Economic Evaluation and Biodiversity Conservation of Animal Genetic Resources

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Preface

Rapidly declining biodiversity has made international and national policies focus on the question of how best to protect genetic resources. Loss of biodiversity does not only concern wildlife, but equally affects agriculturally used species. These species, of foremost importance for the subsistence of humankind, are subject to pressures sometimes similar and sometimes very distinct from those of their wild counterparts. And so are the losses implied by this decline in diversity.

This handbook was conceived within the project *Sustainable conservation of animal genetic resources in marginal rural areas*: *Integrating molecular genetics, socio-economics and geostatistical approaches* (ECONOGENE – EC-QLK5-CT-2001-02461) to review and design methods that can serve as a basis to guide conservation policies for livestock breeds at risk of extinction. It is part of the broader effort of a multidisciplinary research team assessing the diversity of European sheep and goat breeds. The final goal of the project is to assess the impact of current and future policies on these breeds.

Addressed to decision makers and all those who desire a better understanding of the economics involved in the conception of conservation programmes, this handbook reviews the principal issues of natural resources evaluation as they apply to biodiversity conservation. Concentrating on issues of livestock biodiversity, this review does not aim to be a complete guide to the economic literature of biodiversity evaluation, but to illustrate the key points relating to livestock biodiversity using a number of examples taken from the literature.

The handbook is divided into five chapters. Chapter I introduces the issue of global livestock diversity loss and gives an overview of its underlying causes. The principal question of why economics can help in designing conservation policies is posed.

The second chapter introduces the concept of economic value. The value of livestock breeds is not captured completely in the market because of the public good character of genetic resources. For this reason, methods evaluating livestock biodiversity have to go beyond the market place. We review a number of useful methods evaluating livestock and biodiversity values in Chapter III. This forms the core of this handbook.

Measuring these values is central to designing conservation policies. In Chapter IV, we thus turn to the question of how conservation policies can be guided by the concepts of benefits and costs. We adopt Weitzman's approach to the problem of biodiversity conservation. This approach has by now been adapted to and implemented in a number of case studies dealing with livestock biodiversity. Chapter V concludes this handbook with an outlook to current and future policy questions of livestock conservation.

Considering the aim of this handbook, we have decided to include a number of examples that show how empirical research may apply the concepts addressed in this handbook. These examples of empirical research have been referred into boxes that illustrate relevant research in a self-contained manner. We hope that in this way, readers interested in the key issues can find satisfaction in the main text and those interested in going to applied research find guidance in the boxes. We have tried to keep the handbook free of developments that we considered too technical for a broad readership and trust that those interested may profitably refer to the references provided. The handbook provides an extensive bibliography for the reader interested in further details.

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I. Introduction

Biodiversity of farm animal genetic resources (AnGR) has been rapidly declining in recent decades (FAO, 1999; Hammod and Leitch, 1996). A conservative global estimate suggests that at least 28% of farm animal breeds became extinct, rare or endangered in the past century (World Conservation Monitoring Centre, 1992). In most marginal areas, AnGR-based farm systems are among the most important land-uses. Areas currently considered "marginal" have long been the source of several well-adapted local breeds, many of which are presently endangered, either because of substitution with (mostly exogenous) 'improved' breeds or because farmers abandon husbandry and agriculture. It is a widely held belief that the existence of such traditional, well-adapted breeds is a necessary given for viable, sustainable land use in marginal areas (Rege and Gibson, 2003).

I.1   Status of endangerment of breeds

Indicators on the status of endangerment of breeds are available from many sources. At present, the most widely reported indicators pertinent to livestock biodiversity are found in the list provided by FAO through the "Domestic Animals Diversity – Information System (DAD-IS) and the Animal Genetic Data Bank of the European Association for Animal Production (EAAP).

The EAAP data bank monitors information on populations at breed and country levels to keep an eye on development, on the change in the risk of breed extinction and to encourage use and conservation of animal genetic diversity. The farm animal species concerned are buffalo, cattle, goat, sheep, horse, ass, pig, and rabbits. In total, the data bank concerns 46 EAAP member countries and other European countries.

Over the past decade, the FAO has helped collecting data from some 170 countries on almost 6,500 breeds of domesticated mammals and birds: cattle, goats, sheep, buffalo, yaks, pigs, horses, rabbits, chickens, turkeys, ducks, geese, pigeons, even ostriches. The FAO Global Databank for Farm Animal Genetic Resources (DAD-IS) contains information on 6,379 breeds of 30 mammalian and bird species. Population size data is available for 4,183 breeds of which 740 breeds are already extinct and 1,335, or 32%, are classified at high risk of loss and are threatened by extinction.

DAD-IS monitors breeds worldwide and classifies them into seven risk categories: extinct, critical, endangered, critical-maintained, endangered-maintained, not at risk, and unknown. "Extinct" indicates that it is no longer possible to recreate the breed population. Extinction is absolute when there are no breeding males (semen), breeding females (oocytes), nor embryos remaining. "Critical" indicates that the total number of breeding females is less than 100, or the total number of breeding males is less than or equal to five, or the overall population size is close to, but slightly above, 100 and decreasing, and the percentage of pure-bred females is below 80 %.
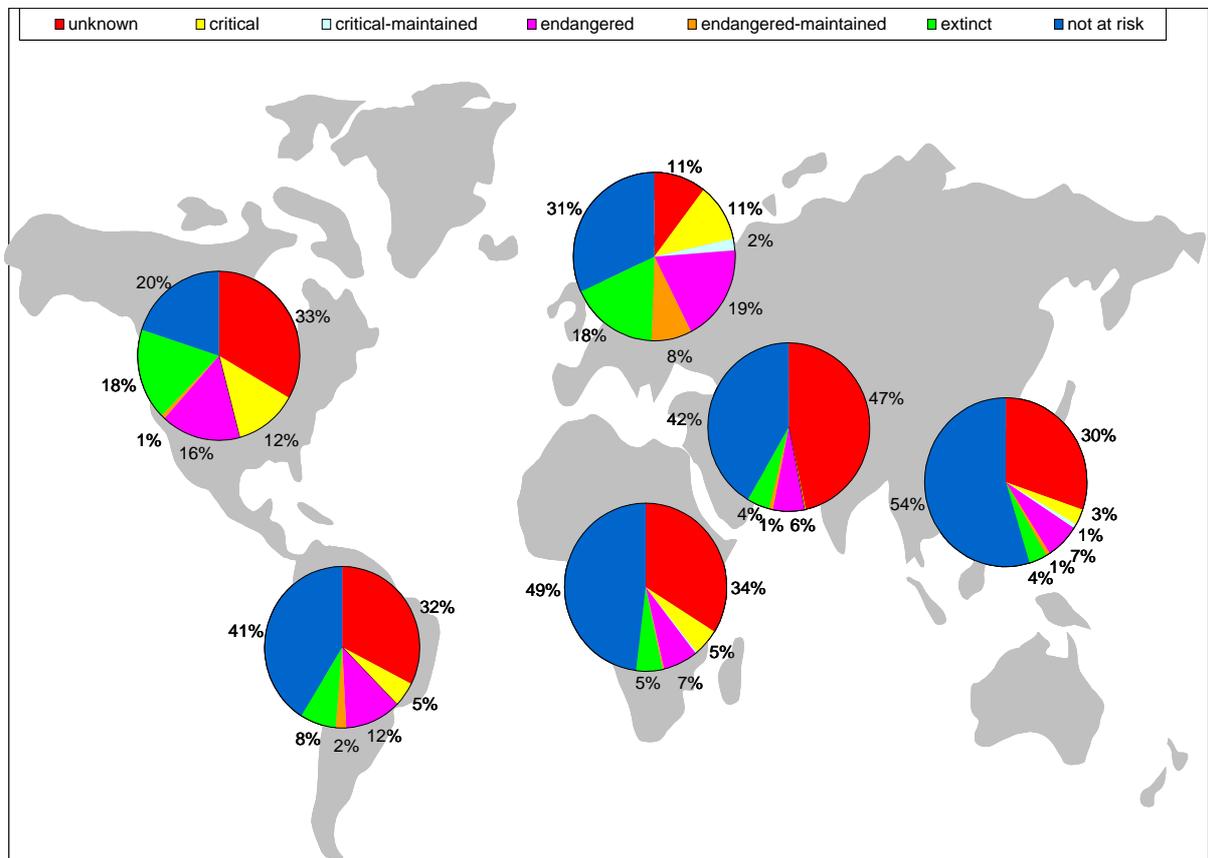
Source: FAO (2003)

Figure I.1 Global summary – Proportion of breeds recorded for all species in each region by risk status category

"Endangered" indicates that: the total number of breeding females is between 100 and 1000; or the total number of breeding males is less than or equal to 20 and greater than five; or the overall population size is close to, but slightly above, 100 and increasing and the percentage of pure-bred females is above 80%; or the overall population size is close to, but slightly above, 1000 and decreasing, and the percentage of pure bred females is below 80%.

"Critical-maintained" and "endangered-maintained" refers to breeds being maintained by an active public conservation programme or within a commercial or research facility. "Not at risk" indicates breeds for which the total number of breeding females and males is greater than 1000 and 20 respectively; or the population size approaches 1000 and the percentage of pure-bred females is close to 100 %, and the overall population size is increasing. Finally, "unknown" covers breeds for which no data are available.

The threat to farm animal biodiversity is displayed in figure I.1, which shows a summary of the status of the world's farm animal breeds. In Europe, the situation of farm animal biodiversity is particularly critical: 18% of the breeds existing in the early 20th century have already been lost. Unless significant changes take place in the driving forces behind biodiversity depletion, 40% of recorded breeds risk becoming extinct over the next 20 years. This figure illustrates the reality that erosion of biodiversity at the breed level is not simply a concern for the distant future, but an active ongoing process.

I.2   Why value biodiversity?

Biodiversity is considered to form the very basis of life on earth. The preamble of the Convention on biological diversity states that the contracting Parties are "conscious of the intrinsic value of biological diversity" and "conscious also of the importance of biological diversity for evolution and for maintaining life sustaining systems of the biosphere." They affirm that "the conservation of biological diversity is a common concern of humankind" and that they are "aware that conservation and sustainable use of biological diversity is of critical importance for meeting the food, health and other needs of the growing world population." The Conference of the Parties (COP) Decision IV/10 acknowledges that "economic valuation of biodiversity and biological resources is an important tool for well-targeted and calibrated economic incentive measures."

As it will be developed in detail in Chapter II, the value of biodiversity is not, or at least not completely, captured by markets. It is an implicit value that constantly tends to be underestimated because of the absence of well-defined property rights. Despite continuous progress in the evaluation of non-market goods, the empirical literature fails to evaluate the entire range of biodiversity benefits (Nunes and van den Bergh, 2001).

One way biodiversity value may be understood is as an asset for future generations. Consistent with this is a view of biodiversity as insurance in the face of uncertainty.

Because the value of biodiversity is not completely captured in markets, its conservation is often at loss in comparison to land-use developments for market goods and access. Internalising the economic value of natural resources beyond the private value of direct use is hence important to fully assess the trade-offs involved in land-use allocations. As some papers have recently outlined (e.g. Costanza *et al.*, 1998; Norton *et al.*, 1998), the natural capital is the very foundation of economics. In this perspective, valuing biodiversity is important because it makes markets and economics commensurate with the actual functioning of the world.

I.3   What is specific to livestock biodiversity?

Livestock *species* are unlikely at danger of extinction themselves. The level of biodiversity which is of concern here is that of breeds and even populations within breeds. In fact, within-breed diversity account for 50 to 70% of total genetic variance (Hammond and Leitch, 1996).

In the case of livestock, the anthropogenic impact on biodiversity is often the most important one, through controlled reproduction and selection, as well as introgression and production decisions impacting the demography of livestock populations.

Some livestock breeds are ancient, but many are relatively speaking recent. Significant amounts of genetic variation are unlikely to have accumulated as the result of mutations. The rate of phenotypic variation brought about by artificial selection in animal breeding is much greater than the rate of 'change' at the genetic level that is measured by DNA markers such as microsatellites (Bruford, 2003). Measures of diversity used in the context of wild species are hence often not suitable as measures of diversity for livestock breeds.

Livestock biodiversity is less implied in the functioning of complex food chains and ecosystems than wildlife biodiversity. However, AnGR generally have implications for

cultural and landscape diversity and are of great significance for the resilience of many agroecosystems. Finally, domesticated animals have primarily direct use values as opposed to wildlife, though this distinction is not as strictly dual as it may appear. In consequence, methods used for the evaluation of farm AnGR need to consider their importance for production systems, agro-ecosystems and diversity as specific for livestock breeds.

I.4 Causes of livestock biodiversity loss

This section focuses on the factors and processes that have contributed to the loss of livestock genetic diversity. The synthesis presented below is based on works by Anderson (2003), Mendelsohn (2003), Rege and Gibson (2003) and Wollny (2003). Broadly, these factors and processes can be grouped in three categories: (1) factors acting directly on the genetic constitution of AnGR, (2) indirect factors and (3) other factors.

i. Direct factors

Trends in population demographics, e.g. urbanisation, as well as technological changes in farming systems and marketing can have negative effects upon animal genetic resources. Commercial production systems tend towards uniformity, whilst livelihood-oriented systems thrive on diversity. 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 the way we have known it has derived in part from the substitution of the more productive assets for the less productive ones, i.e. from the conversion process.

The processes of conversion generate homogenisation and uniformity of inputs, resources, technologies and outputs. These processes have occurred and are still occurring, as well in the developed countries as in developing countries, and they generate great specialisation. For livestock, the process of conversion is characterised by the intensification made possible by the selection, the introduction of exotic breeds and/or crossbreeding and by a shift from diversified to homogenous farming systems.

This dissociation between formerly complementary production activities can be understood as a substitution of economies of scope[1] by economies of scale[2] in the available technologies. Changes in prices and technical progress have induced the adoption of new technologies that have supported this tendency.

Conversion processes have been accelerated by the extension of market systems and the associated process of globalisation. The latter encourages regional economic specialisation and often leads to particular types of livestock production becoming relatively 'uneconomic' in a particular region resulting in the loss of region-specific breeds. Moreover, with economic globalisation, it has become less costly to transfer genetic resources across international boundaries and this increases the possibilities for breed substitution.

Causes of biodiversity loss in AnGR cited above are by and large caused by changes in the available technologies and by changes in the structure of society. However, there are other

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[1] Economies of scope represent the saving in cost that is realized by arranging different production activities into a single production unit. This saving in cost often finds its origin in technological synergies between production activities.

[2] Whereas economies of scope favour diversification, economies of scale encourage larger production units. Generally, a unit of production profits from economies of scale when the average cost of production drops with increases in the number of units produced.

factors directly influencing the viability of farming systems and hence the constitution of farm AnGR.

Theories that have formed the basis of development policies have oriented actions in the field of agriculture towards great simplification and specialisation (Peemans, 2002). Monoculture for crops and controlled environments for 'improved' breeds are much easier to manage centrally. While the output of a production system focusing on a single activity may be larger due to economies of scale, the benefits of diverse farming systems, especially in marginal production regions, have often been neglected. Lack of deeper understanding of agro-ecosystem functioning because of limited knowledge – coupled with a political bias towards centralisation of services including agricultural extension – may be at the root of misguided policies that have evaluated asset productivity on a distorted basis.

Furthermore, agricultural policy has played a major role in fostering uniform and intensive animal production systems. Financial support for investment in housing and veterinary facilities has led to a change towards 'improved' breeds that yield higher returns in controlled environments but lack resistance to difficult environmental conditions.

Regarding globalisation, one aspect has been emphasised by Tisdell (2003). Import of livestock produce from another region may cost less than the locally produced supply. If the latter is the output of an endemic breed, the breed is doomed to disappear. While this change can in some cases be attributed to changes in the underlying economics of the system, in many cases this happened as a result of dumping of export from developed countries with the help of subsidies. These subsidies have rendered exported products available at artificially low prices on markets of developing countries.

The consequences of these processes directly affecting the constitution of farm AnGR can be summarised as follows:
- Genetic dilution or eradication through use of exotic genetic resources;
- Changes in production systems leading to change in breed use or cross-breeding;
- Abandonment of husbandry and/or agricultural activities;
- Changes in producers and/or consumer preferences.

ii. Indirect factors

Although economic considerations can explain why so many indigenous breeds are extinct or at risk, the market may not be the single threat of the loss of the livestock genetic diversity. Mendelsohn (2003) mentions three principal aspects possibly being at the origin of unexpected and undesirable effects of development policies on AnGR: 1) Exporting countries that either supply the grain for livestock or supply the livestock themselves may subsidise modern methods in order to gain market share; 2) International agencies could be subsidising capital-intensive methods in developing countries without determining whether these techniques are appropriate; and 3) developing countries themselves may be favouring new capital-intensive methods because government officials are being inappropriately induced to support such programmes or because the officials have been misguided.

In the context of industrialised countries, the subsidies allocated to the agricultural producers contributed to the reduction of grain prices and indirectly encouraged the development of livestock activities. These subsidies have kept grain prices below their free-market level and

have made capital-intensive livestock techniques more profitable around the world by rendering both the prices of new breeds and of feed artificially low. Reducing the subsidies on crops and livestock exports could help reducing the financial pressure on indigenous breeds and production systems.

In the case of developing countries, the strategy which guided livestock development during the four last decades, conceived in collaboration between the international agencies (IA) and the authorities of these countries, must be re-examined and extended. Indeed, IA have certainly been interested in promoting new methods that they perceived would help developing countries. However, IA also have served the interests of the donor countries.[3] In several cases, this strategy has been to promote capital-intensive livestock techniques of donor countries.

The cases of the bovine breed *Nguri* in South Africa and the pig breed C*riollo* in Mexico illustrate the failure of this strategy (Köhler-Rollefson, 2001). In both cases, farmers were encouraged to substitute their traditional breeds by improved ones. However, after subsequent changes in the national economy and the suppression of external assistance the introduced breeds proved economically non-viable.

The lack of knowledge of the economic value of AnGR could be considered as another significant factor contributing to genetic erosion. Providing incentives to intensify the use and development of local breeds could well be a sustainable strategy. Attaching values to unique traits of specific breeds, i.e. genes or gene combinations, however, is a very difficult task. This aspect is developed in Chapters II and III.

The economic valuation of AnGR is closely linked to the discussion on intellectual property rights (IPR). The failure of existing property-rights systems in genetic resources to provide protection and benefits to local communities is one of the more contentious issues of the Convention on Biological Diversity (CBD). For plant genetic materials, an *ad hoc* system is proposed, which conceptually separates ownership of genetic material from ownership of knowledge.

For AnGR, IPR protection is applicable to animal genetic material with unique characteristics or for some characteristics, which can be induced through technological procedures, as specified by national and international patent regulations.

iii. Other factors

Sudden changes in climatic conditions, the impact of wars and social unrest, and the advent of new or sporadic diseases and epidemics can all further the loss of AnGR. Indeed, when population size falls below a certain level, the genetic diversity is affected in two ways. Firstly, certain genes may be lost from one generation to the next, since a restricted population size limits the sample of the genes available and being passed on.

Secondly, because the number of individuals in the population is limited, the probability is increased that the parents of any new individual are related to each other. This means that the probability of the individual receiving the same genes from the maternal and paternal sides of its pedigree is increased. This in turns means that the genetic variability within the individual is reduced. It is a well established and universal fact that this reduction in variability within an

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[3] The USA alone have more than 50% of votes both in the World Bank and in the International Monetary Fund. 100 developing countries ranking the lowest in terms of purchasing-power-parity GDP share 1% of votes.

individual (particularly a reduction in variability within each locus, or homozygosity) is associated with deterioration in many physical traits, particularly those associated with viability. This impact is known as inbreeding depression.

II.   Economic Values of Animal Genetic Resources

Two circumstances have served to increase the importance of establishing the value of genetic resources (Zohrabian *et al.*, 2003). The first is that in the face of strengthening laws for intellectual property protection of germplasm, the past collegial system of free exchange among researchers is breaking down, requiring that some compensation mechanism for genetic sources emerge. The second event refers to the signature in 1992 of the International Convention on Biological Diversity (CBD). Indeed, the first article of the Convention stipulates what follows:

The objectives of this Convention, to be pursued in accordance with its relevant provisions, are the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources, including by appropriate access to genetic resources and by appropriate transfer of relevant technologies, taking into account all rights over those resources and to technologies, and by appropriate funding.

<div align="right">Article 1. (CDB)</div>

Because markets exist only for finished or nearly finished commercial genetic resources, the value of unimproved materials, or the value added in the long process of introgressing new genes into commercial varieties or breed, cannot be directly measured.

Mendelsohn (1999) evokes at least three arguments which plead in favour of the economic valuation of AnGR (figure II.1):

1. Valuation is critical in developing effective breeding programmes;
2. Valuation is critical to breed conservation programmes;
3. A third motivation emanates from the recent interest in benefit sharing.

These arguments converge towards a central idea: to assist development of policy and management decisions. Concerning the first argument, the principal question is to identify the most important attributes. Stated differently, should the breeders focus on fecundity, weight gain, disease resistance and/or other attributes?

Human preferences regarding genetic traits of livestock differ across regions, countries, communities and production systems. For example, in marginal areas, the most valuable livestock attributes are often those that successfully guarantee multifunctionality and flexibility or resilience in order to deal with variable environmental conditions. In contrast, in zones with high production potential, livestock attributes maximising productivity of specific products under controlled conditions are more valuable. Thus, there is no single answer to such question. However, if breeders could better estimate the value assigned to developing livestock species for particular production systems, they could make better decisions on which breeds to utilise for intervention. This would also help geneticists design better programmes of sustainable intensification, and it would help decision-makers in determining the effort allocated to such programmes.

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│                     Economic valuation of AnGR                                │
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                                    │
                    ┌───────────────┴───────────────┐
                    │ To assist policy development and management decision │
                    └───────────────────────────────┘

  Conservation      Breeding programs    Benefit-Sharing    Roles and         Alternative
  programs                                                  responsibilities   strategies

  Witch genetic     Which attributes     Property rights    Institutional     - Use exotic AnGR
  resources         are most important?                     aspect            -Develop locally
  to conserve?                                                                 adapted AnGR.

