the event of problems arising out of existing production methods.

These various "values" of diverse plant genetic resources and the optimal mode for their conservation have been the subject of an extended debate between states from both North and South. The conservation of "plant genetic resources for agriculture" (PGRFA) is one of the important conservation items on the agenda under the general terms of the Biodiversity Convention. This paper analyses this debate, the forces driving it and the routes to its resolution. It identifies by why it is that the conservation of PGRFA is a contentious issue along North-South lines, and how it is that an answer exists that is to all parties' advantage.

1.1 The Previous Discussions Concerning the Conservation of PGRFA

This conservation problem was first addressed through the establishment of the gene bank system under the Consultative Group for International Agricultural Research (CGIAR) in 1971, and the development of thirteen International Agricultural Research Centres (IARCs) for the assembly of germplasm collections. The thirteen IARCs now manage 227 seed banks in 99 countries which hold 90% of known landraces of such crops as wheat, corn, oats and potatos.

Despite these successes, the problems and deficiencies of exclusive reliance upon ex situ conservation are widely recognised. In part on account of this, the Food and Agricultural Organisation has developed the International Undertaking on Plant Genetic Resources (IUPGR) and its associated resolutions, which provide for an agreed groundwork for regulating PGRFA.

Initially the IUPGR was the statement of a policy of "open access" with respect to plant genetic resources. They were to be made available for access under mutually agreed terms (i.e. by means of bilateral agreements).

More recently the IUPGR (and its associated resolution 5/89) has seen the development of the concept of "Farmers' Rights". These are rights arising from the contributions of farmers toward the conservation of PGRFA specifically, and to the plant breeding and seed industries generally. These rights are vested in the international community (as a sort of "trustee") for the benefit of the world's farmers and farming communities. The farmers are intended to participate fully in the benefits derived from the use of PGR.

It has been generally agreed what form the benefits of these Farmers Rights should take. The mechanism is described as an "international fund" managed by the Food and Agricultural Organisation to support conservation activities particularly in the developing countries.

This international fund remains to be implemented, and there is no agreement as to the scale and source of the contributions that it should contain. Of course, this situation renders "Farmers Rights" largely ineffective. The primary objective of this paper is to assess the most efficient means of implementing the general concept of "Farmers Rights" for cost-effective conservation of PGRFA.

1.2 The Ongoing Discussion Under the Biodiversity Convention

The adoption of the convention on the conservation of diverse biological resources in Rio de Janeiro in the summer of 1992 had a significant impact on the conservation movement for PGRFA. This international convention contains several provisions relevant to the debate on PGRs, and promises future actions (and protocols) to resolve some of the important outstanding issues. To a large extent, it provides a single forum in which to continue the discussions already initiated in other fora.

One important role for the biodiversity convention is that it may provide for the efficient coordination of ex situ and in situ conservation strategies for plant genetic resources, and the provision of a compensation mechanism for the providers of (the raw materials for) each. The biodiversity convention registers these concerns in articles 9, 20 and 21.

In addition, many of the facets of the FAO's resolutions on "Farmers' Rights" have been incorporated into the terms of the convention. (See Articles 9, 20 and 21 of the Biodiversity Convention.) These provisions also discuss the terms of access to genetic resources, and the basis for agreements on the same. Therefore, the convention promises to continue the debate on the terms for access and the basis for compensating the providers of PGRFA.

At this stage, the Biodiversity Convention is a mere "framework convention". By this, it is meant that the convention provides a framework for further negotiations on important issues, but little in the way of concrete terms of an agreement. The convention at present identifies the global willingness to negotiate further to resolve these issues, and it identifies the nature of the issues that the parties must address. It is to be anticipated that future protocols will issue under the convention to reflect agreements on some of the still-outstanding issues of the debate on PGRFA.

1.3 The Purpose of this Report

The general purpose of this report is to provide a conceptual framework for understanding the nature of the agreement that is required in order to implement effective biodiversity conservation for PGRFA. The specific object is to identify the extent to which it is possible for economics to contribute to the resolution of these debates by either: 1) estimating the value of biological diversity in the context of PGRFA; or, 2) indicating the means of appropriating the value of biological diversity in this context.

The answers to these questions are presented in the course of the six subsequent sections of this report. Part A (sections 2-4) analyses the biodiversity problem in the context of PGRFA. Part B (sections 5-6) develops the range and scope of application of the economic methods of value estimation. Part C (section 7) describes the nature of the necessary policy solutions, and the institutions they recommend.

Sections two through four develop the nature of the "problem of biodiversity's depletion" in this context. Section two explains why it is that modern agriculture has an in-built tendency for diversity destruction, and why this is something that is used for the development of human societies. The loss of biological diversity resources in this context is largely the consequence of the advancement of human societies.

Section three identifes the reasons why this process should be a matter for concern, i.e. it identifies the various "values of diversity" that should be considered in balance with the "values of modern agriculture".

Section four indicates why it is that these values are ineffective in halting the progress of conversion to high-yielding varieties across the globe, i.e. it addresses the question why these obvious values are not themselves effective in halting the decline of diversity. There is a bias towards the adoption of high-yielding varieties that lies in the relative appropriability of their benefits (rather than the level of these benefits). At base, it is this externality that is the core problem of biodiversity in the context of PGRFA.

Section five briefly descibes the field of enquiry known as "environmental economics" especially as it pertains to the issues of environmental valuation. This survey gives an idea of the sorts of things that this field is able to do, and what it cannot do. In particular, it identifies from the outset that there exist a large number of values of PGRFA that it is unlikely that estimation techniques can evaluate.

Section six then lists a couple of research projects that might be used to attempt estimations of the value of PGRFA. However, more importantly, it also lists the problems with this approach. It is clear that the values that can be estimated will only be a small part of the total values, and the studies indicated will represent mere case studies with regard to these values (that must be aggregated to represent indicators of the values that they are estimating). Therefore, it is clear from the analysis in this paper that it will be difficult to acquire a clear idea of the full range of value of PGRFA prior to their appropriation, but it is also clear that there are values that may be accurately estimated and that this work has not yet been done.

Section seven then provides an analysis of the implications of an optimal policy approach to biodiversity's conservation. It considers two distinct options: compensation mechanisms and appropriation mechanisms. In both cases, the purpose of the analysis in section seven is to demonstrate how a properly structured agreement can be self-enforcing, and give both producer and consumer what they desire from the agreement. In the context of biodiversity, this means the construction of self-enforcing agreements that assure consumer-states of the effective conservation of diverse resources while simultaneously assuring producer-states of the funds to compensate fully for their conservation.

Section seven first discusses the range of values that are not appropriable, and discusses the nature of the most cost-efficient mechanisms for their preservation. These mechanisms will conserve the optimal amount of diversity if they are based in the creation of a mechanism which will allow the expression of existing willingness-to-pay for diverse resources. In terms of economic incentives, this means demonstrating to consumers that they will receive something concrete for the money that they part with.

Section seven then identifies the range of values for which appropriation is a possible, and preferable, option, and describes the nature of the institutions capable of appropriating the rental values of genetic resources to their host states. Farmers' rights may be given real effect by the creation of a straightforward mechanism for enforcement of an internationally-recognised exclusive purchasing agreement. This method of implementation will maximise the conservation-effectiveness of the appropriated values.

In sum, the purpose of this paper is to show how the general concept of "Farmers Rights" can operate to conserve biodiversity effectively. Farmers rights are essential for the creation of a mechanism for the channelling of rents to the states and individuals hosting genetic resources. These natural resources generate rents within the plant breeding and seed industries at present, and they need to be redirected for purposes of conservation efficiency. The short answer is that there is a simple mechanism (an "exchange") that is available for enforcing these rights, and generating these rents at the level of the host state and its farmers. It is an institution of this nature that will be capable of generating payments for the sustainable conservation of plant genetic resources for agricultural.

Part A

The Nature of the Global Biodiversity Problem in Relation to PGRFA

By Timothy Swanson

2. The Forces Driving the Decline of Biological Diversity Generally

This section commences the development of the framework upon which the policy recommendations in this document are built. It is necessary to explain the economics of the problem of diversity decline before it is possible to explain the economics of biodiversity policy. Part A of the report considers the nature of the problem; parts B and C the nature of the alternative approaches to a solution.

In essence, this section sets forth the nature of the global developmental process that would generate biodiversity decline. In doing so it demonstrates the tension between the drive for human and societal development and the retention of diversity; to some extent, they are not compatible objectives. Therefore, in this section, we paint with a broadbrush; the discussion here is of the general nature of the conflict between development and diversity, and how it applies in the case of plant genetic resources. In section four of the paper we return to the question of the specific problems driving the decline of these resources in particular.

2.1 The forces of conversion.

Estimates of aggregate natural habitat conversions over the past two centuries range from 25 to 50 per cent of the original area. [Myers (1980); IIED (1989)]. Two hundred million hectares of forest and 11 million hectares of grasslands were converted to specialised agriculture between 1960 and 1980 alone, all of it in the developing countries. [Holdgate et. al. (1982)].

Table 2.1: Rates of Conversion of Natural Habitat to Agriculture

Developing	1960 ha.	1980 ha.	Percent. Change
Sub-S. Africa	161m.	222m.	37.8
Latin America	104m.	142m.	36.5
South Asia	153m.	210m.	37.2
S.E. Asia	40m.	55m.	37.5
Developed			
North America	205m.	203m.	0.1
Europe	151m.	137m.	0.0
U.S.S.R.	225m.	233m.	2.0

Source: Repetto,R. and Gillis,M., (eds.) [1988].

All the projections of potential "mass extinctions" are based on extrapolations of land use conversion trends into the final refugia of species diversity, i.e. the tropical rainforests. A fairly conservative estimate would seem to be that the diffusion of these technologies into these final refugia are causing current rates of extinction to be about 1,000 to 10,000 times the historical rate of extinction. [Wilson (1988)]. If the problem of diversity decline is assumed to be described by the processes generating these biologists' projections, then the source of this concern is the conversion of lands to other human-chosen uses. These conversions have occurred for several centuries in some parts of the world, but most recently their progress has been charted across the developing world.

In the developed countries of Europe and the U.S., there is little land conversion still taking place. This is because the process of land use conversion has been completed. The proportion of Europe which is "unmodified habitat" (of at least 4000 sq. km. in area) is now certifiably zero. In the U.S., the proportion of unmodified habitat of this dimension is down to 5% of the American land mass. [World Resources Institute (1990)]. The conversion process has worked its way through most of the northern hemisphere, and it is now proceeding in the same manner across the south. At the "frontier" of this technological diffusion, the rate of conversions remains high.

Table 2.2: Recent Rates of Conversion To Specialised Agriculture (Ten Year Rate - To 1987) (increase in land area dedicated to specified use)

Conversions to Cropland		Conversions to Pastureland	
1. Paraguay	71.2%	1. Ecuador	61.5%
2. Niger	32.0%	2. Costa Rica	34.1%
3. Mongolia	31.9%	3. Thailand	32.1%
4. Brazil	22.7%	4. Phillipines	26.2%
5. Ivory Cst.	22.4%	5. Paraguay	26.0%
6. Uganda	21.4%	6. Vietnam	14.0%
7. Guyana	21.3%	7. Nicaragua	11.8%
8. Burkina F.	19.4%		
9. Rwanda	18.6%		
10.Thailand	17.1%		

Source: World Resources Institute and International Institute for Environment and Development [1990].

The diversity of life forms is in decline because large-scale changes in land use have been occurring across the face of the earth for many centuries, initially in the parts known as the "developed world", and currently in the developing. "Conversion" is the basic force driving the decline of diversity.

In essence, within the natural evolutionary process, the allocation of a portion of "base resource" (land or NPP) was determined in a natural competition between various life forms. In the past ten thousand years, this allocation decision has been usurped by the human species. Base resources (land and NPP) are now allocated by humans to the various species that continue in existence. The land use conversions outlined in the previous section are indicators of the scale and rate of diffusion of this technological change. It is a process which commenced with the initial idea of cultivation and domestication, i.e. the selection of species for use rather than the use of the prevailing species. It is an idea that has diffused across the whole of the globe. Now, human choice rather than competitive adaptation determines the range of life forms that exist on the face of this planet. Recognising that it was possible to select a species to which to allocate the base resource, and then use that species, human objectives rather than evolutionary adaptation became the driving force in determining extinction. From that point on, the competition for base resource allocations was a social process.

2.2 What is "Conversion"?

If homogenisation of the biosphere is the force primarily driving diversity decline (and this is a force generated by human societies), then it remains to explain the nature of the human objective that would generate this force. One of the fundamental economic problems that human societies must resolve is the determination of the form of the assets in which they will hold their aggregate wealth (their "portfolio"). If the optimal portfolio determined by this process is different from the initial, then there will be incentives to convert some existing assets to other forms. This implies disinvestment in some naturally occurring assets, and investment in some other human-preferred ones.

The incentive to disinvest in the naturally-occurring stock of assets in order to invest in the human-selected is referred to as the "conversion process". The natural form of any resource is necessarily competitive with other forms in which humans might hold these same assets. This derives from the fact that human societies now exercise the power to choose whether to hold natural resources in their original form, or to substitute another. (Solow,R. 1974).

This force for conversion extends even to biological resources. For example, a given hectare of land, which is originally growing diverse native grasses, may be converted directly to another grassy plant form such as wheat, because of the enhanced productivity of this resource. Alternatively (and less directly), a tropical forest may be logged and sold with the funds then invested in other national assets (such as education), resulting in the conversion of the natural asset to, e.g., human capital. Once species are viewed as human-held assets, they are subject to the processes by which humans determine their optimal portfolio. Species must be viewed as human-held assets, in a positive model, because humans have demonstrated the capability to determine the continuing existence of almost all species on earth.

This indicates the fundamental nature of the forces driving diversity decline. Human societies are driven by the desire to advance and develop, and economic development derives in part from the substitution of the more productive assets for the less productive, i.e. from the conversion process. However, the application of this economic process *on a global basis* is one of the primary forces contributing to diversity decline. This indicates that the fundamental source of diversity decline is the human reconstruction of the global portfolio of biological resources on which they rely, from which most biological resources (the so-called "diverse" resources) are being excluded. When a given species is not selected for inclusion within this portfolio, then it is subjected to the forces for disinvestment that lead to its decline.

Therefore, once species are perceived as "assets", i.e. as competing "means of producing biological product", it is possible to identify general forces that would threaten all life forms with the prospect of conversion. In short, these assets will be converted if they are inferior assets (when compared with competing methods of production) in terms of productive capacity by themselves or in combination with their ancillary resources (land or management).

2.3 Conversions and "Agriculture"

Human usurpation of the evolutionary function of allocating base resources is not a sufficient explanation for diversity decline. It remains necessary to explain why humans would exercise this power in such a fashion as would cause *diversity* to decline. The key to this explanation probably lies in a technological change that occurred originally about ten thousand years ago; this was the realisation of "agriculture" by human societies.

Agriculture has consisted of the selection of a few prey species, and the expansion of their ranges. Prior to the occurrence of this idea, human societies preyed upon the species over the ranges that the evolutionary process had allocated them (hunting and gathering); afterwards, human societies transported the species they used with them, displacing the naturally selected varieties. The discovery of this strategy (domestication and cultivation) and its implementation constituted a very important part of a technological shift that occurred in the late Pleistocene (about ten thousand years ago). This was a process that was important to the advancement and development of human society and civilisation as we know it, but it is also a process that has generated the potential for a decline in biodiversity as a by-product.

Human advancement through agriculture has not been built directly upon diversity decline, in the sense of the overuse and/or mining of biomass. Rather, human advancement has come through reliance upon a small set of species and the expansion of their ranges (at the expense of other species). The expansion of their ranges (with the simultaneous constriction of other prey species' ranges), and the consequent expansion of the human niche (with the simultaneous constriction of other predator species ranges), has resulted in the global homogenisation of the biosphere. It is this homogenisation which, on the one hand, has generated human development, and on the other, has generated the decline of diversity.

The earliest archaeological evidence of agriculture dates back only about to 6000 or 10000 years ago. This consists of the first signs in the fossil records that human societies were selecting individual species and translocating them with their culture. It is now the case that the biological production "menu" for the bulk of all human society has converged upon a relative handful of species. Of the thousands of species of plants which are deemed edible and adequate substitutes for human consumption, there are now only 20 species which produce the vast majority of the world's food. [Vietmeyer (1986)]. In fact, the 4 big carbohydrate crops (wheat, rice, maize and potatoes) feed more people than the next 26 crops combined. [Witt (1985)]. Although it is estimated that humans have utilised 100,000 edible plant species over their history, barely more than 150 species are now under cultivation. [Esquinas Alcazar (1987)]. In short, humans have come to rely upon a minute proportion of the world's species for their sustenance; these species are termed here the "specialised species".

Human choice resulted in biosphere homogenisation not only at the lower trophic levels, by reason of human selection of prey species. It also resulted in homogenisation at higher levels, by reason of human population expansion (and by reason of the elimination of other predators' prey species). Thus, it was at this same time (about ten thousand years ago) that the human species' population began to record unprecedented growth. The development of human technologies (cultivation and domestication) in the neolithic period enormously expanded the human niche, from the capacity to support perhaps ten million individuals to a capacity of hundreds of millions in a relatively short time period. [Boulding (1978)]. Most paleoarchaelogists date a substantial increase in human populations to this period. [Biraben (1979)].

It is this same process of homogenisation that is at the base of the land use conversions described in section one above. These conversions are occurring now in developing countries, and they remain conversions from diverse uses to "specialised" ones (cattle pastures and cropland). The biodiversity problem, as described in section one, is the result of the diffusion of this same process to the last unmodified habitat on earth. Diversity decline is the by-product of this scoping-in process by which the global biosphere is being homogenised for agricultural development.

2.4 Agriculture and Modern Varieties: The Benefits to Uniformity

Conversion as a concept is able to explain the prospect of replacement with regard to every species in existence on earth. Conversion as an economic force explains only why it is the case that the natural slate of biological resources might be replaced by another human-selected slate on any given parcel of land, depending upon relative productivities, but it does not explain why a small number of species would replace millions across the whole of the earth. That is, this force implies conversion but not necessarily homogenisation. In order to explain the global losses of biodiversity, i.e. *a narrowing of the global portfolio*, it is necessary to identify the nature of the force that would generate this homogenisation of the global biosphere.

Specifically, it is unlikely that a wholly natural process would drive the world toward less diversity. This would require the evolution of both biological generalists (species with superior productivity across many niches) and uniform human tastes (across the globe). In fact, the current drive toward uniformity is contrary to the very idea of evolutionary fitness. Fitness implies competitive adaptation to the specific contours of a certain niche. The evolutionary process generates species that are well-adapted to their own specific niches through a process of niche refinement; that is, a surviving species represents a "good fit" to its own niche. (Eltringham, 1985).

It is equally unlikely that human tastes are so uniform as to demand the homogenisation of biological resources. Communities "co-evolve" in order to better fit with the system in which they participate. It would be expected that the preferences of predators would be determined generally by their available prey species. In fact, there is ample evidence to support this expectation that human communities would prefer to consume the resources they depended upon traditionally. (Cooper, 1993; Swanson, 1991).

This confirms that the depletion of diversity is not a natural phenomenon; rather, it is a socio-economic one. The process of the selection of assets for society's portfolio is an economic decision, determined by forces that shape the perceived relative advantageousness of different assets. There is no reason to expect that nature would have evolved these biological "generalists" that are now monopolising global production, because competitive adaptation and coevolution militate against that conclusion. If it is not the naturally-given characteristics of the domesticated and cultivated species that is determining their universality, then it must be some characteristic related to the economic production system of which they are part. In this sense, the process of homogenisation of the biosphere is a wholly economic process, and not a natural one.

What is the nature of this process? It is being generated by the appropriation of the benefits accruing to uniformity. It is not just the particular characteristics of the species that is determining its selection, but also the uniformity of the variety itself. This is indicated by the fact that diversity is declining within species as much so as across species. Human choice is focusing down to the most particularistic level that plant and animal breeding operations allow.

Table 2.3: The Decline in Diversity at the Level of Varieties.

Crop	Country	Number of Varieties
Rice	Sri Lanka	from 2,000 varieties in 1959 to 5 major varieties today 75% of varieties descended from one maternal parent
Rice	India	from 30,000 varieties to 75% of production from less than 10 varieties
Rice	Bangladesh	62% of varieties descended from one maternal parent
Rice	Indonesia	74% of varieties descended from one maternal parent
Wheat	USA	50% of crop in 9 varieties
Potato	USA	75% of crop in 4 varieties
Cotton	USA	50% of crop in 3 varieties
Soybeans	USA	50% of crop in 6 varieties

Source: World Conservation Monitoring Centre, 1992.

This uniformity is important because it is the characteristic of uniformity in the biological asset that renders it combinable with other factors of production in modern agriculture. That is, it is the common and stable characteristics of the modern variety that make it possible to design with particularity the capital equipment (planting and harvesting machinery), chemicals (fertilisers, pesticides), and all of the other ancillary requirements of modern mass-produced agriculture.

Therefore, the degree of homogenisation witnessed in modern agriculture is explicable by reference to the requirements of "mass production". Industries based on these techniques require that their inputs be standardised, so that they are readily combined, in a carefully controlled environment. Of course, this is precisely the nature of modern land conversion trends to agriculture. Land clearances occur in order to create a uniform base upon which to build the new production system. Then, the new system is created around a standard "production method", constituting the particular variety and the tools that correspond to it. The entire monocultural production system is substituted for the diversity that existed previously, and this substitution generates the net loss in diversity.

The nature of modern agriculture generates the degree of homogenisation witnessed in modern farming systems because it is a mass production-based system. Mass production requires uniform inputs and generates homogenous outputs. This change in technique of production explains the decline in diversity seen within human agricultural systems.

2.5 The Diffusion of Agriculture

Even though mass production in agricultural methods requires standardised varieties for implementation, it is still necessary to explain why the same varieties of the same species are chosen for introduction in all parts of the globe. That is, why is agriculture adopted "in whole" rather than adapted "in concept" in many different environments across the face of the globe? The discussion in this section is concerned with the "specialised species", but it relates equally to the problem of "specialised varieties of specialised species".

Homogenisation of the global biosphere requires some sort of nonconvexity in the societal choice set that would cause previous selections to determine later ones. That is, there is the necessity of a spillover between earlier decisions and later choices.