  -To design better  - To design better   To determine      -Farmers;         Help countries
  conservations      breeding programs;   compensatory      -Breeders;        to determine the
  programs;          - To determine the   payments          -Policy makers,   best strategy for
  - To determine the funds to allocate                      etc.              developing their
  funds to allocate  for such programs.                                       AnGR
  for such programs.
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Adapted from Mendelsohn (1999, 2003)

Figure II.1 Schematic summary of arguments to economic valuation of AnGR

As for the second argument, society might want to protect the genetic stock. The economic valuation of conservation and sustainable use of AnGR can be an effective means of garnering the necessary public and political support, including the development of appropriate policies (Rege and Gibson, 2003). This requires an evaluation of benefits generated by AnGR conservation programmes. There are two reasons to carefully state the benefits of these programmes (Mendelsohn, 2003). First, identified benefits could be quantified so that society has some sense of how much the conservation is worth. Society can then determine how much it wants to spend on a conservation effort. Second, by identifying the benefits, conservation managers will have a better idea of what they are trying to accomplish. The benefits of alternative conservation strategies can guide the design of the programme.

The last argument relates to the concept of benefit sharing cited above. Benefit-sharing has become an important issue in international biodiversity negotiation in search for a just mechanism to remunerate local people for their contribution to livestock development. Benefit-sharing mechanisms evoke property-rights issues and demand alternative forms of payments to compensate for the transfer of these genetic resources. However, without an understanding of the value of AnGR, it is difficult to determine payments.

Taking into account these considerations, this section will treat aspects relating to the various types of values of genetic resources. Particular emphasis will be devoted to the economic bases of these values.

II.1 The public good nature of AnGR

For conventional goods and services, markets provide important information about values. Markets reflect the relative scarcity of traded goods and the preference for these goods. For public goods and externalities, markets are not available to provide such information.

Animal genetic resources fall into this category of public goods. According to table II.1, we can distinguish public goods from private goods along their degree of non-rivalness and non-excludability.

Table II.1 Rivalness and excludability in consumption

	Rival in consumption	Non-rival in consumption
Excludable	Private good	Club good
Non-excludable	Open access resource	Public good

Private goods are excludable and rival in consumption. These properties make markets for these goods work well. An owner can exclude others from the consumption of a resource. Furthermore, the consumption by one person reduces the availability of the good, so that no welfare gain can be achieved by making the good at the same time available to another person.

Public goods are characterised by non-excludability and non-rivalness. On the one hand, a public good is non-rival. The pure notion of non-rivalness signifies that the consumption of a good by one person does not reduce the availability of the good to other individuals. The good hence can be provided "in common". On the other hand, a public good is not excludable. This often leads to a free-rider problem.

While farm animals can be considered as private goods, animal genetic resources embedded in these animals should be considered as quasi-public goods (Scarpa *et al.*, 2003b). Their degree of excludability is low, as animals of a breed carrying the desired genetic resources can often be bought at low cost. Breeds are a natural resource that, if properly managed above a critical population number, retains its property of a renewable resource. Using animals from this breed to one breeding purpose does thus not rival other purposes.

Measuring the value of public goods is difficult because they are not evaluated in markets. Evaluation may also fall foul to the free-rider problem, leading individuals to a systematic understatement of value.

As for public goods, values typically are not exclusively derived from private use of the resource, and it appears useful to first provide a classification of different resource values, before reviewing the methods measuring these values.

II.2 Values under certainty

i. Use and non-use values

We distinguish between use values and non-use values. Use values are those that result from direct use of the resource (Bishop and Woodward, 1995). They include value created by productive activities. In the case of sheep and goat AnGR, production values are primarily those of wool, milk, and meat. Another category of use values includes amenity

values that individuals associate, e.g. to the viewing of a species or to the knowing about a species existence. Having a preference for a breed results thus in value.

Hence defined use values can be distinguished into active-use values and passive-use values. Sticking to our example, the act of tourists viewing a traditional breed results in an active-use value. Active-use values are always complementary to observable consumption and production choices and can for instance be observed when tourists choose to spend their vacation in a particular area for the sake of viewing a particular breed, given all other things equal. Non-market good evaluation techniques try to exploit this complementarity in consumption.

Passive-use values are a second category of use values. In the previous example, citizens might value the conservation efforts for a traditional breed, even if they never visit the region where these are breed. If the region is located in a very remote area and the cost of travelling to the park (expenditures on gasoline, hotel etc.) exceeds the willingness-to-pay for some citizens, they may not visit the park but still value the possibility. In this case it is not possible to exploit the complementarity between the breed of value and the recreational activity. We illustrate using an example (Box II.1).

Box II.1 Passive-use values of woodland caribou preservation

The measurement of passive-use values has become an important issue in environmental economics. Passive-use value is the economic value that arises when changes in environmental quality are not reflected in any observable behavioural change. Since passive-use value is not reflected in observed behaviour, stated preference approaches are used for the elicitation of these values.

Adamowicz *et al.* (1998) estimate the passive-use value of a habitat enhancement programme in a study of Mountain-dwelling woodland caribou habitat. Woodland caribou are listed as "threatened" by the Wildlife Act of Alberta. Lands managed under forest management agreements contain superior woodland caribou habitat. To protect this habitat, restrictions need to be imposed on the industrial and recreational uses of this land.

Adamowicz *et al.* (1998) employ the contingent valuation method to estimate the value of an old-growth forest programme. Under this programme, lands are removed from forestry activity and a wilderness area is created. It requires that recreational activities be restricted in the area (no fishing, no hunting, or off-road vehicles). Biologists predict that under these conditions the caribou population to increase from the current level of 400 individuals to a viable population of 600 individuals. The proposed programme thus contained attractive features (building a viable caribou population) and unattractive features (employment effects and restrictions on recreation).

A referendum-type question was employed to measure respondents' willingness to pay (WTP). WTP was measured using a proposed tax increase ranging from Ca-$ 1 to 150. Respondents could bid for or against the programme given the tax amount indicated or respond "I don't know". The survey was conducted on a random sample of residents in Edmonton, Canada. A total of 402 valid responses was obtained.

The data were analysed in the random utility framework using a conditional *logit* model. Under a linear specification, welfare measures result in an average WTP of Ca-$ 142.82 per individual.

References:
Adamowicz, W., P. Boxall, M. Williams, and J. Louviere, 1998. Stated Preference Approaches for Measuring Passive-Use Values: Choice Experiments and Contingent Valuation. *American Journal of Agricultural Economics,* 80: 64-75.

Because the increase in value is not complementary to observed actions, empirical evaluation methods relying on complementarity cannot be used. It has been argued that, to

capture this passive-use value, only contingent evaluation methods can be employed (Bishop and Woodward, 1995).

Non-use values are compounded by existence values and bequest values. Existence values are those that are not related to direct, neither present nor future, use of a species but to the simple fact that people value the existence of a species without ever directly using it. Existence value can partly be motivated as bequest value by altruism towards future generations. Said in another way, existence values may be interpreted as sympathy to nature, and cultural or regional values. Feelings of responsibility for nature, the desire to leave a cultural legacy to future generations, may lead to positive values for the preservation of farm animal genetic resources.

A strict definition of existence values, which is adopted in this discussion, approaches the existence value from a non-anthropocentric view. The value is attributed to the existence of the breed and not to the valuation by people. The existence is of value in itself and does not depend on active or passive use by humans. In this respect, existence value is not commensurate with the concept of economic value that is based on the notion of human preferences. Consequently, we will not consider it in this discussion without denying the importance of existence value outside the realm of economics.

ii.   Value of diversity

In all that has been said before, value is attributed to specific traits of breeds because of their intrinsic use or non-use value. As explained above, traits have to be interpreted in a large sense to include phenotypic expressions typical for traditional breeds as related to cultural and historical passive-use values.

In addition, diversity in itself can be of value. It is not only important to preserve one species or another because of their specific values, but when choosing the right mix of species to preserve, the diversity of the mix will also be of importance. Diversity is of importance in production and consumption. In the following, we will discuss the two contexts as a source of diversity value.

a.   Diversity in production

Production environments can be diverse. Sheep and goat are raised in different conditions. Sheep used in pasture management on the British Island have distinct properties from those used in Mediterranean mountain regions. Because of varying conditions, the productive use value of a breed depends to a large extent on the environment in which they are evaluated. Indeed, the development of distinctive breeds is in part due to the diverse production environments in which the breeds have been developed.

Current agricultural practices lead to a loss of diversity because nowadays breeds have to be less adapted to regional environmental conditions. The increase in capital use in agricultural production increases the potential of high-yielding uniform breeds. Capital intensive production technologies have been adopted by farmers in many regions in Europe. These technologies reduce the need for adapted breeds even in adverse environmental condition.

b. Diversity in consumption

It is common in economics to attribute value to diversity. The standard axiom of preference convexity leads automatically to this property. The convexity axiom can be presented as in figure II.2.
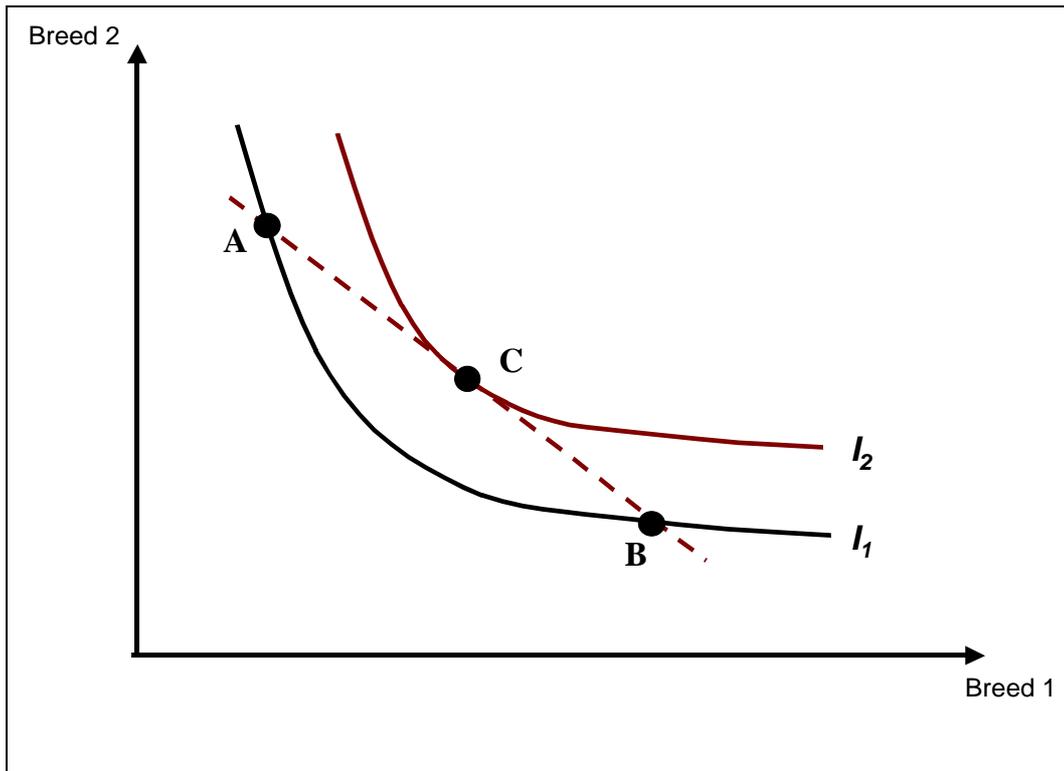
Figure II.2 Preference convexity

In this figure the two axes measure the population sizes of breeds 1 and 2. The indifference curve I_1 indicates the combinations of (breed 1, breed 2) to which the consumer is indifferent, e.g., points A and B. A more balanced mix of breeds, as in point C, where populations of breed 1 and breed 2 are about equal in size, would lead to a higher degree of utility for the consumer. He could then achieve indifference I_2 which indicates a higher level of utility.

II.3 Values under uncertainty

According to Swanson (1998) two types of value best describe the role of genetic resources in agriculture: *information* and *insurance*. These values are of particular importance when considering decision making under uncertainty and when considering the search for new breeding strategies adapting breeds to an ever-evolving environment.

i.   Option value

Many conservation efforts for genetic resources are motivated by the desire to preserve a diverse gene pool that can serve as a source for future breeding. In the past much of agricultural breeding and development 'aid' has concentrated on the propagation of few 'improved livestock breeds'. This has led to a loss in genetic diversity. Genetic erosion has resulted from this concentration on few 'improved' breeds. An estimated 16 % of uniquely adapted breeds have been lost since the beginning of the last century and another 30 % are at risk of becoming extinct (FAO, 1999, cited in Drucker *et al.*, 2001). A species, once extinct, would be lost forever.

The genotype-environment interaction can limit to an important extent the productivity of improved livestock breeds in unfavourable environments. In addition, intensive livestock breeds concentrate often on single-use breeds, i.e., either milk, wool, or meat. Multiple-use breeds are left at a disadvantage. Multiple uses and adaptive traits are of particular importance in marginal rural areas and under difficult environmental conditions.

Conservation of genetic diversity gives an option to use alternative traits and to develop new ones in the future. Because decision making on breed development is characterized by inherent uncertainty about future developments of market and natural environments, this option can be highly valuable. A resource of no interest in one situation can be particularly useful under alternative conditions. Moreover, uncertainty about market and policy conditions can also enhance the desire for diversity conservation in order to *insure* against adverse scenarios. In such uncertain environments, many decision-makers behave risk averse. They add a risk premium to the value of a resource such that the total value attributed to the resource exceeds its expected use value.

Suppose a farmer considers two alternative scenarios, one where the demand for goat-milk products increases and another where market conditions remain constant. Thus the expected value of keeping a specialized trait will be the sum of the probability-weighted respective profits under each scenario. But because the farmer is risk averse, he adds an additional value to the conservation of the trait. The total value, the option price, results as the sum of expected surplus plus the option value:

Option price = Expected surplus + Option value

With regard to the preservation of animal genetic resources, farmers may not fully consider the uncertainty over future developments in their decision. Indeed, even if they do not preserve a specific trait, others may. Thus they rely on others to preserve the desired degree of diversity. This free-rider problem relates to the public good character of animal genetic resources and is likely of considerable importance in explaining the erosion of animal genetic diversity.

In contrast to the diversity value valid in situations *without* uncertainty, discussed under II.2.*ii*, this option value is defined in a context *of* uncertainty. Decisions about conservation are made before uncertainty about future environmental and market conditions is resolved.

This type of value has been discussed by Swanson (1998) as portfolio value. The value is derived from the retention of a relatively wide range of assets within the agricultural production system. A portfolio of different breeds allows spreading the risks posed by an inherently uncertain production environment that is subject to random environmental

conditions and disease pressures. Variability of returns is smoothed out by having (i) a broader portfolio of assets (breeds) within a species, (ii) a wider portfolio of assets (agricultural commodities) within a country, and (iii) a wider portfolio of assets (available methods of production) across the globe. Society has a preference to conserve a larger portfolio of breeds than under risk neutrality. Diversity is conserved for the sake of future adaptation of breeds to changing environmental conditions and in a desire to improve their economic performance.

ii. Quasi-option value

A second value associated to decision making under uncertainty is the quasi-option value (Arrow and Fisher, 1974). In contrast to the option value that is motivated by risk aversion and the resulting risk premium, the quasi-option value arises even under risk neutrality (table II.2). It results from the irreversible nature of breed loss. It measures the benefits that accrue, because learning about the value of preservation leads to more informed and better decisions. A more informed decision reduces the risk of taking the wrong decision that can be very costly, or even impossible, to reverse. A positive quasi-option value encourages the conservation of resources until uncertainty about future scenarios has been resolved and more information about the true value has been obtained.

The learning potential embedded in genetic resources has been analysed with respect to the possibility to develop new plant varieties (Evenson, 1997) and in the search for new pharmaceutical products via bioprospecting (Simpson, Sedjo, and Reid, 1996; Rausser and Small, 2000). The latter study is also of interest for the *in-situ* conservation of agricultural genetic resources. Simpson, Sedjo, and Reid have found that the value of a single species lost, its scarcity value, will be small because biodiversity is abundant. However, Rausser and Small (2000) claim that biotechnology companies do not search randomly but use research leads and prior information to guide their search for new production. They show that promising research leads can induce significantly higher biodiversity value.

In-situ conservation of agricultural genetic resources allows gaining important information about the value of a breed. Landraces have formed on the basis of human selection processes over long time horizons. They have accumulated a stock of previously successful strategies and 'traditional' farmers have survived by observing their performance in their specific production environment. Subsequent selection and use of desirable traits and characteristics have aided in creating these landraces adapted to the particular environment. Animal breeders can make use of this knowledge when searching new strategies to improve the genetic resource base of a breed.

As a consequence, knowledge about the merit of traditional breeds is available from local breeders that have developed this breed over long time horizons. The knowledge of useful breed characteristics, e.g. environmental adaptability or disease resistance, increases the *information* value of this resource, even if its scarcity value derived under complete ignorance is small.

Table II.2 Biodiversity values

Value	Description/Origin	Main Characteristics
Values under Certainty		
Use values		
Active-use values	■ Production ■ Consumption ■ Amenity	■ Static ■ *Ex-post*
Passive-use values	■ Amenity	■ Static ■ *Ex-post*
Non-use values	■ Existence value ■ Bequest value	■ Sympathy toward animal ■ Intergenerational altruism
Diversity values	■ Variety in space ■ Variety in production and consumption	■ Maintain variability ■ Preference for diversity
Values under Uncertainty		
Option value	■ Option to use alternative traits and to develop new ones in the future	■ Static ■ Risk aversion ■ Soft uncertainty
Quasi-option value	■ Preference for flexibility ■ Hysteresis, learning about breed values	■ *Ex-ante* ■ Dynamic ■ Risk-neutrality ■ Hard uncertainty (irreversibility)

All values discussed in sections II.2 and II.3 are summarized in table II.2. Some values, such as active-use values related to production and consumption can readily be measured in markets. Others are more difficult to capture.

II.4 The concept of value on the consumer and on the producer side

To measure economic value, a multitude of empirical methods is available. These methods make use of economic concepts in demand and supply analysis. Before explaining the methods, it will be useful to review the underlying theory that allows evaluating resources from data collected in surveys and markets.

i. Value to consumers

A common measure evaluating welfare impacts of a price change on the consumer is the consumer surplus. Consumer surplus is defined as the area under the demand curve and above the price. As an example we will consider the impact of technical change in meat production (figure II.3). An increase in productivity reduces the marginal cost of meat production. The supply curve shifts downwards. At the market level, the price for meat decreases from P_0 to P_1. The change in consumer surplus resulting from the increase in production hence is measured by the shaded area, ΔCS, in figure II.3
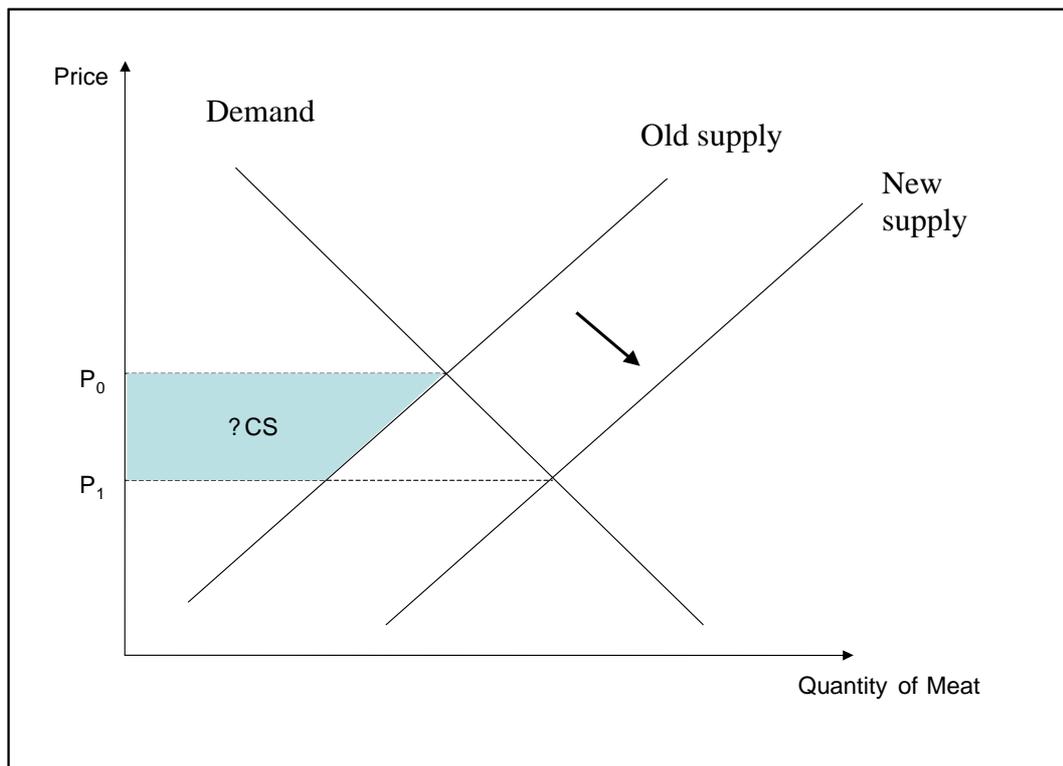
Figure II.3 Change in consumer surplus

Consumer surplus is an exact welfare measure only under particular hypotheses on consumers' preferences. If these conditions are not met consumer surplus can only serve as an approximation to consumer welfare.

There are alternative, exact, measures of welfare on the consumer side: compensating and equivalent variation. The former is based on the level of utility before a proposed price change, the latter is based on the level of utility after the proposed price change.

a. Compensating variation

After a price change, the compensating variation (CV) measures the necessary change in income, R, that maintains the initial level of utility at new prices. Consider an economic agent consuming two goods: meat and other consumption goods. The price of the other consumption goods is normalized to one.