The technological change known as agriculture was of this nature. The idea that originated about ten thousand years ago was centred on the idea of creating species-specific tools and technologies, and translocating a particular species in combination with its techology as a single "method of production". That is, the idea concentrated on the development of the technologies for efficient agricultural production *that were focused upon a single set of species*. The result was the development of two new important factors of production in the production of biological goods: species-specific capital goods and species-specific learning. It is the combination of these factors, together with the specialised species, that generates the force for biosphere homogenisation. As a single method of production (species-tools-experience), the originally selected species are able to outcompete the naturally-existing ones at any given location on account of the tools and experience that come with them. Agriculture became embedded in certain early-selected species.

The accumulation of the capital goods specialised to these species goes hand-in-hand with the adoption of these species. This may be seen wherever the "conversion frontier" exists. For example, the number of tractors in Africa increased by 29% over the past ten years; they increased by 82% in South America; and by 128% in Asia. During the same period the number of tractors decreased by 4% in North America. (World Resources Institute, 1990). Societies that are introducing the specialised species do so in part because these species are tailored to the tools that are used with them. It is the combination of species and species-specific tools that constitutes a "method of production". When a conversion decision is being made, a country will consider all of the possible methods of production (species/capital goods combinations) in a search for the most efficient method.

The other important factor introduced into the production of biological goods was species-specific learning. With more experience with a particular species, it was possible to become even more efficient in its production (by reason of increased understanding of its biological nature, as well intervention to determine the same). This information became another crucial factor for agricultural production, but it existed only in one form - embedded in the received forms of the domesticated and cultivated species.

It is the nature of this final factor that generates the forces for the convergence of the biosphere upon a small set of specialised species. It is the dynamic externality inherent within accumulated knowledge and learning that generates the nonconvexity within the system, so that human choice falls again and again upon the same small set of life forms. Specifically, accumulated knowledge in this context is a *nonrival good* in the sense of Romer (1987; 1990a; 1990b). That is, it is of the nature of a "design or list of instructions" that is distinct from the medium on which it is stored, and thus (as pure information) it may be used simultaneously by arbitrarily many agents without added cost. The accumulated experience in regard to the specialised species is inherent within the capital goods and species as they stand, and is available at no added costliness to the marginal user. (Romer, 1990b).

Agriculture originated approximately ten thousand years ago in the Near East. It consisted of a set of ideas, a set of tools, and a set of selected species. At that time and in that locale, each of these selections was locally optimal. However, the set of ideas-technology-species were transported out of that region as a single unit, as the continuing investments in this combination caused the ideas and tools to become embedded in the chosen species.

A nonconvexity was introduced within the decision making process, by reason of the nonrival nature of the information embedded in the specialised species (that would be costly to produce for any diverse species). This is the essential difference between the specialised (domesticated) species and the diverse (wildlife) species. For one group, an information set is publicly available as an input into their production; for the other, it is necessary to construct that same information.

The global conversion process has consisted of the extension of these chosen species' ranges. As a consequence, much of the face of the earth has been re-shaped in order to suit these few species and the tools used in their production. It is the diffusion of this "bundle" of ideas-tools-species that is at the base of the biodiversity problem.

Just as the initial technological changes within agriculture narrowed the range of species used in biological production, the more recent changes have been narrowing the range of varieties of a species being used. Uniformity becomes increasingly important, as techniques and capital goods becoming increasingly focussed. The agrichemical revolution of the past half-century has focussed agriculture on a small number of varieties for which the characteristics of their predators and nutrient requirements were well-known. The diffusion of modern agriculture became embedded within a method of production that consisted of "specialised variety" - its chemicals - its capital goods; this was the source of the green revolution.

2.6 Conclusion

Biodiversity decline has been portrayed here as the outcome of uniformity within the development process when applied to the biosphere. Human societies realised the possibility of developing the biosphere about ten thousand years ago, with the advent of agriculture. Since that time societies have chosen the portfolio of living assets on which they will rely, rather than using that which nature had allocated to that territory. The chosen species have become a part of the overall "method of production" humans use in biomass production. As this same development strategy has diffused across the earth, it has resulted in the homogenisation of the biosphere, and the decline of diversity.

With the advent of the agrichemical industry, the forces that had shaped the selection of the small set of species that constituted the domesticated or cultivated species were applied at the level of intra-species varieties. The larger investments in species-specific tools and technology required even greater uniformity in the biological asset used in the process. The green revolution was driven by the diffusion of these mutually specialised methods of production: modern variety - specialised chemicals - specialised tools. The conversion of agricultural lands to the technologies implicit within the green revolution meant that the world's agriculture concentrated increasingly upon the same set of modern varieties. This is the process by which development has been in conflict with diversity.

3. The Global Values of Biological Diversity (PGRFA)

The global value of biological diversity derives from its capacity to contribute to the various systems (economic and ecological) upon which human societies depend. One of the most important systems supporting human societies is the "biological production system", i.e. the system that provides the human species with the biological product (foodstuffs) upon which it depends.

This section concerns the value of biological diversity in the support of this system. Ironically, one of the primary means by which human societies have developed their biological production systems is through the **depletion** of diversity. That is, as presented in section two, human societies have created today's biological production system ("modern specialised agriculture") around the idea that the homogenisation of biological inputs maximises biological production; this of course results in the elimination of diversity, especially as this technology diffuses across the entirety of the earth.

The idea of a value of biological diversity for input into biological production systems derives from the premise that the homogenisation of a large part of the biosphere engenders an ultimately unstable system. Small parts of the biosphere may be made homogenous, so long as large parts remain diverse, but as more and more of the biosphere is converted there is an implicit (and rising) costliness to these conversions. Biodiversity must then be maintained in order to contribute to the stability of the specialised system that is replacing it.

This section develops these general ideas of the nature of biodiversity's values in maintaining the stability of the specialised system; that is, it develops a framework to explain how the depletion of biodiversity (in order to enhance the productivity of the biological production system through specialisation) simultaneously reduces the the anticipated productivity of that same system by reason of the consequential losses of diversity and its values.

This section will explore the nature of biodiversity's values: *portfolio effects* and *informational values*. These ideas are explored in some detail here in order to demonstrate the precise nature of these values, and their various components.

These values are shown to be integrally related to the process of biodiversity conversion outlined in section two. The value of biodiversity can only be given meaning within the context of a particular land-use decision, i.e. in determining whether it is socially optimal to convert the marginal piece of land to specialised agricultural production. It is the value that should be considered in determining whether this conversion process should continue unabated.

Section 3 of this paper develops the precise nature of these values. Section 4 then explores the reasons why these values are not being given effect. Parts B and C of the paper (sections 5, 6, and 7) explore the alternative forms of intervention available to rectify this situation, and to internalise the value of diversity in agriculture.

3.1 The Opportunity Cost of Conversions

The previous section developed the idea of a "force for specialisation" implicit within the technology of agriculture. It showed that the introduction of the methods of mass production into the biosphere would result in a process of homogenisation very similar to that which has been witnessed. The by-product of such homogenisation must be the loss of diversity.

FIGURE 1

Figure 3.1 demonstrates one possible framework for viewing the nature of this conversion process. It shows the relative benefits and costs of each successive land conversion (from diverse to specialised species) from both the perspectives of the individual society undertaking the conversion and the global community. The "demand for conversions" represents the average benefits perceived by the society undertaking conversions, which equates with the average benefits perceived by the global community. Figure 4.1 demonstrates that each society will view the average benefits from converting its lands as positive (although declining due to prior conversions and saturated markets) and the marginal costliness (the "supply curve of conversion") as very low and decreasing (due to the positive externalities discussed in the previous section). For this reason the process of conversion continues with no apparent end.

There is another force which should enter into decision making concerning this conversion process. This is the geometrically increasing costliness of the final conversions of diverse resource stocks (or, alternatively, the marginal value of biologically diverse resources). This is represented by the upward sloping *marginal cost curve* in Figure 3.1, which includes the marginal opportunity cost of the loss of these diverse stocks of lands and resources. This curve represents the globally perceived costliness of the next land use conversion by a developing country.

The loss of diverse resource stocks necessarily entail global costliness, in terms of irreplaceable insurance and information services, and hence these losses should be considered as an opportunity cost in the supply of converted lands. The purpose of this section is to explain why it is that the marginal cost curve set out in Figure 3.1 will take this shape.

The marginal cost curve in 3.1 states that the marginal costliness of successive state conversions will be rapidly increasing, once a substantial part of the terrestrial surface has been converted to specialised resources. That is, the costliness of land use conversion is not the same but depends crucially on the number of prior conversions to have occurred. The first land conversions probably had little impact on the aggregate global level of biodiversity, and hence had little impact on the stability and resilience of the then prevailing systems. The last land conversions will have a very different impact on these same systems.

For example, one possible reason for this nonlinearity is the observed relationship between conversions of land area and loss of species stocks is nonlinear. (MacArthur and Wilson, 1967). Species-area functions are said to follow an Arrhenius (log-linear) relationship. Studies in island biogeography demonstrate just such an empirical relationship, indicating that the conversion of ninety per cent of land area results in losses of about fifty per cent of the species diversity. (Wilson, 1988). The real importance of this relationship lies in its implications regarding the final conversions of the residual territory. In general, this final ten per cent of conversions will entail as great of losses of diverse resources as did the initial ninety per cent. Therefore, to the extent that global costliness is directly related to the loss of species diversity, this costliness would be increasing geometrically with the final conversions.

Therefore, with the passage of time (and successive conversions), there are two countervailing forces which should determine the globally optimal stock of biodiversity: the aggregate benefits from specialisation and the aggregate benefits from diverse resources. The conversion process should halt when the marginal global value of the next conversion is negative, or alternatively, when the marginal value of retaining the resources in an unconverted state is positive. In the context of Figure 3.1, the global process of conversion should be halted by the force of the value of global biodiversity at the point of intersection between the marginal cost curve and the demand curve. Clearly, the existence of such opportunity costs to conversion is a necessary condition for the existence of either a problem of biodiversity, or a solution. Their existence is the subject of this section.

3.2 The Distinction Between Marginal and Total Values of Biodiversity

It will be necessary to discuss a couple of definitions concerning the value of biodiversity, in order to make clear the concept under consideration here. First, it is important to discuss the distinction between the value of diverse biological resources and the value of biological diversity. The former is an all-inclusive category, encompassing the tangible and intangible flows of goods and services from all biological resources that exist in areas that have not been subject to human conversion. In contrast, the latter term corresponds only to the value of "diversity" (as opposed to "uniformity" or "homogeneity"); it is the value that flows from the mere fact of nonconversion.

In this latter sense *biodiversity* represents two general components: first, it is the value of the goods and services generated by the evolutionary process (as they encapsulate a 3.5 billion year history of adaptation and coevolution); and second, it is the value of retaining a production strategy on earth distinct from the "specialised" one. These values, i.e. the values of global biodiversity, are the subjects of the latter three subsections of this section.

Using the framework developed in Figure 3.1 a very concrete meaning may be given to the concept of *the value of global biological diversity.* This is the opportunity cost of the conversion of diverse resources to specialised ones. There are both "total" and "marginal" concepts to be distinguished. The total value of global biological diversity would correspond to the total area under the marginal cost curve in Figure 3.1. *The marginal value of biological diversity (MVBD)* would correspond to a specific point on this curve, i.e. the costliness of taking the marginal step in the conversion process.

In both cases the concept corresponds to the opportunity cost of further conversions. However, the distinction is important because one is an operational concept and the other is not. It will never be possible to give precise meaning to the concept of the total economic value of biological diversity. This is because the diversity of life forms on earth is one of the fundamental components for maintaining stability in the biological production system sustaining human societies. As diversity goes to zero (total global conversion), the level of instability introduced implies that there is little prospect for human production systems to sustain themselves over any significant time horizon. Therefore, as conversion spreads to the last corners of the earth, its opportunity cost must be unbounded, as all human-sourced values must depend upon the maintenance of the biological production systems that sustain human societies. This is represented in Figure 3.1 by the area under the marginal cost curve, which is unbounded as conversions approach totality.

The functional notion of economic value as applied to biological diversity is the marginal one. The value of biological diversity cannot be divorced from the sequential decision making process of which it is an essential part. *MVBD* is the global opportunity cost of the **marginal** (or next) conversion.

This section discusses the "stock-related values" of biological diversity. These are the true global values of biological diversity, i.e. the values that flow uniformly to the global community from the mere fact of nonconversion. In the ensuing discussion, the stock-related values of biological diversity are broken down into three distinct components corresponding to their static (*portfolio) value* and also to their dynamic value (i.e. the *expected value of information in the context of retained options)*. The purpose is to explain how the mere fact of nonconversion is capable of rendering global value through the insurance and information that diversity renders to the biological production system.

3.3 The Portfolio Effect - The Static Value of Biodiversity

There is one obvious advantage which diverse resources have over specialised, i.e. their "pooling" capacity. If the global community is concerned not only with the mean yield of its biological resources but also with its variability, then their capacity to reduce global variability (via the pooling of distinct assets) is a desirable trait.

Global conversion upon a small slate of specialised species necessarily increases the variability in global yields. This is because the aggregate variability of all biological asset yields is not the simple summation of the individual variabilities of these assets. Aggregate variability instead depends crucially upon the independence of asset yields, i.e. the absence of a systematic correlation between them. Even if each of the different forms of biological assets has the same innate periodic variability (σ^2), the aggregate variability of these assets is equal to that variance divided by the number of independent assets (e.g. σ^2/C). This is known as the *portfolio effect*, and it derives from the fact that independent variabilities will have a cancelling out effect within the portfolio. (Dasgupta and Heal, 1979).

The reduced portfolio effect is one of the important categories of increasing global costliness with successive land use conversions. There are three distinct forms that this portfolio effect takes in order to reduce variability from the retention of diverse biological resources.

First, there is a species-specific portfolio effect from the use of a nonspecialised species. A specialised species is human-selected for certain traits, and then much of the the genetic material in future generations derives from this single selection, eliminating much internal genetic variability within the species; this is the impact of specialisation on "genetic drift". Specialisation makes use of uniformity in its inputs, and so there are disincentives to the utilisation of the widest range of varieties. A biological resource that is not used in specialised production is itself a wider portfolio because there are likely to be a much larger number of varieties in existence, and therefore in potential or actual use.

Secondly, there is a nation-wide portfolio effect from retaining diverse resources. That is, domestic variability of production can be reduced when the state retains a larger number of independent methods of production. This portfolio effect is geographic rather than biological in origin, but it flows equally from the conversion process.

Thirdly, there is a distinct international portfolio effect. The retention of any single state's diverse resources has the potential to reduce the aggregate variability of global biological production. As in the case of the domestic portfolio effect, this is also a geographic rather than a biological phenomenon, but depends upon the existence of a wider range of production methods in use at any given time in any society on earth.

In order to demonstrate with precision the impact of one land use conversion on the social value of biological production, it is necessary to discuss the general nature of the global system of biological production. First, it is important to note that all biological product used by humans is, at base, the same commodity: the flow of biomass from stocks of base resources (land). This flow might be measured in a common unit, (e.g. usable mass, volume or energy), and then all of the various actual and potential agricultural products would simply represent the usable flows of energy/matter derived from various forms of production. In this schematic, a "species" (or even a specific variety) is simply a distinct "method of production" for a common production unit, i.e. usable biomass.

Then the "portfolio effect" value to retaining diversity derives from the maintenance of a range of different methods for channeling the sun's energy to human society; alternatively, the cost of successive conversions is the increasing reliance of an ever-larger human society (built upon the increased average productivity of specialisation) upon a decreasing number of available methods of production.

To demonstrate this effect and the costliness it implies, assume that the annual production of usable biomass/energy is achieved by means of the use of the range of existing species. Global product is determined by the sum of the global yields for each of the components of Y^d and Y^{sp} (representing the yields from the diverse and the specialised methods of production, respectively). That is, these aggregate production vectors may now be considered to represent D and C observations respectively (corresponding to the number of distinct "methods of production" available in the two sectors) on a common unit of production, i.e. the aggregate biomass/energy output from D+C distinct methods of production. Given this definition, the annual productivities of all species will be a random variable (e.g. defined in terms of energy yield per unit of base resource), which may be described by reference to the various moments of its distribution in a given year.

In order to make the analysis most straightforward, let us assume that each country with a "specialised production sector" produces a vector of specialised resources of the same dimensionality, c. This is a selection of methods of production from the "global menu", C. Therefore, this would indicate that each country produces, say, a dozen distinct specialised commodities (i.e. c=12) chosen from a menu of about one hundred (i.e. C=100) for which modern agricultural methods of production are generally available.

Countries with substantial quantities of nonspecialised lands in biological production produce a much wider range of outputs (each country having distinct methods of production of dimensionality d) chosen from a much wider range of possibilities (of aggregate dimensionality D). For example, the number of nonspecialised "traditional food and fruit crops" in any one country might be, say, in the hundreds or thousands (i.e. d=1000,say) while the aggregate number of globally available edible foodstuffs has been estimated to be at least two hundred thousand (i.e. D=200000). (Esquinas Alcazar, 1993).

Therefore, the key difference is the dimensionality of the production methods available. In point of fact, states with substantial quantities of unconverted lands choose their individual production vector from an aggregate vector Y^{sp}, whose dimensionality (C) is measured only in the dozens. In contrast, the dimension d is probably in the hundreds or thousands, and the dimension D is certainly in the millions.

The difference in dimensionality is important for the creation of a "portfolio effect" both locally and globally. Any state that retains its diverse resource vector rather than converting to the specialised maintains a much broader range of assets upon which to rely (d rather than c). Equally, this state is also investing in maintaining the existing dimensionality of the aggregate diverse resource vector (i.e. D); this contributes to the portfolio effect at the global level. Finally, the narrower range of diversity inherent within a specialised variety (e.g. the smaller number of varieties in use) means that there is a narrower portfolio with regard to that individual crop. These three portfolio effects may be derived analytically to produce the following expression for the aggregate portfolio effect derived from nonconversion of the marginal lands.

MVBD - Portfolio Effect (PE)

These terms give precise meaning to the various components of the global portfolio effect, as described above.

The main equation in (3.1) gives the expression for the aggregate value lost from the conversion of the marginal lands in a given country from "diverse" to "specialised" methods of production. (This conversion is represented by a change in output from these lands from y^d, dimensionality d, to y^{sp}, of dimensionality c). The equation states that such a change in production methods (motivated by the pursuit of increased average yields) must necessarily incur a loss of value in terms of the portfolio effect.

Terms (A)-(D) separate out the various components of this general portfolio effect.

Term (A) indicates that the portfolio effect derives from the impact of variability on society. If global society did not care about the riskiness of variability, then there would be no loss of value by reason of the loss of the portfolio effect. However, societies do care about risk and this is indicated by the nonlinearity of their objective functions (which will be discussed in more detail in the next section); this aversion to risk is indicated by the expression of nonlinearity in (A) (i.e. $W''<0$).

Term (B) represents the species-specific portfolio effect, in that the use of a species in a traditional farming practice implies the retention of a wider range varieties, and these represent distinct methods of production in and of themselves (thus generating an aggregate variability that is less than that for a specialised species that consists of a single variety). In essence, there is a portfolio-effect-within-a-portfolio-effect here; the variability of the diverse species is reduced by the number of independent methods of production (varieties) that its retention implies. More generally, a diverse or traditional food crop contains a wider range of genetic variability than does a specialised. For each diverse species, the inherent variability of production is reduced by reason of this innate portfolio of distinct characteristics.

Term (C) captures the idea of greater variability stemming from the use of a smaller slate of resources within the boundaries of a particular state - the intra-national portfolio effect. Assuming that each species represents an "independent" method of production, in that the production from each is not correlated with that of other distinct species within that state (because different pests and environmental conditions affect each differentially), a wider menu or resources will reduce intra-state variability. This portfolio effect derives from the division of the variability of the product from the respective sectors by the number of species inherent in each; since the number of species is much lower in the specialised sector, the net effect of conversion is a loss of this "pooling effect".

Term (D) captures the nature of the interaction between production methods in use in the various states. For the group of countries whose lands are planted in specialised crops, the aggregate variability of the group must necessarily be greater because the productive assets are more closely correlated. That is, there is less opportunity for production effects to "net out" across distinct assets; this implies a higher covariance (cov). Therefore, the marginal state's decision to convert its lands from diverse to specialised production will necessarily increase the covariance of global yields - a reduction in the international portfolio effect.

Therefore, the conversion of marginal lands from the traditional to the "modern agricultural sector" represents an unambiguous increase in global yield variability, precisely because this conversion represents a small movement on a global basis towards universally more specialised production. To the extent that global variability matters to human societies, then the increasing average yield from the conversion of biological production systems must be traded-off against the also increasing variability of these same yields.

It is important to emphasise that this is not a form of variability that can be resolved through other forms of insurance contracting, as this is increasing *global variability*. This will be developed further in section 4, but
it is worth flagging here the point that the retention of diverse genetic material is the only method for retaining the beneficial impacts of the portfolio effect outlined here. The "insurance" provided in this way cannot be provided through any other form of financial market or governmental intervention, but only by means of halting inefficient conversions.

3.4 Dynamics (Exogenous Information): "Quasi-Option Value"

The portfolio value of diversity is an entirely static concept; that is, it is a concept that exists independently of all considerations of time. Even if there were no concern whatsoever for next year's harvests, it would still make sense to invest in a portfolio of distinct assets in order to assure this year's harvest. The remainder of this section will discuss the nature of the values of diversity that depend upon the importance of the temporal dimension, i.e. these are values that exist because the future matters to society. We are concerned about biodiversity not simply because it will assure today, but equally because it can contribute to tomorrow.

One of the meaningful facets of the passage of time is the accumulation of information, in the sense that an uncertain outcome is revealed in a subsequent period. Making decisions concerning the future implies choosing a path under conditions of uncertainty. The passage of time gradually erodes this uncertainty by supplying "information". Information is acquired when outcomes arise that demonstrate how decisions in the past should have been made, and better indicate how decisions for the future might be made. In decision theory, information accumulates over time in the sense that outcomes of random variables affecting the decision maker's framework are revealed, and beliefs as to the future are better defined. (Cyert and DeGroot, 1987).

Placing the problem of global biodiversity into a dynamic decision making framework also places the role of information accumulation at the core of biodiversity. This gives a very specific meaning to the passage of "time": it is the process by which relevant information arrives at the decision maker. (Then, information may be seen as valuable by reason of eliminating relevant uncertainties with its arrival). Therefore, in a dynamic framework, halting the conversion of lands still in diverse resource production equates with "buying time", and a society would want to "buy time" for the accumulation of information that this implies.