In figure II.4 the preferences of the consumer are mapped using the indifference curve, U. The budget constraint is presented by the straight line. Before the price change, the optimal level of consumption results in point A.
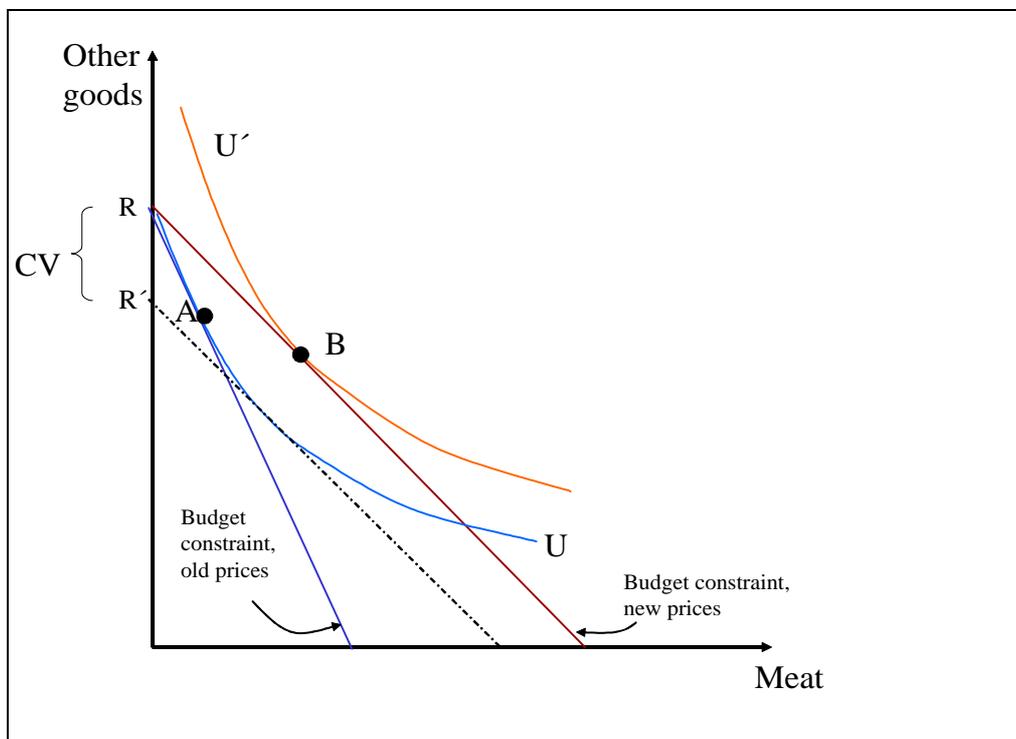
Figure II.4 Compensating variation

Following a reduction in the price for meat, the budget constraint rotates outwards. The consumer can reach a higher indifference curve, U´, representing a higher level of utility. The compensating variation, CV, is the change in income that would leave the consumer indifferent between the situations with and without the price change. Since the price of meat decreases, the amount of goods that can be bought at a given income increases. The economic agent is thus willing to pay and amount equal to the difference between R to R´, without being worth off.

b. Equivalent variation

Given a price change, the equivalent variation (EV) measures the change in income that at old prices would be necessary to obtain the same, equivalent change in welfare.

Figure II.5 demonstrates the idea. Since a price change makes the consumer better off, it would be necessary to increase the income of the consumer if he were to forego the price change and increase his utility by as much as done by the price change.
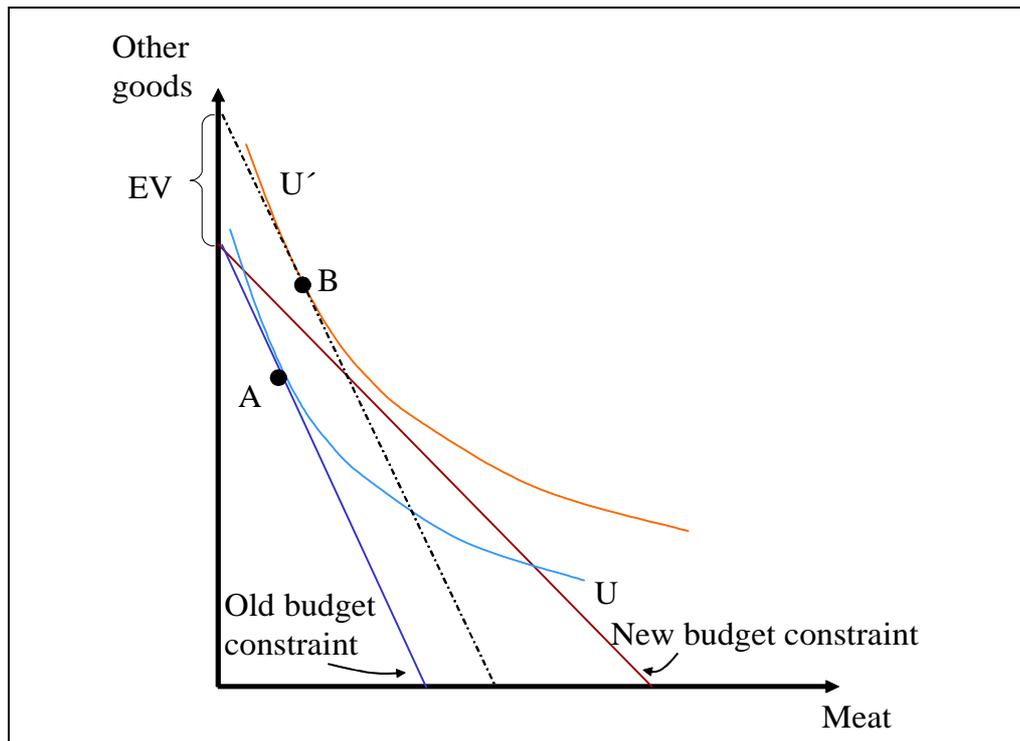
Figure II.5 Equivalent variation

In general, CV and EV will not be equal. The variations measure the distance between indifference curves and this distance depends on the point of evaluation. For normal goods[4] we obtain: $CV \leq \Delta CS \leq EV$.

ii. Willingness to pay and willingness to accept

Empirically, compensating and equivalent variation are evaluated using the concepts of willingness-to-pay (WTP) and willingness-to-accept (WTA). Table II.3 shows the relationship between willingness to pay and willingness to accept and EV and CV.

Table II.3 CV, EV, WTP and WTA

	Compensating variation	Equivalent variation
Price fall	WTP Amount of income the consumer is willing to pay to obtain the price fall.	WTA Amount of income the consumer is willing to accept foregoing the price fall.
Price rise	WTA Amount of income compensating the increase in price.	WTP Amount of income the consumer is willing to pay to avoid the increase in price.

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[4] For a normal good, consumption will increase with income.

iii. Evaluation on the producer side

Two approaches to measure producers' valuation of breeding traits exist in the literature. One focuses on a pure profit-maximization objective. According to Hotelling's lemma the first derivative of the profit function with respect to output prices gives the product supply curve, the derivative with respect to input prices yields the derived demand curve for inputs.

We illustrate at the example of a change in technology, such as a change in genetic traits. A increase in productivity shifts the supply curve downwards as in figure II.7. Using either the supply curve or the derived demand curve, measures of producer surplus can be obtained.
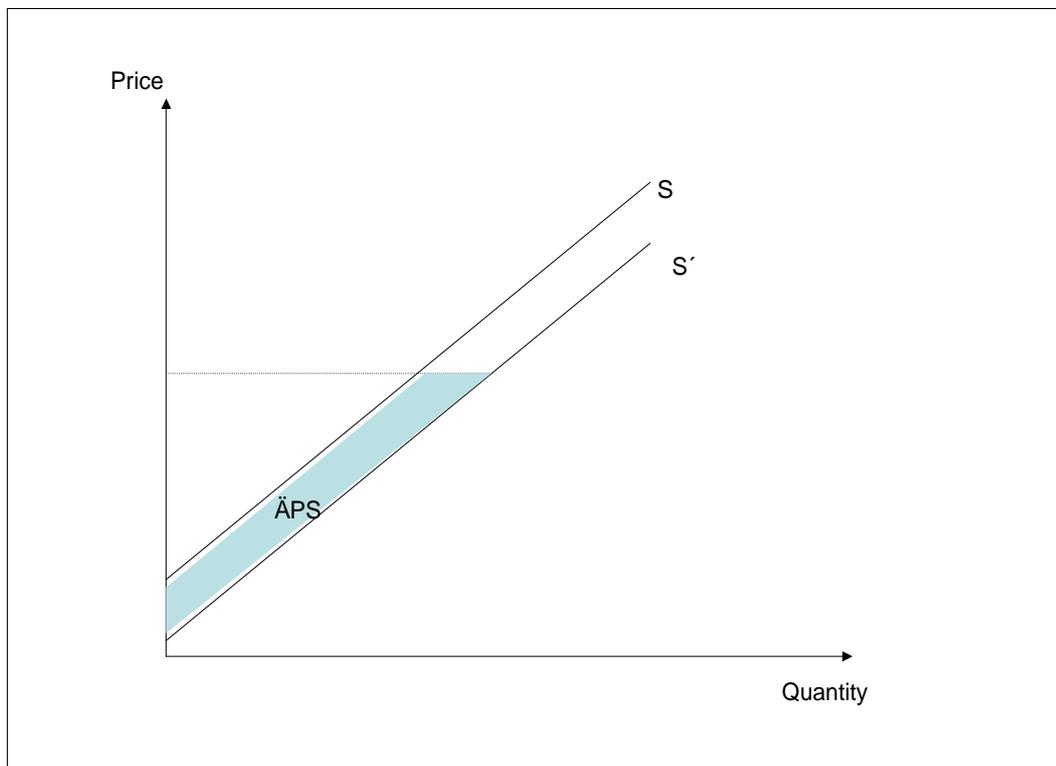
Figure II.6 Producer surplus

Producer surplus is measured as the area above the supply curve and below the price. The change in producer surplus of the productivity gain, assuming constant market prices, is measured by the shaded area, ΔPS, in figure II.6. Similarly, producer surplus can be evaluated using the derived demand curves (Just *et al.*, 1982).

Farmers' choices might directly influence the status of endangerment of a breed. Norton, Phipps, and Fletcher (1994) have shown that if farmers personally value conservation activities, then compensatory payments can be lower than profit loss incurred from conservation. Because their utility is increased by satisfaction about conservation, the impact of income loss on utility is partially compensated. A number of empirical studies have confirmed that farmers actually value conservation. Dupraz *et al.* (2000) employ the willingness to accept approach in a contingent valuation study and show that farmers are willing to implement environmental practices even if the compensation payment is less

than the revenue lost. Hubbell and Carlson (1998) have analysed pesticide use of US apple growers. They have shown that the choice of a pesticide is not only determined by pesticide productivity but also by its environmental and user safety. This research shows that farmers do not exclusively base their choices on profit-maximizing motives.

A second approach to measuring the value of conservation to farmers thus focuses not exclusively on the profit maximization motive but is based on the utility function of the farmer. Assuming that different breed characteristics influence not only farmers' profits but also their utility directly, surveys often proceed using Lancaster's approach. According to Lancaster (1966) a good is not valued because of itself, but because of the characteristics it carries. Farmers' utility is a function of different breed characteristics. Denoting these characteristics by a vector $(t_1, t_2, \ldots, t_n)$, the utility function of the farmer then depends on these characteristics:

$$U(t_1, t_2, \ldots, t_n)$$

Under these assumptions, the theory of choice under utility maximization applies and the same surplus measures as in the consumer case can be used.

III.   Evaluation Methods for Animal Genetic Resources

Much of the literature on the economics of biodiversity has dealt either with wildlife preservation, in particular in the context of the US endangered species act (e.g., Weitzman) and in relation to bio-pharmaceutical research (e.g., Simpson, Sedjo, and Reid, 1996; Rausser and Small, 2000), or the value of plant genetic resources (e.g., Evenson *et al.*, 1998). Recently Rege (1999) and Drucker, Gomez, and Anderson (2001) have provided a review of methods that can serve the economic evaluation of farm AnGR. They mostly draw on methods that have been employed in the study of plant genetic resources.

We can distinguish two different types of approaches to the evaluation of animal genetic diversity: approaches based on profit maximisation and approaches based on utility considerations. Within the first set of approaches, the partial budgeting approach is a pure accounting approach not taking into account subsequent adjustment in production techniques and markets. While very restrictive from an economic point of view, it is widely used in agricultural administrations to determine the subsidies paid for the *in-situ* conservation of rare breeds. Box III.1 relates to an example of Belgian Rural Development Plan.

Box III.1 Rural development plans subsidising rare animal breeds

The European Union co-finances rural development plans in its member countries (EC 1257/99). Agri-environmental programmes aiming to improve environmental practices and conservation measures are part of these plans. In many countries, the programmes offer subsidies to farmers for raising traditional animal breeds.

The Belgian Rural Development Plan, passed into law in 2001, pays subsidies for the following breeds:

Species	Breed	Subsidy/animal/year
Cattle	Rouge de Belgique	120 €
Sheep	Mouton laitier belge	20 €
	Mouton entre Sambre et Meuse	
	Mouton ardennais tacheté ou mouton des collines	
	Mouton ardennais roux ou Voskop	
	Mouton Mergelland	

The subsidy rate has been fixed on the argument that the traditional breeds to not respond to the demand of the meat processing sector that demands very uniform animals of the type Blanc-Bleu Belge for beef or Texel for sheep. As traditional breeds cannot respond to this demand, breeders face losses in the order of 370 € per cattle or 37 € pr sheep.

References:
Région Wallonne (2001). Le plan de développement rurale – Période 2000-2006. Translation of Regulation EC/1257/99 in Regional Legislation. Namur, Belgium.

Other approaches go further, in that they introduce a full framework of farm-level decision making. They may either be based on a profit maximizing framework, or on a utility function approach. The latter use either revealed preference or stated preference data.

III.1 Approaches based on the profit function

One way to create a cost effective biodiversity preservation programme is to compare the contribution of species preservation with the cost of doing so. Evaluating the cost to farmers of *in-situ* preservation is often done using a partial budgeting approach.

i. Partial budgeting

Some of the agri-environmental programmes in place in the European Union address the issue of on-farm preservation of traditional, local livestock breeds. Subsidies are paid for the continued usage of breeds typical for the region or in status of endangerment. The subsidies paid are calculated on the basis of a partial budgeting approach estimating lost revenue and/or additional cost of undertaking the conservation activity in comparison to the best available alternative. Box III.2 shows an empirical application of the partial budgeting approach. In addition to Box III. 1 showing the logic in defining the level of a subsidy, Box III.2 illustrates the procedure more detailed in the African context.

Box III.2 Sheep fattening in Burkina Faso: Biological performances and profitability

Sheep fattening is an activity increasingly practiced by agricultural producers in Burkina Faso. Complementing traditional practices of fattening, research has developed improved techniques which currently interest producers. These techniques combine traditional agricultural inputs and agro-industrial products. Indeed, the zootechnical and veterinary inputs were divided into exchangeable (cotton cake and cubed bran, parasite treatment, vaccine, salt) and non exchangeable inputs (labour, crop waste products and depreciation). In order to evaluate the biological performances and the financial profitability of these new techniques, Somba (2001) adopted a partial budgeting approach.

The purpose of this study was to identify the factors affecting the economic and biologic performance of lamb fattening operations in rural areas in Burkina Faso. Eighty-three rams supplied by 24 producers were involved in the test The study related to three sheep breeds (*Mossi, Metis and Babali*). Two rations were proposed (proposed ration) during fifty days for two sets of sheep. However, the producers have adapted these rations (effective ration) according to their financial capacity and their experience regarding fattening. Table A presents the composition of these rations by groups of animals. These two rations are made up of feed traded on international markets and of non-tradable home-produced feed.

Table A. Composition of the fattening rations (% in mass)

Animal Groups	Group 1		Group 2	
Feed	Proposed ration	Effective ration	Proposed ration	Effective ration
Cubed bran	30	41	25	31
Cotton cake	0	0	10	19,5
Cowpea haulms	34,35	28,95	35	17,33
Groundnut hay	28,41	16,76	20	9,9
Stems of sorghum	7,24	13,29	10	22,27

Body weight changes and financial operations were monitored. A weight gain model was built to explore growth determinants. Results show that growth performance depends on the combination of *feed* and *sheep breeds* rather than on feed only. Table B summarizes the average economic data obtained in the follow-up-evaluation of the operation.

Table B. Summary of economic results of sheep breeds and feeding strategies in Burkina Faso

Variables	Group 1	Group 2
Average group size	7	8
Operating profit per group (F CFA)	56.265	55.825
Average cost of tradable factors per group	11.585	13.808
Average cost of non-tradable factors per group	1.581	1.612
Rates applied to taxes and tariffs	(%)	
Cotton cake and cubed bran	18,00	
Parasite treatment	53,00	
Vaccine	6,00	
Salt	53,22	

The *partial budgeting approach* was applied to compute three cost-benefit ratios (CBR): the global cost-benefit ratio (*RG*), the cost-benefit ratio of tradable factors (*RTF*), and the cost-benefit ratio of non-tradable factors (*RNTF*). The rates used for the taxes and tariffs are deferred on the table B. The aim had being to show the perverse effect of the tariffs and taxes of importation of the inputs on the financial profitability of

the fattening. The various ratios were obtained using the following formula:

$$RG = \frac{CTF + CNTF}{B}$$

where *CTF* and *CNTF* are the total costs of the exchangeable (tradable) and non-exchangeable (non-tradable) factors, respectively; *B* is the benefit. The activity is regarded as financially profitable if the ratio is lower than 1. The results reported in (table C) indicate that sheep fattening is a profitable activity. The various ratios are smaller than one. In addition, the investment received by sheep in group 1 was financially more profitable. The strong consumption of exchangeable factors in group 2 and the price level of sheep are the principal causes.

Table C. CBR with and without fiscal policy

Groups	With fiscal policy			Without fiscal policy		
	RG	*RNTF*	*RTF*	*RG*	*RNTF*	*RTF*
1	0.31	0.04	0.27	0.22	0.03	0.19
2	0.38	0.04	0.34	0.28	0.04	0.24

In the same way, the current marketing policy on the zootechnical and veterinary inputs influences negatively the financial performance of breeding in general and sheep fattening in particular. Indeed, by abolishing the taxation of inputs, the performances would improve significantly. Abolishing the financial policy improves the financial profitability of sheep fattening by 35% and 34% for rations 1 and 2, respectively.

References:

Somda, J., 2001. Performances zootechniques et rentabilité financière des ovins en embouche au Burkina Faso. *Biotechnoogie, Agronomie, Société et Environnement*, 5: 73-78.

The advantage of this method is that it is easily implemented and that the necessary data is available via accounting sheets etc. The disadvantage is that it models farmers' choices as artificially inflexible. The partial budgeting approach assumes that inputs are used in constant proportions. Furthermore, all other farm activities are considered to not be affected by the husbandry of the endangered breed.

ii. Farm simulation models

Farm simulation models can overcome the inflexibility of the partial budgeting approach. Depending on the depth of the model, all farm activities may be included. Precise technical relationships have to be established between production processes, inputs and outputs. AnGR are modelled as part of the input set determining the available production technology.

We follow Groen (1988) to explain the principal components of a farm simulation model evaluating AnGR. Groen developed a simulation model to estimate the economic value of black and white dairy cows in the Netherlands.

The principal structure of a farm simulation model is shown in figure III.1. Inputs flow into and outputs exit the herd enterprise. Inputs and outputs can be modelled as market goods or goods internally produced and processed. Also labour and capital may be freely bought on the market or restricted using suitable constraints. At the farm level, inputs are constraint by roughage production, and available capital and family labour. Concentrates, additional roughage and labour can be bought in the market place.
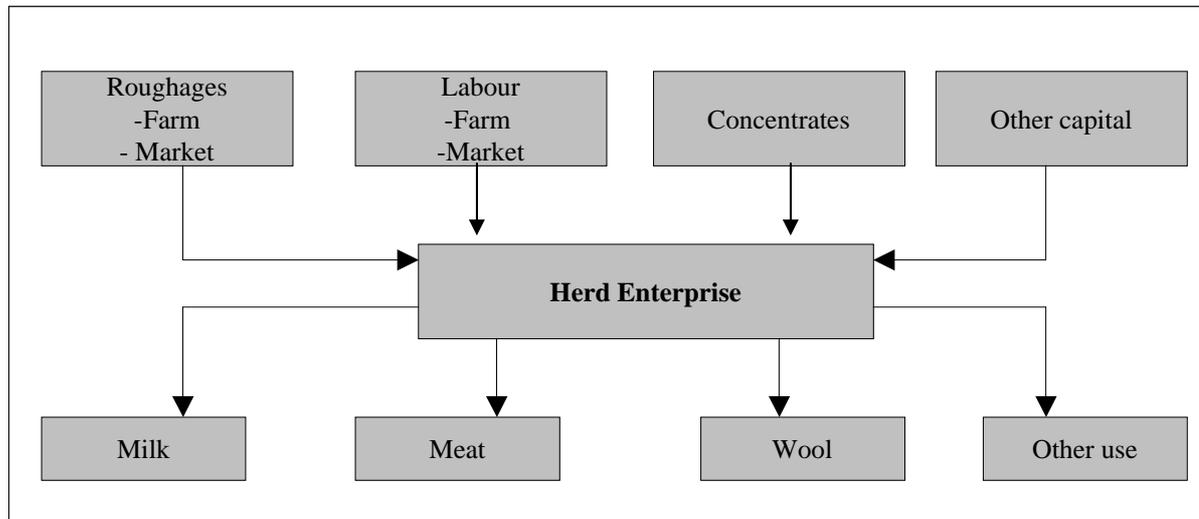
Figure III.1 Structure of a farm simulation model

If a detailed link between genetic traits and farmers decision-making is desired in the modelling exercise, then simulation models can use mathematical animal growth and yield models whose parameters are determined by the genetic traits of the herd.

The model is then divided into two parts: (1) an objective function, usually based in the maximization of profits or the minimization of costs, and (2) a set of constraints linking inputs and outputs according to technical relationships. Often the model is built on what is considered a representative farm that describes the typical circumstances under which the breed is kept. The simulation model can be extended to other types of farms that differ in the technological and institutional constraints that the farms are subjected to.

The model can be used to estimate the economic value of genetic traits using farm level simulations. A change in AnGR can change the relationships between inputs and outputs represented by the animal growth model or the yield parameters. Using alternative types of model farms, the economic value of genetic traits can also be estimated for differing production environments. Production environments can differ according to weather and soil conditions influencing roughage production or climate and disease pressures influencing the animal growth model. Ladd and Gibson (1978), for example, designed a methodology to generate economic values of genetic traits for different types of farms in the US state of Iowa (Box III.3).

To adapt the simulation model to farms producing multiple outputs for multiple markets, data are needed on stylized technical relationships between input and outputs in all farm activities and across all farm typologies. These should account for possible input and output substitution across farm activities.

Models for a number of individual farms can be aggregated and subsequently integrated into a market model. As the production technology changes, market price changes will results. These can be simulated using the appropriate demand elasticities. The resulting price changes in turn will change the parameters to producers, who will adapt to the changing market environment.

The advantage of simulation models is that the modelling of the production relationship is more realistic than in budgeting approaches. Substitution effects in input and output

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choices are taken into account. However, this method requires detailed data on (technical coefficients and prices) and technical knowledge to relate production functions to genetic traits.

Box III.3 Microeconomics of technical change

Breeding and animal selection cause technical change that may lead to modifications in the economic environment and to changing prices. The genetic traits selected are those desired by individual farm operators, product processors or consumers. For an animal breeder, the relative importance of a trait, or the relative value of a genetic type, does not only depend on the average value of a trait as measured in experimental studies. It varies with the production system under consideration, prices, and constraints governing the production processes of an individual farm. In this framework, Ladd and Gibson (1978) designed a methodology to generate economic values of genetic traits for different types of farms in the US state of Iowa.

The authors define economic value as the amount by which maximum profit may be expected to increase for each unit of improvement in the genetic traits. To develop a measure, they formulate a linear programming model of the farm's profit-maximizing problem. This approach makes it possible to generate the maximum level of profit when some parameters of the linear programme change in response to a change in the genetic composition of livestock. The procedure was used to measure economic values of three heritable characteristics in swine: backfat (BF), feed efficiency (FE), and average daily gain (ADG). Three types of Iowan farms are considered:

- Farm I: This type of farm may farrow its own pigs, buy feeder pigs, or do both. It has a central farrowing house that is fully insulated and environmentally controlled and that has a 25-sow capacity. It has partial confinement growing-finishing units sufficient to house 250 head of 220-pound market hogs during the summer and has two boars. The farm's purchased inputs are: all feed and feed additives, veterinary and medical expenses, fuel and power, feeder pigs and breeding stock purchased, and transportation of animals purchased or sold. Input-output coefficients were based on experience of typical Midwestern swine operations and cooperative extension service. Characteristics of hogs grown are summarized in table A.
- Farm IA: The only difference between farms I and IA is that farm IA had 140 hours of family labor available whereas farm I had 160 hours;
- Farm II: Two aspects distinguish farms I and II. Farm I can farrow four times a year and has two boars, whereas farm II can farrow twice and has one boar. Farm II uses a pasture farrowing system, while farm I has a central farrowing house.

The analysis covered the 22-month period from 1 November 1972 through August 1974. This allowed for two complete cycles of breeding, gestation, feeding, and marketing. Prices of outputs and variable inputs used in the analysis were monthly Iowa prices during this period.

Table A. Phenotypic measures of market hogs

Trait	Market Weights (pounds)				
	180	200	220	240	260
Backfat (inches)	1.3	1.38	1.46	1.54	1.62
Feed efficiency[a]	3.4143	3.4656	3.5222	3.5850	3.6545
Average daily gain[b]	1.5246	1.5804	1.6298	1.6728	1.7109

[a]: Pound of feed per pound of gain;
[b]: Pounds of gain per day.

The linear programme model adopted for each farm is conceived as follows:

$$Max\, Z = \sum_j c_j x_j$$

$$\text{subject to } \sum_j a_{ij} x_j \leq a_{i0}; \quad 0 \leq x_j$$

In this model, x_j is the level of the jth activity, c_j is net revenue per unit of jth activity, a_{i0} is total amount of fixed resource available to the farm, a_{ij} is the amount of ith fixed resource used in production of one unit of output by activity j, and Z is the total profit. Let Z_0 and x_{i0} be the optimal solution values of Z and x_j. Suppose that the genetic value of the trait that is changed is g_h and that it is changed by the amount dg_h. The objective is to determine (dZ_0/dg_h).

Z_0 can be treated as a function of the parameters c_j, a_{ij}, and a_{i0}. The change in g_h will affect some of the c_j and a_{ij} because changing genetic composition of livestock will affect some input-output coefficients or some products prices. The parameters c_j and a_{ij} can be expressed as functions of the implicit parameter g_h, and (dZ_0/dg_h) can be evaluated.

To obtain the economic value of the hth trait, it is necessary to divide (dZ_0/dg_h) by the number of animals (n_{h0}) produced of species of livestock undergoing genetic change. Then the economic value (EV_h) of the hth trait is:

$$EV_h = \frac{dZ_0}{dg_h} \bigg/ n_{h0}$$

Backfat (BF) was assumed to increase and decrease by 0.15 inch. These changes will be referred to as $\pm 1 \sigma$ changes because 0.15 inch is one standard deviation. The only parameters of the linear programme affected by changing BF are selling prices for market hogs. Making appropriate change in the c_j's to reflect the $\pm 1 \sigma$ changes in BF yielded the EV in table B. These economic values are in terms of dollars per slaughter hog marketed. A 1σ decrease in backfat increased net income of farm I by 96¢ and increased net income of farm II by 81¢ per slaughter hog marketed.

Feed efficiency (FE) is measured as (number of pounds of feed)/(number of pounds gained) for a fixed number of days fed. ADG is defined as (number of pounds gained)/(number of days fed). The EV of a trait is measured by varying only that trait. To permit varying FE and ADG independently, the authors changed pounds of feed fed to change FE, and they varied number of days animals were fed to change ADG. FE was assumed to increase and decrease by 0.15 pound of feed per pound of gain. These are $\pm 1 \sigma$ changes in FE. The only parameters of the linear programme affected by changing FE were the coefficients that measure quantities of feed fed to produce 100 pounds of market hog.

Average daily gain (ADG) was increased and decreased by 0.15 pound of gain per day fed. These changes will be referred as $\pm 1 \sigma$ changes. Changing ADG by changing number of days that animals were fed changed labor and space needs and costs of fuel and power. For farm I, the increase in net income resulting from a 1σ increase in ADG is only 40% of the decrease in net income resulting from a 1σ decrease in ADG. The effect on net income of varying ADG was much greater for the farm with reduced labour resources (farm IA) than for the other farms.

Table B. Economic values for Backfat, Feed Efficiency, and Average Daily Gain in Dollars per Market Hog

Farm	Traits	dg_h = Genetic Change	
		+1 σ	-1 σ
I, IA	Backfat	-0.95	0.96
I, IA	Feed efficiency	-1.44	1.44
I	Average daily gain	0.09	-0.21
IA	Average daily gain	0.94	-1.02
II	Backfat	-0.77	0.81
II	Feed Efficiency	-1.12	1.19
II	Average daily gain	0.08	-0.10

Globally, measured in absolute value, FE had the largest EV for all three farms, and ADG had by far the smallest EV for farms I and II, whereas BF and ADG had nearly the same EV for farm IA. For each trait EV was larger for farm I than for farm II. Economic values computed by this procedure show that values may vary among farms having different factor endowments, managerial capabilities, market outlets, or product-mixes.

References:
Ladd, G.W. and C. Gibson, 1978. Microeconomics of Technical Change: What's a better Animal Worth? *American Journal of Agricultural Economics*, 60: 236-240.

A further problem is that simulation models often apply a linear functional specification for the objective function and the constraints. In principal, this approach assumes a Leontief technology where inputs are combined in fixed proportions.

However, changes such as the replacement of breeds or the change in the number of animals often lead to adjustments in the overall organization of the farm. They also lead to adjustment in the input mix, such as the use feed and veterinary services. These changes are rarely captured by linear programming approaches. Farm simulation models can overcome this inflexibility by using a more flexible form for the production function and many models now are based on more flexible specifications.

iii. Deterministic and stochastic R&D models for AnGR

Models of research and development (R&D) analyse the question of how progress in breed characteristics affects economic returns. They can evaluate R&D programme *ex-ante* based on simulation models or *ex-post* based on observed data. In an attempt to measure R&D they are often dynamic in character.

Models of R&D are used to evaluate the efficiency of R&D projects by comparing the amount of invested funds and resources to economic returns due to resulting technological change. They serve as a basis for benefit-cost analyses of research on animal genetic traits.

Quantifying R&D models *ex-ante* is very difficult. Precise estimates of research possibilities and their estimated values have to be obtained. Also precise information on AnGR and the possibilities for genetic trait development is needed. Still, this method is important as it provides a means to measure the value of AnGR for R&D processes.

A brief look at the literature shows that a number of methods can be used to estimate the effect of R&D in the development of AnGR. Box III.4 illustrates the evaluation of trypanosomosis resistance in African cattle. Mitchell *et al.* (1982) attempt an economic appraisal of pig improvement research in Great Britain in the 1970s. Comparing benefits to costs of research (private and public) on farm and research budgets, they estimate annual costs at approximately £ 2 10^6 and annual benefits at £ 100 10^6.

Evenson (1997) has shown that the improvements in rice varieties have been international in character. He uses a hedonic analysis to determine the factors enhancing the development of new rice varieties. Access to and international exchange of genetic resources of farmer-selected "landraces" was vital. More than ninety percent of the green revolution rice varieties were developed from genetic resources originating in more than one country.

R&D models can also be used for valuing pre-commercial genetic resources. Indeed, genetic improvement has been a major contributor to agriculture productivity, but many questions about the economics of animal or crop breeding, such as the value of pre-commercial breed or germplasm, remain unanswered. Recently, these questions arise more and more frequently in response to the emergence of private firms engaged in AnGR improvement programmes and benefit sharing according to international agreements. The emergence of private firms developing new traits generates a growing need to answer these questions.

Recently, Zohrabian *et al.* (2003) employ a method that has not been used previously, *Maximum Entropy* (ME), to estimate net marginal benefits from exploring an accession for use in plant breeding. This study estimates the marginal value of poorly characterized materials contained in the U.S. national germplasm system. The soybean cyst nematode is the pest examined in this research. Within the search theoretic framework, the authors

apply a ME method to estimate the probability and the expected improvement in pest susceptibility relative to its previously observed level. Results reveal a large ratio of expected benefits to the cost of the search for resistance to a specific pathogen, suggesting that an expansion of the US soy bean collection is economically justified.

Box III.4 An *ex-ante* economic and policy analysis of research on genetic resistance to livestock disease: Trypanosomosis in Africa

Numerous diseases hinder the development of animal breeding in the world. Tsetse fly-transmitted trypanosomosis is one of the principal obstacles to African livestock production. Losses due to this disease are estimated at US-$ 1.6 billions. Considerable efforts have been applied to fight this disease, especially by applying trypanocidal medicines, by controlling transmitting vectors (Tsetse fly) and by exploiting the inherited genetic resistance against the diseases carried by some indigenous breeds. In view of the loss of effectiveness of trypanocidal medicines and the difficulties involved in suppressing the disease transmitting vector, priority should be given to increase the trypanotolerance by selection of appropriate breeding animals within a breed or by cross breeding.

Research results of past years show that the two principal indicators of trypanotolerance, and more specifically of the values of hematocrite, and of parasitaemia are strongly correlated to the economic performance of animals. Therefore, two principal directions have to orient future research. The first requires the identification and conservation of trypanotolerant breeds that have to be strengthened by other important economic traits. The second requires to reinforce non-tolerant animals by traits of trypanotolerance while preserving their important economic traits. Considering these aspects, Falconi *et al.* (2001) have undertaken an *ex-ante* economic evaluation of these livestock development strategies.

The overall objective of this study was to establish the likely magnitude of benefits relative to costs under alternative assumptions on research progress. This was achieved by quantifying the implications for aggregate and regional welfare of different scenarios of research duration toward key milestones. The overall strategy pursued was based on a three-step process (figure A). First, research target zones were identified and characterized in the usual fashion. Second, potentials for technology generation and adoption were specified and, third, potential costs and benefits of research initiatives were quantified.
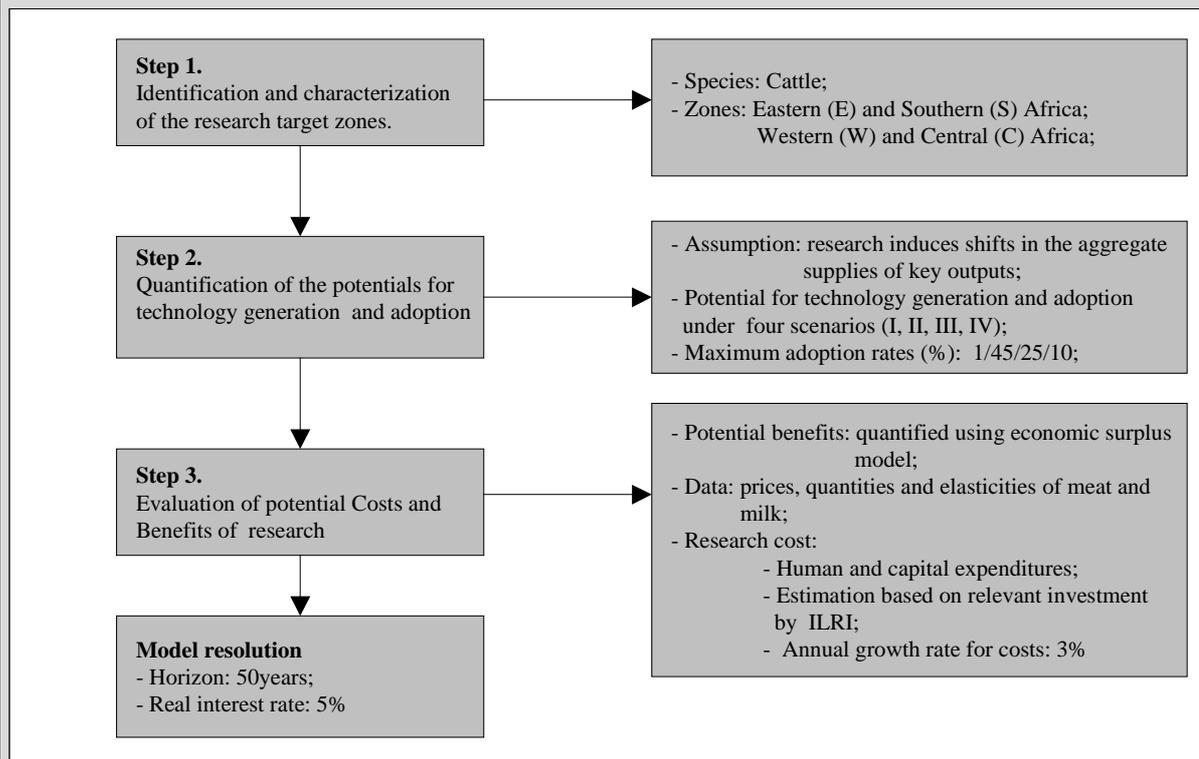
Figure A. Steps in the modelling of Trypanosomosis research

Given the uncertainty that characterizes the results of typanotolerance research, the authors have evaluated the costs and the benefits of technological progress under specific hypotheses. The scenarios of technology development and adoption consider quantitative field-based research on trypanotolerance and biotechnology assisted research (marker-assisted selection and marker assisted introgression). The scenarios (I/II/III/IV) differ in particular in the time laps in years required to construct a cattle QTL map (not applicable/30/12/7), maximum adoption rates in percentage (10/50/50/50) and cumulative years to maximum adoption (1/45/25/10). Lower time lapses thus lead to increasingly optimistic estimates.

Table A. Potential welfare impacts of research across regions under alternative scenarios of technology development and release (million US$, Percent of total benefits in brackets).

Scenarios*	Scenario I	Scenario II	Scenario III	Scenario IV
Producer benefits	14.17 (43)	29.19 (43)	122.10 (43)	215. 06 (43)
Consumer benefits	18.06 (57)	38.69 (57)	159.36 (57)	280.68 (57)
E & S Africa				
Producer benefits	3.22 (10)	18.28 (27)	75.83 (27)	133.57 (27)
Consumer benefits	4.29 (13)	24.41 (36)	101.22 (36)	178.28 (36)
Total E & S	7.51 (23)	42.69 (63)	177.05 (63)	311.85 (63)
W & C Africa				
Producers benefits	10.95 (34)	11.16 (16)	46.27 (16)	81.49 (16)
Consumers benefits	13.77 (43)	14.03 (21)	58.15 (21)	102.40 (21)
Total W & C	24.72 (77)	25.19 (37)	104.42 (37)	183.89 (37)
Total benefits	32.23 (100)	67.88 (100)	281.46 (100)	495.74 (100)
Total costs	6.38	52.49	53.81	53.81
Benefit:cost ratio (BCR)	5.05	1.29	5.23	9.21
Internal rate of return (IIR)	32	2	12	31

* The scenarios I, II, III and IV considered correspond to field-based, pessimistic biotechnology, moderately optimistic biotechnology and highly optimistic biotechnology, respectively.

In scenario I, the costs present a fifth of the generated benefits, yielding a benefit-cost ratio of 5.05, and an internal rate of return of 32% that largely exceeds the interest rate considered at 5% (table A). For the second scenario, the benefits cover hardly the costs and the internal rate of return is lower than the interest rate. The research investment thus is not profitable.

As for the third scenario, the benefit-cost ratio is similar to that of scenario I, but the internal rate of return is only about 12%. The last scenario yields a relatively high benefit-cost ratio and internal rate of return. In all scenarios and all regions, the consumer surplus generated is relatively large in comparison to the producer surplus. Interregional comparisons show that the potential productivity gains are particularly large in the Western and central region in scenarios I and IV. Results suggest that field-based research on aggregate yields significantly lower potential benefits than biotechnology research. However, the results have been derived under specific assumptions about the institutions that govern the dissemination of research results.

References:
Falconi, C.A., S.W. Omamo, G. d'Ieteren, and F. Iraqi, 2001. An *Ex-Ante* Economic and Policy Analysis of Research on Genetic Resistance to Livestock Disease: Trypanosomosis in Africa. *Agricultural Economics*, 25: 153-163.

III.2 Approaches based on the utility function

Demand models can be specified on two types of data: revealed choice data or stated choice data. Revealed choice data are observed in the market place. They represent real choices of real people. However, for many goods, such data is not available. Market data on livestock resources is normally collected at the species level and not at the breed level. Even if it were, data may not be detailed enough or may not permit to evaluate resources that are rare and not often observed. When observed choice data is missing, one has the possibility to obtain stated choice data by facing individuals with hypothetical choices to be made. Responses to these hypothetical choices can be recorded and analysed using the appropriated techniques.

i.   Revealed choice data

a.   Econometric demand and supply estimation

In principal, the value of a good in the market can be estimated by demand and supply estimation. If it is possible to obtain market prices and individual transaction data involving consumer and input commodities for farm animal production and to link it to phenotypic traits and AnGR, then it would be possible to estimate the demand and supply equations for these goods explained by phenotypic traits and AnGR (Scarpa, 1999).

The problem with this approach is that there are few production data and hardly any consumption data available that split up production and consumption by breed. Animal products, such as milk, meat, and wool, are often sold in bulk and then processed and mixed so that the link between traits and consumer goods bought is not easily measured.

One possibility, however, exists, if the breed is used to produce a unique, breed related product. In the European Union, many products of designated origin are protected by EU regulation. The production techniques specified for the accredited products also sometimes specify that the product can only come from a particular breed. An analysis of the market for this product could allow estimating the market value of the breed.

b.   The hedonic value approach

Hedonic analysis is based on the assumption that the value of an animal is a function of the phenotype (and genotype) characteristics of the animal. It is based on Lancaster's (1966) approach to the modelling of demand as explained in chapter II. The total value (P_i) of an animal (Q_i) can thus be decomposed into values of individual traits $\left[Q_i = \left\{ q_1, ..., q_k, ..., q_K \right\}_i \right]$. The contribution of each characteristic to the total value is estimated via econometric methods:

$$P_i = f\left(q_1, q_2, ..., q_K \right)$$

Explanatory variables have to control for changing environmental conditions to avoid confounding trait effects with other farm environmental variables determining the overall values of the resource. Thus, the marginal value of a specific characteristic can be calculated as:

$$P_k^i = \frac{\partial f(Q)}{\partial q_k}$$

This marginal value describes how the variation in price in response to a given animal attribute varies, keeping everything else constant. This marginal effect can be linked to the appropriate consumer-behaviour functions, such as the Hicksian demand or the indirect utility function, depending on the framework employed and the data available (Scarpa *et al.* 2003b).

Evenson (1997) has used hedonic methods in the estimation of the value of rice plant genetic resources in India. Endogenous variables measuring rice variety productivity were pesticide use and rice total factor productivity. Explanatory variables included varietal resistance traits and other productivity determining variables such as extension service, intensification programme, farm size, and roads.

Mendelsohn (1999) evokes that hedonic analysis can be applied in two different ways. It could be done on products heading to market to determine the value of alternative characteristics of those products. For example, one could examine the fat content of milk or meat and measure the value consumers place on that attribute. Alternatively, one could do a hedonic analysis on breeds and animals being selected or purchased by farmers. In this case, attributes that are largely valuable for production would also be included (weight gain, longevity, disease resistance, etc.).

The hedonic price technique has been widely used to estimate marginal values for animal characteristics (Farminow and Gum, 1986; Lambert *et al.*, 1989; Jones *et al.*, 1992; Richards and Jeffrey, 1996; Jabbar *et al.*, 1997; Jabbar and Diedhiou, 2003). Box III.5 illustrates an example of genetic merit of dairy bulls in Alberta using hedonic pricing (Richards *et al.* 1996).

Farminow and Gum (1986) have estimated a static feeder price differential model using data from two Arizona auction markets. To capture the effect of certain characteristics on the animal price, the authors adopted a non-linear model which expresses the prices as a function of weight, number of head in a sold lot, sex, breed, and year of sale. Estimation of a short-run feeder cattle price differential model resulted in an equation with a good empirical fit that is in agreement with theoretical expectations.

In the context of Kansas livestock markets, Lambert *et al.* (1989) applied a static premium and discount analysis to determine whether certain management or marketing practices affect the price of feeder cattle at auction. Two types of characteristics were considered: animal characteristics (sex, weight, muscle, frame horns, breed, condition, fill, health) and market characteristics (price, lot size, market location, auction sale order). The analysis showed that marketing price can be enhanced by selling heavy muscled, crossbred cattle with either medium or large frame in large size lots.