This makes the expected value of this information one of the important categories of value to be derived by halting the conversion process. This value of biological diversity is unambiguously positive when two conditions are met: 1) if information relevant to decision making does in fact arrive over time by reason of an exogenous process; and 2) if the conversion of the marginal state's resources reduces the dimensionality of the biological production system (i.e. D+C as defined above). These conditions guarantee nonnegative value because an irreversible narrowing of the choice set over time (in terms of reductions in the dimensionality of the gross biodiversity vector) renders information useless which would be otherwise valuable in the decision making process. Information is valuable, but only if the choices that it implies remain available.

This makes clear what the concept of *option value* means in the context of biological diversity. It represents the value of retaining the larger choice set until the next period's information arrives. It is, strictly speaking, the *value of flexibility* in sequential decision making, or *the expected value of information*. (Conrad, 1984; Hanneman, 1990). Its value in this context is clearly positive.

This result differs from much of the literature on option value, which is inconclusive as to the sign of option value. (Johansson, 1987). The unambiguity of the result in regard to biodiversity is derived from two premises. First, the framework developed here focuses on a global process represented as a sequence of restrictions of the global choice set. That is, this framework presents the problem of global biodiversity as a sequential narrowing of the choice set with regard to the methods of production ("species") available for capturing biological product. If two distinct sets have an equal number of different elements (or two production vectors have common dimensionality but distinct components), then "option value" (the value of selecting one set rather than the other) is indeterminate *ex ante*. However, the problem of global biodiversity is best represented as a narrowing of the entire global choice set (of the available methods of production) rather than a substitution between elements, and the value that this flexibility implies when relevant information arrives. Then, the fundamental reason for indeterminancy is removed. (Dasgupta, 1988).

The primary reason that option value is clearly positive in this analysis is attributable to the specificity with which that term is used here. Here the "option value" of biological diversity refers only to the dynamic values flowing from *diversity*, and this excludes many of the other values of diverse biological resources. Specifically, option value as a concept most appropriately applies only to those values that flow from the existence of a dynamic facet to a problem, and the uncertainty inherent in decision making across time. (Miller and Lad, 1984; Pindyck, 1991).

Option value is thus restricted here to mean only the value to be derived from retaining flexibility within a sequential decision making framework. With the arrival of information over time, the value of this retained flexibility must be positive. In this sense, the option value of biological diversity must always be positive. It is more accurately related to the idea of "quasi-option" value. (Arrow and Fisher, 1974).

This value of diversity derives from another form of "portfolio effect", but this time it is the value to be derived from maintaining a wider portfolio of assets for the purpose of reducing variability across time; it is a "dynamic portfolio effect". Uncertainty implies a degree of variability with regard to expected future yields; retaining diversity is a means of investing in options that may prevent excessive volatility under certain future conditions. It represents a trade-off of reduced current yields for an increased assurance of some minimum level of yield in the future. In this sense this "informational value" of diversity is another form of "insurance value" as well.

In the case of biodiversity it is the value of the **enhanced expectation** of future benefits to be received by virtue of the maintenance of a wider portfolio of assets in the present. The value to be received will ultimately flow to the global community in terms of either increased mean yields or reduced variability; however, retaining these options has value in excess of the discounted value of the benefits to be received. Societies wish to assure their flows of biological product across time as well as across space; again, there is no substitute for the retention of a diverse portfolio of assets in order to perform this purpose.

Finally, it is only important to retain options to the extent that it is anticipated that "information" will arrive exogenously (out of the environment) to render these options important for future decision making. It remains to explain why it is that this will occur. In sequential decision making, information is the occurrence of nondeterministic change in the decision making environment. That is, between periods there must be some relevant alteration in the environment that cannot be predicted with certainty; the passage between decision periods reveals the "state of nature" which could otherwise only be probabilistically projected. It is this sort of unknowable uncertainty that is at the base of a positive "option value".

The nature of the biological world assures precisely this result. It is the very essence of a dynamic system, in which the processes of mutation, selection and dispersal continuously alter the natural "state of nature". In regard to small organisms, such as bacteria, viruses, and insects, these biological processes can occur very rapidly, literally reproducing thousands of generations in a single year. The biological process is evolutionary, not deterministic, and to the extent that it can be understood, it is too complex to predict.

It is the continuous state of motion within the biological world which guarantees that time produces relevant information. The nature of this information in a biological world is the type and extent of the shifting of the human niche. The insurance that we have for adapting to such shifts is the diversity of the species upon which we rely, or upon which we might rely. Marginal conversions represent losses of such options. The expected marginal value of biological diversity includes as a component the expected value of receiving information prior to the foreclosure of options. The value of this component is clearly positive.

3.5 Dynamics (Endogenous Information): "Exploration Value"

It was noted above (in equation 3.1) that the intra-species variability would be lower for a diverse species than for a specialised one, on account of the portfolio effect that would exist across varieties. This is true by definition because specialised production would involve the use of many fewer independent varieties than would traditional production; this would imply highly correlated production and hence higher variability.

This is the implication of the static analysis; however, in the dynamic case, the result is reversed. This is because specialised production would be directed toward high mean/low variability biological assets. The variability occurs in the aggregate, because so many individuals specialise in precisely the same assets; this derives from a high covariance in production from the use of assets that in fact have low individual variability.

The result is reversed when the use of these same varieties is analysed over time. Over many years of use, the individual distributions of the yield from specialised biological assets will be very well-known, implying a very small amount of information to be gained from their use. Unused, and less-used, biological assets are relatively unknown quantities. The expected variability of any individual nonspecialised biological asset is quite large over time, especially relative to its expected mean, precisely because so little is known about it. That is, the expected information to be acquired from the exploration of these commodities is much higher than it is with the specialised assets (on account of their relative obscurity), and this *exploration value* is positive. This is termed the expected value of endogenously generated information, because in this case the value of diversity derives from the increased flow of information that results from making use of diverse forms of resources.

Therefore, nonconversion not only maintains the choice set at its differentially greater size, it also maintains the information flow at its differentially greater rate. The marginal conversion reduces the potential information set and the potential choice set in a single act. The reduction of either alone is costly in a sequential decision making framework. Therefore, the expected value of endogenous information is also invariably positive; it is the value of retaining options that may turn out to be far more valuable than is presently known given use and investigation.

3.6 Conclusion - The Global Values of Biological Diversity

The global value of biological diversity has been given a very specific definition in this section. It is the global impact of the marginal conversion of land use to specialised biological resources. This global impact has four components, two static and two dynamic (i.e. information-based). The information-based values of biodiversity will ultimately feed through the static components; however, in any given period there is also the expected value of this future flexibility.

The Components of the Value of Global Biological Diversity

(A) Net Mean Yield Differential -
This is the difference in expected average yields between the use of land in a traditional versus a specialised form of production. In general, this difference is pronouncedly negative, and it is the driving force behind the conversion of land use and the loss of biological diversity.

For example, any given individual contemplating the conversion to high yielding varieties will be enticed into doing so by reason of the expected gains in average yields. The impact in aggregate has been the "Green Revolution": the increase in worldwide grain yields at a rate of nearly 3% per annum over a period of thirty years.

(B) Porfolio Effect -
This is the static value of the retention of a relatively wider range of assets within the biological production system. This generates value so long as a society is averse to risk and thus has a distaste for yield variability. Yield variability is smoothed by reason of nonconversion because this implies: 1) a broader portfolio of assets (varieties) within the species; 2) a wider portfolio of assets (agricultural commodities) within the country; 3) a wider portfolio of assets (available methods of production) across the globe.

The studies of crop yield variabilities during the course of the green revolution have indicated that there has been a corresponding increase in variability going hand-in-hand with the increased average yield. (Hazell 1990). The studies further demonstrate, that the vast majority of this enhanced variability is traceable to the reduced portfolio effect across space (inter-national and intra-national) rather than within species.

(C) Quasi-Option Value (Options given Exogenous Information) -
This is the value of retaining a wider portfolio of assets across time given that the environment is constantly changing and rendering known characteristics far more valuable than they are currently considered.

For example, this is the value of the retention of certain varieties of cultivated species (unknown to be of any great value) but which are found to be of enhanced value when a particular form of pest or disease becomes more prevalent. It is the change in the value of a known characteristic by reason of an unforeseeable change in the environment.

(D) Exploration Value (Options given Endogenous Information) -
This is the value of retaining a wider portfolio of assets across time given that the exploration and use of these assets will generate discoveries of currently unknown traits and characteristics.

For example, this is the value of the retention of a given area of forest because it is possible that certain wild relatives of cultivated varieties will be found within that forest, and these relatives may generate new and valuable characteristics if investigated. It is also the category of value that would apply to the retention of a particular variety of

More importantly, it is the value of the retention of some manner of evolutionary process intact for lesser-used varieties, in the event that some unforeseen trait might be developed over time. For example, the continued cultivation of a wide range of varieties of wheat within a natural environment might result, through interaction with nature and the farmer, in the unforeseeable generation of a desirable trait (such as general drought intolerance). This is because there are a large number of suppressed traits within the body of any given phenotype, which may come out in response to use under a wide range of natural conditions over time.

The Marginal Value of Biological Diversity - Process and Policy

The values of biological diversity developed within this section have been formulated in a particular way for a specific purpose. They are representative of the values that exist that should be given effect for the purpose of halting the process of conversion within agriculture. This is the meaning of the concept of "the marginal value of biological diversity": it is the counterweight to the value of increased production from modern high-yielding varieties.

The "marginal value of biological diversity" is equal to the sum of the values of terms (B), (C) and (D), and this value is strictly positive in the context of the decision whether or not to convert the marginal piece of land to modern agricultural varieties. It is also clear that the value of term (A) has been pronouncedly negative over many years, inducing successive resource conversions by individual farmers worldwide.

The problem of global biodiversity exists because the values represented by (A) are wholly appropriable by the individual farmer electing to convert its land, while the values (B), (C), and (D) are only appropriable to a very small (and increasingly small) extent by that farmer (as will be developed further in section 4).

The role of global biodiversity policy is to halt conversions at the optimal point in the conversion process in order to preserve the flows of the values (B), (C) and (D). (Term (A) represents the "incremental costs" of biodiversity supply within this context, i.e. the opportunity costs undertaken by any one country if it is to supply the global benefits represented by terms (B), (C), and (D).) Part B of the paper will discuss the alternative policies available for this purpose.

4. Externalities in National Portfolio Selection: Unappropriated Values

Species are particular forms of "natural capital", i.e. they are assets (from the perspective of human society) potentially useful for their capacity to generate goods and services to that society. For this reason, humans have an instrumental objective to fulfill in retaining other species on earth - for the flow of goods and services that they will render to humans.

However, as with any asset subject to human determination, societies must also determine in which forms of assets they will invest, and in which they will disinvest. There is no reason, in economics, that the naturally-determined portfolio of "natural assets" would be the human-preferred portfolio. For this reason each species is subject to individual appraisal in the process of determining the portfolio of assets.

This section considers the theory that explains how humans determine the precise portfolio of assets that they will hold. It will also explain the extent to which individual portfolio construction derives from that preferred by their societies, i.e. how governmental policies drive individual portfolio determination. Then it will compare the aggregate portfolios that these choices imply with the portfolio that would be preferred by the global community. This section will demonstrate that there is reason to believe that individual societies will invest insufficiently in diversity, unless the global community intervenes to correct for the difference between national and global objectives. In effect, the "global values of biological diversity" (as outlined in section four) are not given enough weight by individuals and nations in making their conversion decisions, due to the unappropriated global values of diversity.

4.1 The Economic Theory of Optimal Portfolio Selection

Portfolio selection theory has been developed for many years in the field of financial economics. (Merton, 1992). The basic idea of portfolio theory is that individuals will select an optimal portfolio of assets by considering both the aggregate mean yield and the aggregate variability of the set of assets. That is, any particular asset (x) will be seen as generating a return that will be variable under differing conditions, but it will also be generally known what the average yield (the "mean" μ) and the variance around that average (the "variability" σ) will be.

Financial theorists noted long ago that individual investors would not simply choose that portfolio that maximised the expected value of the set of assets, i.e. the portfolio that would consider only the means and not the variabilities of the assets. This is because individual's objective functions (with regard to the benefits received from a set of assets) are not linear; they are "concave". This means that the individual is more concerned with getting some flow from the set of assets rather than getting the maximum amount of flow, i.e. the individual values the first units of flow from its portfolio moreso than the last. Therefore, variability becomes an equally important concern of the individual (as the mean), in that it might place some of the "first units of flow" into jeopardy.

Financial theorists have postulated that individuals respond to uncertainty in the construction of their portfolios by behaving as if they balance both mean and variability when making their decisions regarding assets. This implies an objective function that would be something as follows:

The Mean-Variance Framework in Optimal Portfolio Theory:

$$\max_{x} \; U(y) \equiv \mu_y - A\,\sigma_y^{2}$$

$$\begin{aligned} \text{where: } U(y) &\equiv \textit{theflowofbenefitsyfromaportfolioofassetsx} \\ \mu_y &\equiv \textit{themeanyieldfromtheportfolio} \\ A &\equiv \textit{the Pratt - Arrow index of absolute risk aversion} \\ \sigma_y^2 &\equiv \textit{the variability of the flow from the chosen portfolio} \end{aligned}$$

Therefore, in this theoretical framework, individuals construct their optimal portfolios by weighting the impact of an asset on both the aggregate mean and the aggregate variability of the portfolio's yield. The weight given to the variability of the portfolio is dependent upon the individual's relative "risk aversion", i.e. the person's distaste for riskiness in return.

"Risk aversion" is simply another term for describing the non-linearity of the individual's objective function. The more that the individual places greater weight on the first-received benefits than the last (i.e. the more curvature to the objective function), the more averse is that individual to riskiness. The "Pratt-Arrow measure of absolute risk aversion" is a measure of the curvature in the individual's objective function, and it provides one such index for weighting the individual's relative concern for riskiness in portfolio returns.

The implication of the mean-variance framework is that individuals will take the variability of yield into consideration when constructing their portfolios. There is ample evidence to support the applicability of the M-V framework in the context of individual farmer decision-making concerning the choice of crop varieties to plant. (Robison and Brake, 1972; Hanson and Ladd, 1991; Herath, Hardaker and Anderson, 1982). All of these studies, and many more, indicate that farmers select from the entire menu of available crop varieties (tradition and specialised) in order to construct their individually optimal crop portfolio. In many cases, these farmers will select some portion of "traditional" varieties and some proportion of "high yielding" (or specialised) varieties in order to accomplish this object. Therefore, it is apparent that farmers are risk averse, and that they take this aversion into consideration when deciding upon the set of crop varieties they will use; therefore, the portfolio decisions of individual farmer's are driven by concerns about both maximising yield and minimising variability.

The remainder of this paper analyses the extent to which farmers' decisions will reflect the global values of diversity, as developed in section three. Specifically, this implies analysing the extent to which individuals will demand diversity for their **insurance** and **informational** characteristics. Section 4.3 analyses the factors that determine the extent to which individuals will demand diversity for the assurance that it will provide, and section 4.4 explains why this will necessarily be deficient (given the failure to appropriate the full values of diversity). Section 4.5 turns to the facet of informational value, and demonstrates how this will be similarly undersupplied due to appropriation failures.

4.2 The Individual Demand for Diversity - Insurance

Not only will individual farmers take both means and variability into account when constructing their portfolios, they will also pursue the assurance of a minimum level of production in constructing their portfolio. In financial economics this is known as the "Cox-Wang nonnegativity constraint"; in the context of agricultural choices, it is known as the "Cash Crop - Food Crop" decision.

The Cox-Wang nonnegativity constraint simply states that individuals will incorporate the downside risk of a complete loss of income into their portfolio decision making process. That is, under certain conditions (e.g. the absence of credit markets), it is simply not feasible to allow the yield from the portfolio to fall to zero. Then, the individual constructing the portfolio will take this absolute constraint into consideration when choosing the assets within the portfolio. (Merton, 1992).

In particular, the nonnegativity constraint implies that, if there is a particular asset (or set of assets) for which the uncertainty concerning its variability is virtually zero (because its distribution is well-known and stable), then this asset will be used by the individual like a surrogate insurance policy. In effect, the particular asset will be included in the portfolio (even if its average productivity is much lower than other available assets) to the extent that the individual wishes the assurance of some minimum return.

This analysis is shown in Figure 4.1 below. It shows the set of available assets within the shaded region, demonstrating the range of means and variabilities that they are expected to produce. While to the left of this set lies another asset, with a relatively low mean and a relatively low but certain variability. The individual consumer will use a combination of the optimal portfolio selected from the assets available together with the "assurance asset" in order to avoid a worst-case of negative income.

[Figure 4.1]

This general analysis applies equally within the agricultural context. In essence, farmers will want to select their set of crop varieties in order to provide achieve their own mean-variability trade-off, but also to assure the achievement of some subsistence level of food supplies.

This is the basis for the cash crop-food crop distinction. Farmers will plant some crops to the extent that they are assured to produce a subsistence level of edible matter. After that level is assured, they will then plant whatever set of crops it is that will achieve the optimal cash flow (given their individual trade-off of mean and variability in the flow of cash). Again, this has long been known and established within the context of portfolio choice between traditional and high-yielding varieties; farmers will plant the traditional varieties to the extent that they will provide the necessary assurance of subsistence. (Nowshirvani, 1971).

Therefore, there are in-built forces for the maintenance of diverse resources within individual farmer's portfolios. These diverse resources will be retained by individual farmers for several reasons:

a) the contribution to that farmer's portfolio's mean yields;
b) the contribution to that farmer's portfolio's reduced variability; and
c) the contribution to that farmer's assurance of subsistence.

In addition to these supply-side factors in favour of diversity, there is also the demand-side impetus for its retention. The primary reasons why individuals would demand diverse resources would be attributable to locally-evolved preferences and/or micro-environments. (Brush and Taylor, 1992; Cooper, 1993). Given that there are reasons in "tastes and technology" for the retention of diversity (preferences and assurance), and there are agents capable of registering and implementing these reasons (the farmers), it remains to explain why it is that there is an inefficient bias against diversity. That is, given the capacity of individual farmers to construct individually optimal portfolios, it remains necessary to demonstrate why these portfolios are suboptimal. Otherwise, there is no biodiversity problem, only the conversion of the former portfolios into new, improved portfolios.

4.3 Farmer Substitution for Diversity-Supplied Assurance

Clearly, individual farmers have an incentive to invest in the acquisition of assurance for their annual incomes, and this often equates with assuring their annual harvests. In the past this assurance was nearly always supplied through the mechanism of the crop itself, by means of investment in a diversity of crop forms. Currently, this is not the case. For most farmers, there are now many other avenues to the acquisition of insurance other than the crop itself.

The suboptimality of individual portfolio construction lies in the substitution of "inappropriate" forms of insurance for diversity-supplied assurance and the nonappropriability of certain forms of services of diversity. The former will be outlined in this section; the latter in the next.

As stated above, individuals will supply themselves with some form of subsistence assurance whenever this is possible, even by means of the manner in which they will select the productive assets on which they will depend. In that instance, they will select some well-known forms of assets that act as the assurors of their survival. In the past, this motivation equated with the use of a diversity of traditional crop forms.

However, now the individual's motivation to supply diversity as assurance will be much reduced. This is because there are other means by which the individual may be supplied with "subsistence assurance" other than the use of traditional varieties. These methods (surveyed below) include:

1) the substitution of other biological assets for the traditional varieties;
2) the substitution of other (usually human) assets for biological;
3) the accumulation of other (financial assets) and the substitution of "self assurance"; and
4) the substitution of other (governmentally supplied) assurance.

In essence, the farmer's objective is solely to assure for one season's subsistence, and to the extent that any asset is available to accomplish this objective, it is a substitute for this traditional role of diverse resources. The increasing availability of new markets, of governmental assistance and of information on new varieties renders the old method of assurance unnecessary.

4.3.1 The Substitution of New Varieties for Traditional

At the initial introduction of new varieties into new areas, there was little information or experience with these assets as compared with the traditional varieties. However, in one generation's usage, this relationship can be reversed, and the new group of farmers may become far more accustomed to the new varieties and the new methods of production. Then there is no assurance value to the old varieties, even if they have been used in the region for hundreds or thousands of years. In essence, the information set involving traditional varieties (which provides the relative amounts of assurance accruing to the different crop forms) can be lost in a single generation and replaced by the information available on high yielding varieties. Then this information serves as the insurance for individual farmers.

4.3.2 The Substitution of Other Assets for Biological Ones

One of the clear relationships in the adoption of exclusive reliance upon high yielding "cash crop" varieties is the correspondence between the integration of the rural markets and the decline of "food crop" production. When a rural area is better-connected by roads and transports to population centers, the conversion to specialised crop production occurs quickly and completely. (Fatchamps, 1992). Some studies have even noted that the distance to a metropolitan area closely correlates with the degree of adoption of modern agriculture. (Brush and Taylor, 1992).

This result is probably best-explained within the assurance framework as well. The availability of the urban centre provides not only the obvious market for the produce, but more importantly it provides a market for any other assets of the farmer as well.
In particular, the rise of urban areas and industries within developing countries provides a readily available outlet for surplus rural labour supplies occasioned by reason of seasonal crop failures. If this should occur, there is now an alternative source of income (through the application of the farmer's

labour) other than the land. This outlet market provides an alternative source of assurance for the farmer, and thus displaces the traditional crop varieties.

In essence, the integration and industrialisation of formerly traditional economies makes the value of other forms of capital (in this case, human capital) realisable on short notice. This characteristic is known as "liquidity" of assets, and the point here is that the modernisation of economies renders many forms of assets more liquid, and hence there is a reduced demand for subsistence assurance through agricultural methods.

4.3.3 The Accumulation of other Marketable Assets

The availability of an urban center in an industrialising society renders other assets of the farmer susceptible of liquidation in times of distress, but equally importantly it also maintains some level of "effective demand" for these assets. In a non-industrial society, when the rural area was entirely isolated, there were no buyers for farmers' assets in times of distress; all incomes in the region moved together. The development of industry within these countries unlinks the fortunes of country and city dwellers, so that there are some still-existing markets in times of rural distress. This means that any accumulated assets of the farmer (tools, animals, cash) can be translated into income in times of crop failure, serving as assurance for that event.

4.3.4 Conclusion - The Substitution for Diversity Assurance

The literature on cash crop versus food crop production has found that specialisation within the agricultural sector follows on from the integration of markets into a developing economy. The effects of such variance are found to be "lower variance in prices, less covariance between individual output and aggregate supply and more elastic demand because of trade possibilities". Such integration has been found to be a determinant of the rate of modern agricultural adoption throughout the Third World. (Fatchamps, 1992).

In essence, what is occurring here is the substitution of other forms of assets as assurance mechanisms for the role formerly played by diversity. This is entirely rational behaviour from the perspective of the individual farmer, as the only form of assurance desired by the individual is something to assure "subsistence" in the event of crop failure. In that case, the ability to liquidate other asset forms in the event of a crop failure is adequate to meet the requirements of the individual's limited objective.

The problem is that the individual farmer formerly performed this function in a way that also satisfied the objectives of global society, i.e. the object of preserving diversity for the global values described in section 4. The acquisition of self-assurance through asset liquidity solves the farmers' assurance problem without addressing the global objective. These methods of "self-assurance" in times of crop failure allow the farmer to select a crop portfolio that ignores the problem of yield and income variability.

In the final analysis, it is the role of government to ensure that individual objectives coincide with societal ones. In this case, it is clear that economic forces are driving a wedge between the two. Section 4.4 analyses how governments might be expected to respond to this divergence, and presents some evidence on how they in fact do this.

4.4 Governmental Incentives to Supply Diversity

The analysis of section three demonstrated that diversity could supply assurance through the "portfolio effect", both by providing a diversity of production methods across space and across time. Individuals operating on an individual plot of land would have an incentive to utilise this "portfolio effect" to assure themselves, as was indicated above, in the absence of other means of insurance. Now that other means are available, this assurance is no longer being provided by the individuals. They are now pursuing the highest average yield, and acquiring insurance by other means.

It is the government's role to ensure that in the aggregate the optimal level of assurance is being provided for that society. This section examines whether individual governments have adequate incentives to provide the optimal amount of diversity for insurance purposes. The short answer is that governments do not have much incentive to supply the optimal level of diversity, because only a small proportion of the benefits from diversity are appropriated by the supplier state. Therefore, governments will have the incentive to encourage their citizens to pursue high yielding varieties (rather than diversity), and the evidence indicates that this is what they in fact do.

Although insurance and information are very different values emanating from biodiversity, they are the same for the purpose of the analysis of the externalities and policies of concern. Insurance simply relates to those values of diversity that concern variability reduction, while informational values may ultimately take the form of either mean enhancement or variability reduction. In the remainder of this analysis, we will focus exclusively upon the analysis of insurance values (with the implication that the values of diversity that take the form of mean enhancement may be addressed in analogous fashion).

A country investing in diversity will necessarily provide "insurance" for both itself and the remainder of the world; this insurance may be of any one or more of four possible types.

a) intra-species portfolio effect;
b) intra-national portfolio effect;
c) inter-national portfolio effect; and
d) informational values for reduced variability.

"Insurance" is the payment of a fixed premium (here, the foregoing of the increased mean yield from high-yielding varieties) in return for a reduced amount of variability (here, the generation of values under certain conditions that would not otherwise exist). The portfolio effects described in section three are clear instances of pure insurance values: the reduced mean yield is sacrificed in exchange for reduced correlations between yields.

As mentioned, the informational values described within section three may take either of two forms: yield-enhancing or variability reducing. Quasi-option value is an insurance value when it derives from the retention of a wider range of characteristics in order to solve certain unforeseeable forms of problems (with severe downside implications) that may arise under unpredictable future conditions. Exploration value is an insurance value when it derives from the retention of a set of phenotypes in the event of the possible identification of an already-existing but unknown trait for use to reduce variability (for example, the identification of a suppressed capacity for drought resistance).

The core problem of the undersupply of biodiversity derives from the failure of "host societies" (i.e. the citizens of states hosting diverse resources) to appropriate all of these various values from diversity. Many of the above values of biodiversity flow generally to the benefit of all of the peoples of the earth, rather than specifically to the persons actually retaining the diversity.

First, consider the facet of the portfolio effect that is wholly internalised, i.e. the intra-national PE. This effect indicates that the conversion of a society's diverse resources to specialised varieties will result in an enhanced variability in **national** agricultural output. This results from the fact that all farmers' harvests are now linked to the same set of environmental conditions; if the conditions are too cold, or too wet, or a certain sort of pest appears, then all farmers' harvests are affected similarly. The consequence is that there is no "cancelling out" of differing effects of similar conditions, and hence there is enhanced variability in yields.

The impact of this form of enhanced variability will be internalised to this society, because the effects will be felt by no one else other than those within the country. Therefore, the state should be concerned to provide the optimal amount of assurance for the portfolio effect that is wholly intra-national.

On the other hand, the state will take little notice of the portfolio and informational effects that provide global as well as national benefits. The two most significant forms of this effect are the inter-national and the informational effects.

The loss of the inter-national portfolio effect derives from the increasing losses of diverse resources globally, and the impact of these losses on the stability of all biological productions systems on which humans rely. As much of the biosphere becomes increasingly concentrated on just a few varieties, the issue of the stability of the entire system is raised. Although a single conversion of diverse resources contributes only marginally to this effect, the aggregate impact of total global conversion must be very destabilising (as shown in Figure 3.1). (This analysis is very similar to the analysis of "Global Warming": a phenomenon for which there is a clear potential for catastrophe but great uncertainty as to the location of the "danger level").

The informational/insurance values of biodiversity retention derive from the prospect of identifying new methods for minimising variability in food production within retained stocks of diversity (through discovery of unknown traits or realisation of unforeseeable conditions). Any individual country may be willing to invest in its diversity retention to the extent to which it will itself benefit from this strategy, but it will fail to take into account all of the benefits that this strategy may render to other nations (because it will view such benefits, under existing property rights systems, as nonappropriable).

If a single governing body managed the entirety of the globe's biosphere, then the correct objective would be for it to manage the process in order to take these effects into account. The result would be an aggregate amount of unconverted lands retained for their contribution to the stability of the production system, in a manner that would maximise global as well as local food security.

In general, the existing incentives are for individual states to ignore the majority of the value of biodiversity's retention. This is because each state will only benefit by a fractional amount for the actions that it takes to assure against global instability, but it must itself bear the full costliness of the investments that it must take to afford that insurance.

This is the problem of a "global public good": it is a good or service that all of global society wishes to provide but for which there is no generating mechanism in place. Therefore, in a world in which land use conversions are wholly regulated by individual sovereign states, it is axiomatic that there would be certain "global public goods" that would go unprovided; there is simply no mechanism in place to register the inter-national impacts of these individual state decisions. This form of externality affects each of the forms of insurance that are listed above other than those with wholly intra-national effects.

4.5 Governmental Responses to the Incentives to Supply Diversity

It is apparent that most of the impacts of investing in diversity flow globally, resulting in little incentives for states to take these benefits into account in determining their agricultural (and land use conversion) policies. The result is that most governments provide very few if any incentives for their citizens to invest in diversity, and quite a few incentives to encourage their citizenry to convert to the highest yielding varieties.

These incentives can take many different forms. First there are the most direct forms of intervention, such as the policies against crossing of varieties in Indonesia and Zimbabwe that discourage all practice of traditional agriculture. (Cooper 1993). Then there are the subsidies to the various inputs to specialised agriculture (pesticides, fertilisers, irrigation water, machinery) that encourage conversion across the developing world. Third, there are the well-documented subsidies to the outputs of specialised agriculture (agriculture commodities) that have encouraged conversions for many years both in the developed world and in the developing (via aid policies, e.g. Botswana).

The problem of biodiversity decline lies in the fact that, despite the fact that the individual farmers no longer perceive the need to invest in diversity, the reasons to retain diversity for its global values remain unchanged. This creates a situation where individuals are rapidly converting diverse stocks (formerly retained for the individual benefits they rendered) while the global need for diversity remains as great as ever.

4.5.1 Government Responses: Crop Insurance Programmes

Governments also encourage conversions by approaches that provide alternative methods of insurance to their citizens. This can be accomplished directly for the crops themselves - by the creation of crop insurance programs - or indirectly (as discussed above) for other forms of income maintenance - by the mere provision of better infrastructure and transport facilities. In either case, the government's supply of alternative forms of insurance displaces the individual's supply of diversity in order to serve this purpose.

In developed countries, and increasingly in the developing, there is government intervention in agriculture to provide insurance in times of crop failures. The form that government intervention takes determines the incentives for the minimisation of risk within agriculture.

One means of reducing the risks associated with yield fluctuations is to diversify the portfolio of crops moving away from mono-culture. Intercropping, spatial diversification, staggered planting, and hoarding are surprisingly efficient in reducing income risks. Such practices have been employed by agriculturalists for centuries.

However, diversity is not the only means for providing crop insurance. The market itself will do so, if the risks are insurable. And, there is not necessarily any reason to intervene if this is the case, because farmers themselves could then choose the least expensive basis for insuring their crops, allocating their "insurance policies" between the market and diversity.

However, this is only the case if insurance markets are able to operate effectively, in many cases they do not. This is because market insurance operates by means of the pooling of independent risks. That is, in many circumstances individuals may face uncertainty, but society as a collective of individuals faces approximate certainty. This is attributable to 'the law of large numbers'. In essence, insurance works effectively when an individual farmer does not know whether his/her crops will fail this year, even though the failure rate for crops in that region for any given year is known and relatively stable over time.

The primary assumption that drives the insurance principle is that the probability of a crop failure for any given individual is independent of that for anyone else. That is, when risks are faced by all persons uniformly, it is not possible for an insurance market to operate. This is because it does no good to "pool" a risk if everyone will incur the loss at the same time.

It is apparent that the assumption of independence fails in the case of crop insurance in the U.S. The agricultural sector is one that faces pronounced comovements in output. It is self-evident that individual agents' probabilities of experiencing a crop failure are not independent when techniques and varieties become standardised. A fact which is borne out heavily in the data. The government is required to subsidise the insurance companies, in order that continued cover is provided.

U.S. Summary of Multiple Peril Crop Insurance Protection
(summary of all crops for all states by year)

Year	Protection (millions $)	Total Acres Insured	Total (000s)
1981	5981		58324
1982	6125		54918
1983	4370		36542
1984	6620		55492
1985	7167		63360
1986	6219		64004
1987	6079		64798
1988	6957		73799
1989	13563		139365
1990	12511		142870
Total	75592		753468

Source: American Association of Crop Insurers, (1991)

In short, the crop insurance market in the U.S. has not operated effectively, probably on account of the correllation of risks. The US experience reflects that insurance cover has been difficult to develop and administer, with the private sector being unwilling to provide complete insurance. The current insurance program dates only to the Crop Insurance Act of 1980, which allowed private insurance schemes to operate in this area, but the evidence from this period is clear.

The Federal Crop Insurance Corporation (FCIC) currently subsidises the premia paid by farmers by about 30%. The amount of government subsidy can be seen in the difference between Total Premium and Farmer Premium. The total costs of the protection offered including the subsidy and administration costs are shown in the following table.

Nature and Extent of All Government Costs
('000s of US $)

	Premium Subsidy	Excess Losses
1981	46995	30471
1982	91990	132250
1983	63669	297971
1984	98296	204314
1985	100224	242438
1986	88043	233806
1987	87536	466900
1988	107830	585678
Total	684583	1731597

Source:"Report of the commission for the Improvement of the Federal Crop Insurance Program". Washington D.C.

During the 1980s, the U.S. government spent $3.8 billion on crop insurance programs for U.S. farmers. This is a very important fact, for two reasons.

First, this is indicative of the extent of the crop failures occurring under specialised agriculture. Although eight years is insufficient grounds for the ascertainment of any trend, the movement toward crop insurance is definitely a developing trend.

Secondly, and more importantly, it is obvious that these markets were requiring substantial government subsidies for operation. The U.S. government spent $685 million on direct subsidies in order to encourage the operation of the market.

Crop insurance programmes operating through methods of "pooling risks" cannot be effective, because of the correlation of the risks involved. It is not possible to replace the assurance function of diversity through the insurance markets. Nevertheless, it has recently been suggested in the economic literature (Miranda, 1992) that the failure of crop insurance programmes in the U.S. could be remedied by the adoption of "area-yield" insurance. These are policies that would recognise the correlation in farmers' returns under poor environmental conditions, and then compensate the group of farmers only in the event of a fall in average yield across a large area. The idea is to avoid the problem of compensating individual farmers for poor farming practices, while compensating the group in the event of the

occurrence of a "joint risk" (such as a pest or drought); however, this identifies the reason that these programmes fail, not the basis for their rectification.
It is necessary to pool uncorrelated risks for a financial instrument to operate successfully; the pooling of the practititioners of modern agriculture cannot satisfy this condition.

At present the natural form of insurance (diversification of the agricultural portfolio) is not being allowed to operate. It is instead being preempted by a government policy that is encouraging the substitution of the financial market by its subsidisation. This sort of policy discourages farmers

from using natural diversity for the provision of insurance, even when it is the only means of doing so. National governments are responding perversely to variability by encouraging farmers to continue the process of specialisation that is causing this variability to exist.

4.5.2 Government Responses: Gene Bank Network

The need to supply insurance is also being met by the establishment of *ex situ* gene bank networks. However, the attempted *ex situ* solution addresses only one of the four distinct forms of insurance values, i.e. the quasi-option aspect, and it is not clear that it accomplishes this object very satisfactorily.

As mentioned above, there are both insurance and informational motivations for diversity conservation. Insurance is provided by diversity when variability is reduced; diversity-supplied information may take the ultimate form of either variability reduction or yield enhancement.

It is likely that the gene bank approach focusses on the latter to the exclusion of the former. It concentrates its efforts and resources on those varieties that are most closely related to those in production, and virtually ignores all species that are not currently in production. This is the approach that would be recommended by a strategy of yield enhancement; it focusses upon the retention of those varieties within which it is known that traits exist that will be useful in currently-practiced agriculture under a foreseeable range of environmental conditions.

The insurance values of biodiversity concern more wide-ranging (unforeseeable) conditions and more widely-varying (unknown) potential phenotypes. They are not so useful as near-term inputs into production, as they are essential as medium-term or long-term provisions against the unforeseeable. The informational values of diversity (for yield enhancement) are very likely appropriable in the near term by commercial organisations. The true insurance values are unlikely to be taken into consideration, even by the existing gene bank network.

In addition, current attempts at *ex situ* conservation do nothing to address the other ("static") externalities within the conversion process, i.e. the problems deriving from the instabilities introduced within the current harvest year from reliance upon so narrow of a production method portfolio. The continued conversion of the biosphere to a small set of homogeneous varieties must ultimately generate high global costliness, and this costliness is registered in these other forms of porfolio effect value as well.

Therefore, although it is theoretically possible for a gene bank network to perform some of the necessary tasks of biodiversity conservation, it is unlikely that the existing network is actually constructed for this object. It is probably geared more toward yield enhancement strategies than variability reduction. In addition, no *ex situ* approach is capable of generating all of the values emanating from diversity conservation; some of these values (i.e. the static ones) require an *in situ* approach.

4.5.3 Governmental Responses: Informational Property Rights

It is important to note once again that in the case of both forms of informational values, quasi-option and exploration, the contribution to the agro-economy may take the ultimate form of either enhanced mean yields or reduced variability. To a significant extent, the problem of biodiversity conservation for agricultural purposes could be rectified if these informational values could be rendered operationally effective.

In addition, it is not that difficult to conceive of approaches that might resolve this side of the problem. All that is required is some mechanism for compensating investments in "*in situ* gene banks": lands retained in an unconverted state and explored for potentially useful varieties under prevailing conditions. A review of the two forms of values (exploration and quasi-option) will illustrate.

It is economically rational to maintain a large group of unknown life forms (that are perceived to be largely valueless), precisely because the variability in returns will be very large given how little we now know about these individual organisms. This variability may be translated into either an enhanced mean or a reduced variability in production. This is the value of prospecting, or "exploration value".

It is also reasonable to retain a more well-known (but equally valueless) group of life forms for potential agricultural usage, on account of unforeseeable shifts in existing environmental conditions. This is the value derived from exogenous information, or "quasi-option value".

These values are treated as "global public goods" at the producer-state level under existing property rights systems, but they need not be, and they are not treated as public goods at all other levels of the plant breeding industry. The values are potentially appropriable, as it is equivalent to stating that there are a large number of "genetic lottery tickets" distributed across the globe in correspondence to the amounts of unconverted lands (largely within developing countries). A few of these tickets will pay "jackpots" to the global agricultural system at some unknown point in time. The biodiversity problem is that the tickets may be lost long before their true value is revealed.

This facet of the biodiversity problem need not exist, if the "host state" for the unconverted land were allowed to keep the proceeds from the jackpot if it retained the land that contains the ticket. This prospect of a return might then be sufficient to induce the retention of large quantities of diverse lands (as many countries vied for a single jackpot).

The real biodiversity problem is that the "jackpots" derived from retaining less well-known plants on diverse agricultural lands have not generated returns for the "host state". They are captured further up the vertical chain within the seed industry. These companies are able to develop the find as a new plant variety, and claim propietary rights over the ultimate product. (Juma, 1989; Hobbelink, 1990). That is, it is very likely that the rents generated by this "exploration value" are appropriated (rather than dissipated), but at a level within the agricultural industry far-removed from the individuals making decisions concerning land conversions. This phenomenon of "absentee rent capture" creates a very poor set of incentives for conservation. (Swanson, 1989; Swanson, 1994).

Furthermore, under existing institutions, there is no real prospect for this to change in the immediate future. (Swanson, 1992; Sedjo, 1992; Kloppenburg, 1990). Therefore, given the unlikelihood that any future returns from these lottery tickets will be appropriated, the host state will see little reason to invest in the retention of diverse resources for this purpose.

In sum, the informational values of diversity may ultimately be appropriable within the agricultural sector, but it is essential that they are appropriated at the correct "level" of the industry for conservation effectiveness. Rents should always be collected, for purposes of maximising aggregate welfare, by those best able to invest in the resource generating them. (Hart and Moore, 1992). The best investors in *in situ* diversity conservation are the host states (and the individuals making conversion decisions), and so property right systems should allow these states (and especially their "farmers") to capture the portion of agricultural value attributable to diversity.

As an aside, it is interesting to note that, should existing institutions be modified to make it possible for host states to appropriate these "exploration values", then the problem would be reverse; there would be incentives to oversupply rather than undersupply diversity for these purposes. This is because probabilistic returns tend to generate excessive aggregate efforts to appropriate them; this is the nature of a "patent race". Should states acquire some part of the rights to any "jackpots" acquired by reason of their investments in the retention of diverse lands, it would be anticipated that these rights would translate more than proportionately into efforts to appropriate these values.

4.6 Conclusion - Externalities in the Appropriation of Global Values

This section commenced with the "ground level" incentives determining diverse resource supplies because it is at this level that the decisions are taken that determine whether lands are converted or not. However, it was quickly found that these ground level incentives were themselves determined by higher orders of incentives, and in particular by the developments occurring within the farmer's country and the actions taken by its state. In general, the events over the past few decades have transpired to cause individual farmers to replace diversity-supplied assurance with other forms. This is another one of the driving forces behind the decline of biodiversity.

It would be the responsibility of national governments to combat this trend, and to cause individual farmers to take the benefits of diversity to be taken into account; however, it is more typically the case that governments are leading the movement toward other forms of insurance by means of a wide range of policies. Governments create incentives to conversion both directly through subsidies to specialised agriculture and indirectly through subsidies to other forms of assurance.

The core problem of biodiversity is that the most of the values of diversity (outlined in section three) are not being channelled through the hands of citizens of the host state. This means that the state that invests in diversity-retention bears all of the costs of that act with no reasonable expectation of receiving a greater proportion of the benefits. At base, this is the problem of biodiversity: it is the absence of institutions for either "cost-sharing" or "benefit-appropriation". Part B discusses the capacity of economics to place a value on the benefits from genetic resources. Part C investigates the general nature of the institutions that might be able to remedy the biodiversity problem.

PART B

The Valuation of the Contribution of Plant Genetic Resources

By David Pearce & Raffaello Cervigni

5. Techniques for the Valuation of Environmental Resources [By David W. Pearce]

This section provides an introduction to the field of environmental economics, especially as it applies to the questions of valuation. Much progress has been made in the past decade in the development of a methodology for placing values on various resources and services never before given a monetary valuation; this section identifies these approaches and indicates the range of uses for which they were developed. Equally importantly, this section also gives an indication of the limits to environmental economics and the range of values that cannot necessarily be estimated by the use of these methods.

In short, environmental economics has made great strides in providing concrete answers to previously unanswerable questions; however, it has not yet developed the capacity to say something definitive on every environmental resource or service. This will be an important point to keep in mind while reviewing the remainder of the analysis within this report.

The reader who is familiar with the various concepts of economic value, and the methods used to estimate these values, may move directly to section 5.4 without a loss of continuity. For the remainder of our audience, the following sections are intended to indicate the scope application for these methods and their potential applicability to the problem of the value of PGRFA

5.1 The Issue

The concept of 'economic value' of an environmental resource is measured by individuals' **willingness to pay** (WTP) for increases in the resource, or by individuals' **willingness to accept compensation** (WTAC) for losses of the resource. Economic value is therefore **anthropocentric**: it is based on human preferences for or against changes in the amount or quality of the environmental asset in question. Moreover, economic values are, at least in principle, expressible in monetary units since both the WTP and WTAC concepts can be expressed in monetary terms (although they do not have to be in money terms). Clearly, other ethical values are relevant to decisions about the protection of environmental assets. It is possible to argue that the assets have intrinsic value that may be expressed as 'rights' to existence, for example. This view is widely held with respect to living resources, although it is less widely held with respect to plant resources.

There are particular reasons for focusing on economic values, of which the most important is that the preference-based approach is best suited to the real-world contexts in which choices are made about the quantities and qualities of the resources in question. For example, PGRs increase or decrease due to habitat change. In turn, habitat change is motivated by the apparent need to clear land for agriculture or some other form of economic development. The economic value of that land conversion is expressed in terms of the flow of outputs for human consumption - food, timber, etc. Those flows of outputs are measured in money terms. By expressing the value of PGR conservation in money terms, then, we secure a **direct comparison** between the 'value' of PGRs and the value of the alternative land use that is generally inconsistent with PGR conservation.

Why does a direct comparison matter ? The main reason is that it permits the **quantity** of conservation or development to be determined. Adopting the 'rights' approach, for example, produces 'all or nothing' outcomes. If it is morally wrong to deplete biological diversity, then it is wrong for all diversity, not just some of it. Yet conserving all diverse resources is infeasible in a world where population growth promises a 50% increase in the next 30 years. Put another way, the economic approach permits **priorities** to be determined.

The problem with the economic approach is that many of the functions of environmental assets have no market. Hence economists have developed a number of ways in which **non-market values** can be estimated for resources that lack markets for their functions and services. This non-market problem is less true of PGRs since they have a clearly identifiable uses for crops that will eventually be markets, although **measuring** that economic value is complex.

We briefly review the methodologies for 'revealing' economic value in non-market contexts, and then focus on the relevant methodologies for PGRs.