Box III.5 Establishing indices of genetic merit using hedonic pricing: An application to dairy bulls in Alberta

The genetic correlations between the zootechnical characters of economic importance and their heritability constitute essential ingredients in the establishment of genetic evaluation methods of livestock. In the context of the dairy production in Canada, *The Lifetime Profit Index* (LPI) is a measure of genetic valuation that is currently being used by the *Artificial Insemination* (AI) industry to rank dairy bulls. This index makes use of information concerning production and type scores to provide a measure of the expected contribution of a bull's offspring to dairy enterprise profitability. Each bull is scored for a series of characteristics based on production and longevity records of its daughters. The score for each characteristic is based on performance relative to the Breed Class Average (BCA).

The LPI represents one method of linking selection for genetic characteristics with the economic value of those traits. It measures the expected contribution of a bull's offspring to dairy enterprise profit over a five-year period, using a combination of production and longevity characteristics. Globally, the LPI currently used by the dairy industry is based on a combination of production and type proofs, using BCA scores for each bull. The value to a farmer of using a bull with an improved set of genetic traits is estimated by projecting the changes in profit from increasing the production value per animal. This index is currently being used by AI units in Canada as an overall *measure of genetic merit*. However, this approach based on the LPI has some weaknesses and limits. These limits can be summarized as follows:

- the costs and returns of the representative farm derived from the Ontario data are not likely to be representative of all dairy producers in Canada;
- the Ontario records yield estimates of the average cost associated with a given change in milk production, whereas producers are concerned with improving their profits;
- the longevity traits of each bull will be different, but the relevant lifetime of the offspring is defined to be five lactations for each bull
- the weights on each component of the LPI are determined on an *ad hoc* basis, they have no basis in optimal economic behaviour;
- the method assumes a fixed production technique, although technology is constantly changing in the industry.

In order to overcome the limits of the LPI, Richards et Jeffrey (1996) examine an alternative approach to measuring genetic value. Specifically, a *hedonic pricing model* (HPM) was used to determine the implicit value to dairy producers of genetic traits for pure-bred Holstein dairy bulls in Alberta through the statistical analysis of market price data for semen. The *Box-Cox/Tobit* model (first model) is estimated considering semen price as a function of individual production and longevity characteristics. These include milk volume, protein content, fat content, general conformation, some measure of body capacity, the quality of the feet, legs, and mammary system, the "popularity" of the bull and the supply of a bull's semen. The ability of the HPM model to explain semen price variation relative to the LPI is tested by comparing the HPM with a similar statistical model that uses only the LPI and the supply (*dummy*) as regressors (second model). The results are reported in table A.

The first model suggests that the most important characteristics used by Alberta dairy producers in valuing dairy bulls are milk volume, protein and fat content, general conformation, body capacity and the popularity of the bull. Indeed, the marginal values in table A (MV_A and MV_L) may be interpreted as representing the value of individual implicit characteristics. For example, if the proofs of two bulls are identical and average in every respect except that one has a + 10 milk rating and the other has a +11, then the former is expected to sell for $0.51 more per dose. Similar interpretations may be made for the other coefficient estimates.

The estimated coefficient for feet, legs, mammary system and body capacity suggest that synergies exist among type categories. Because "final class" is an all-encompassing measure of type, it is influenced by the quality of an animal's feet and legs, body capacity and mammary system. Therefore, the marginal effect of a plus deviation bull for more detailed class categories is expected to be small when final class is included as an explanatory variable.

With regard to the effect of supply on the price, if an AI unit decides to take a previously active bull out of service (for example, the supply dummy variable changes from 0 to 1), the price of semen would then be expected to rise by $2.25, on average. Future research in this area would benefit from more complete data on the supply of each characteristic.

The second model shows that the LPI represents a highly significant explanatory variable for the semen

price. The likelihood dominance criteria (LDC) was used by the authors in order to test if the LPI model hypothesis is shown to dominate the hedonic price specification. If this is the case then the LPI is regarded as a superior measure of genetic merit, and vice versa. This test (LDC) confirms that the HPM dominates the LPI version. This result implies that if a composite were to be constructed that nested the two competing hypotheses, it would never be the case that the HPM would be rejected in favour of the LPI.

Table A. Tobit model estimates: Marginal characteristic values (first model), LPI and supply as explanatory variables (second model)

Models	First Model				Second Model	
Variables[a]	Coefficient	t-ratio	MV_A[b]	MV_L[b]	Coefficient	t-ratio
Constant	-81.439	-5.625	-	-	-13.364	-7.300
Milk	1.935	10.417	0.514	1.411		
Fat	13.733	4.414	5.051	13.874		
Protein	25.993	4.035	10.207	28.037		
Final class	1.101	4.032	0.382	1.049		
Body capacity	0.238	2.333	0.101	0.277		
Feet and legs	0.256	2.837	0.125	0.343		
Mammary system	0.379	2.207	0.137	0.376		
Daughters	0.025	4.036	0.001	0.003		
Supply	0.563	1.938	2.245	6.166	0.490	1.63
LPI					0.827	2.88
λ	0.550	11.828				
R	0.790				0.62	
σ	3.252				23.132	
LF	-594.328				-636.213	

[a]: Most of the variables included in this analysis represent various components of the bull proofs. For example, Milk refers to milk production, Final class refers to the breed class average score for the final class assigned to the bull, etc., Daughters refers to the number of daughters for each bull and is used as a proxy for repeatability, and supply is the variable used as a proxy for effect of supply on the price of semen. At a 5% level, the critical t-value is 1.64.
[b]: MV_A refers to the marginal value of each characteristic for the observed or actual values of the dependent variable. MV_L refers to the marginal value of characteristics latent dependent variable.

The implications emanating from this research are various and concern different aspects of the potential applicability of the HPM as a valuable tool to AI units' marketing managers, dairy breeders, and policy makers. Briefly, these implications relate, among others, to the following aspects:
- longevity considerations in the HPM are more consistent with economic theory. In other words, this model implicitly embodies the multi-period consequences of any breeding decision;
- the HPM implicitly measures producers' tendency to be risk averse;
- the model is not restricted to estimating the values of only quantifiable traits, qualitative traits may be included and would act to 'shift' the whole function up or down;
- it can constitute a powerful marketing tool in determining the price for bulls that are just entering the system, and also may be used as an indirect test of the effect of policy on genetic progress in the dairy industry.

References:
Richards, T.J. and S.R. Jeffrey, 1996. Establishing Indices of Genetic Merit Using Hedonic Pricing: An Application to Dairy Bulls in Alberta. *Canadian Journal of Agricultural Economics*, 44: 251-264.

The investigation realised by Jones *et al.* (1992) was interested in the quality factors affecting transaction price differentials for fed steers and heifers in southern Kansas. The conceptual model adopted in this research assumes that the demand for fed cattle is derived from the demand for wholesale beef which is derived from the demand for beef by consumers. The derived demand for fed cattle shifts as consumer demand is modified or when fabrication or marketing costs of processed beef changes. The results indicate that transaction prices are significantly affected by average weight, the percentage of cattle expected to qualify for the grade "choice", the "select"-to-"choice" carcass price spread, finish uniformity, breed, the number of head purchased from the feed yard by a single buyer during the day, the packer, the feed yard, the day of the week the cattle sold, and the number of bids.

Another study was undertaken in the derived savana area of southwest Nigeria to determine the prospects for conservation through use and possible improvement of the *Muturu*, a West African shorthorn breed known to be in decline throughout southern Nigeria (Jabbar *et al.*, 1997). Two principal goals were pursued. The primary objective was to improve understanding of farmers' breeding practices and breed preferences in order to help target private and public programmes of breed conservation and improvement. A secondary objective was to evaluate participatory and quantitative techniques for assessing livestock owners' breed preferences and signals sent to farmers by livestock.

Thus, analysis of farmers' breeding practices and breed preferences confirmed a strong trend away from *Muturu* and identified the traits farmers find least desirable about the *Muturu* relative to other breeds. Concerning analysis of cattle market prices, an implicit or hedonic price function was estimated to relate the price per animal to its various attributes and characteristics. The results showed small, but significant, price differences by breed.

In the context of farmers' breeding practices and breed preferences in southwest Nigeria, Jabbar and Diedhiou (2003) identify milk yield, disease resistance, animal size, handling easiness, market value, and easiness of grazing as important attributes in livestock owner's minds. They make the interesting observation that the preservation of these characteristics does not necessarily imply the preservation of breeds. The greatest threat to the individual breeds comes from cross-breeding which might preserve the most important characteristics of each breed, but at the same time lead to their disappearance.

Data needed for hedonic studies are prices on animal market transaction or productivity estimates. These serve as dependent variables. In addition, data on genetic traits and AnGR are needed as explanatory variables together with variables measuring the characteristics of the production environment.

The advantage of the hedonic method is that it can help obtaining precise estimates of the use values of single traits and of specific AnGR. Difficulties arise because it requires a large amount of detailed information and a careful definition of the traits being considered in the analysis.

ii.   Stated choice methods

a.   Contingent valuation methods

When no revealed choice data are available, contingent valuation (CV) studies are commonly used to evaluate resources. Because revealed data are typically absent for non-market goods, particularly environmental goods and resources, the method has largely developed in the environmental economics literature. It has also been used in the marketing literature to evaluate the market potential of new products.

CV was developed as a contribution to benefit-cost analysis, which in its modern form is best understood as an account of the prospective contribution of some proposed project or policy to the satisfaction of human preferences. The central focus on preference satisfaction oriented benefit-cost analysis toward the measurement of economic surplus and of the value of non- market goods and amenities. This approach was specifically

designed for enlisting survey research methods to obtain benefit estimates that are consistent with rigorous welfare change analysis (Randall, 1997).

The CV method exploits data on hypothetical decisions. As no real choices are observable, individuals are faced with alternative hypothetical scenarios of which they have to choose one. To make valid inferences, the scenarios to be evaluated have to be described in great detail. And a 'price' has to be put on each scenario to attribute a value to the scenario in question.

Main steps	The NOOA guidelines
Step 1. Design of survey tool and specification of the sample	**Conception of tools** - Use personal interviews; - Use a WTP rather than WTA; - Use dichotomous choice format; - Use an accurate scenario description; - Favour a conservative design (more likely to under- rather than overestimate WTP); - Provide a "no answer" or "don't know" option; - Include follow-up questions to the valuation question; **Identify the sample** - Use a representative sample (rather than a convenient sample).
Step 2. Test of evaluation tool	- Adequately pre-test the survey instrument; - Carefully pretest any photographs and illustrations used.
Step 3. Execution of survey	- Remind respondents of undamaged substitutes; - Remind respondents of budget constraints; - Check respondents understanding; - Deflect warm glows (overstatement of WTP to appear generous).
Step 4. Econometric analysis and presentation of results	- Cross tabulate the results; - Check temporal consistency of results.

Adapted from OECD (2002) and Randall (1997)

Figure III.3 General design of and the NOAA guidelines for contingent valuation studies

The CV method uses the concept of willingness to pay (WTP) or willingness to accept (WTA). An alternative scenario is often evaluated in comparison to an existing scenario by asking how much a person is willing to pay or willing to accept, to switch from the existing

situation to the hypothetical scenario. A general procedure of contingent valuation studies is presented in figure III.3.

In response to the increased used of contingent valuation methods, the US government had appointed an expert panel of economists known as the NOAA panel in the beginning 1990s. They gave advice on the procedures to follow in contingent valuation studies. A summary of their recommendation is also given in figure III.3.

Contingent valuation studies are done via surveys on a representative sample of the population that would be affected by the scenario in question. The survey can be done by mail, by phone, or face-to-face. It is important to give a precise definition of the scenarios to be evaluated to minimize any bias of the estimates that may result from wrong or incomplete information. The valuation question can be asked as open or closed question.

The responses from a contingent valuation survey can be analysed using different econometric tools. When closed, referendum-type questions are used, statistical analysis is usually based on logistic or *probit* estimation methods, specifying the average WTP/WTA. Using appropriate methods of aggregation, an overall estimation of the benefits and costs of the policy in question can then be conducted. This approach is generally used to estimate costs of the conservation programmes. However, it can also be used to measure the benefits generated through these programmes (Box III.6).

Pearce and Moran (1994; cited in Drucker *et al.*, 2001) argue that the CV method is a promising option for biodiversity valuation in general because: it is the only way to elicit non-use values directly; the potential for information provision and exchange during the survey process offers scope to experiment with respondents knowledge and understanding of biodiversity; and it can be used as a surrogate referendum on determining conservation priorities based on public preferences.

However, Evenson (1993; cited in Rege, 1999) has pointed out that CV methods seem to be "ill-suited" to measuring the value of genetic resources, since an average individual knows little about germplasm collections, breeding techniques, etc. Only specialists are competent to understand the breeding process. But restricting the sample only to specialist causes a bias in the estimation which is similar to the non-response bias in standard CV studies stemming from population segmentation. Moreover, if the researcher does not take explicitly into account a clear definition of the institutional framework within which the good or resource has to be valued, the danger of strategic bias could be very high.

Box III.6 Cost-benefit analysis of *in-situ* conservation of the Pentro horse

The Pentro horse is an Italian breed that was strongly associated with the ancient traditions and local identity of the Molise region in southern Italy. In the past, transhumant herders used the horse because of its rustic nature to travel along the cattle-tracks. The tradition of transhumance, that is of the seasonal migration of cattle and sheep towards better grazing lands, is amongst the oldest of this region and is very relevant in popular culture. At present, the Pentro horse is mainly bred for meat production.

This breed is currently subjected to a process of genetic erosion. Lower productivity in comparison to other breeds and the disappearance of transhumance constitute the main causes at the origin of this genetic erosion process. Also, agricultural policy played an important role in starting the extinction process. Indeed, while some support had been provided for the breeding of cattle, no financial or technical support has ever been in place for horse breeding. This policy contributed indirectly to the progressive distinction of this breed, which has gradually been replaced with cattle.

With only 150 horses, the Pentro horse falls into the FAO category of endangered animals. According to FAO

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guidelines, the population of this breed should increase to 1,000 horses in order to reduce the probability of extinction to much lower levels. In this respect, a cost-benefit analysis of a conservation programme was conducted by Cicia *et al.* (2003). In this study, the authors chose an *in-situ* programme because most of the potential value of the Pentro horse flows from use-value and nostalgic value. These values cannot be captured by consumers if the conservation programme is conducted *ex situ*.

Two principal aspects have been considered in this research: the construction and the calibration of a local horse population model and estimation of the economic benefits of conservation. Based on demographic parameters, the growth model for this breed was conceived to calculate the number of years necessary to reach the threshold of 1,000 horses and to estimate the costs linked to its conservation. The model estimates a necessary time span of 14 years to reach a population of 1,000 horses. The costs of the conservation programme were estimated based on the growth model. Since the objective is the conservation of the breed by reaching 1,000 reared horses, the breeding costs to conserve this population were calculated as well as the foregone revenues from annual sales of horses enjoyed in the absence of the conservation programme. Globally, these costs are estimated at about 258 Euros/horse/year.

Concerning the second aspect, the economic benefits of conservation were estimated using dichotomous choice contingent valuation survey data. The data were analyzed assuming a random utility model. In order to increase efficiency of the estimated model parameters and to avoid bias due to various effects, the procedure called "*one and one half bound*" was adopted. Using this format, the respondent is told that the amount to be paid can vary between a minimum and maximum value. After which, one of the two values is randomly chosen. If the value chosen is the minimum value, and the respondent answers positively, then the respondent is asked if he/she is willing to pay an amount equal to the maximum value of the interval. If on the other hand, the respondent answers negatively to the request for a minimum amount, there is no further request. In the case in which the maximum value of the interval is chosen, a similar procedure takes place: The willing to pay (WTP) question is reiterated if it answers "*No*" at the first bid by proposing the lower one, while there is no follow-up in the case of acceptance.

In order to reduce the bias, which may be caused by the lack of information on such a complex subject as biodiversity, respondents received a booklet. This booklet described the problem of biodiversity and presented the case study of the Pentro horse, highlighting the benefits and costs related to its conservation and loss, also mentioning other domesticated breeds and non-domesticated animal species facing extinction.

Table A shows the estimates of mean and median WTP values under the two model specifications, base and covariates models. Under the first model, the truncated mean value is 33 Euros while the median value is 19 Euros. Taking into account the number of families living in Molise (117.138), the corresponding total sums of the aggregate values are about 3.8 million Euros for the mean and 2.2 million Euros for the median. The second value may be important to local politicians, given the interest in median-voter behaviour in a referendum context.

As regards the covariates model, both the mean and the median values are higher than those from the first model. For this model, the socioeconomic covariates that show significance include the degree of education, family income, knowledge of the Pentro horse prior to the interview, and membership in environmental associations.

Table A. Parameters of WTP distribution (Base and covariates models)

		Base model		Covariates model	
	Parameter	Estimate	Aggregate	Estimate	Aggregate
IC $_{0.05}$	Lower bound	30	3 464 942	31	3 652 949
(truncated mean	Median	33	3 872 582	35	4 095 730
At 103 Euros)	Upper bound	37	4 280 223	39	4 538 512
IC $_{0.05}$ (median)	Lower bound	17	1 936 198	21	2 452 477
	Median	19	2 225 372	24	2 792 589
	Upper bound	22	2 550 603	27	3 168 456

Values in Euros

The results of the cost-benefit analysis are reported in table B. The computed values correspond to two discount rates (0 and 3.5%) under the two specifications of the model. For all the scenarios considered, the estimated benefits of the conservation of the Pentro horse breed exceeded the estimate social costs required to active the programme, as derived from the bio-economic model, even under a zero discount rate. Knowing that

there currently is no conservation programme for this breed of horses, these results are of particular importance.

Table B. Cost benefit analysis

	Base model		Covariates model	
	Mean	Median	Mean	Median
Discount rate 3.5 %				
Total benefits	3 872 582	2 225 372	4 095 730	2 792 589
Total costs	990 444	990 444	990 444	990 444
Net present values	2 882 138	1 234 928	3 105 286	1 802 145
Benefit to cost ratio	3.91	2.25	4.14	2.82
Discount rate 0 %				
Total benefits	3 872 582	2 225 372	4 095 730	2 792 589
Total costs	1 330 108	1 330 108	1 330 108	1 330 108
Net present values	2 542 474	895 264	2 765 622	1 462 481
Benefit to cost ratio	2.91	1.67	3.08	2.10

Values in Euros

These results show that this combined approach could be useful to support policy-making for conservation in regions with a long history of breeding domestic animals. Here, the issue of allocating scarce funds to a large and growing number of economically non-viable animal breeds facing extinction is becoming of considerable importance.

References:
Cicia, G., E. D'Ercole, and D. Marino, 2003. Valuing Farm Animal Genetic Resources by Means of Contingent Valuation and Bio-economic Model: The Case of Pentro Horse. *Ecological Economics*: forthcoming.

b. Conjoint Analysis and choice experiments

Conjoint analysis is a method that has long been used in marketing studies. Just as the hedonic value approach, it is based on the Lancaster's approach to the utility function. It assumes that the utility of a good does not come from the good itself but from the attributes that are embedded in the goods. A good can thus be described by a set of attributes that determines its utility to an individual.

In recent years, contingent choice experiments (CE) have been developed. CEs are an extension of the conjoint analysis combining it with ideas of contingent valuation studies. While pure conjoint analysis has contented itself with a ranking of products and a prediction of choices, CE exploit the structure of conjoint choice analysis to obtain a measure of WTP/WTA. Similar to conjoint analysis and the contingent evaluation method, CE are based on hypothetical choices. But instead of comparing the WTP/WTA across two scenarios in which several attributes may change at a time, they consider an experimental design in which several variables are varied individually (Louviere, Hensher and Swait, 2000).
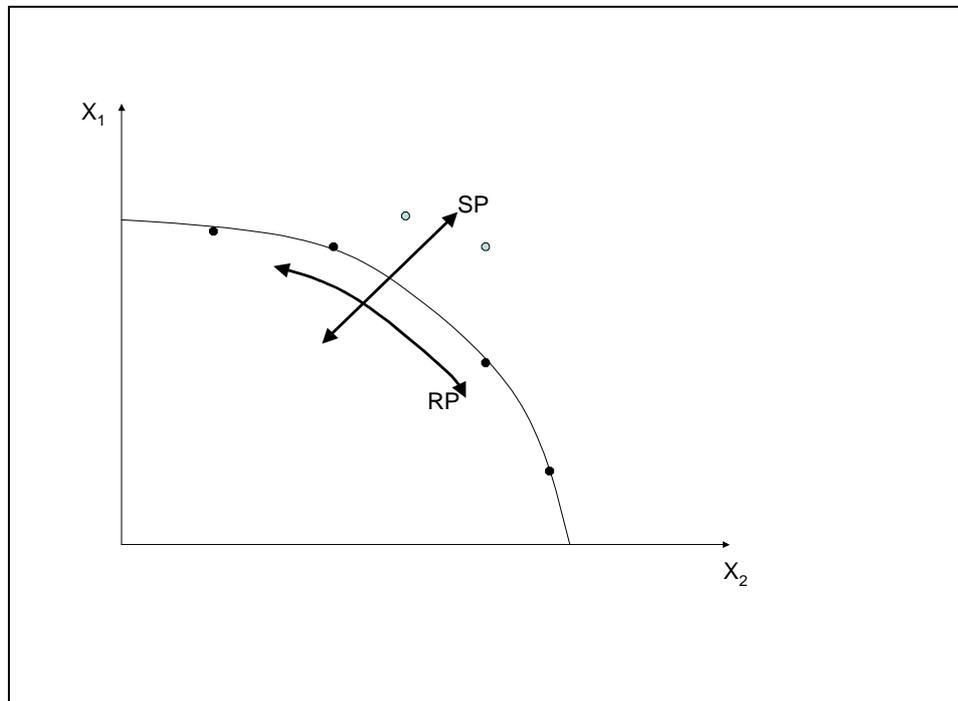
Figure III.4 The technological frontier and the roles for revealed preference and stated preference data

The advantage of the contingent choice experiment method over 'simple' contingent valuation studies is the added flexibility and scope of the study. It becomes possible to evaluate individual traits. Figure III.4 illustrates this point. Two characteristics of a good (breed), x_1 and x_2, are to be evaluated. Revealed preference data are only suitable to evaluate changes along the technological frontier, because only existing goods can be evaluated. Using this method, the degrees of freedom may not be sufficient to identify the value of individual characteristics. Stated choice data can also evaluate goods that, in the specified form, do not exist. Stated preference data, such as contingent valuation data, can thus evaluated options outside the existing technological frontier. CV data, however, is often restricted in evaluating only one or few scenarios in which several characteristics change at the same time. Choice experiments and conjoint analysis can overcome this limit by implementing experimental designs that vary characteristic levels in a way that permits the estimation of individual effects.

Within the survey of a choice experiment, the consideration of substitutes is part of the selection process. Goods are differentiated based on attributes and the respondent chooses a good within the set of available alternatives. In this exercise, the existence of substitutes is explicitly recognised. In traditional CV studies, the role of substitutes is relegated to a reminder sentence or two in the description of the good. Figure III.5 presents a summaryof the stages involved in a CE.

```
┌─────────────────────────────────────────────────────────────────────────────────┐
│  ┌──────────────────────────────┐        ┌──────────────────────────────┐       │
│  │ Identify the potential       │───────▶│ Review of available literature│       │
│  │ characteristics              │    │   └──────────────────────────────┘       │
│  └──────────────────────────────┘    │                  │                        │
│               │                       │                  ▼                        │
│               ▼                       │   ┌──────────────────────────────┐       │
│  ┌──────────────────────────────┐    │   │ - Focus group meeting        │       │
│  │ Final choice of characteristics│──┘   │ - Evaluate alternative       │       │
│  │ for including in the survey   │──────▶│   question formats and       │       │
│  │ instrument                    │       │   contents (levels of an     │       │
│  └──────────────────────────────┘       │   attribute that are salient  │       │
│               │                          │   to the survey respondent)   │       │
│               ▼                          └──────────────────────────────┘       │
│  ┌──────────────────────────────┐                       │                        │
│  │ Choice of a type of conjoint │       ┌──────────────────────────────┐       │
│  │ analysis                     │──────▶│ Ranking format, binary choice │       │
│  └──────────────────────────────┘       │ format, rating format or      │       │
│               │                          │ graded-pair comparison.       │       │
│               ▼                          └──────────────────────────────┘       │
│  ┌──────────────────────────────┐                       │                        │
│  │ Experimental design and      │──────▶┌──────────────────────────────┐       │
│  │ stimuli                      │       │    Choice of profiles         │       │
│  └──────────────────────────────┘       └──────────────────────────────┘       │
│               │                                          │                        │
│               ▼                          ┌──────────────────────────────┐       │
│  ┌──────────────────────────────┐       │ - Development of a survey     │       │
│  │ Data collection              │──────▶│   instrument (verbal          │       │
│  └──────────────────────────────┘       │   descriptions, paragraph     │       │
│               │                          │   descriptions or pictorial   │       │
│               ▼                          │   representations)            │       │
│                                          │ - Test and modification of    │       │
│                                          │   the survey instrument;      │       │
│                                          │ - Elaboration of the final    │       │
│                                          │   version of the survey       │       │
│                                          │   instrument.                 │       │
│                                          └──────────────────────────────┘       │
│                                                          │                        │
│  ┌──────────────────────────────┐       ┌──────────────────────────────┐       │
│  │ Main effects estimates and   │──────▶│ Statistical and econometric   │       │
│  │ relative importance of       │       │ analysis                      │       │
│  │ characteristics              │       └──────────────────────────────┘       │
│  └──────────────────────────────┘                                               │
└─────────────────────────────────────────────────────────────────────────────────┘
```

Figure III.5 Steps of implementation of the choice experiments

CEs model individuals' preferences by considering the tradeoffs that they are willing to make. The use of focus groups comprised of individuals drawn from the population of interest allows the researcher to determine what attributes are important to the survey population. Further, the focus group allows the researcher to hone in on changes in the levels of an attribute that are salient to the survey respondent.

Four types of CE surveys can be constructed. A ranking format asks the subject to rank alternative scenarios each with different attributes and levels from most to least desirable. Closely related to ranking is the binary choice format, in which the subject is presented with two or more scenarios and is asked to choose the scenario that is most preferred. The rating format asks the subject to rate the different scenarios on a bounded integer scale from very desirable to undesirable. The rating format is desirable because it captures the intensity of the individual's preferences, which gives a measure of cardinality and it allows ties between scenarios. Ratings differ from rankings in that ranking is done relative to other scenarios whereas ratings are independent of alternative scenarios. A fourth format is the graded-pair comparison. Subjects are asked to consider two scenarios at a time and are asked to rate the intensity of their preference for one scenario over the other. The choice of format to be used depends on the researcher's output requirements and the nature of the good or resource being examined.

Data collected in a CE are analyzed using standard limited dependent variable statistical methods. For example, CE studies involving discrete choices, categorical, censored, and ordered choices are typically analysed various versions of *logit*, *probit*, and *tobit* models. Rating data may be analysed using double-hurdle tobit if the cardinality in the data is important or *probit* and ordered *probit* (Box III.7) if only an ordinal structure in the data is assumed (Boyle *et al.*, 2001). Rank data are analysed with ordered *probit/logit* and conditional *logit*, choose-one is analysed with binary *probit/logit*.

As regards empirical applications relating to the genetic characteristics, the construction of the survey requires a careful definition of traits and their measurement to ensure that farmers understand the evaluation exercise. And in addition to the classical conjoint analysis it permits the estimation of WTP/WTA.

CEs help to assess how farmers value certain breed traits by measuring the relative importance of various attributes on the choice process. The approach can be embedded in the random utility model which renders it suitable for the econometric analysis of hypothetical choices. It is more general than contingent valuation methods that have frequently been used to measure, e.g., farmers willingness to accept payments in return for participation in agri-environmental programmes.

In the case of animal genetic resources, one can vary several phenotypic or genotypic traits and evaluate the value of individual traits individually. Breed characteristics are described by τ, i.e. traits such as reproductive performance, milk yield, adaptation to landscape, resistance, rusticity, etc. Relevant policy variables are compensation payments for farming in marginal areas or for keeping traditional breeds. Using a questionnaire farmers are asked to choose the breed among a limited choice set describing alternative attribute combinations. These attributes are combined in the experimental design in a way such that an estimation of the underlying preference structure is possible.

Using this approach, a farmers' utility function can be estimated using the methods cited above. The approach can be adjusted to account for heterogeneity via mixed *logit* models (McFadden and Train, 2000) where estimated coefficients may vary across individuals according to environmental and household characteristics. The estimated preference structure can be used as an input to the farm decision model where farm decisions influence the diversity function. The estimated structure of farmer's preferences can also help to specify the benefit function in a cost-benefit analysis of farm animal conservation programmes, in particular with regard to the specification of the direct benefits to particular breed traits.

CEs have been found to accurately predict the likely success of new products in consumer studies. It has been used in studies evaluating willingness to pay for environmental amenities (Adamowicz *et al.*, 1998) and in the evaluation of breed traits (Scarpa *et al.*, 2003a, 2003b; Tano *et al.*, 2003; Sy *et al.*, 1997).

Tano *et al.* (2003) used conjoint analysis to measure the value of cattle traits in West African countries where literacy is low, where cattle perform multiple functions, where low input management is the norm, and where cattle are exposed to a number of tropical diseases and other environmental stresses. They found fitness for traction, disease resistance, and reproductive performance to be the most important traits. Weight gain and milk yield are also important characteristics but less valuable than the other listed above.

When choosing pigs in Mexico, Scarpa *et al.* (2003a) find that farmers in Mexico care about weight increase, feed costs, disease resistance, and bathing frequency when choosing pigs. Scarpa *et al.* (2003b) also examine the value of cattle characteristics. The results showed that Kenyan farmers valued weight, condition, some breeds, and sex.

In this last research, Scarpa *et al.* (2003b) investigate the performance of choice experiments by conducting an external test of preference consistency. The authors proceed by comparing values for cattle attributes derived from CE data with those obtained using a hedonic analysis of actual transactions by the same population of traders in the same markets and over the same period. The results indicate that CE estimates pass the external test and appear to be adequately precise in estimating values for cattle traits that are relevant in market transactions.

The CE approach is receiving increasing attention in the economics literature as well as in policy circles. In particular, NOAA recommended this approach as a tool to measure in-kind compensation for damaged natural assets. However, certain difficulties emerge when applying this approach for breed conservation or selection programmes. These difficulties relate to the scale of utility definition. Indeed, for these programmes, several operators are concerned: producers, consumers, but also the nation in its international relations and its choices of repartition. The producers do not all aim for the same objective, and interest conflicts are possible between different groups of producers (breeders, fatteners etc.) and between producers and users. As regards conservation programmes and/or breeding schemes, the adequate definition of the operators concerned is a question of first importance.

As an example, the appropriate strategy for any breeding programme would therefore be to set suitable selection goals that match the production system rather than ambitious performance objectives, which cannot be reached under the prevailing environment. The definition of a breeding goal based on a participatory process is an essential step for a village or community based conservation programme. The policy, therefore, should promote decentralised decision-making and ensure the participation of animal owners among other stakeholders in the process of formulating a breeding goal (Wollny, 2003).

Box III.7 Estimating the values of cattle characteristics using an ordered *probit* model
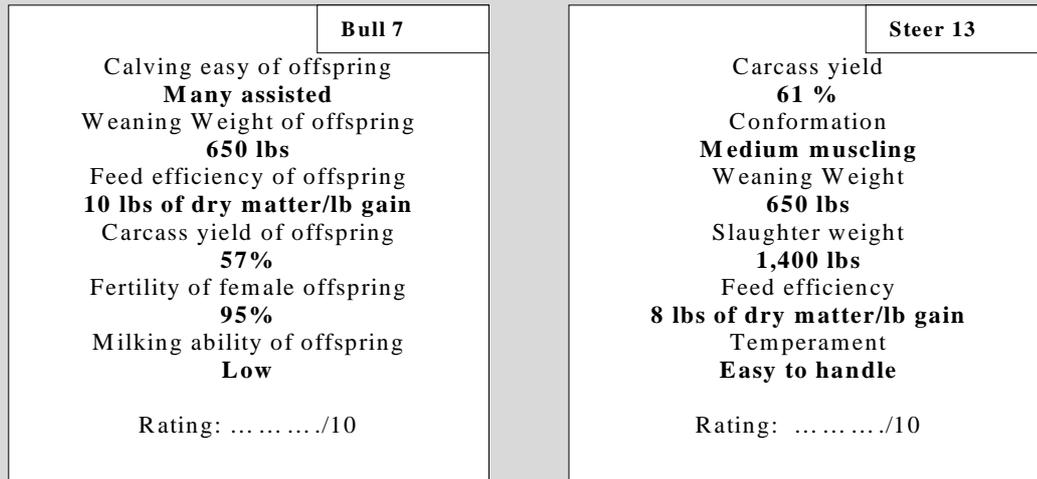
It is recognized that the market prices of animals are related to specific traits contained in the animals that are of interest to buyers. However, there is no definite account of the value of each trait embodied in the animals. Indeed, the market price is a composite for the bundle of genetic characteristics that defines the overall quality of beef animals. In fact, market prices do not specifically provide *signals* on the marginal value of specific characteristics that are important to operators in different segments of the market system. The establishment of "link" between economic criteria and the improvement of genetic characteristics requires the availability of information relating to marginal contribution of specific characteristic to quality.

Unable to observe effective behaviours on cattle markets in Manitoba, Canada, Sy *et al.* (1997) evaluated the preferences for different cattle (steers and bulls) characteristics using the conjoint analysis methodology. For this purpose, the North American beef production system was conceptualized as a system with three different and interdependent major segments: 1) purebred breeders or seed stock producers; 2) commercial producers (cow-calf operators); and 3) feeders. The methodological procedure adopted in this work concerned four principal stages:

1. review the literature to develop a list of important cattle characteristics and producers attributes for potential inclusion in the questionnaire;
2. organization of focus group meeting with cattle producers from different locations in the study area in order to evaluate alternatives question formats, contents and elicit general advice;
3. development of the survey instrument, initial pretesting, modification and preparation of a final

version;
4. collection and econometric analysis of the data.

Taking into account this considerations, eighteen bull profiles and eighteen steer profiles, each with different levels of six characteristics, were chosen and included in the questionnaire. There were three components to the survey instrument: an evaluation of characteristics of bulls with respect to the performance of their offspring, an evaluation of steers with respect to their characteristics, and background information about the farm operation and primary manager. Each bull and steer was presented to the respondent in the questionnaire in form of a "card" which listed the characteristics of that popular animal. Examples of cards used are presented in figure A. Respondents were invited to evaluate the different profiles using an eleven-point (0-10) preference scale.

Bull 7
Calving easy of offspring
Many assisted
Weaning Weight of offspring
650 lbs
Feed efficiency of offspring
10 lbs of dry matter/lb gain
Carcass yield of offspring
57%
Fertility of female offspring
95%
Milking ability of offspring
Low
Rating: ………./10

Steer 13
Carcass yield
61 %
Conformation
Medium muscling
Weaning Weight
650 lbs
Slaughter weight
1,400 lbs
Feed efficiency
8 lbs of dry matter/lb gain
Temperament
Easy to handle
Rating: ………./10

Figure A. Typical Cards for a Bull and a Steer from the Survey

As regards econometric analysis, an *ordered probit* model was employed. This approach made it possible to generate, among other results, the relative importance (RI) of each animal attribute, on the one hand, and the partworth values of animal attributes to different segments of the beef industry, on the other hand.
The results corresponding to these two aspects are shown in table A and B, respectively. For the first aspect, the RI was computed by taking the difference between the highest and the lowest partworth value of an attribute over the sum of the ranges for all attributes. The RI allows to make comparison between attributes and to reveal which attributes producers value more.

The results obtained for the cross-listed attributes were generally as expected (table A). For bulls, the most important attributes are "calving easy" and weaning weight, whereas for steers, slaughter weight and temperament appeared most significant. The comparison of the RI between steers and bulls, for the same attributes, indicates significant differences. For example, weaning weight for bulls accounted for 26 % of the producers preference, the second important attribute. In contrast, for steers, this attribute accounted for only 17 % of the producers preference, third in the rank of importance.

Table A. Relative importance of animal attributes (%)

Animal Attributes	Bulls	Steers
Calving easy	34	-
Fertility	6	-
Milking ability	17	-
Weaning weight	26	17
Feed efficiency	10	16
Carcass yield	7	11
Muscling	-	13
Slaughter weight	-	21
Temperament	-	22
Total	100	100

Concerning the second aspect, in order to capture the impact of producers' background on preference for animal attribute, producers were segmented based on production activity. Three producer profiles were

considered: breeders, feeders (producers whose herd had more fed cattle than breeding females and calves combined), and cow-calf operators (who had more calving cows than purebred cows and fed cattle combined).

Table B. Partworth values of animal attributes to different segments of the beef industry

	Industry by segments		
	Breeders	Cow-Calf	Feeders
Characteristics of bulls			
Calving easy	0.770	0.814	0.809
Weaning weight 650 lbs	0.692	0.652	0.538
Feed efficiency 10 lbs	-0.268	-0.268	-0.315
Carcass yield 61%	0.152	0.152	0.152
Fertility 95 %	0.134	0.134	0.092
Milking ability high	0.309	0.273	0.222
Steer attributes			
Carcass yield 61 lbs	0.151	0.188	0.188
Muscling heavy	0.126	0.157	0.157
Weaning weight 650 lbs	0.334	0.322	0.286
Slaughter weight 1,400 lbs	0.200	0.278	0.280
Feed efficiency 10 lbs	-0.242	-0.242	-0.242
Temperament easy	0.260	0.323	0.274

The partworth values for each segment (table B) are computed by adding partworths of a "typical" producer to the incremental partworth value due to producer profiles. As expected, breeders have high preferences for reproduction traits (fertility, milking ability and weaning weight) as compared to product traits (carcass yield, slaughter weight, etc.). In contrast, feeders have the highest preferences for feed efficiency and slaughter weight relative to the other producer groups. The preferences of the intermediate group of cow-calf operators,, tend to be similar to breeders' preferences on reproduction traits and to feeders' preferences on product traits.

References:
Sy, H. A., M.D. Farminow, G. V. Johnson, and G. Crow, 1997. "Estimating the Values of Cattle Characteristics Using an Ordered *Probit* Model". *American Journal of Agricultural Economics*, 79: 463-476.

iii. Consumer valuation of AnGR

Genetic traits determine not only the productivity of animals but also influence the quality of their products. Despite the fact that food demand has a low income elasticity, demand for high-quality and regional foods may be much more income elastic. Consumers are willing to pay higher prices for varieties and goods with preferred eating quality, which they substitute for lower-quality goods consumed at lower income levels (Unnevehr *et al.*, 1992). Smale (2001) cites examples of traditional low-yielding rice varieties that are grown in different Asian countries to fetch price premiums in local and export markets.

Values of quality attributes of food can be measured using market prices and demand via econometric and hedonic regression methods. Also hypothetical methods such as the contingent valuation method and CE could be used.

These hypothetical methods could also serve to measure use and non-use values that consumers see in breed conservation (see Box III.6 for an example). They probably also are the only methods that permit valuing the 'cultural' values embedded in local, traditional breeds. However, it is unlikely that consumers will be able to rationally judge the current and future opportunities of using AnGR and to guide a good conservation policy.

IV. Biodiversity and Decision Making

IV.1 Setting priorities for conservation

Human choices have an impact on biodiversity loss and decisions in husbandry as in agriculture as a whole are largely influenced by agricultural policies. Here, two aspects of choices are to be addressed: on the one hand choices that affect diversity, and on the other hand choices that have to be made concerning conservation measures. Many of the former are largely outside of the scope of this handbook although some important issues are raised in the conclusions. The latter are dealt with in more detail here.

If we focus on public policy related to conservation measures, decisions are made under a constraint on the budget allocated to these programmes. Decisions taken under some *exogenous* budget constraints imply the question of how to best allocate the available budget. In other words, decision makers have to choose what to preserve and to establish priorities. Weitzman (1992; 1993; 1998) developed a useful framework to tackle this issue. His approach to the problem will be described in this section.

IV.2 Weitzman's approach

i. The theoretical basis

Weitzman (1992; 1998) poses the question of the optimal degree of biodiversity conservation from a public policy perspective. The approach is sensibly the same when addressing the diversity of a set of any 'items' (species, populations, genes, etc.). It is applied here to the case of livestock breeds. The level of diversity to preserve depends not only on the number of breeds preserved, but also on their genetic distinctiveness. Once a measure of diversity is defined, the problem can be expressed as the maximisation of a social objective function, including direct benefits derived from a set of breeds together with their diversity. The problem is thus to maximise the benefits of individual breeds together with their contribution to diversity subject to a budget constraint on policy funds.

Measures of distinctiveness, *d*, can be based on such microcharacteristics as microsatellite markers, mitochondrial DNA, etc. Diversity $V(S)$ is calculated as explained in Weitzman (1992) as the solution to a dynamic recursion conceived as

$$V(S) = \max_{i \in S} \{V(S \setminus i) + d(i, S \setminus i)\} \tag{IV.1}$$

where S denotes a set of n breeds, $S \setminus i$ a subset excluding breed i, and $d(i, S \setminus i)$ denotes the genetic distinctiveness of breed i from the subset $S \setminus i$. In a discursive manner, this recursion calculates the contribution of every breed within set S to the total measure of diversity.

One important aspect of this diversity function relates to the importance of a breed for the diversity of the set S. Consider a subset $Q \subseteq S$ and a breed $j \in S \setminus Q$ that is added to Q. Then the gain in diversity is a function of how distinct is j from Q. This in turn is given by the dissimilarity between j and its closest neighbour in Q, i.e. $d(j, Q) = \min_{i \in Q} d(i, j)$. It implies

that the addition of an element j increases the diversity of set Q by at least its distance $d(i, j)$

$$V(Q \cup j) \geq V(Q) + d(j, Q) \tag{IV.2}$$

Equation (IV.2) can be used for any elements $i \in S$ and we define the diversity of the set of breeds S as

$$V(S) \geq V(S \setminus i) + d(i, S \setminus i) \tag{IV.3}$$

If we let $V_i^d \geq V(S \setminus i) + d(i, S \setminus i)$ and apply (IV.3) to all elements in set S' then we obtain

$$V(S) \geq V_1^d; \ V(S) \geq V_2^d; \dots; V(S) \geq V_N^d \qquad \forall i \in S; \ i = 1, 2, \dots, N$$

which can be simplified as $V(S) \geq \max_{i \in S} V_i^d$. This is not sufficient to define a unique function of diversity of all diversity functions thus defined. Weitzman (1992) has taken the one which corresponds to minimum V as

$$V(S) = min \ V$$

subject to $V = V(S \setminus i) + d(i, S \setminus i) \ \forall i \in S$

The solution to this problem gives the recursion (IV.1). The initial condition is a normalisation constant for the diversity of a set including a single breed, $V(i) = V_0$. This normalisation constant could be set to the appropriate value according to the data at hand.

Equation (IV.1) gives a unique diversity function with the following properties:

- adding an item identical to those already in set S does not change diversity;
- if an element is added, the resulting diversity is at least equal to the one prior to the item addition (monotonicity in items);
- if each pairwise distance increases, then the diversity of the set increases as well (monotonicity in distances);
- distances are continuous, i.e. if pairwise distances are slightly modified, then the change in diversity is also minor.

Theoretically, the dynamic recursion implies computations of number $n!$ for a set of n items. In the following, a property is described that allows reducing the number of computations to 2^n. This property is called the link property.

There exists one item, called the link one, $g \ (\in S)$, for which the inequality (IV.3) is satisfied as equality, i.e. $V(S) = V(S \setminus g) + d(g, S \setminus g)$. In other words, g is one of two items that are the closest neighbours in the set. Having identified the two items (g, h), the one which is the link item has to be determined by solving $V(S) = \max(V_g^d, V_h^d)$, where $V_g^d = V(S \setminus g) + d(g, S \setminus g)$ and $V_h^d = V(S \setminus h) + d(h, S \setminus h)$ so that the link item is the one which satisfies $\max[V(S \setminus g), V(S \setminus h)]$. Then the dynamic recursion becomes

$$V(S) = d(g, h) + \max\{V(S \setminus g), V(S \setminus h)\} \tag{IV.4}$$

ii. Procedure

Applying equation (IV.4) recursively, a rooted directed tree can be built. The following steps are to be taken:

1. start with a zero value of diversity, $V(S) = 0$;
2. find the two closest items (here, livestock breeds) and add $d(g, h)$ to diversity;
3. determine which is the link (g) and which is the representative breed (h) using $g = \text{argmax } \{V(S \backslash g), \, V(S \backslash h)\}$;
4. as $V(S) = d(g, h) + V(S \backslash g)$ consider then the set without g, i.e. $S \backslash g$;
5. go back to step 2 until there is one single item left, add the constant V_0 and stop.