5.2 Total Economic Value

The total economic value (TEV) of a resource is generally classified as being made up of **use** and **non-use values**. Use values are as they sound - the value arising from making actual use of something (consuming it, visiting it, etc.). A use value can relate to a use now, or to a WTP to keep the resource in being for potential future use (an **insurance** value of **option** value). Non-use values relate to the WTP for something even though no actual use is made of it, nor is any use intended in the future. This is very relevant for biodiversity, for example, because most people will not experience the direct benefits of the biodiversity, nor may they ever do so. Yet many people want diversity to be present, perhaps because of some feeling of intrinsic value, some sense of 'stewardship' or some motive of bequeathing an intact environment to future generations.

5.3 Estimating WTP and WTAC

Environmental benefit estimation techniques have advanced significantly over the past twenty years.

The first distinction is between **direct** and **indirect** approaches. Although definitions vary, direct approaches look at techniques which attempt to elicit preferences directly by the use of survey and experimental techniques, such as the Contingent Valuation and Contingent Ranking methods (see below). People are asked directly to state or reveal their strength of preference for a proposed change. Indirect approaches, on this interpretation, are those techniques which seek to elicit preferences from actual, observed market based information. Preferences for the environmental good are revealed indirectly, when an individual purchases a marketed good with which the environmental good is related to in some way. The techniques included here are, Hedonic Price and Wage techniques, the Travel Cost method, Avertive Behaviour and Damage Function approaches. They are all indirect because they do not rely on people's direct answers to questions about how much they would be willing to pay (or accept) for an environmental quality change.

Figure 5.1 provides an overall classification of the various techniques.

5.3.1 Direct Approaches

Boxes 1 and 2 give an outline of **contingent valuation** and **contingent ranking** approaches. In each case the approach is based on direct questioning of respondents as to their WTP or WTAC sums of money (CVM), or their ranking of alternatives one of which is then 'anchored' in a market price (CRM). CM operates by asking questions such as 'Are you willing to pay X' for some defined and identified change in environmental quality or in the quantity of an environmental asset. Numerous biases may occur, not the least of which is the hypothetical nature of the question - i.e. will people really be WTP 'X' in the event that the environmental asset really does have to be increased or decreased in quality or quantity ? There are numerous test for such biases and the modern approach to CVM permits most biases to be avoided at the outset by careful questionnaire design, and for remaining biases to be identified and estimated through subsequent statistical analysis.

This group of techniques will often be the only method available for valuing **non-use** values. The indirect approach techniques can only measure **use** values, for reasons that will become apparent later. As such the direct approach has a very important role to play in environmental benefit estimation, being able to measure use and non-use values. It should always be remembered that values obtained from indirect techniques although failing to capture non-use values, are never meant, theoretically or empirically to capture these values in the first place.

5.3.2 Indirect (Production Function) Approaches

Indirect approaches are almost certainly more relevant to PGRs than direct approaches. Some economists classify all indirect techniques as 'production functions'. Within the indirect group of techniques, there are certain techniques which can be grouped together. These are collectively known as **Surrogate Market** techniques. They involve looking at markets for 'private goods' and services which are related to the environmental commodities of concern. Private goods are goods that when consumed by one person cannot be consumed by another. They contrast with 'public' goods, such as air quality, that can be enjoyed by more than one person in such a way that one person's enjoyment does not affect another person's enjoyment. The goods or services bought and sold in these surrogate markets will often have as complements (or attributes) and substitutes the environmental commodities in question. Individuals reveal their preferences for both the private marketed good and the environmental good when purchasing the private good. They leave what is called a 'behavioural trail' as they make actual decisions that affect their lives. These techniques are therefore sometimes preferred by policy makers because they rely on actual choices rather than the hypothetical choices involved in the direct approaches. Surrogate market approaches include Hedonic Price and Wage techniques, the Travel Cost method and the Avertive Behaviour method. **Damage Functions** comprise the other main category of indirect techniques. Damage functions involve estimating some dose-response function, and then using market prices (sometimes adjusted to account for economic distortions such as taxes and subsidies) to value the response. For example, if air pollution affects crops, then the output lost can be multiplied by the market price to obtain a measure of the loss. Box 3 outlines the main features of the damage function approach. Somewhat confusingly, damage function approaches also embrace a context in which an input is related to an output and the resulting effect is valued at market prices. This is relevant to PGRs since they are an input to a process giving rise to an output - crops or other products. So, damage functions are sometimes called 'production function' approaches as well.

Within the surrogate market group of techniques, further demarcation can be made between the Hedonic Price and Wage techniques (known simply as **Hedonic**) and the Travel Cost and Avertive

Behaviour Techniques (known as **Household Production Function** approaches)[1]. We explain in detail the differences between the two later, but basically they are concerned with different assumptions about consumer choices and fixed prices.

[1] The Household Production Function approaches should not be confused with Damage function techniques (sometimes referred to as production function techniques) or with what Mäler [1991] calls the Production Function approach (see later). According to Mäler's classification, all the techniques described here as indirect techniques are subcategories of what he calls the 'Production Function Approach'.

The Household Production Function (HPF) approach places values on environmental resources by specifying some familiar structural relations (restrictions) between the environmental services of interest and other private goods. The approach argues that the environmental resource and private goods are demanded as intermediaries in a households production process, together with time, to produce service flows. The approach describes how goods and services are used and so enables us to see how the environment affects the service flows. In a HPF, the environment enters the individual's behavioural/preference function through the restrictions of **perfect substitutability** and **weak complementarity**. The values of the environmental resource are found by looking at changes in the expenditure on goods that are substitutes or complements to the environmental resource.

Perfect substitutability means that the environmental good and the private good are substitutes: a one unit reduction in the environmental good, for example, must be associated with an increase in the private good by some constant ratio[2]. This is the basis of the **Averting Behaviour** technique, which looks at how averting inputs substitute for changes in the environmental good of concern. Examples here include; looking at expenditures on improved ventilation in order to reduce the exposure to radon in houses; valuing the costs of siltation from upstream erosion by looking at the expenses that farmers incur when installing protection structures. Weak complementarity means that when the demand for the private marketable commodity is zero, then the value of the environmental good is also zero. In other words the value of the environmental good is entirely due to its use alongside the private good. Weak complementarity is a generalization of perfect complementarity (where a resource and some input must be used in constant proportions), in that the value of an environmental good is zero if demand for the other input is zero.

This is the fundamental idea underlying the Travel Cost approach. Travel is used to infer the demand for recreation by virtue of the fact that it is a weak complement, i.e. when the quality of the recreation site changes, we look at how expenditures on the marketable complement, travel, change. The Travel Cost method estimates the demand function for recreational facilities and finds how visitation to a site changes - how the demand curve will shift - if an environmental resource in the area changes.

The hedonic approach differs in that it operates through private good price changes rather than the private good quantity change. The hedonic pricing approach looks at markets in some private good for which the environmental good of concern is again a weak complement (or attribute), in order to infer individuals' preferences for environmental quality. An example of this is the property market, in which one of the attributes of housing influencing an individual's decision to buy or sell, is the level of environmental quality, e.g. air pollution in the surrounding neighbourhood. Given that different locations of property will have different levels of environmental attributes and that these attributes affect the stream of benefits from the property, then the variation in attributes will result in differences in property values (since property values are related to the steam of benefits). The Hedonic price approach looks for any systematic differences in property values between locations and tries to separate out the effect of environmental quality on these values. The resulting 'implicit prices' found for environmental quality must then be related to consumers' tastes and preferences in order to find the willingness to pay for the attribute. In order to estimate the value of changes in the environmental resource using Hedonic pricing, weak complementarity is assumed and the supply of the private marketable good is assumed fixed. A change in environmental resource availability will then be capitalised in the market price of the private good and so it is possible to estimate the value of changes in the environmental resource by looking at these market prices. The difference between the HPF

[2] This constant ratio is known technically as the 'marginal rate of substitution'.

approach and the hedonic pricing approach is that HPFs work, through changes in quantity, and therefore expenditure (since price fixed) of the complement or substitute good, while hedonics work through changes in the price of complement goods.
Boxes 4 and 5 outline the features of the HPF and damage function approaches.

5.4 Economic Valuation and Plant Genetic Resources

Which of the preceding techniques is most relevant to PGRs? One purpose of this report is to ascertain the extent to which economic estimation is a useful approach for the resolution of the problem of biodiversity conservation. That is, when can the methods mentioned in this introductory section be utilised to guide policymakers in the construction of rational plans for biodiversity conservation, and when are other methods required?

In section 6 we will return to the precise answers to these questions, indicating what sorts of studies can be done and what alternatives to these approaches exist. At this juncture, we will give a brief preview of our results that will indicate the nature of the task at hand.

The answer to our questions concerning the value of PGRFA is that PGRs have a number of distinct values. First, they are explored for use as inputs in the plant breeding industry for the purpose of enhancing yields of existing agricultural crops (exploration value for yield enhancement). Secondly, the conservation of the diversity of PGR in current agricultural usage contributes to current social welfare through creating more stable systems at the present time (the portfolio value), and by maintaining a pool that may be explored for the ascertainment of traits that might contribute to the future stability of agricultural production (exploration value for reduced variability). Thirdly, the conservation of a diversity of PGRFA also creates a pool of resources available in the event that environmental conditions alter substantially, rendering known traits more valuable (the quasi-option value). That is, a measure of the **benefits** of PGRs should strictly embrace:

(a) the direct contribution to the value of products produced with PGRs (*exploration value for yield enhancement*);

(b) the value of avoiding output variability and providing for future sustainability (across countries and across time) (*portfolio values* and *exploration value for reduced variability*); and

(c) the value of maintaining potentially valuable traits in the event of environmental shifts (*quasi-option value*).

We will see that there are promising methods for estimating the contributions of genetic resources to mean agricultural yields, and also (to a lesser extent) for estimating a few of the portfolio values of diverse resources. However, to a large extent, the solution to the problem of biodiversity depletion will have to be implemented in the absence of the quantification of many of its important values. This does not mean that biodiversity is not valuable, only that the appropriation of its value may be a better approach than estimation in generating the optimal quantity of conservation.

The role of economic valuation in this instance is more likely to be for the purpose of indicating the existence of significant values in particular case studies (such as the contributions of gene banks to the breeding of particular varieties of wheat, for example). It would be possible (with unlimited resources) to undertake a large number of case studies and to aggregate these values into a accurate estimate of the contributions of gene banks to plant breeding generally, however even this manner of proceeding will omit from consideration most of the range of different forms of biodiversity's values (its portfolio and quasi-option values). These values are just as real, but more difficult to estimate.

Therefore, this report will show how the nature of the biodiversity problem indicates that either estimation or appropriation methods are reasonable ways to proceed towards an agreed solution to the problem, and that the choice between the methods depends in large part upon the relative cost-effectiveness of the alternatives. This report sets out these alternatives, and indicates the relative merits and demerits of each.

BOXES

Each box outlines the features of the technique. Reference is made to tests of 'validity'. Theoretical validity refers to the consistency of the method with the precepts of economic theory. Convergent validity refers to the test whereby the answer from one technique is compared to the answer from another technique. In some cases, similarity of results will add credibility to the answer. In other cases, there may be reason to expect that one technique will give a higher value than another technique. Repetition validity refers to the answers being similar if the same technique is applied to similar contexts. Criterion validity refers to the values bearing some relationship with real market behaviour.

BOX 1

CONTINGENT VALUATION

Range of Applicability — Extensive since it can be used to derive values for almost any environmental change. This explains its attractiveness to 'valuers'. Only method for eliciting non-use values.

Procedure — The method involves setting up a carefully worded questionnaire which asks people their WTP and/or WTAC through structured questions. Various forms of 'bidding game' can be devised involving 'yes/no' answers to questions and statements about maximum WTP. Resulting survey results need econometric analysis to derive mean values of WTP bids. Literature tends to suggest that most sensible results come from cases where respondents are familiar with the asset being 'valued'.

Validity — The literature has identified various forms of potential bias. 'Strategic bias' arises if respondents make bids that do not reflect their 'true' values. They may do this if they think there is a 'free rider' situation. But there is limited evidence of strategic bias. Hypothetical bias arises because respondents are not making 'real' transactions. Expense usually limits the number of experiments involving real money (criterion validity), but some studies exist. Convergent validity is good. Construct validity - relating values to expectations about values of other measures - is debated, especially the marked divergence in many studies between WTP and WTAC.

Case Study — Case material is extensively reviewed in R.Mitchell and R.Carson, Using Surveys to Value Public Goods: the Contingent Valuation Method, Resources for the Future, Washington DC, 1989.

BOX 2

CONTINGENT RANKING

Range of Applicability	Unknown but could be extensive. Limited number of studies exist for environmental context and are confined to 'private goods' -i.e. goods purchased in the market place. It is unclear how extensive the application could be for environmental goods but this is under investigation in the context of house location decisions.
Procedure	Individuals are asked to rank several alternatives rather than express a WTP. Alternatives tend to differ according to some risk characteristic and price. Idea could be extended to a ranking of house characteristics with some 'anchor' such as the house price being used to convert rankings into WTP.
Validity	Not widely discussed in the literature but appears theoretically valid. Too few studies to test other validity measures but initial results suggest CRM WTP exceeds CVM WTP.
Case Study	W.Margat, W.Viscusi, J.Huber, 'Paired Comparisons and Contingent Valuation Approaches to Morbidity Risk Valuation", Journal of Environmental Economics and Management, Vol.15, 1987.

BOX 3
DAMAGE COST ('PRODUCTION FUNCTION') APPROACHES

Range of Applicability	Extensively used where 'dose-response' relationships between pollution and output or impact are known. Examples include crop and forest damage from air pollution, materials damage, health impacts of pollution. Limited to cases where there are markets - i.e. cannot estimate non-use values. Replacement cost approaches also widely used because it is often relatively easy to find estimates of such costs. Replacement cost approaches should be confined to situations where the cost relates to achieving some agreed environmental standard, or where there is an overall constraint requiring that a certain level of environmental quality is achieved.
Procedure	Dose-Response: take physical and ecological links between pollution ('dose') and impact ('response') and value the final impact at a market or shadow price. Most of the effort usually resides in the non-economic exercise of establishing the dose-response links. Multiple regression techniques often used for this. Replacement Cost: ascertain environmental damage and then estimate cost of restoring environment to its original state.
Validity	Dose-response : theoretically: a sound approach. Uncertainty resides mainly in the errors in the dose-response relationship: e.g. where, if at all, are threshold levels before damage occurs; are their 'jumps' (discontinuities) in the dose-damage relationship ? An adequate 'pool' of studies may not be available for cross-reference. Criterion validity not relevant since presence of 'real' markets tends to be a test in itself -i.e. revealed preferences in the market place are being used as the appropriate measure of value. Replacement Cost: validity limited to contexts where agreed standards must be met.
Expense	Dose-response can be costly if large databases need to be manipulated in order to establish dose-response relationships. If D-R functions already exist, method can be very inexpensive and with low time demands. Replacement cost is usually very inexpensive as standard engineering data often exist.
Case Material	US Environmental Protection Agency, Costs and Benefits of Reducing Lead in Gasoline: Final Regulatory Impact

Analysis, EPA-230-05-85-006, Washington DC, February 1985

BOX 4a

HOUSEHOLD PRODUCTION FUNCTIONS I : AVERTIVE EXPENDITURES

Range of Applicability	Limited to cases where households spend money to offset environmental hazards, but these can be important - e.g. noise insulation expenditures; risk-reducing expenditures such as smoke-detectors, safety belts, water filters etc.
	Has not been used to estimate non-use values though arguable that payments to some wildlife societies can be interpreted as insurance payments for conservation.
Procedure	Whilst used comparatively rarely, the approach is potentially important. Expenditures undertaken by households and designed to offset some environmental risk need to be identified. Examples include noise abatement, reactions to radon gas exposure -e.g. purchase of monitoring equipment, visits to medics etc. Technique needs to be managed by experts as significant econometric modelling is usually required.
Validity	Theoretically correct. Insufficient studies to comment on convergent validity. Uses actual expenditures so criterion validity is generally met.
Expense	Econometric analysis on panel and survey data usually needed. Fairly expensive.
Case Study	M.Dickie, S.Gerking, M.Agee, 'Health benefits of Persistent Micropollutant Control: the Case of Stratospheric Ozone Depletion and Skin damage Risks', in J.B.Opschoor and D.W.Pearce (eds), Persistent Pollutants: Economics and Policy, Kluwer, Dordrecht, 1991.

BOX 4b

HOUSEHOLD PRODUCTION FUNCTIONS II: TRAVEL COST METHOD

Range of Applicability	Generally limited to site characteristics and to valuation of time. Former tends to be recreational sites. Latter often known as discrete choice - e.g. implicit value of time can be estimate by observing how choice between travel modes is made or how choice of good relates to travel time avoided (last case has been used to value women's water collection time in developing countries). Cannot be used to estimate non-use values.
Procedure	Detailed sample survey needed of travellers, together with their costs of travel to the site. Complications include possible benefits of the travelling, and presence of competing sites.
Validity	Theoretically correct, but complicated where there are competing sites and multi-purpose trips. Some doubts about 'construct validity' in that number of trips should be inversely correlated with 'price' of trips -i.e. distance travelled. Some UK studies do not show this relationship. Convergent validity generally good in US studies. Generally very acceptable to official agencies and conservation groups.
Case Study	K.Willis and J.Benson, 'Valuation of Wildlife: A Case Study on the Upper Teesdale Site of Special Scientific Interest and Comparison of Methods in Environmental Economics', in R.K.Turner (ed), Sustainable Environmental Management: Principles and Practice, Belhaven Press, London, 1988.

BOX 5a

HEDONIC PRICING I : HOUSE PRICE METHOD

Range of Applicability	Applicable only to environmental attributes likely to be capitalised into the price of housing and/or land. Most relevant to noise and air pollution and neighbourhood amenity.
	Does not measure non-use value and is confined to cases where property owners are aware of environmental variables and act because of them (as with avertive behaviour).
Procedure	Approach generally involves assembly of cross sectional data on house sales or house price estimates by estate agents, together with data on factors likely to influence these prices. Multiple regression techniques are then needed to obtain the first estimate of an 'implicit price'. Technically, a further stage of analysis is required since the multiple regression approach does not identify the demand curve directly. Often this stage of the analysis is omitted because of complexity.
Validity	Theoretically sound, although final estimate is not of a demand curve as such (see above). Markets often may not behave as required by the approach. Data on prices and factors determining prices often difficult to come by. Limited tests of convergent validity but reveals encouraging results.
Case Study	D.Brookshire et al., 'Valuing Public Goods: A Comparison of Survey and Hedonic Approaches', American Economic Review, Vol.72, No.1, 1985.

BOX 5b

HEDONIC PRICING II: WAGE RISK METHODS

Range of Applicability	Limited to valuation of morbidity and mortality risks in occupations. Resulting 'values of life' have been widely used and applied elsewhere, e.g. in the dose-response approach.
Procedure	As with HPM, the approach uses multiple regression to relate wages/salaries to factors influencing them. Included in the determining factors is a measure of risk of accident. The resulting 'wage premium' can then be related to risk factors to derive a so-called value of a statistical life.
Validity	Theoretically sound. Convergent validity may be tested against CVM of risk reduction, but wage-risk approach measures WTAC not WTP.
Case Study	A.Marin and G.Psacharopoulos, 'The Reward for Risk in the Labour Market: Evidence from the United Kingdom and a Reconciliation with Other Studies', Journal of Political Economy, Vol.90, 1982.

6. Estimating the Benefits of Plant Genetic Resources for Food and Agriculture: Suggested Approaches [By Raffaello Cervigni]

This section sets out an agenda for future research in this area. It focuses on the identification of a number of databases that might be used for the purpose of estimating various facets of the global value of biodiversity; it does not focus on each individual value of diversity and its relative capability for estimation. This is because the prospects for estimation are determined by the existence of relevant datasets, and in the case of PGRFA there are not many of these. Therefore, in this section, the various values of PGR that are able to be estimated are identified, and the nature of those projects detailed.

6.1 Global Benefits of Plant Genetic Resources: Can they be estimated?

Plant genetic resources (PGR) are a crucial input to both farming and plant breeding operations. A large pool of genetic resources makes it easier to select the genetic traits necessary to produce high yielding varieties (HYV); this is one part of what we have termed "exploration value". By estimating the impact of the previous use of germplasm collections, it is possible to infer the magnitude of the value of retaining collections for purposes of future explorations. At the same time, the adoption of a large number of plant varieties reduce the risk of a widespread environment shock (e.g. occurrence of pests or diseases), which could negatively affect production and farmers' income. This second type of benefit has often been defined as a sort of "insurance" service, and it is equivalent to one manner of "portfolio value" that we have identified. By looking at national crop insurance data, it is possible to see how changes in diversity have impacted aggregate risks in that nation's agriculture.

These yield and insurance values represent two useful measures for estimating the benefits deriving from PGRFA, even though they are only partial estimates of the aggregate value. They are proposed not because they are likely to represent the greater part of diversity's value, but because these are the values for which data exists. The following sections outline possible ways of measuring those values, given the information which is known to exist. Before proceeding to this, it is important to express some *caveats* about the meaning of these estimates.

First, as indicated above in the previous sections, these two values (i.e. exploration and insurance values) are terms that categorise most of the values of PGR; however, we are investigating here only particular subsets of these two values. The exploration value of diversity examined here will be only that part related to mean yield enhancement. This is the primary concern of the plant breeding industry, and the study proposed here would be looking at only this sub-part of exploration value.

This would be a novel study. There is already in existence a substantial literature on the contribution of gene banks and plant breeding programmes to agricultural output. (Byerlee and Moya, 1993; Fehr, 1984; Evenson, 1991; Evenson and Gollin, 1993). These studies do not attempt to disaggregate between the various factors of production used in plant breeding; they are intended to estimate the total contribution of public expenditures to enhanced agricultural outputs.

The study discussed here would utilise the existing databases to disaggregate between the various factors of production in plant breeding, and their respective contributions to agricultural production. This would allow for the precise identification of the contribution of genetic resources to enhanced yields, separating this out from the contributions of human capital, technical equipment, and time and effort. Such a study is necessary to focus on the specific contribution made by genetic resources.

However, the values that would be estimated would have to be aggregated in order to cumulate to the total value of PGRFA. The estimates that we can give concern the values of very specific collections (e.g. the wheat collection at CIMMYT, the rice germplasm collection at IRRI), but all of these contributions would have to be aggregated to get the total contribution of PGR for enhanced yields, even in this one application.

Secondly, the "insurance value" of diversity is even more difficult to assess. The study proposed here concerns the impact of differing crop production methods on crop failures, using US crop insurance data. This study is being proposed primarily because it is the most significant dataset concerning the matter, and it would be capable of demonstrating the degree of connection between crop production methods and yield variability. However, it is difficult to see how this would improve upon existing studies. The work of Hazell and Anderson has previously analysed the relationship between the adoption of high-yielding varieties and output variability, in both developed and developing countries. (Anderson and Hazell, 1989; Hazell, 1986,1989). In addition, there are already numerous studies demonstrating the farmer's selection of crops in reaction to the provision of various forms of assurance (government, market integration, etc.) (Brush, Bellon, and Schmidt, 1988; Herath, Hardaker, and Anderson, 1982). This study would examine this "farmers' demand for assurance" relationship in more detail, but this is also of little incremental value.

This is because the more problematic "assurance values" are not captured in farmers' demands for crop assurance. The more troublesome values are "international" (system resilience-based) and "intertemporal" in nature. The farmers' demand is based solely in the motivation to assure a single season's harvest; it is the government's role to assure these other values. It is very difficult to ascertain any objective evidence of governments' attempts to assure these values, with the exception of the establishment of the plant germplasm gene bank network.

This brings this introduction to its final point. One of the most interesting studies that might be conducted would be an analysis of the relative cost-effectiveness of in situ and ex situ conservation techniques. It is not clear from the literature whether this has been attempted, but it seems to be the case that there are many concerns about the security of the gene bank network as a long term solution to the problem. (Orians, Brown, Kunin and Swierzbinski 1990). An attempt to assess the probabilities of gene bank failures and the costliness of optimal gene bank replenishment would make for an interesting case study, but one that is not completely analysed here. This sort of relative cost-effectiveness analysis could be useful in establishing the role of in situ methods in biodiversity conservation.

In short, this paper identifies a number of interesting studies that might be undertaken in order to estimate the contribution of PGRFA in various ways. However, it must be emphasised that these values do not approach an aggregate valuation of diversity's contribution because they do not address all of the facets of that value, and because (for the facets that they do address) they do so only in the context of particular case studies. With sufficient resources made available, it would be possible to rectify the latter problem (by conducting a large enough number of case studies) but it will not be possible (given current techniques) to ascertain values for all of the important facets of PGRFA.

6.2 Genetic contributions to yield increases: a Production Function Approach

The last few decades have witnessed spectacular increases in crop yields worldwide. Larger agricultural yields generate substantial benefits in terms of alleviating famines and poverty in many developing countries. Improvements in technological conditions which are largely responsible for these increases include the widespread use of chemical fertilizers, pesticides, irrigation techniques, but especially the generalized adoption by farmers of advanced plant varieties, featuring several desirable characteristics, like high yields, pest and disease resistance, resilience to climatic stresses.

Several attempts have been made to try and separate the different components of advancements responsible for yield gains. In many cases, measures have been provided of the percentage of increase attributable to the introduction of new varieties[3]. The economic benefits of the new varieties is then given by the product of this percentage by an appropriate unit price of the crop under investigation.

These measures provide an estimate of the total value of the new plant varieties. That is, the value of all the stages of the breeding process, and the value of all the inputs involved in that process. The purpose of this section is to sketch a framework to isolate the value of one set of input to the breeding process, namely plant genetic material.

6.2.1 Analytical Framework

For expositional convenience, it is helpful to formalize the approach with some equation. Suppose that at any time t the production of a given crop, y, can be represented by a production function, i.e. a functional relationship between the quantity produced and the inputs employed in production:

$$y_t = f(a_t k_t^y, b_t l_t^y, s_t, u_t) \qquad \textbf{3}$$

where k is capital, including fixed equipment, energy, fertilizers, etc; l is labour, a and b are two technical progress coefficient (for example $a=e^{mt}$ and $b=e^{nt}$), s is seed variety used, and u is a random variable representing climate, pests and other environment factors.

Yield varies over time and space. Time series of yields averaged spatially (i.e. across farms, counties or regions) normally display an upward trend for almost all countries. Time-increasing yields can then be explained with increased or more efficient use of the k and l inputs, or with changes in the s variable. The studies mentioned above attempt to isolate the contribution of the s variable to the increase in average yield over a give time span, $\Delta y(s)$, and then value this contribution at an appropriate shadow price[4] p, so that the benefits from genetic improvement, B(s) are given by $B(s)= p\Delta y(s)$.

The s variable, however, is not a primary input, but is itself the result of a production process which combines genetic material, g, labour, l^s and capital, k^s into improved seed varieties:

$$s_t = h(c_t k_t^s, d_t l_t^s, g_t) \qquad \textbf{4}$$

where c and d are two technical progress coefficient (for example $c=e^{pt}$ and $d=e^{qt}$) reflecting growing breeding knowledge emobodied in labour abd capital. Under ideal conditions of competitive markets,

[3]See, for example, the contributions to the volume edited by Fehr (1984).

[4]The price is normally chosen in such a way to eliminate policy distortions like tax, subsidies, exchange rate over- or under-valuation. For this reason in many cases world rather than domestic prices are used. Notice that in any event the use of a fixed price is valid only as a partial equilibrium approximation. If a new variety increases the supply of a given crop worldwide, this will affect the equilibrium price of the crop, so that the price and quantity effect on consumer and producer income should be evaluated jointly.

the returns from the use of a new variety, s, should be used to remunerate the factors employed in its production. One of the production factors, g, is however not transacted in markets in the same way capital and labour are. Genetic material often lacks a definite owner who can appropriate the returns from its services. As a result, no systematic statistics exists on the value of genetic material exchanged between suppliers and breeders.

A measure of the value of genetic material could however be approximated by the difference between the benefits of the improved variety and the cost of all other factors (capital, labour, etc) employed in breeding operations. The cost of these factors should obviously include an appropriate rate of return on investment in human and financial capital.

If we define as B_i the sum of discounted benefits of a given variety i, and C_i the sum of discounted cost of its development (after including some appropriate rate of return on the physical and human capital invested[5]), then R_i, the overall value of the genetic input to the development of that variety is given by:

$$R_i = B_i - C_i \quad \mathbf{5}$$

The R_i term should capture the returns to an hypothetical owner of the genetic information embodied in variety i of providing that information to plant breeding activities. Notice that such a value refers to the whole lot of genetic material contained in the given variety. In many cases, varieties are the results of a large number of crosses among wild relatives, landraces and advanced breeding lines. As the number of crosses increases, so does the amount of genetic information contained in the developed variety; and it increases the more, the higher is the number of its progenitors which are themselves the result of crosses.

The complete genealogy of the released variety could be very complex; in order to estimate the value of each the genetic steps which lead to developing the released variety, we should be able to measure what is the yield value added and what is the cost of the particular cross. That is, to produce estimates of the B and C variables *at each stage* of the breeding process. Apart from being extremely complicated, this may not be possible when some of the progenitors served only for breeding purposes, and have never been used for actual production (or no information has been recorded).

Estimation of equation 5 requires detailed information on actual breeding activities. These information could be provided by breeders in the private or in the public sector, but it may not be equally accessible for obvious confidentiality concerns of private breeders. A possibility would be to approach the International Agricultural Research Centres members of CGIAR (Consultative Group on International Agricultural Research). One of them, CIMMYT, possesses a large database on wheat varieties, which appears to be particularly suited for a detailed analysis. The way in which this could be carried out is illustrated in the following section.

6.2.3 A possible case study: the wheat varieties database at CIMMYT

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[5]As noted above, new seed varieties are introduced as a result of labour and capital being used in breeding operations, but also as result of technical change in terms of more efficient use of those factors. When the stock of human capital resulting from technical progress increases, specialized labour (i.e. scientists' effort) is likely to command a higher rate of remuneration. Therefore, when applied over sufficiently long periods of time, the analysis summarized in the text should use some measure of rate of return on human capital which appropriately reflects the growing value of scientific knowledge. In some cases, such a growing value should be provided by market data. For example, it is quite likely that salaries of specialized breeders have been growing over time in real terms.

The *Centro Internacional de Mejoramiento de Maiz y Trigo* (CIMMYT), possesses a database of all wheat varieties released by National Agriculture Research Systems (NARS) in the developing world from 1966 to 1990. For each variety, this database includes source germplasm, type of wheat (e.g. spring habit, winter habit, bread wheat, durum etc.), ecological niche (e.g. rainfed, irrigated) and the approximate area covered by varieties grown in 1990.

Information concerning source germplasm seems to be accurate enough as to enable investigators to trace back partial or complete genealogies of the released varieties. That is, it may be possible to identify many, and in some cases all of the ancestors of the modern varieties.
Retrieval of information contained in this database, along with consultation of experts within (or outside) CIMMYT could enable to reconstruct plausible estimates of cost and benefits of developing selected wheat varieties. It may not be possible to provide estimates at the individual variety level, because the unit of account for cost measurement is often the research program. Each research program may lead to the development and release of more than one variety, and it may be difficult (or arbitrary) to divide the cost of the program among the different variety developed.

On the costs side, relevant variables are likely to be:
- the time length of the development process, or of the research program;
- the number of scientists involved, divided by level of qualification, area of expertise, etc.;
- for each scientist type, estimates of the cost per scientist, including salaries, benefits, and overhead cost;
- some measure of experiment station and support services cost, plus some measure of annualized capital cost of fixed assets and equipment.

On the benefits side, the following elements seem to be necessary:
- Type of benefit provided by the new variety (e.g. increased yield, higher and/or prolonged pest resistance, lower requirement of pesticide, fertilizer, and so on);
- Measure of the benefit, standardized[6] in terms of increased yields, as provided by the results of evaluation trials.
- Extent of areas where the improved variety is sown[7]. This measure, multiplied by the increase yield, gives the aggregate increase in yield.

Data on the adoption of new varieties are not available for all countries, but in a few countries, including Brazil, Argentina, the Punjabs of India and Pakistan, and Egypt, detailed statistics are available on wheat varieties sown by farmers over time (Byerlee and Moya, 1993).

Both costs and benefits would have to be discounted over relevant periods of accrual (which may not be the same for costs and benefits) by using (possibly different) discount rates appropriately reflecting the opportunity cost of capital.

In summary, the main outcome of the analysis of the CIMMYT database would be an estimate of the economic benefit of wheat genetic resources in terms of their contribution, relative to other inputs to the

[6]Higher pest resistance decreases the probability of yield losses in a given year, or across a given time period, and therefore increases the average yield; a lower requirement of pesticide or fertilizer increase yield at any given input cost.

[7]This variable depend on policy and institutional factors, like efficient seed multiplication and marketing, extension efforts, etc. This implies that the benefits of a new variety can be substantially increased by appropriate changes in these policy and institutional variables.

breeding process, to increases in wheat yields. These estimates would be calculated only those countries where data on varieties adoption is available.

6.2.4 Possible additional research with this database: Comparative costliness of ex-situ vs in-situ conservation

The large variety of information contained in a database like CIMMYT's could make it possible to conduct also other types of analysis. In particular, it could enable to evaluate the comparative costliness of ex-situ vs in-situ conservation[8].

From the pedigree of the released varieties[9], it should be possible to ascertain how many wild varieties have been used in any particular breeding program, and what is the geographical origin of these wild relatives. A sample of areas (say 5 or 10 areas) which have relatively contributed more to the program could then be selected. These areas, which are likely to be areas of high genetic richness, have played the role of natural repository of germplams.

The **cost** of securing this supply of germplasm *in-situ* is given by the opportunity costs of conversion (the foregone benefits from the alternative, most profitable use of land), plus the possible direct costs of establishing conservation facilities (e.g. infrastructure against intrusions and encroachment, costs of screening programs). The opportunity costs of conservation may be low or negligible if there is little or no threat of conversion. Direct and opportunity costs may be in principle estimated, so long as the necessary information is available in the areas identified as genetically rich.

Conversely, the germplasm could also be conserved *ex-situ*, essentially in gene banks. Information on the costs of gene banks should readily be available, or it should be possible to obtain it. These costs will comprise initial labour and capital establishment costs, plus recurrent maintenance and operations costs. It should be possible to work out the average cost of conservation per variety (or per other genetically homogenous unit) per year, which would include a fraction of the initial and of the recurrent costs.

Multiplying this figure by the number of wild relatives employed in the program, one could derive the cost that would have been incurred had the wild relatives been conserved *ex-situ*. Comparison between the estimates of the *in-situ* and *ex-situ* costs could give some indication on the relative cost-effectiveness of the two techniques.

The validity of such a comparison would rest on the following assumption:
- Wild relatives are collected at time t_0, say, but the *in-situ* cost is measured at time t. It is assumed that (discounted) direct and opportunity costs of conservation measured at time t were the same at time t_0.
- In-situ and ex-situ techniques are perfectly fungible for conserving the variety under investigation.

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[8] *In-situ* conservation involves maintenance of genetic resources in their environment of origin, where they will be subject to a dynamic process of continuous evolution. *Ex-situ* conservation comprises all those techniques entailing collection of the resources from the environment, and relocation or storage in man-made facilities.

[9] Reconstruction of varieties' genealogy has already been attempted for the case of rice: see Evenson (1991) and Evenson and Gollin (1993). The methodology followed by these authors to evaluate the benefits of plant genetic material is however different from the oone outlined in the previous section, since it is based on direct econometric evaluation of the impact of the different traits of genetic material on rice yields.

This study requires much further development but the initial indications are that an interesting case study might be constructed about the relative cost-effectiveness of the two different forms of plant germplasm conservation. The database at CIMMYT enables the estimation of the various facets of costliness and the rates of degradation of the genepool at a bank. If a time series of data is available in a traditional farming community, this might be used as some basis for comparison. In sum, the indications are good that some sort of a comparative cost effectiveness study could be constructed with the cooperation of an institution such CIMMYT, but we have not yet had the time to construct the project or to adequately assess its feasibility.

6.3 Insurance Values

Agriculture is an economic activity subject to a high degree of uncertainty. This emanates from its natural, economic and socio-political environment. Natural factors like climate, weather and the occurrence of pests and diseases influence crop yields. The economic and socio-political environment governs demand factors, like incomes, and supply factors, like credit, which interact in determining the equilibrium on the market for agricultural crops.

All these elements are largely outside the control of farmers, and contribute to create a risky environment in which they have to operate. If farmers are not indifferent to the existence of risk, i.e. if they perceive the existence of risk as a cost, they will engage in activities aimed at reducing such a costs. Insurance is a particular form or risk-reducing activity. It is broadly defined as a contingent contract, in which a farmer pays a price, called premium, in exchange for a return payment called indemnity, which is *contingent* upon the occurrence of a given event which affects negatively the returns from agricultural activity (i.e.
yield or price fluctuations).

Insurance, however, is not the only form of risk-reducing practice. In many historical or geographical situations where insurance markets are not available or not well functioning, farmers adopt other forms of risk reducing activities. One of these activities which has been traditionally used in many different times and countries is crop diversification, at both the species level (type of crop) and genetic level (variety cultivated). Using a broad genetic pool in agriculture guarantees that the insurgence of a particular source of crop failure (like pests or diseases) does not harm all cultivations with the same intensity.

If two or more forms of risk reducing activities are available, a question arises about their comparative merits. The purpose of this section is to illustrate a conceptual framework for analysing the comparative advantages of crop insurance versus genetic diversification as agricultural risk-reducing activities, and their degree of complementarity or substitutability. Stemming from this analysis, an empirical approach is suggested which could be used to provide estimates of the benefits of genetic diversification in terms of its risk-reducing characteristics.

As reported in previous section, High Yielding Varieties (HYV) have been increasingly adopted by farmers worldwide. The consequent huge increase in mean yields has been obtained at the cost of a narrower genetic base. At the same time, average yield increase has been accompanied by an increased variability of yields. Statistical studies[10] suggest that the phenomenon is more due to increasing cross-

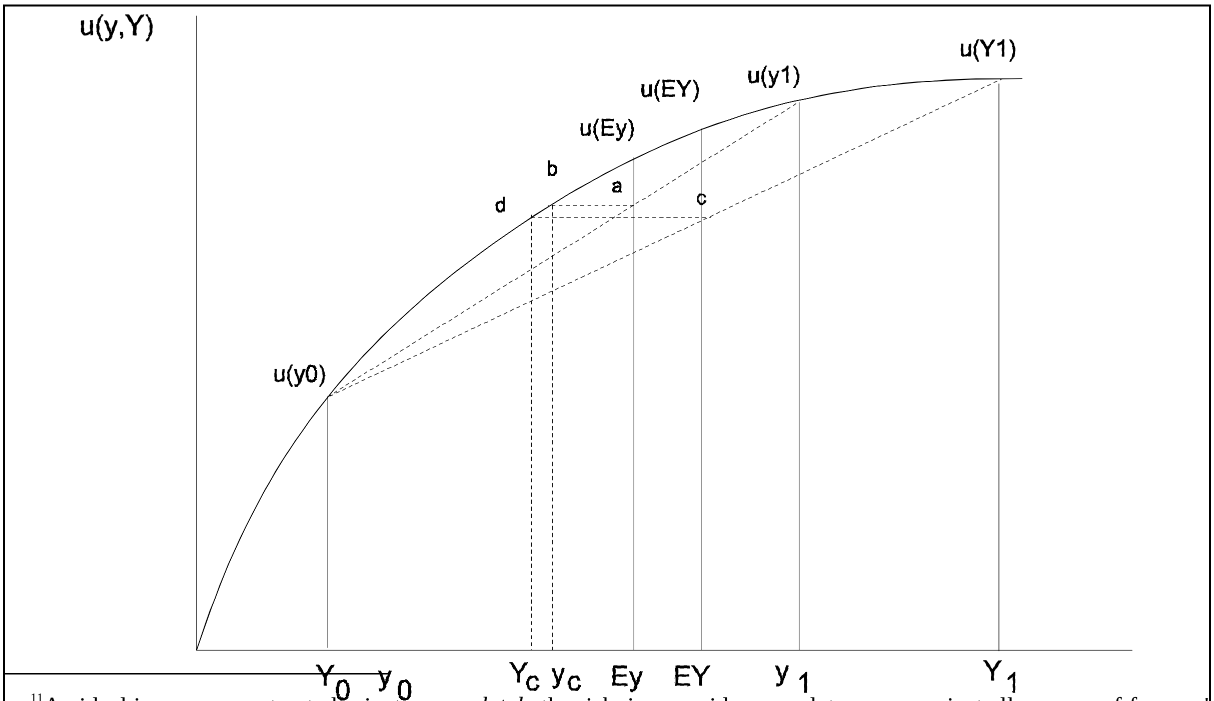
[10]See, for example, Hazell (1984), and the various essays collected in Anderson and Hazell (1989).

section covariance, rather than to increasing time-variance at the farm level. That is to say, when a given type of crop failure occurs, it seem to affect many farms and regions at the same time. According to some experts, this suggests that the widespread adoption of HYV, and the consequent narrower genetic base is responsible for the observed increased variability of yields. Does the use of HYV impose an higher cost of risk to farmers and to society? How do they respond to such an increase in risk?

6.3.1 A conceptual framework

In an insurance contract, farmers trade off a given reduction in their average income against a reduction of the risk they face[11]. Similarly, by adopting a diversified, rather than a homogenous genetic base for their production, farmers give up increases in average yields in exchange for a reduction in yield risk associated with the lower likelihood of a generalized crop failure. It is plausible that if both risk reducing activities are available, farmers would use a combination of both of them.

In 1 a utility function for money of a representative farmer is drawn. Assuming that the price of the crop is constant, the money revenue changes only with the yield of the crop, y. Only two states of the world are assumed possible, designated with a 0 subscript (bad state, low yield) and a 1 subscript (good state, high yield). If the farmer uses a large genetic base, yield varies between y_0 and y_1, whereas if a narrower genetic base is used, the upper bound of the range increases to Y_1. The average yield with low



[11]An ideal insurance contract eliminates *completely* the risk, i.e. provides complete cover against all sources of farmers' income variation (crop price and yields, input costs including interest rate, government policy and so forth). Since such a contract is unlikely to exist in reality, only a *partial* reduction of risk would normally be available.

Figure 1

yielding varieties (LYV), which are supposed to entail the use of a larger genetic base, is Ey; the average yield with high yielding varieties (HYV) is EY, with EY>Ey.

Under a LYV regime, the maximum insurance premium that the farmer is willing to pay is given by Ey-y_c; under HYV, the maximum premium is EY-Y_c, which is larger than the former premium. At the same time, the utility attainable with an insurance contract is higher under LYV than under HYV: a=Eu(y)>c=Eu(Y). In this particular example, the farmer spends *more* and ends up with a *lower* utility if adopts HYV and narrows the genetic base of its production. In contrast, by using a larger genetic base, the farmer could save (EY-Y_c) - (Ey-y_c) in terms of maximum insurance premium; furthermore, he would obtain a utility gain of b-d=Eu(y)-Eu(Y).

Notice that this result does not hold true in general. In fact it depends upon the way the adoption of HYV affects the range (i.e. the difference Y_1-y_1) and the probability of the different outcomes. It is possible to construct cases in which adopting HYV entail a welfare *gain*, despite of the higher demand for insurance. The analytical condition on which 1 is based is derived in a simple model reported in Annex 1.

In the case illustrated by 1, adopting a diversified genetic base in production has two beneficial effects. It leads to a welfare gain, and to a lower demand for insurance. The second effect can be observed, whereas the first can not, although it cam be inferred from the second by making assumptions about the shape of the utility function. Note that the lower insurance payment considered here is a benefit from the point of view of the individual farmer. From the point of view of society, a lower demand for insurance has more complicated implications. On the one hand, it reduces the income of those who supply insurance services; on the other hand, it frees resources which could be employed for alternative uses. The final effect on social welfare may be not so easy to measure. However, the saving on farmers' insurance bill may a useful first order approximation of the insurance benefit of plant genetic resources.

6.3.2 Empirical estimation of insurance values

The previous framework is clearly very simplified. In practice, we observe a complex pattern of variation of the genetic based used by farmers, and, when insurance market are sufficiently developed, a complex pattern of variation of the demand for crop insurance. In the simple paradigm considered above, farmers decide on whether or not to genetically specialize production, and choose how much insurance to purchase, on the basis of a decision rule which only depend on the shape of the utility function and on the change in average yields. In reality, farmers choose both the degree of specialization, and the expenditure on insurance premium on account of many other factors not included in a simply expected utility model like the one above.