The interested reader is referred to the example in Box IV.1.

The partial contribution of each breed i to the diversity of the set is

$$PC_i = [V(S) - V(S \backslash i)] \, / \, V(S).$$

This parameter may be used as a criterion to establish conservation priorities. Choosing to preserve either breed i or breed j ($\in S$) generally means preserving j only if $PC_j > PC_i$, i.e. if $V(S \backslash i) > V(S \backslash j)$. However, this criterion does not take into account an important factor: the extinction probabilities p_i and p_j of breeds i and j. In order to preserve the maximum diversity at a given point in time, such as at the end of a conservation programme, we should use the concept of expected diversity EV. This concept is explained here following Simianer *et al.* (2003).

Considering all possible (2^N) subsets Q ($\subseteq S$), EV is the probability-weighted diversity of all the subsets. It is assumed that all probabilities are independent. After t years, a breed existing today will still exist with probability $x_i = (1 - p_i)$, where p_i denotes the extinction probability of breed i. A vector **K** contains the indicator variables $k_i = 1,\ldots, N$ where $k_i = 1$ if breed i exists at time t and $k_i = 0$ if breed i is extinct, so that the probability $P(\mathbf{K})$ that a given situation where a subset Q exists while $S \backslash Q$ is extinct is computed as

$$P(\mathbf{K}) = \prod_i (k_i + (-1)^{k_i} p_i) \tag{IV.5}$$

So if $V_{\mathbf{K}}$ is the diversity of the set which is not extinct at time t, the expected diversity EV at the end of the time period is:

$$EV = \sum_{\forall \mathbf{K}} P(\mathbf{K}) \, V_{\mathbf{K}} \tag{IV.6}$$

Then, the marginal diversity of a breed i, V_i', describes the increase (decrease) of expected diversity when the extinction probability decreases (increases) of one unit:

$$V_i' = \frac{\partial EV}{\partial p_i} \tag{IV.7}$$

We can then define another criterion to establish conservation priorities, the conservation potential, CP_i:

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$$CP_i = p_i\,V_i' = p_i\ \frac{\partial EV}{\partial p_i}.$$

Box IV.1 Example on the Weitzman approach

This example aims at illustrating Weitzman's approach to expected diversity using a set of four species. It was cited by Thaon d' Arnoldi *et al.* (1998). While being based on the literature, improvements were brought to this example, as well as an extension to integrate the concept of marginal diversity. Let us consider a set, S, of four primate species. Pairwise distances are given in the following matrix:

	Go	Or	Hyl	Hys
Go	0			
Or	357	0		
Hyl	532	477	0	
Hys	498	488	126	0

The closest neighbours to be found in the set, S = {Go, Or, Hyl, Hys}, are Hyl and Hys. The diversity of the species in this set results as V{Go, Or, Hyl, Hys} = Max [V{Go, Or, Hyl}, V{Go, Or, Hys}] + d(Hys, Hyl).

Now we need to know which element is the link in the couple (Hyl, Hys). The following matrices contain pairwises distances for the subsets {Go, Or, Hyl} and {Go, Or, Hys}:

	Go	Or	Hyl
Go	0		
Or	357	0	
Hyl	532	477	0

	Go	Or	Hys
Go	0		
Or	357	0	
Hys	498	488	0

The diversity functions for these subsets are calculated as:
V{Go, Or, Hyl} = d(Go, Or) + max [V{Go, Hyl}, V{Or, Hyl}]
         = d(Go, Or) + d(Go, Hyl) (so or is the link element in {Go, Or, Hyl})
         = 889
V{Go, Or, Hys} = d(Go, Or) + max [V{Or, Hys}, V{Go, Hys}]
         = d(Go, Or) + d(Go, Hys) (so or is the link element in {Go, Or, Hys})
         = 855

This shows that V{Go, Or, Hyl} > V{Go, Or, Hys}, and the link element in the couple (Hyl, Hys) is thus H Consequently the representative is Hyl. Considering the remaining set after the suppression of the link eleme i.e. {Go, Or, Hyl}, we find that the neighbours are (Go, Or), with Or as the link element.

This information then makes it possible to compute the total diversity, which is worth 1015 = d(Go, Hyl) + d(C Or) + d(Hyl, Hys), and to draw the corresponding taxonomic tree (figure A). The link Hys in V{Go, Or, H Hys} is placed between the representative Hyl and the closest neighbour Or of Hyl in {Go, Or, Hyl}. The link in {Go, Or, Hyl} is then placed between the representative Go and the closest neighbour Hyl of Go in {Go, Hy resulting in a final order of Go, Or, Hys, Hyl.

The total Weitzman diversity of a set *S*, $V(S)$, is identical to the sum of the ordinates of all nodes of the tree the tree is drawn horizontally (Reist-Marti *et al.*, 2003). The $V(S)$ is not identical to the sum of the length of horizontal branches, as Weitzman (1992) and Thaon d'Arnoldi *et al.* (1998) suggest, but the sum of the bran lengths has to be reduced by the total height of the tree to give the diversity, as can be easily verified in t example.
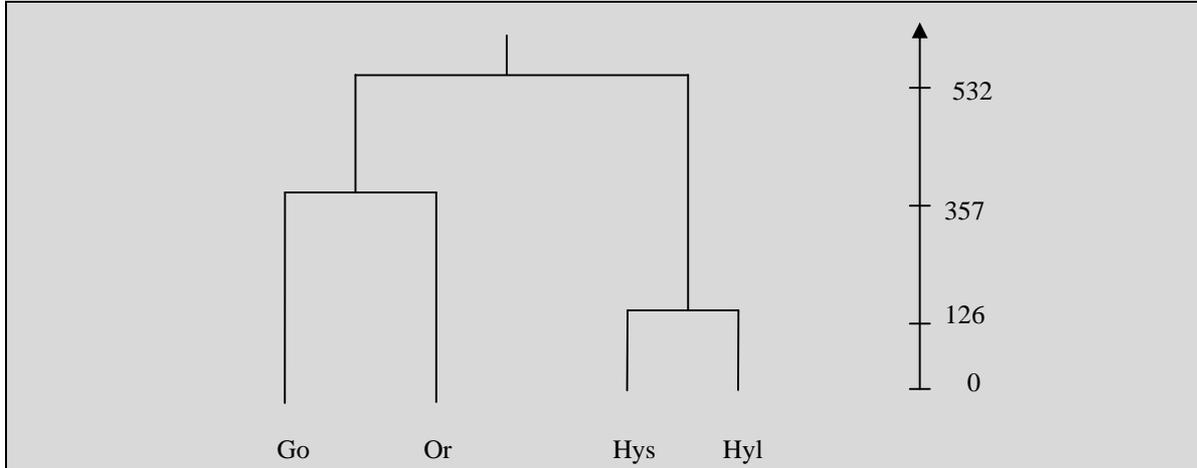
Figure A. Dendrogram of relationships among four species of primates

On the basis of these results, the partial contribution of each species can be computed. This parameter only depends on the position of the species in the tree topology, but not on the extinction probability. The concept of marginal diversity (MD) describes the magnitude of change of the total diversity if the extinction probability of the respective species is increased by one unit. Simianer *et al.* (2003) has shown that the MD of species (*i*) depends on the position of the species in the tree and the extinction probabilities of the neighboring species in the tree, not on the extinction probability of species (*i*) itself. To illustrate this concept, we will consider values (taken in an arbitrary way) of the probabilities of extinction for the four species. Let us consider 0.30, 0.40, 0.50 and 0.60 as extinction probabilities for species Go, Or, Hyl and Hys respectively, and the diversity of a set containing a single species, $V(i)$, is normalised to 100.

Let **K** be a vector of size 4 containing the indicators variables k_i, i=1,..4, where k_i=1 if species i exists and k_i=0 if it is extinct at a given point in time. Hence, **K** reflects a situation where a subset of the total species still is existing and the complementary subset is extinct. The probability that a specific situation, characterized through a specific vector **K**, arises can be computed as mentioned in equation IV.5.

From the above, 2^4 different combinations of present and extinct species are possible, for which the representative probabilities can be computed as described. Let $V(\mathbf{K})$ be the diversity of the set of species not extinct, i.e. of the k_i's with k_i=1. The expected diversity can be computed as shown in equation IV.6. The corresponding variance is as follows:

$$Var[V(S)] = \sum_{K=1}^{16} P(K)(V(K))^2 - \left(\sum_{K=1}^{16} P(K)V(K) \right)^2$$

The marginal diversity is then given by equation IV.7. This definition is taken from Simianer *et al.* (2003) and differs in sign from the original definition given by Weitzman (1992). The first derivative of the expected diversity with respect to the extinction probability of a given species in the set is a scalar. Thus, if we consider species $i \in S$, two conditional expectations can be defined, E($V|k_i$=1) and E($V|k_i$=0), in the other words, the expectation of diversity in the case of species i being conserved or extinct, respectively. The overall expectation is:

$$E[V(S)] = (1 - p_i)E(V \mid k_i = 1) + p_i E(V \mid k_i = 0)$$

and the marginal diversity is

$$\frac{\partial E[V(S)]}{\partial p_i} = E(V|k_i = 0) - E(V|k_i = 1)$$

which is independent of p_i. Hence the expected diversity is a linear function of the extinction probability of any species in the set are kept constant. The last equation provides a basis for an efficient algorithm to compute the marginal diversities for all species, since

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$$E\left(V \mid k_i = 0\right) = \frac{\sum_{\forall \mathbf{K}, k_i=0} P_{\mathbf{K}} V_{\mathbf{K}}}{p_i} \quad \text{and} \quad E\left(V \mid k_i = 1\right) = \frac{\sum_{\forall \mathbf{K}, k_i=1} P_{\mathbf{K}} V_{\mathbf{K}}}{1 - p_i}$$

Table A recapitulates the procedure adopted for computing the various parameters of the diversity of the set S. In the given set of four species, the actual diversity is 1115. The expected diversity is 588.4 (with a standard deviation of 349.54), i.e diversity is expected to be reduced by 526.6 in absolute terms or by 47%.

Table A. Procedure adopted to computing the various parameters of the diversity function

	16 different combinations															
	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12	K13	K14	K15	K16
Go	1	1	1	0	1	1	0	1	0	1	0	1	0	0	0	0
Or	1	1	0	1	1	1	0	0	1	0	1	0	1	0	0	0
Hyl	1	1	1	1	0	0	1	1	0	0	1	0	0	1	0	0
Hys	1	0	1	1	1	0	1	0	1	1	0	0	0	0	1	0
	Probabilities and diversities of 16 different combinations															
$P_{\mathbf{K}}$	0.084	0.126	0.056	0.036	0.084	0.126	0.024	0.084	0.036	0.056	0.054	0.084	0.054	0.036	0.024	0.036
$V_{\mathbf{K}}$	1115	989	758	714	955	457	226	632	588	598	577	100	100	100	100	0
	Expected diversity and the corresponding variance															
E[V(S)]	588.4															
Var[V(S)]	122175.24															

Table B reports the contributions, the partial contributions and the marginal diversities of each species of the set S. For example, the extinction of the species Go generates a reduction of the diversity of the set S estimated at 401 in absolute terms or 36%, whereas the loss of diversity relating to Hys is estimated with 126 only at 11.30 %. Using the marginal diversity criterion, the results suggest that the expected diversity of the set S is reduced by 389 if the extinction probability of species Go is increased by one unit. Correspondingly, the marginal diversity of the other species are –360, –342 and –288 for Or, Hyl and Hys respectively.

Table B. Contributions, partial contributions and marginal diversity of each species

	$C_i = V(S) - V(S\backslash i)$	$PC_i = ((V(S) - V(S\backslash i))/ V(S))*100$	Marginal diversities V_i'
Go	401	35.96 %	-389
Or	357	32.01 %	-360
Hyl	160	14.34 %	-342
Hys	126	11.30 %	-288

References:

Reist-Marti, S.B., H. Simianer, S. Marti, J. Gibson, O. Hanotte, and J.E.P. Rege, 2003. Weitzman's Approach and Breed Diversity Conservation: An Application to African Cattle Breeds". *Conservation Biology*: forthcoming.

Simianer, H., 2002. Noah's Dilemma: Which Breeds to Take Aboard the Arc? 7th World Congress on Genetics Applied to Livestock Production. Montpellier, France, 19-23 August, 2002.

Thaon d'Arnoldi, C., J.L. Foulley, and L. Ollivier, 1998. An Overview of Weitzman's Approach to Diversity. *Genetics, Selection and Evolution*, 30: 149-161.

This approach can be extended to consider the utility of the subset existing at time *t*. A certain direct utility U_i is linked to the use of a specific breed *i*. This utility may be directly related to production activities as the utility emanating from income gained with the respective breed. It may also be defined more largely to include utility from other active and passive uses. Following the same reasoning as above, we can define an expected utility of the subset *Q* ($\subseteq$ S) existing at time *t*, *EU*. An objective function, $\Phi(Q)$, can then be defined as

$$\Phi(Q) = EV + EU \ .$$

The problem is then the maximisation of the objective function as follows:

$$\max \; \Phi(Q) \hspace{8cm} \text{(IV.8)}$$

$$\text{subject to} \; \sum_{\forall i \in Q} b_i \, x_i \leq B$$

where B is the total preservation budget available, and b_i the share of the total budget which is allocated to the preservation of breed i.

Weitzman (1998) has developed a simplified linear function as an easy general guideline for preservation decision making:

$$R_i = \left(V_i{'}+U_i\right)\left(\Delta x_i / b_i\right)$$

where R_i is a ranking criterion, and breed i is best ranked according to the magnitude of its marginal diversity, its direct utility and the budget allocation effectiveness, i.e. the increase of survival probability per unit of budget spent. The explicit assumption that Weitzman has made is to "imagine somehow that $[V'_i]$ has been made commensurate with U_i". This aspect, though, raises many difficult issues that are object of ongoing research.

Building on this framework, Simianer *et al.* (2003) have developed a budget allocation algorithm. They assume that investing some financial resources b_i in breed i alters extinction probabilities. Given that p_i is a non-linear function of funds, extinction probability will be reduced by $?p_i$ as a function of both p_i and b_i, i.e. $?p_i = f(p_i, b_i)$. They describe an iterative, gradient-type procedure to optimise the allocation of shares of a total budget to a set of breeds so as to maximise total expected diversity. A share of total budget is allocated to each breed i. The increase in expected diversity is calculated, resources are allocated to the breed for which this increase is maximum and survival probabilities and marginal diversities are recalculated. The iteration is repeated until the budget constraint is just met. This approach needs the definition of a functional relationship between the amount of budget spent and the reduction of extinction probabilities. So far, this is one of the major limitations, as it is discussed in the following section. In the following, the way Simianer *et al.* (2003) attempted to tackle this issue is presented.

The criterion of risk of extinction adopted is the increase of the inbreeding coefficient used in population genetics, $?F$, which is linked to the effective population size, N_e:

$$\Delta F = 1/2 \, N_e .$$

The basic assumption is that the extinction probability is directly proportional to the inbreeding coefficient, i.e. $p_i = \gamma \, \Delta F$.

The authors developed three models of the effect of spending a share of the budget B on a breed or population:

- one where there is an additive effect on N_e proportional to the funds spent per animal;
- one with a multiplicative effect on N_e proportional to the funds spent per animal;
- one with a multiplicative effect on N_e proportional to the funds spent per population.

The first model corresponds to a situation where farmers tend to replace animals of one breed with animals of another breed and a premium is paid in order to compensate the supposed economic inferiority of the breed being replaced so that farmers be encouraged to keep it.

In this case, if a sum b_i is spent for conservation of breed i, then the expenditure per animal is b_i/N_e. It is assumed that the effective population is increased to $N_e^* = N_e + \lambda \frac{b_i}{N_e}$, where $\lambda > 0$ is an arbitrary constant which is equal for all populations and for all breeds. Furthermore, $\Delta p_i = \gamma \left[(2N_e^*)^{-1} - (2N_e)^{-1} \right]$, which yields

$$\Delta p_i = -\frac{4\lambda b_i p_i^2}{\gamma^2 + 4\lambda b_i p_i^2} \, p_i \qquad\qquad (IV.9)$$

The second model corresponds to situations where the strategy adopted is to keep population size constant. The information is brought to farmers by extension workers, so that the cost is proportional to the population size.

In this case, the same spending of b_i/N_e per animal results in $N_e^* = N_e + \nu \, b_i$, where ν is a constant. We have:

$$\Delta p_i = -\frac{2\nu b_i p_i}{\gamma + 2\nu b_i p_i} p_i \qquad\qquad (IV.10)$$

In the third model, the effect is assumed to depend only on the amount of money spent per population, irrespective of its size. This corresponds to situations where information is brought to farmers through already established channels at little or no extra cost.

In this case, spending b in population (not breed), gives $N_e^* = (1 + \eta \, b) \, N_e$, where η is also a constant. Thus we have

$$\Delta p_i = -\frac{\eta b}{1 + \eta b} \, p_i \qquad\qquad (IV.11)$$

Box IV.2 Noah's Dilemma: Which breed to take aboard the ark?

The Weitzman model searches for an optimal biodiversity preservation programme under a budget constraint. In developing the model, the central issue is to elaborate a cost-effectiveness formula or criterion that can be used to rank priorities among biodiversity-preserving projects. In this model, the objective function relates to two distinct components: the genetic diversity of the set and the utility emanating from elements in the set. Taking into account the difficulties related to the measurement of the utility component, the majority of the empirical applications of this approach to AnGR conservation has only dealt with genetic diversity. The paper by Simianer (2002) constitutes the single reference available which has integrated aspects related to the utility in addition to the aspects related to genetic diversity. The example presented below aims at showing the approach followed by the author in order to associate genetic characteristics and genetic diversity. This synthesis is based on works by Simianer (2002), Simianer *et al.* (2003) and Reis-Marti *et al.* (2003).

Material: The application uses a set of 26 African taurine and sanga cattle breeds. Table A gives breed names, breed types, status of risk according to the FAO, origin, extinction probabilities (p_i) that are used to compute marginal diversities (V_i') and the presence of specific traits.

Table A. Information on sample and breed characteristics and endangerment of 26 African cattle breeds

Breed name	Type	Origin of sample	Risk status	p_i	V_i'	Specific traits		
						TPT[*]	TTB[*]	HF[*]
Abigar	Sanga	Ethiopia	not at risk	0.47	-0.045			
Afar	Sanga	Eritrea	not at risk	0.43	-0.081			
Africaner	Sanga	South Africa	not at risk	0.30	-0118			
Ankole	Sanga	Uganda	not available	0.45	-0.104			
Baladi	Taurine	Egypt	not at risk	0.43	-0.117			
Baoulé	Taurine	Burkina Faso	not at risk	0.48	-0.113	+	+	
Barotse	Sanga	Zambia	not at risk	0.57	-0.064			
Blonde d'Oulmès	Taurine	Morocco	not at risk	0.47	-0.180			
Danakil	Sanga	Ethiopia	not at risk	0.50	-0.070			
Kaokoland	Sanga	Namibia	not available	0.57	-0.065			
Kapsiki	Taurine	Cameroon	not at risk	0.67	-0.078			
Kavango	Sanga	Namibia	not available	0.47	-0.094		+	+
Kuri	Taurine	Chad	not at risk	0.56	-0.076			
Mashona	Sanga	Zimbabwe	not at risk	0.32	-0.054			+
Muturu	Taurine	Cameroon	not at risk	0.43	-0.376	+		
N'Dama	Taurine	Senegal, Guinea, Guinea-Bissau and Gambia.	not at risk	0.33	-0.181	+		
Namchi	Taurine	Cameroon	not at risk	0.47	-0.106	+		
Nguni	Sanga	South Africa	not at risk	0.20	-0.053		+	+
Nkone	Sanga	Zimbabwe	endangered	0.50	-0.100			+
Pedi	Sanga	South Africa	endangered	0.63	-0.134		+	+
Raya-Azebo	Sanga	Ethiopia	not at risk	0.37	-0.061			
Sheko	Taurine	Ethiopia	not at risk	0.77	-0.061			
Somba	Taurine	Benin	not at risk	0.50	-0.081	+		
Tonga	Sanga	Zambia	not at risk	0.47	-0.052			
Tuli	Sanga	Zimbabwe	not at risk	0.32	-0.066	+	+	+
Watusi	Sanga	Uganda	not at risk	0.57	-0.085			

[*]: TPT: trypanotolerance; TTB: tolerance to tick-borne disease; HF: high fertility.

Genotype data and genetic distance: Allele frequencies of 15 autosomal microsatellite loci derived from individuals of the 26 breeds are used. All breeds were represented by 35 individuals, except for the Baladi (40), Blonde d'Oulmès (31) and Muturu (21). To overcome the differences in sample sizes between breeds, genetic distance matrices were derived from allele frequencies in bootstrap samples. All bootstrap samples were of equal size (n=35), and 100 replicates were drawn. Reynolds' genetic distance d_{xy} was used because it is considered well suited for short divergence times as they occur in breed diversification:

$$d_{xy} = \frac{1}{2} \frac{\sum_a (x_a - y_a)^2}{1 - \sum_a x_a y_a}$$

where x_a and y_a are frequencies of the ath allele drawn in population x and y.

Extinction probabilities: To model the future trend in breed diversity, the extinction probabilities over a chosen time period must be defined for each breed. For most breeds, some indications of the status of risk of extinction, mainly based on population size, can be found in the scientific literature. However, there are many other factors affecting the survival of a breed. Hence, a model is developed that includes ten variables. These variables were

assigned values between 0 (no impact on risk) and 0.1 (high impact on risk), except for population size that was set at 0.3. Although nine variables had equal weight, population size was weighted three times stronger because the number of animals is a direct and thus crucial measure of the extinction probability of a breed. The variables selected are the following:

- four variables describing the population: total population size (1) and its change over time (2); distribution of the breed (3), and risk of indiscriminate crossing (4);
- organization among farmers (5);
- establishment of a conservation scheme (6);
- the political situation in the countries concerned (7);
- two variables describing the present value of the breed: specific traits (8) and socio-cultural importance (9);
- a variable (10) acting as a correction factor for unreliable information.