First, the correlation between increased specialization and increased variability is still the object of debate[12] between researchers, and it may not be so unobjectable to farmers as it is to some of the experts. Second, the demand for insurance heavily depends on the type of public policy prevailing in each country. Many governments[13] subsidize crop insurance on account of the high premia that even a

[12]Singh and Byerlee (1990), for example, analysing wheat yield data, find that country size and climate factors explain most of the differences in yield variability, whereas high yielding varieties and fertilizers have no significant impact. Another important finding is that there is evidence that variability in wheat yields may have *declined* rather than increased over time, at least in developing countries.

[13]For example, the US government subsides the premium paid by farmers on Multiple Peril Crop Insurance (MPIC) by about 30%. In the period 1981-1988, the total expenditure on subsidies was of US$ 685m. (Source: Report of the Commission for the Improvement of the Federal Crop Insurance Program. Washington D.C.).

competitive insurance market would charge on highly correlated risk. Insurance subsidies may have incentive affect on the adoption of alternative risk-reducing measures. The causal link with genetic diversification may even be inverted. Because government intervention induces an artificially high demand for insurance, farmers may have less incentive to diversify. If this was the case, a (government induced) increase in crop insurance demand would be responsible for specialization, rather than being caused by it.

The empirical analysis should reveal how much less insurance would farmer be willing to purchase as a result of genetic diversification. This implies that an appropriate modelization and econometric estimation of the demand for crop insurance should be carried out. This should take into account the economic and institutional complexities briefly summarized above. Next, two approaches could be followed. The first would be to directly include some measure of genetic diversification into the set of explanatory variables, verify that the estimated coefficient is negative[14], as one would expect, and then evaluate the extent of possible insurance savings on the basis of the estimated elasticity coefficient.

The second approach would include some measure of yield variability (e.g. last period's state or county variance) among the explanatory variables. One would expect that as variability increases, so does the demand for insurance. It could then be possible to measure the reduction of insurance demand due to genetic diversification under different assumptions about the ability of diversification to reduce yield variability.

6.3.3 A possible case study: crop insurance in the US

The current US crop insurance scheme dates to the crop insurance act of 1980, which introduced a government subsidy of premia paid by farmers to private companies. The market is now fairly well developed: in 1990 total acres insured amounted to 142m, with protection guaranteed for US$ 12 billion, and total premia collected (including subsidies) of US$ 821 m (source: American Association of Crop Insurers, 1991).

Data on insurance purchases in the US is available at a pretty good level of disaggregation. Information on several aspects of the insurance contract, including type of insurance, crop insured, acre coverage, premia, liability, indemnities paid, is contained in a database owned by the National Crop Insurance Services. This information is recorded at the county level starting from the late seventies, and, at the farm level, starting in the early 1980s. (Farm level data, however, may not be possible to acquire for confidentially reasons).

Information on varieties adopted per type of crop, and hence on degree of genetic heterogeneity in cultivation, should not be difficult to gather from each state's agricultural statistics, and agriculture census. This information should be available at the county level. It should be also possible to reconstruct time series of county-level average yield per type of crop, to analyze the pattern of yield variability over time.

The proposed study would attempt to analyze whether there is any systematic relationship between an appropriately chosen measure of genetic diversification, and the demand for crop insurance. This

[14]Diversification variables (at the crop, and not at the variety level) have already been used as explanatory variables in econometric studies of the demand for crop insurance. In a study of crop insurance in Montana, Niewuwoudt and Bullock (1986) find that the entropy and Herfindahl indexes are highly significant in explaining the demand for crop insurance with the expected signs, implying that producers insure more in specialised cropping areas.

relationship can be analyzed at both the cross-section level, and at the time-series level. In the first case, by verifying whether there is any relationship between counties with a high degree of specialization, and counties with a high (or low) demand for crop insurance).

In the case of time series analysis, the relationship can be observed for any given county over time. The analysis could be further combine the two approaches, should panel data be available for both the two sets of variables.

Annex 6.A A simple model of choice of varieties and insurance

A representative farmer cultivates a given crop, the yield of which, _, is a random variable. For simplicity, suppose it can only take on two values, corresponding to two states of the world, 0 (bad outcome, low yield) and 1 (good outcome, high yield). The farmer has a concave von Neumann-Morgenstern utility function for money income. Sale of the crop is his only source of income. Supposing a fixed unit price of the crop, and expressing the yield as net of cost, which is expressed in terms of crop too, then _ is the farmer's net income, so that we can consider utility as a function of the yield: u=u(_).

The farmer has the choice of cultivating two varieties: a low yielding variety (LYV), which yield is y, and a high yielding variety (HYV), the yield of which is Y. We will assume that the bad outcome under HYV stays the same as under LYV: $y_0=Y_0$. On the other hand, the good outcome under HYV is higher: $Y_1>y_1$. We further assume that the HYV has a larger average and a larger variance than the LYV. Finally, the probability distribution of outcomes will not, in general be the same under the two varieties. The essential elements of the model are as follows:

0

	Bad outcome	Probability	Good outcome	Probability	Average	Variance
LYV	y_0	π	y_1	$1-\pi$	Ey	Var(y)
HYV	$Y_0=y_0$	p	Y_1	1-p	EY	Var(Y)

Under each of the two varieties, the farmer, who is risk-averse by assumption, will demand insurance. His maximum willingness to pay (i.e. the maximum premium R) for (fair) insurance is given by the difference between the average yield and the certainty equivalent: R = E_-$\_c$. The certainty equivalent is the yield which gives the same utility of the average utility. That is, $\_c$ solves: u($\_c$) = E[u(_)]. The farmer faces the following trade-off. Under LYV, he will obtain a lower average yield, but face a lower cost of risk, given lower variance. Under HYV, higher average yields can be obtained at the cost of higher cost of risk (higher variance).

However, in both cases the farmer can purchase insurance, which will enable him to eliminate the cost of risk in exchange for a reduction in average yields. The following questions arises: under which regime will the farmer be better off once insured? Under which cultivation regime will the farmer spend less in insurance?

It turns out that the answer to this question depends on the exact extent to which the probability distribution of outcome changes when switching from one regime to the other, for given utility function, initial probability distribution, and change in the good outcome. In particular, we have:

$$E[u(Y)] \; < \; E[u(y)] \_ \frac{u(Y_1)-u(y_1)}{u(y_1)-u(y_0)} \; < \; \frac{p-\pi}{1-p} \qquad \textbf{6}$$

That is, the farmer will be worse off under HYV than under LYV depending on whether the LHS in the second line of 6 is less than the RHS. If this condition is fulfilled, than it will be an optimal policy for the farmer to purchase a combination of "natural" insurance, given by adopting a more diversified genetic portfolio, and of market insurance. If condition 6 is not satisfied, than it would be optimal for the farmer to purchase only market insurance.

Keeping u, Y_1, y_1, y_0 and π fixed, inequality 6 can be solved in terms of p, the probability of bad outcomes under HYV. Notice that not all the values of p satisfying 6 are admissible, because some of them will entail EY<Ey, against the initial assumption of higher average yields under HYV. This restrictions can be easily expressed analytically[15], but for a graphical illustration, a numerical example has been displayed in 2. This assumes u=10-exp(-0.5y), y_0=5, y_1=10, Y_1=15, π=0.2.

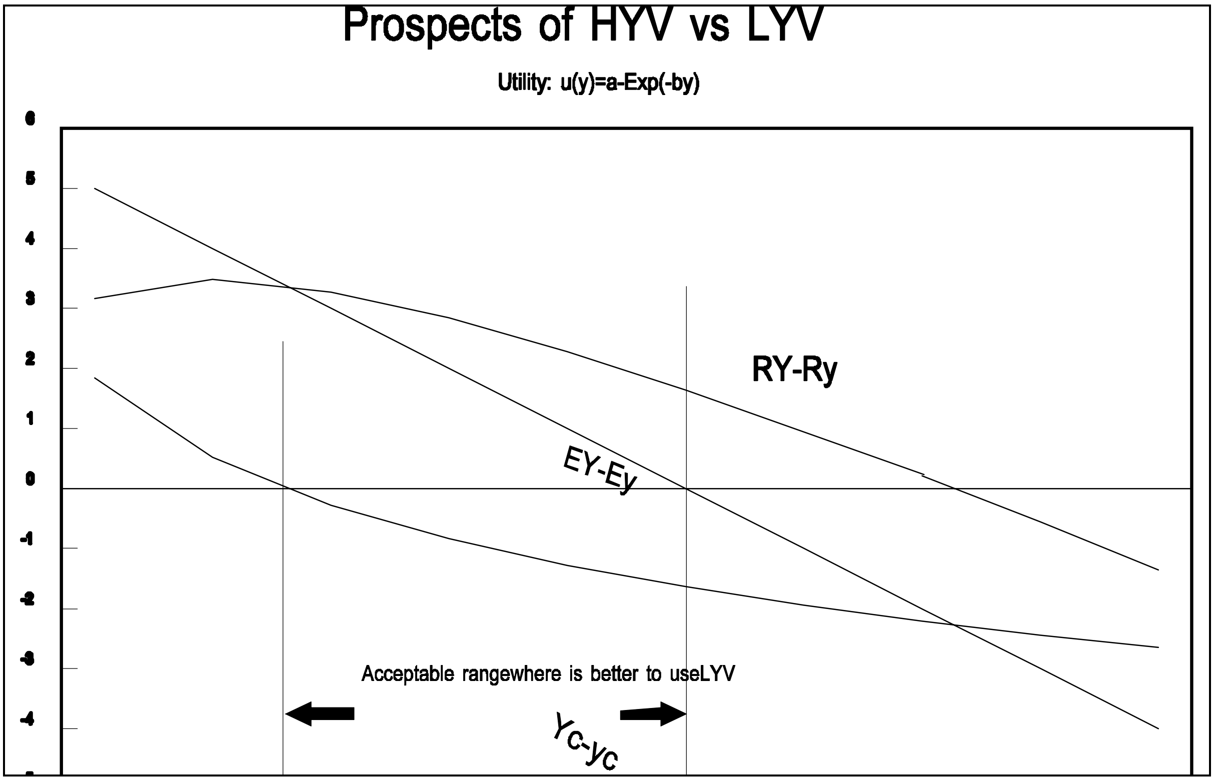


Figure 2

[15]This can be done by simply imposing on 6 the restrictions related to mean and variance:

$$E(Y) > E(y) \_ \frac{r+\delta}{r} \; > \; \frac{1-\pi}{1-p} ; Var(Y) > Var(y) \_ \frac{(r+\delta)^2}{r^2} \; > \; \frac{\pi(1-\pi)}{p(1-p)}$$

where r is the original range of variation of yield,r=y_1-y_0 and δ is the increase in the good outcome, δ=Y_1-y_1.

The acceptable range of values of p where is better to use low yielding variety is approximately p=(0.28, 0.6).

What about expenditure for insurance premia? It turns out that when condition 6 is satisfied, farmers will always spend less in insurance under LYV than under HYV. In fact the only case in which the reverse is true (i.e. insurance expenditure higher under LYV than under HYV) is when $EY<Ey$, i.e. when average yields are lower under HYV than under LYV. A case which has to be ruled out by definition. Again with reference to 2, this happens for $p \geq 0.82$.

PART C

Optimal Policies for the Conservation of PGRFA

By Timothy Swanson

7. Optimal Biodiversity Policy - Creating Incentives for Optimal Biodiversity Conservation

It is now possible to commence bringing together the various parts of the previous sections into a single framework for optimal biodiversity conservation. Section 2 indicated the nature of the economic forces at work shaping the biosphere into a more homogeneous set of assets; without the forces for conversion used for the betterment of human societies, there would be no threat to diversity. Section 3 discussed the reasons why these conversions represent a cost as well as a benefit to human societies; diversity performs services of value just as does homogeneity. Section 4 provided the reasons why the values of diversity were systematically underappropriated by those deciding whether to undertake conversions.

The conservation of the optimal amount of diversity will require the correction of this bias toward conversion. This implies that institutions must be implemented so that host states either: 1) appropriate the values of diversity at the same rate that they appropriate the values of uniformity (i.e. conversion to high-yielding varieties); or 2) receive compensation for foregone conversions.

The difference between the two approaches depends on the preferred approach to resolving the uncertainties surrounding the values of biodiversity; it is the difference between using (in economists' terms) "prices vs. quantities" for the implementation of a policy. If the values of diversity are easily estimated (but difficult to appropriate), then a quantity-based strategy is preferred; that is, relative certainty about values implies a reasonable estimate of the amount of diversity that should be retained, and this "quota" of diverse lands may then be allocated to various host states through compensation mechanisms. Alternatively, if there is great uncertainty about the global values of diversity, then it is better to work on creating appropriation mechanisms that charge a "price" to users; in this way the optimal amount of biodiversity conservation is determined through the expressed willingness to pay within the market.

This section addresses the general nature of the institutions available to implement either approach: *compensation mechanisms* and *appropriation mechanisms*. It then discusses the application of these institutional forms in the context of PGRFA.

7.1 International Agreements to Conserve Biodiversity: Optimal Compensation Mechanisms and Appropriation Mechanisms

The creation of incentives for the conservation of the optimal level of biodiversity requires the development of an "international institution". This institution could be as simple as a single agreement between some agency representing the "global community" and a particular "host state"; however, it is important to realise that even these agreements should be constructed under the auspices of an overarching "multilateral agreement". This is because the conservation of biodiversity is a problem that concerns the flow of values from a group of "host states" to the "global community". Any action taken by the global community with regard to one host state will have an impact on the perspectives of all others, and it is important to take explicit notice of this fact. Therefore, the first point is that any institution to resolve the problem of biodiversity decline must be conceived as a multilateral agreement between the global community and the group of potential host states; it must be resolved by means of international agreement.

The second point is that any such agreement will only have prospective effect; that is, in terms of incentives, "history" has only limited importance. The optimal amount of diversity may be conserved (assuming that this point has not already been passed) by creating incentives that take only current and future (and not past) contributions to global values into account. That is, the economic analysis of incentive systems states that, for the most part, "bygones are bygones"; it focuses on the importance of the issues of efficient incentives with regard to the future and ignores the issues of distribution and equity with regard to the past. For the most part, the two sets of issues are not closely connected.

They become disentangled because the idea of an economically efficient agreement is one that is self-enforceable through its own dynamic construction. It does not rely upon a history of fair dealing or reasonableness for its implementation, but instead works on a period-by-period basis. The host state receives the compensation amount at the end of each period that will reward it for the previous period's conservation efforts, and induce it to undertake another period's efforts.

The amount paid is determined by mechanisms that assure that both the host state and the global community are "getting what they pay for", and thus the agreement is self-enforcing each and every day. This mode of operation does not require any accumulated working relationship or an external enforcement mechanism; if either party to the agreement feels that the other party's performance is unsatisfactory, then full satisfaction is received by means of withholding one's own performance. In this fashion, the incentives to conserve biodiversity (and to pay for its conservation) are put into place on a daily basis.

Therefore, the nature of a solution to the problem of biodiversity losses will be an international agreement that provides for some dynamic structure of payments for the benefit of the host states, in order to compensate them for their conservation efforts or to aid them in the appropriation of the values of their diverse resources. The next two sub-sections detail how these two alternative forms of international agreements would operate.

7.1.1 International Compensation Agreements

As mentioned above, the source of diversity's decline can be remedied through a system of strategic international payments. This system of payments would necessarily be conditional upon the host state's application of them to the conservation of some specified part of its diverse resources.

The level of these payments would be dictated by the amounts required to purchase the required "factors of production" for the specified diverse resources and the difference in the appropriated values. That is, the conservation of biodiversity in the context of PGRFA concerns the substitution of one system of production (traditional agriculture and extractive uses of "natural habitats") for another (modern agriculture). The two methods of production would rely upon distinct sets of assets and tools, and generate different forms of outputs. A system of compensation would have to pay for the net costs of the additional factors of production required, and also for the difference in benefits appropriated.

A crucial feature of any international scheme of payments based on conditionality (here, payment conditional on specific application) is its necessarily dynamic nature. That is, it is only possible to re-structure the owner-state's decision making process if the payment is offered at the end of each period that the state takes the specified action. (Swanson, 1992).

The simplest example of such an international compensation scheme would be the designation of some parcel of land as a "reserve" under an international trust fund agreement. A "reserve" in this context means the dedication of a given land area to only those uses consistent with the maintenance of its diverse resource base, such as a restriction to use only for plant-prospecting. Such an agreement would have as its objective the acquisition of the rights to all uses of the land - for the preservation of the values that will flow to the global community from such a restriction. The trust fund would be established to provide the flow of compensation to the state in an amount necessary to compensate for such forgone uses.

This is, in general, a problematic approach. First, this agreement, to be effective, would require the payment of a substantial periodic compensation fee (corresponding to each of the required "factors" required for the conservation of the diverse resources, i.e. land, management, diverse resource stocks). Secondly, such an agreement is an extreme approach to resource conservation that denies local communities most of the uses of their local resources. This approach is costly for both global and local communities, entailing higher management costliness and greater-than-necessary intervention within the rights of sovereign states and local communities. Such an extreme approach to conservation should be reserved for extreme situations; what is required is a mechanism which will acquire only the smallest number of uses necessary for the preservation of the diverse resource base.

The conservation of diverse resources will often be compatible with a wide range of forms of resource utilisation. It is possible to allow many of these uses to continue while restricting a few in order to protect particular values of biodiversity. This is because an "absolute property right" in a tract of land represents a "bundle" of many distinct rights and uses. The function of most "zoning" laws under national legislation is to allocate the various rights of use regarding a piece of land between a number of competing individuals and groups. The purpose of an international compensation agreement would be to create a self-enforceable mechanism to accomplish the same thing at the international level.

Given that the rights of use with regard to a particular piece of land are separable, this means that land uses may be divided between the "global" and the "local" communities in ways other than "all or nothing". Then the international community may intervene selectively to acquire only designated rights of use in a particular tract of land.

This is, in essence, the development rights approach to diverse resource conservation; to the extent that the international community wishes to reduce the development intensity away from the local optimum (of high intensity conversion and use), then it must be willing to provide a stream of *ex post* payments to compensate for the foregone development and to pay for the additional factors required (management, land, stocks). The approach of selective intervention has the twin advantages of decreasing the required global funding required while increasing the benefits flowing to local communities from local resources.

Generally, an efficient international compensation scheme would be of the form of an *international franchise agreement*. (Swanson, 1994b). This is a three-way agreement (between owner-state, international community and franchisee) in which the international community provides a stream of rental payments to the owner-state in return for its agreement to "zone" a piece of land for use only for restricted purposes (as specified within the international franchise agreement). That is, the land would be franchised for use to individuals or groups within the local community ("franchisees"), but only for those uses consistent with the agreement between the national government and the "international community".

The franchising mechanism allows for the efficient allocation of "land uses" between the global and local communities. If the global community wishes to restrict certain local land uses, then it must be willing to pay the full rental value of those uses. Similarly, the uses that remain for the franchisee are likewise charged at their full rental rate. Then these rental rates are determined in a limited auction (e.g. the global community could make bids for the same limited rights of use in a number of different tracts of land across the world) and only those states which wish to accept the international bid are bound by the conditions of agreement. In this way the "incremental burdens" of diversity conservation (through use restrictions) are only undertaken voluntarily, and only if the price paid by the global community is sufficient to induce agreement.

At the same time, an international franchise agreement also creates an enforcement mechanism for the channeling of these funds into diversity conservation. By paying a periodic rental rate, the international community is assured of receiving a stream of conservation benefits in return for its payments because, if the use restrictions are not enforced, the international community retains the right to withhold payment of future rents. In this fashion, the agreement is rendered "dynamically consistent": each party has the capacity to withhold performance in each period until it sees the other fully perform its own obligation, and thus each party is capable of self-enforcing the agreement.

Therefore, a franchise agreement is simply an economically efficient form of contracting to provide certain services; here, the services to be rendered are those of the diverse resource stocks. The crucial components of such a contract are the efficient allocation of the various uses of a tract of land between global and local communities - in the context of a self-enforcing agreement.

7.1.2 International Appropriation Agreements

The alternative to the subsidisation of the costliness of the conservation of diverse resource systems is the enhancement of the returns derived from diverse resource production. The former option effectively reduces the costliness of making the decision not to convert diverse resources; the latter option (analysed here) effectively increases the benefits from investing in diverse resource systems. Therefore, the impact of either approach is the same on the host state's decision making regarding land use conversion.

Market regulation is a policy based on assuring that the host state receives the full value from its diverse resources. At present, this is the opposite of what is occurring with respect to most diverse resources. African countries had been capturing about five per cent of the value of their raw ivory exports during the height of the ivory trade. (Barbier et. al. [1990]). Tropical bird harvesters around the world acquire between one and five per cent of the wholesale value of the animals. (Swanson [1994]). This is even true with regard to many exports of tropical forest products. (Repetto [1990]). The host states of diverse resources do not place much effort into the appropriation of the benefits of diverse resources, choosing to encourage conversions instead. Market regulation reforms are intended to redress this balance.

The crucial element to this approach is the creation of a price differential for diverse resources that is available only to those host states conserving their diverse resource stocks. That is, the idea is to increase the "rental value of the resource": the perceived value intrinsic to the resource itself (as perceived by its producer/harvester). Therefore, these price differentials represent the enhanced appropriation of value by those states investing in diverse resource conservation.

The price differential creates the capacity for some manner of dynamic conditionality, as is required in an effective agreement. The prospect of receiving the price differential constitutes the inducement to meet the conditions required to be entitled to the differential, and the receipt of this entitlement (combined with period inspections) constitutes the incentive to continue satisfying these conditions.

The conditions that would be specified to receive this entitlement would be "stock-related", i.e. they would specify the levels of the conservation of lands or stocks of diverse resources required to be included within the price-differential regime. These stock constraints could take the form of a number of hectares of specified diverse stocks or diverse production methods or even hectares dedicated to restricted uses. The idea is to find some sort of surrogate for the level of anticipated global benefits that will be derived from the host state's conservation activities.

The price differential is implemented via market regulation in the consumer-states. The simplest form of such an agreement would be a restriction on all purchasers to acquire the diverse resource only from the "listed suppliers". Such "exclusive purchasing agreements" will always create a premium for the favoured suppliers and a penalty for the disfavoured. The key to the success of such agreements is the investment by the consumer states into the discrimination between the two sets of imports; to the extent that consumers invest each period in barring imports from "nonlisted" producers, an enhanced rent will be available to the listed.

The importance of a truly international agreement (i.e. multilateral) is made clear in this context. The extent of the price differential will depend entirely upon international enforcement of the ban on unlisted producers; otherwise, a single noncompliant state may act as a conduit for unlisted suppliers, mixing the two sources and exporting both as "high price" commodities. In the final analysis the extent of such piracy determines the ultimate price differential achievable by sustainable producers, because it is capable of flooding the market with competing supplies. Therefore, the development of mechanisms to minimise the impacts of such pirates is essential to the success of a rent appropriation mechanism.

A bilateral agreement is also an inadequate means of appropriating these values. A bilateral agreement may assure a particular market to a particular supplier, but the highest price that the consumer state will be willing to pay will be dependent upon the exclusivity of its rights in the subject resources (otherwise it owns nothing). Since the producer state cannot guarantee exclusivity (because of other potential producers and potential leakages to other consumers), the value of its resources is much enhanced if a simultaneous agreement is reached with all other significant consumer states to recognise the exclusivity of its rights in the goods traded with other consumer states. Then these consumer states receive these exclusive rights in the transaction, and their willingness to pay is determined by their belief in the assurances of the other consumer states. The distinction between an international and a bilateral agreement for purposes of value appropriation is the creation of this assurance of exclusivity and the value that it represents.

Rent appropriation is therefore dependent upon the efforts of all consumer states to enforce the discrimination between sustainable and nonsustainable producers of diverse resources. The extent of international cooperation and individual (consumer state) investments will determine the existing price differential.

The differential rents available to sustainable producers may be further enhanced by virtue of management of the quantities traded between suppliers and consumer states. The maximum rental available may then be determined, and the maximum produced quantity that this implies would be allocated between the various host states, developing a form of a cartel-based pricing system for the resource.

The important point to remember is that this enhanced rental value is being paid not only for the good in trade, but also for the global services that its production method implies. So, if sale of a particular commodity (such as Brazil nuts) that is produced within a sustainable production system implies the retention of this system, then this strategy implies the retention of all of the other services the system generates. Then a subsidy to Brazil nuts is only a means of cross-subsidising all of these other unpaid goods and services. The incentive to conserve both arises out of the fact that the production method (combined with the use restrictions) generates jointly both the tangible and the intangible goods and services.

An example of this cross-subsidisation approach has been attempted in Sub-Saharan Africa. After the ban on the ivory trade in 1989, several of the sustainable producers of elephants grouped together to form an "Ivory Exchange", based in Malawi. The idea of the Southern African Centre for Ivory Marketing (SACIM) is to provide a verifiable conduit for ivory flowing from managed elephant stocks, and thus to provide a mechanism for consumer states to assure their purchases from sustainable producers. The enhanced rental value that would result would subsidise not only sustainable elephant populations but also all of the other wildlife and systems that live on the lands dedicated to these populations. (Swanson and Pearce, 1989.)

In summary, the idea of such exclusive market agreements is to allocate the consumer markets only to those owner-states investing in their diverse resources. The owner-states that choose to mine their diverse resources will otherwise drive down the prices, and rents, available to all states providing diverse resource flows. An agreement to restrict consumer markets to those owner-states that invest in their diverse resources (and the systems from which they derive) creates a price differential: a price premium target to all sustainable producers and a price penalty target to all nonsustainable. Such a mechanism might be used in a wide variety of circumstances, where the stock-related investments are directly linked to the final product.

7.1.3 The Use of "Intellectual Property Right" Regimes as Value Appropriation Mechanisms

Another example of an exclusive purchasing scheme would be any form of an *intellectual property right regime*. Such a regime would also allot specific markets in all consumer states to specific producers in order to compensate for diverse resource investments, but the connection between the market and the investment would be less direct (as compared with diverse resource investments that directly generate tangible flows and jointly generate global services). That is, in this case, the jointness of production requirement is done away with in the context of these forms of exclusive purchasing agreement; otherwise, the mechanism is identical to those discussed in section 7.1.2 above.

The role of any form of intellectual property rights regime is to provide a basis for compensating investments in stocks that do not generate directly compensable flows; specifically, intellectual property regimes reward inappropriable investments in information with rights in discrete markets. It has transpired in modern societies that investments in human forms of capital (e.g. education and training) have become very important for production and growth; however, the outputs from these investments are usually intangible and nonappropriable, e.g. ideas and insights. (Romer, 1990).

If there were no protection for human capital-generated services, then the pirates of the world would simply watch for innovations and then copy these inventions and market them to the consumer states themselves. International agreements provide consumer states with the assurance that their purchase of an idea or innovation will be assured of its exclusivity, and therefore they are able to pay the producers of such innovations a differential price in accordance with this exclusivity. The extent of the universality of these agreements and the extent of individual states' efforts to enforce them determines the values that flow to human capital investments.

In essence, the innovators in these markets are analogous to the "sustainable producers" of ideas; these are the states that are producing ideas by investing in humans. The pirates in the markets are analogous to the "nonsustainable producers"; they are not investing in humans and only supply innovations to the extent that other invest. If the price to both groups were the same, then there would be no incentive to invest in human forms of capital. Intellectual property laws provide the price differential for those states able to demonstrate such investments, and thus they maintain the incentives for continuing investments in the production of these intangible forms of services.

The distinction between intellectual property rights regimes and the other forms of value appropriation described above lies in the criterion of "jointness of supply". In the case of the market regulation mechanisms described above, intangible flows of services could be assured by reason of the jointness of their production with tangible goods; elephant ivory implied investments in wildlife lands. In the case of the services flowing from human capital investments, there is no requirement that there will be a tangible good that will issue with the idea; this "surrogate" must instead be created in a fashion that will adequately reward the intangible services being generated.

This is the distinct function of an intellectual property rights regime; it carefully describes a specific exclusive consumer market that is offered as a reward for a general idea. The idea is then released to the global community for general and widespread use, while the specified consumer market operates as an international exclusive purchasing agreement to create the award for the innovator.

A concrete example is the innovation of the optimal sized racquet head, developed from a more general formula that determined the optimal trade-off between wind resistance (too large of a head) and required accuracy (too small of a head). The inventor of the "oversized" tennis racquet determined that a racquet of 117.5 square centimeters was optimal for tennis. In fact, this represented an investment in the creation of a pure idea that would not have been appropriable through marketing of tennis racquets (because other sellers would have immediately entered the market with the same head). In addition, the value of the idea was also far more general than the specific application of tennis, as the same formula could be applied in many other sporting contexts.

However, the intellectual property rights regime awarded this inventor with a protected market right in all racquet head sizes between 100 (the original size of a tennis racquet head) and 135 square centimeters. All consumer states then, effectively, entered into an exclusive purchasing agreement with this innovator for these sizes of racquets. This protected market then acted as compensation for the investment in information-creation made by this inventor.

The important point about the nature of the intellectual property regime is that the exclusive rights in the tangible good did not match up very well with the actual idea being awarded; to some extent, there was little "jointness of supply". The innovator's idea was more specific than the range of tangible goods allocated, but this product market area was what was required in order to compensate the idea adequately. Similarly, the innovator's idea was also far more general than simply this one application would indicate; however, the patent allowed the more general uses of the idea to flow into the public sector while allotting a range of more specific uses to the inventor. Therefore, the tangible good acts as an award for the provision of intangible services, but it does not need to "match up" with the intangible services as well as in the case of the market mechanisms mentioned previously.

It is equally possible to link protected markets to investments in diverse resources stocks, because these stocks also feed into various industries in an indirect and usually inappopriable fashion. Just as investments in human capital will generate information (ideas and innovations), investments in human capital also generate informational values. The problems are virtually identical: How is it possible to encourage societies to invest in forms of capital that generate inappropriable but important goods and services?

For example, many pharmaceutical innovations are developed from a starting point of knowledge derived from the biological activities of natural organisms. When a new start is required, it is often inititated by returning to the uncharted areas of biological activity (unknown plants and insects), but after the long process of product development and introduction, there is no compensation for the role played by the diverse resource in inititating the process. The informational input supplied from the diverse resource system goes unpaid-for, and this means that there will be no incentive to invest in the natural capital that generates this information.

A "genetic resource right" system could be constructed that would be analogous to an intellectual property right system. There would not be anything in this that would conflict with existing regimes; it would simply represent an extension of this idea for compensating intangible services into realms other than those deriving from human-capital investments. To a large extent, the extension of "intellectual property" regimes to include natural resource-generated information simply levels the playing field between those societies which are more heavily endowed with human capital and those which are more heavily endowed with natural forms of capital. It is a very rational approach to the resolution of the biodiversity problem, just as the adoption of the Paris Patent Union one hundred years ago was a rational approach to the problem of protecting investments in human innovations in industry.

7.2 The Implementation of "Farmers' Rights"

The application of the concepts developed in the previous section is straightforward in the context of PGRFA. If it can be assumed that the meaningfulness of the concepts of "Farmers Rights" and an "international fund" is the expression of the desire (on the part of the global community) to create a system that will create an optimal set of incentives for the conservation of PGRFA, then the application of the concepts developed above to the global values of PGRFA is all that is required.

The first objection to this premise might be that the host states see the object of the IUPGR more broadly than this. For example, they might instead see this as an expression of a "debt owing" for past contributions of PGR to the developments that created the green revolution.

The short answer to this position is that, irrespective of the merits of this position, the maximum amount extractable from the global community will be dependent solely upon the prospect of future benefits to be rendered. The global community may be willing to allocate some proportion of this maximum amount between "past injustices" and "future incentives", however, this will only have the effect of reducing the aggregate amount that the market will pay (because if it reduces future incentives for biodiversity conservation, it will reduce the anticipated future benefits to the global community and hence their willingness to pay). Therefore, the only objective of the IUPGR that will have any chance of being implemented is the one that establishes optimal incentives for future conservation practices; it is important that this is the objective analysed so that it is implemented effectively.

This does not mean that this analysis of the IUPGR is biased toward one perspective or the other; it only means that the common ground for an international agreement is to be found in the area of this single viewpoint. The motivating idea behind any international agreement is to provide an institution through which all societies in the world can gain; in this case, through the assured maintenance of an optimal amount of biological diversity by means of the effective compensation of its host states.

There is only one crucial question to be answered prior to proceeding with the discussion of the implementation of "Farmers' Rights", i.e. to what extent can the global values of PGRFA be estimated prior to appropriation? If it is believed that this can be accomplished outside of the market, then "compensation-based" instruments may be relied upon exclusively; if it is not possible to assess with any accuracy the global values of PGRFA in the absence of some attempts at appropriation, then it will be necessary to combine compensation-based instruments with "appropriation-based" instruments.

Part B of this paper gave an indication of the methods that might be used to resolve this preliminary issue, and the manner of the studies that might be accomplished. However, even with these studies done, it will be apparent that they will only narrow the range of uncertainty marginally; it is likely that there will be a role for attempting to create appropriation mechanisms in this context on account of the extent of uncertainty.

This report suggests two new international institutions (probably of the nature of protocols to the Biodiversity Convention). One of these protocols would be based on the idea of implementing a "compensation-based" regime and the other on implementing an "appropriation-based" regime.

7.2.1 International System of Reserves for PGRFA

The compensation-based regime would be developed out of an international system for the purpose of generating a set of "reserves" for the conservation of PGR. These reserves could conceivably be of the following types:

a) *traditional farming reserves* - In order to preserve resources for exploration value and to maintain portfolio effects, the global community would wish to acquire all rights of use incompatible with traditional agricultural practices in certain tracts of land. In effect, the global community would pay the differential costliness of the restricted land use.

b) *biodiversity prospecting reserves* - In order to preserve resources for exploration value, the global community would wish to acquire all rights that were incompatible with long-term prospecting (e.g. any burning, clearing or conversion) to certain areas of land with high potential for future contributions to agricutlure (e.g. high plant diversity).

The international system to develop these reserves could be best managed within a single institution that would establish these as *international franchises*. This institution would perform the following tasks:
1) policy making - The institution would need to ascertain the optimal quantities of each of the various forms of reserves (determining the range of uses that would be allowed in each). 2) franchising - The

institution would have to develop the mechanism for auctioning the rights to host states (to host reserves). 3) monitoring - The institution would have to inspect the reserves to ascertain that they were being used in accordance with their agreed restricted uses. 4) periodic payment - The instituton would make periodic payments to any state adequately enforcing the terms of it franchise. 5) termination of franchises - The institution would have to terminate any franchise that did not meet the terms of its agreement.

The problem of extracting willingness to pay (from the global community) is solved implicitly within this institution. In essence, willingness to pay will be closely linked to the observation of tangible benefits (i.e. the effective conservation of diverse resources). Here, the institutional form contains assurances of conservation effectiveness (and cost-effectiveness) and this has the effect of inducing payments for the anticipated benefits. To a large extent, the resolution of the biodiversity problem is the creation of mechanisms for putting "willing buyers" and "willing suppliers" together. The creation of a mechanism that will assure consumers of conservation effectiveness (value for money) is the means by which this problem can be resolved.

7.2.2 International PGR Exchange

Many of the values of PGRFA are already being appropriated within the agricultural economy, but not at the level of greatest conservation-effectiveness. Industries exist for the purpose of incorporating newly identified useful traits within existing plant varieties (capturing one facet of exploration value). These same industries commence screening of supplies of genetic material if an environmental shift requires an adaptation of existing varieties (capturing quasi-option value when successful). Gene banks have been establish to feed into these industries.

Why does this appropriation of the values of diversity not generate incentives for the optimal amount of conservation? It is because value must be appropriated at the right level of an industry for incentives to inhere. Capture at a more distant level may have little or no impact on conservation-effectiveness, depending upon the entity's capacity to invest in the retention of diversity.

To date, the rents that have been captured from the diverse resource have been appropriated by distant levels of the industry: plant breeders and seed companies. These rents are generated when a company is allowed a monopoly right on the sale of a particular plant or seed variety. In an attempt to generate a return to the human capital invested in such innovations, the plant breeders rights and seed patents allotted to such companies capture the rents created by the combination of both human intellectual factors and natural genetic factors of production.

Investments in natural capital generate intangible forms of services just as surely as do investments in human capital. The rectification of the asymmetry in the treatment of these different forms of capital under international law should be one of the objectives of the Undertaking. The rents generated by natural capital investments should be returned to their investors, and the rents generated by human capital investments should be returned to theirs.

How is it possible to separate out between the contributions of genetic resources and human resources in the plant breeding industry? The means of appropriating rental value is the creation of internationally-recognised exclusive rights. These are enforced through state-enforced exclusive purchasing (i.e. forebearance from "piracy"). This develops the price differential that accrues only to those states with rights vested under the international regime.

It would be straightforward in theory to render these rents appropriable by the host states. One such system would allow for the certification of "exchanges" for the trade in PGR. An exchange system would have as a membership requirement the allocation of a specific quantity of lands in a host state to either traditional agriculture or plant prospecting activities. It would then require plant breeders and seed industries to purchase their genetic resources from this exchange (not from one another or other reserves). Any newly-marketed seed or variety would have to be able to trace all of its characteristics to legitimately acquired specimens. The exclusive purchasing requirement would generate the rents for its members.

This payment of rents for genetic resources is long overdue with regard to most plant genetic resources. It is economic nonsense to allow plant genetic resources to remain within the public domain at the most important levels for conservation effectiveness. It accomplishes little purpose to doubly-subsidise plant breeders for their investments in human capital (by allowing them to appropriate the contribution of the natural capital as well), since they are not in a good position to invest in the conservation of the base resources over the long run.

The hosts states generating plant genetic resources should be allowed to capture this value in return for investments in the retention of the diverse resource systems from which they are derived. They could do this most easily by means of the creation of "exchanges" that make these resources available exclusively through such mechanisms, and the global community could assure their continued provision by means of exclusive purchasing from these exchanges. The existing gene bank network should be made to evolve into an exchange system in order to generate these rental payments.

7.2.3 International Genetic Resource Rights Generally

There are other forms of property rights systems that are less centralised than the exchange option. For example, the international agreement could provide for exclusive purchasing from the first party to register a particular genetic resource, rather than the first party to place a sample with an exchange. Then the rents would accrue by reason of the consumer states' enforcement of this exclusive purchasing obligation.

The exchange concept is built upon this more fundamental right, but it is a more cost-efficient mode for adminstering the system. As always, the key to appropriability is exclusivity, and the key to exclusivity is consumer recognition of this right. Any new property right regime involving international industries will be dependent upon member state enforcement to give it effect. Otherwise, "pirate states" will effectively nullify its operation.
The advantage of an exchange system over any other genetic resource right system is its international transparency; states will have their legitimate purchases of genetic resources occur in an international forum. The granting of later monopolies (plant breeder rights, seed patents, etc.) should then be made contingent upon the tracing of all genetic stock back to an exchange transaction. This will minimise the incentives to deviate from the agreement.

If a non-exchange based genetic resource right system is elected, the regime would then operate through central registration and private trading. A state would qualify for inclusion within the regime by means of investing in stocks of diverse lands for the restricted purpose of exploration (and compatible uses).

Then any discoveries within these areas should be made subject to internationally-recognised exclusive rights upon registration with some sort of centralised office (analogous to a patent office).

The registration office would then have the responsibility for determining the scope of the monopoly rights afforded by the registration. In the case of claims to genetic resource rights to traits of biological materials, it would probably be necessary for these claims to be based upon the specification of particular genes and their characteristics upon filing.

As with any registration-dependent right, the first registrant would be entitled to the entirety of the monopoly right. Thereafter, any user of the gene would have to acquire a license from the registered owner prior to its marketing; otherwise, an action for infringement would lie.

The rents generated by these monopoly rights should create incentives for conservation. Host states with diverse resources would invest in "certified prospecting reserves", and charge fees and command royalties for any discoveries within the reserve on account of the internationally-recognised exclusivity in the discoveries found there.

Note that the creation of genetic resource rights requires only a small embellishment upon existing laws, which currently proscribe the taking of rights in "mere discoveries". The existing laws require a substantial amount of human intervention as an indication of a significant amount of investment in human capital to warrant its reward. In the context of biodiversity, the information-generating role of human capital is replaced by that of natural capital (diverse systems). Therefore, mere discovery should be sufficient for the award of property rights in naturally-generated substances, so long as they are derived from substantial land areas that are internationally- certified for prospecting purposes.

7.3 Conclusion: Appropriating the Value of PGRFA for Biodiversity Conservation

This introduction to the ideas of the appropriation of the economic value of PGRFA is necessarily brief and incomplete. The purpose of this document has been to describe the problem of biodiversity in this context from beginning to end, and thereby indicate the general nature of its solution. If the basic ideas put forward in the previous sections of this paper are accepted, the conclusion is inescapable that the institutions described in this section are what is required to resolve the problem in this context.

The nature of that solution comes in the form of a proposal for two new institutions: a *compensation mechanism* and an *appropriation mechanism*.

There are certain forms of diversity's value that are inappropriable by anyone or any state individually. It is in everyone's interest to maintain these values, but it is difficult to supply them because they are of the nature of global public goods. This is true for some of the portfolio effects and exploration values attendant to biodiversity.

The solution to this problem is the creation of an *international reserve system* that compensates host states for any franchises placed within their boundaries. The system of reserves developed under such an agreement then serves to generate the flow of inappropriable values from plant genetic resources.

How can it be assured that this system will generate the right amount of funding and hence the correct number of reserves? An international franchise agreement system solves this problem by putting a mechanism into place that will allow "willing buyers" to acquire the amounts of diversity they desire from "willing suppliers". The value of biodiversity is then expressed in this willingness-to-pay when consumers see that their object is assured by virtue of the right form of institution. Therefore, values (even very intangible ones) can be appropriated so long as their flow is assured by the appropriate mechanism. The mechanisms described in this section were devised to provide the assurance of continued flows of diversity's services, and in this manner it is expected that the willingness-to-pay will be induced from the consumer states and their citizens.

Other values flowing from plant genetic resources are appropriable (e.g. exploration value for yield enhancement); in fact, they are already being appropriated, only at the wrong level of the industry for purposes of conservation-effectiveness. Plant breeders rights and seed patents allow the final stages of the industry to capture the rents from both human and natural capital. For conservation effectiveness, the rents from the natural capital should be separated out and returned to investors in those forms of capital.

These rents may be captured at the earlier stages of the industry through the institution of a *plant genetic resource exchange system*. Such a system would essentially displace the currently-prevailing open access system at the world's gene banks. The banks would have to institute membership requirements for storage of a country's depositions (requirements that restrict membership to those countries investing in the retention of diverse plant genetic resources), and an international agreement would render it illegal to purchase plant breeding stocks from any source other than an exchange.

Such an exchange system would perform the same function as any other exchange (such as a stock exchange); it would certify that the commodity acquired was "genuine", i.e. from a sustainable producer of PGRFA. It would in turn generate the rents that are attributable to the natural capital component of the industry. Once these rents began to flow to sustainable producers of plant genetic resources for agriculture, the correct incentives to conserve these resources would be in place.

The exchange system concept is a simple demonstration of the general idea of creating internationally-recognised *genetic resource rights*. These are rights that derive from the first registration of a particular gene with a central office, analogous to any other form of right that derives from prior registration (trademarks, copyrights, patents). Producers of new seeds and varieties would then be required to show licenses for the use of any newly-incorporated genetic material. These licenses would then generate the rents to the registered owners.

The exchange system is built upon the more fundamental idea of a genetic resource right, but it builds upon the existing institutional apparatus (the gene bank network) and it minimises the cost of administering the system. With a PGR exchange system, there is no need to break the registration down beyond the level at which the genetic resource exists in nature. A supplier state need not pay for the analysis of the specimen, or the creation of specific registration documents; the natural specimen deposited with the exchange and the registration requirements are one and the same. If the supplier wishes to register more specimens, then it must simply deposit more samples with the exchange. It is the requirements for exchange membership (that the specimens are acquired and deposited in the course of a "sustainable" operation) that creates the incentives to conserve the diverse resource.

The concept of "Farmers' Rights" is long overdue for implementation. It makes no sense to allow certain fundamentally important factors of production to earn no return. This will certainly create incentives to underinvest in their continued supply, as has been witnessed over these many centuries. If these genetic resource inputs are to remain available in future, a system for compensating investments in their retention must be instituted now.

As mentioned at the outset of this paper, this has long been a contentious issue between North and South. It has been approached as if a "zero sum game", i.e. an increase in appropriable value for one group will coincides with a loss for the other. However, rent appropriation for the states hosting genetic resources does *not* necessarily imply a loss in net value for consumer states. The essence of the "commons problem" in economics is that situations exist where cooperation between the various users of the resource can produce a gain for all.

In the case of PGRFA, the optimal conservation of the resource will undoubtedly yield a substantial increase in the benefits to the global community (a gain for all) by means of a relative increase in the rate of appropriation by the host states. The former is a policy instrument for assuring the latter. When discussing values such as the stability of the entire agricultural system, it is important to recognise that the gains from investments in diverse resources are likely to outweigh costliness resulting from the redistribution of rents to the most effective investors in those resources.

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