The extinction probability of breed i, p_i, was computed as the sum of the values of the 10 variables described above and rescaling the sum to a value between 0.1 and 0.9:

$$p_i = \left[\frac{0.8}{1.2} \times \sum_{a=1}^{10} p_{ia} \right] + 0.1$$

The rescaling was done to rule out the possibility that a breed may be considered completely safe from ($p_i=0$) or entirely doomed to extinction ($p_i=1$). The planning horizon considered is 50 years. This means, 50 years from now breed i will be extinct with probability p_i and still be around with probability ($1-p_i$).

The conservation model: Two models are developed that are distinguished by their objective function. The first objective function only refers to the maximization of expected diversity. The second is a combination of diversity and preservation of specific breed traits.

Financial and other resources are most efficiently used if the loss of diversity is minimized or, equivalently, the expected diversity ($E(V)$) at the end of the considered time horizon is maximized. The mechanism considered supposes that by investing a certain share (β) of the available resources in breed i, the extinction probability p_i of this breed will be changed to $p_i^* < p_i$, resulting in $E^*(V) > E(V)$.

By assuming that the conservation effect ($\Delta p_i = p_i^* - p_i < 0$) is a function of both the actual degree of endangerment of the breed, p_i, and the amount of resources b_i invested in the conservation of this breed, two types of functions were considered ($\Delta p_i = f(p_i, b_i)$). The increase of the average inbreeding coefficient in a population, ΔF, is considered to be a useful criterion for the risk that the population might become extinct. The ΔF may be linked to a breed's effective population size (N_e) by ($\Delta F = 1/2N_e$). An increase in conservation budget is assumed to have the desirable property of causing a reduction in ΔF, and hence in p_i as explained in the main text. The relationships considered lead to the functions IV.9. to IV.11. In the following IV.10. is adopted.

Optimum allocation of a limited budget to a set of breeds: Let $B = \{b_i\}$ be the total budget available for conservation activities that is to be spent on a set of breeds. There are two basic problems to solve:
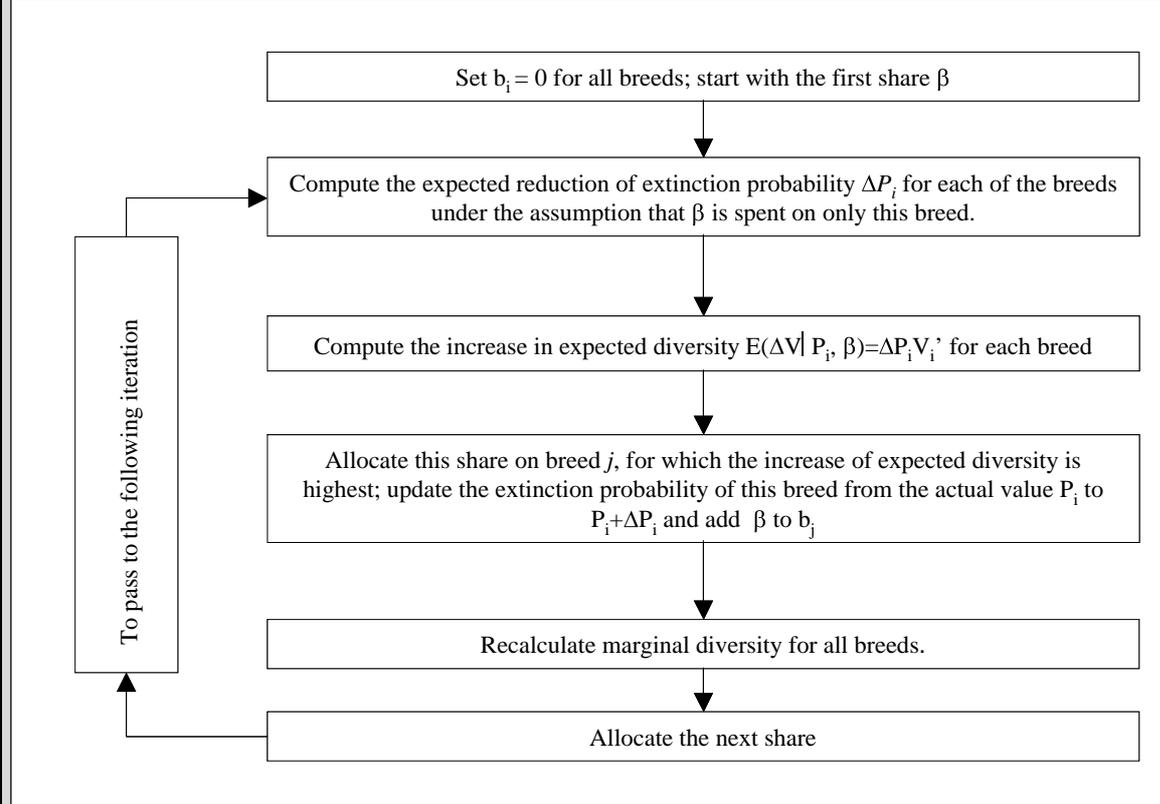- which of the breeds in the set will receive financial support, and which ones will not receive any funding;
- how (in what proportion) should the available funds be distributed to those breeds that will receive funding.

The strategy adopted consists in calculating the increase in the expected diversity of the set, $E(\Delta V)$, and to allocate the financial resources b_i to the breed which generates the maximum increase in the expected diversity:

$$E(\Delta V \mid p_i, b_i) = \Delta p_i V_i{}'$$

Empirically, the budget available for the conservation, B, is split in equal amounts, b_i, and the problem of optimization is subjected to an iterative procedure (figure A). This consists in granting, each time, the (b_i) amount in favour of the breed which contributes more to the improvement of total expected diversity.

Figure A. Iterative procedure of allocating financial resources for conservation

Set $b_i = 0$ for all breeds; start with the first share β
Compute the expected reduction of extinction probability ΔP_i for each of the breeds under the assumption that β is spent on only this breed.
Compute the increase in expected diversity $E(\Delta V | P_i, β) = \Delta P_i V_i$' for each breed
Allocate this share on breed j, for which the increase of expected diversity is highest; update the extinction probability of this breed from the actual value P_i to $P_i + \Delta P_i$ and add β to b_j
Recalculate marginal diversity for all breeds.
Allocate the next share

To pass to the following iteration

Taking into account these considerations, three different allocation strategies were compared for a given total amount of funding:

- A "watering can" strategy: each breed obtains an identical share of the total funds;
- A "panic" strategy: one third of the available funds is allocated to each of the three breeds with highest extinction probability, respectively;
- The "optimal allocation" strategy as described above.

Beyond diversity – utility: The methodology presented above focuses on conservation of between breed diversity. It accounts in no way for specific properties of certain breeds, which may make one breed more 'valuable' or 'worthwhile conserving' than another breed. Such differences may be reflected by 'specific traits' present in some breeds. Three traits were considered: trypanotolerance (TPT), tolerance to tick-borne diseases (TTB), and high fertility (HF). Table A indicates the breeds that are reported to show one or several of these traits. The integration of these traits was implemented by defining the utility $U(\mathbf{K})$ of a subset $\mathbf{K}$ of all breeds as follows: an indicator variable s_{ij} is 1 if breed i carries trait j and is 0 otherwise. For a given set $\mathbf{K}$ of breeds, we have

$$\widetilde{S} = \prod_j \max_i \left(k_i s_{ij} \right)$$

where $k_i = 1$ if breed i exists at time t (here, 50 years) and $k_i = 0$ if breed i is extinct, as explained in the main text. $\widetilde{S} = 1$, if there is at least one breed in the set for each of the j traits, and is $\widetilde{S} = 0$ if at least one of the specific traits was lost in the set. Using this variable, the utility is defined:

$$U(\mathbf{K}) = \begin{cases} D(\mathbf{K}) & if \quad \widetilde{S} = 1 \\ 0 & if \quad \widetilde{S} = 0 \end{cases}$$

Based on this definition, expected and marginal utility can be calculated along the same lines as was demonstrated for diversity. Similarly, an optimal allocation of resources can be found that maximizes expected utility.

Results

Genetic diversity: The diversity computed for the given set of breeds takes the value of 2.631. Without intervention, the expected diversity at the end of the planning horizon is 1.483 (±0.301), in other words, genetic diversity is expected to be reduced by 43.6 %. With model parameters $\gamma=45$ and $\nu=0.001$, the total conservation budget to be allocated to the 26 breeds was chosen in such a way that the "watering can" strategy assigning 1/26 of the total budget to each breed, respectively, resulted in a 10 % reduction in diversity loss (figure B). As regards the "panic" strategy, one third of the total budget was spent to conserve the three most endangered breeds (Sheko, Kapsiki and Pedi). While the respective extinction probabilities were substantially reduced (for example, from 0.77 to 0.32 for Sheko), the resulting expected diversity was only reduced to 1.585, corresponding to a 9.1 % reduction of diversity loss.

Figure B. Percent gain of expected diversity by allocating conservation funds in an optimum way (solid line) compared to "watering can" (discontinuous line) and "panic" (dotted line) allocation of the same budget.
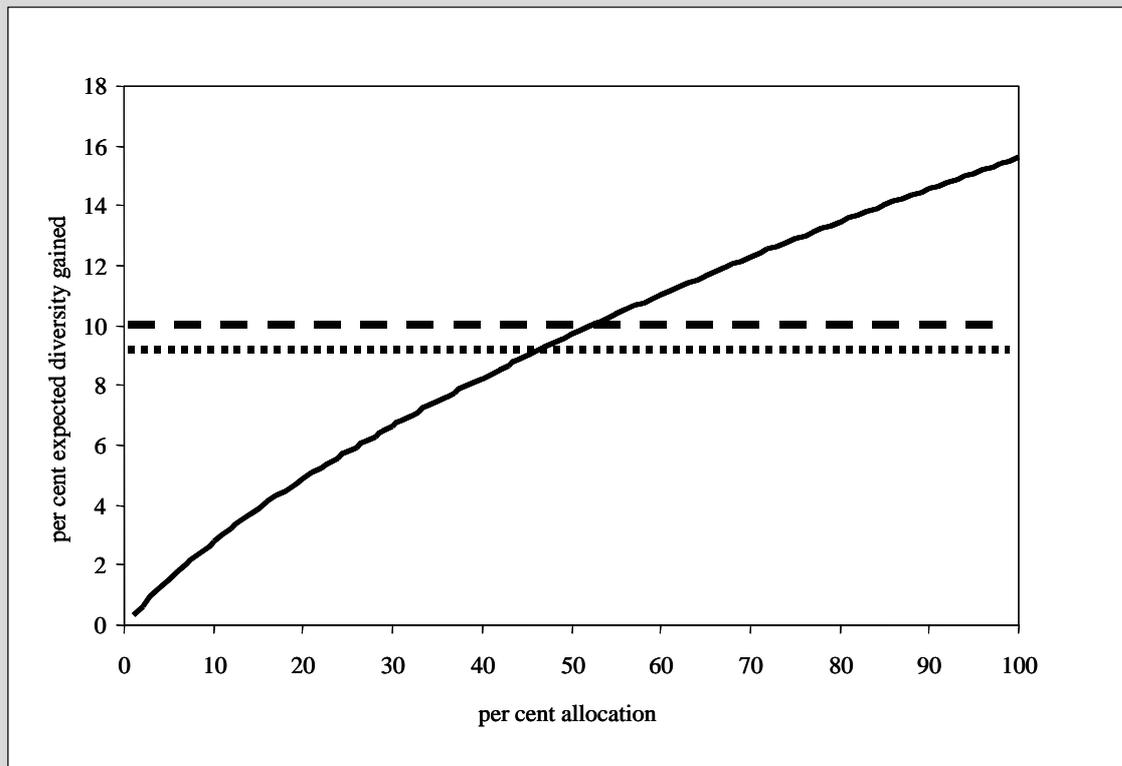
Using the optimal strategy, the expected diversity is 1.663 corresponding to a 15.7 % reduction of diversity loss. By comparing the results of the different strategies, it turns out that the optimal strategy is more efficient than the "watering can" approach, preserving 57 % more diversity. In other words, to achieve the same conservation effects, it is sufficient to spend only 53 % of the funding used in the "watering can" approach. Figure C shows the distribution of the budget to each breed under a scenario of optimal allocation. Thus 35 % of available funds are assigned to Muturu, the genetically most distant breed in the set. Only nine breeds among 26 breeds receive some funding.

Utility: Breeds retained under the maximum criterion of utility, i.e. Pedi, Nkone and Kavanko (the latter being not on the list if the decision is based on diversity only) all show some specific traits. Their additional funding was taken from the breeds which do not show any of these specific traits. Also Baoule loses some funding although it is known to be both tolerant to trypanosomiasis and to tick-born diseases. Tuli, the only breed showing all three specific traits, receives no funding neither under "the maximum diversity" nor under the "maximum utility" criterion, which probably is due to its low extinction probability and marginal diversity.

Figure C. Maximum likelihood tree of the 26 breeds and optimum allocation of conservation funds maximizing expected diversity (black bars) or expected utility (white bars)
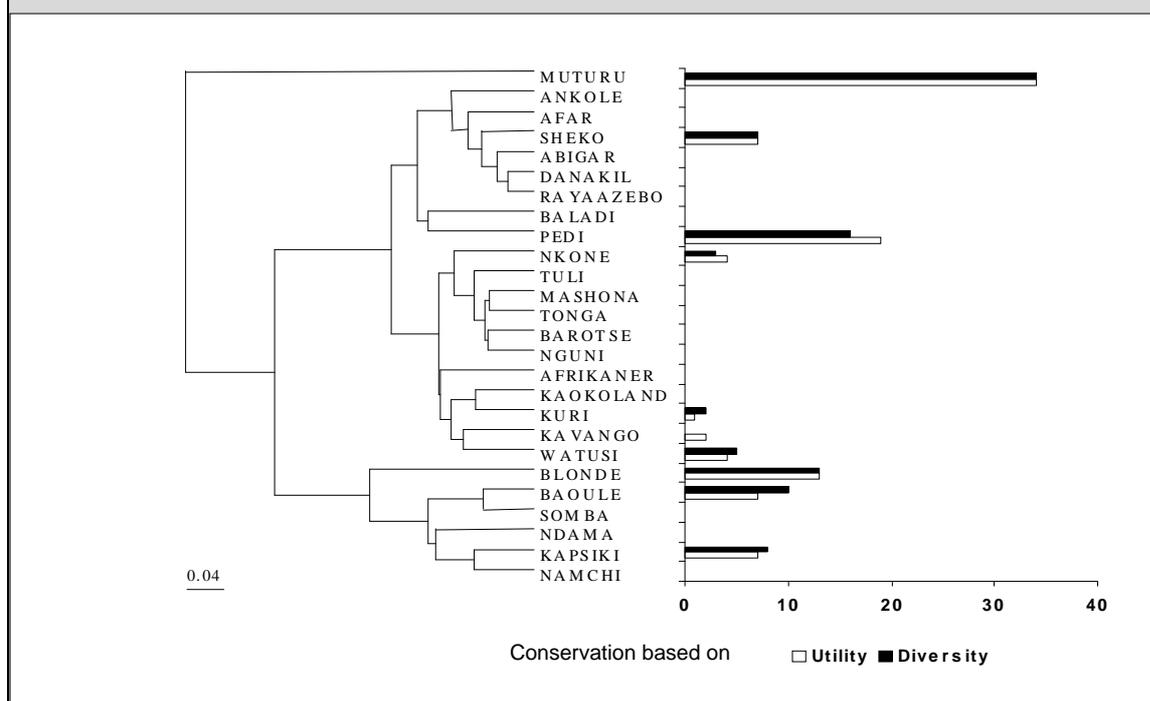
References:

Reist-Marti, S.B., H. Simianer, S. Marti, J. Gibson, O. Hanotte, and J.E.O. Rege, 2003. Weitzman's Approach and Breed Diversity Conservation: An Application to African Cattle Breeds. *Conservation Biology*: forthcoming.

Simianer, H., 2002. Noah's Dilemma: Which Breeds to Take Aboard the Arc? 7th World Congress on Genetics Applied to Livestock Production. Montpellier, France, 19-23 August, 2002.

Simianer, H., S. Marti, J. Gibson, O. Hanotte, and J.E.O. Rege, 2003. An Approach to the Optimal Allocation of Conservation Funds to Minimize Loss of Genetic Diversity between Livestock Breeds. *Ecological Economics*: forthcoming.

iii. Examples of applications

Only a few papers are available that have applied Weitzman's approach to AnGR diversity (Thaon d'Arnoldi *et al.*, 1998; Laval *et al.*, 2000; Cañon *et al.*, 2001; García *et al.*, 2002; Marti and Simianer, 2002; Simianer, 2002; Simianer *et al.*, 2003). An overview of their empirical object of analysis and the measure of distance used is provided in Table IV.1.

One major problem limiting the application of this approach is the establishment of extinction probabilities. García *et al.* (2002) have developed this aspect by adopting an approach based on genetic processes, namely those linked to genetic drift.

Table IV.1 Overview of empirical applications of the Weitzman approach

Reference	Species	N	Location	Distance/method
Thaon d'Arnoldi *et al.*, 1998	Bovine	19	France/UK	Nei + Cavalli-Sforza
Laval *et al.*, 2000	Porcine	11	Europe	Reynolds + Nei
Cañon *et al.*, 2001	Bovine	18	Spain/France/Portugal	Nei
García *et al.*, 2002	Bovine	8	France/Spain	Reynolds
Marti and Simianer, 2002	Bovine	49	Africa	Reynolds/Max. Likelihood
Simianer, 2002	Bovine	26	Africa	Reynolds/Max. Likelihood
Simianer *et al.*, 2003	Bovine	23	Africa	Reynolds/Max. Likelihood

Thaon d'Arnoldi *et al.* (1998) provide a good synthesis of the approach. They cite an example derived from Weitzman (1992) that is developed in detail and further extended in Box IV.1. The Weitzman approach is then applied by these authors to data on biochemical polymorphisms of 18 French and one UK cattle breeds. They quantified the loss of diversity caused by extinction of any subset. They found that the ranking of breeds for conservation priorities was consistent for the two distances they used (Nei and Cavalli-Sforza). These authors also put emphasis on the fact that any phylogenetic interpretation of the results should be used with caution and that although trees might tell a story that best fits diversity observed they may not necessarily be telling the 'true' story. Caution is necessary because, given the exchanges known to have occurred in their past histories, e.g. introgression, domestic breeds are not likely to have resulted from a strict tree-like branching process.

The work by Laval *et al.* (2000) is based on 11 porcine breeds from six European countries, including a small sample of wild pigs. They evaluated diversity on the basis of 18 microsatellite markers and found that average heterozygosity varied between 0.35 – 0.60. They found that breed differentiation was significant and used the genetic distances to construct phylogenetic trees. One explanation of the divergence of the two German breeds was to be found in a genetic drift model. However, no reliable phylogeny could be inferred among the remaining breeds. They conclude that using genetic distances between breeds of farm animals in a classical taxonomic approach may not lead to a reliable, clear picture. They also found that the results were not entirely consistent over the two measurements of genetic distances used.

Cañon *et al.* (2001) undertook a study on 18 local cattle breeds from Spain, France and Portugal, using 16 microsatellite markers. They grouped breeds using the Weitzman approach and performed a multivariate analysis. Since variation between breeds was very high in their set, individuals were assigned to their breed of origin with a probability of 99% and results based on the Weitzman approach could be considered more reliable than in other studies. They questioned to what extent the correspondence analysis and the Weitzman approach could give similar results, stressing that the former captures within-breed diversity while the Weitzman approach fails to do so. Regardless of the approach, three out of the four breeds which contributed most to diversity were always present. In their sample, differences between the two approaches seemed to be minor. These authors, too, called for caution with respect to the Weitzman diversity function when interpreting the graphical representation as a phylogenetic tree. Assumptions on the force considered determinant for genetic variance (random drift or mutation) are of major importance. Rank correlation was significantly related to which basis was adopted for the calculation of distances, i.e. either the effective population size or the size of the alleles.

Most authors agree that one of the major drawbacks of the Weitzman approach is that it does not account for within-breed diversity. As said above, another drawback is the non-availability of well-defined extinction probabilities. García *et al.* (2002) intended to eliminate

these two problems by calculating the probabilities of genetic extinction. A set of 8 local French and Spanish cattle breeds was selected, 50 animals per breed were genotyped for 10 microsatellite markers. Their results are interesting in relation to the difficult task of determining extinction probabilities. Another approach consists in adopting a simulation based process of population viability analysis, in such programmes as VORTEX (Bruford, 2003; Coulson *et al.*, 2001; Frankham *et al.*, 2002).

In the paper by Marti and Simianer (2002), 49 African bovine breeds have been studied, divided into two groups, one with 20 zebu and 3 zenga breeds, another with 10 taurine and 16 sanga breeds. They used the estimate of extinction probabilities for each breed over 30 to 50 years from Reist-Marti *et al.* (2002). Two important assumptions were made for their calculations: that similar breeds are fully interchangeable and that lowering the extinction probability by one unit costs the same for every breed. They use the marginal diversity criterion, affirming its usefulness as an efficient criterion for the allocation of limited budget resources. They also admit that getting good estimates of the extinction probabilities – a precondition for reliable results – might be difficult. It is interesting to observe that they consider the tree built following Weitzman as a maximum likelihood tree, while Cañon *et al.* (2001) and García *et al.* (2002) state that such trees are not maximum likelihood trees.

Simianer (2002) is a very interesting paper, and the sole example of an empirical application of the Weitzman approach attempting the integration of utility of the breeds. This paper is presented in detail in Box IV.2.

Simianer *et al.* (2003) develop the approach in depth, providing an attempt to model the effect of the allocation of funds on the change in extinction probabilities, as well as discussion on the optimal allocation procedure and some theoretical extension of the approach to account for utility. The latter is more developed in Simianer (2002) and in Box IV.2. The former has been presented in paragraph IV.2.*ii*.

iv.   Discussion

The Weitzman approach has the merit of presenting a rigorous and theoretically well-developed framework to tackle the issue of maximising the effectiveness of conservation policies. There are, though, two major underlying assumptions which are at the same time two important limitations of this approach. These are discussed in this section.

In this approach, it is assumed that a meaningful measure of biodiversity is applicable. For practical purposes, most studies applying Weitzman's approach have used genetic distances as a measure of biodiversity. On the basis of such a measure, priorities are established, i.e. resources for conservation are allocated to some items (species, breeds, populations,…) and not to others. There is no place for uncertainty in the approach. Yet no scientific agreement has been reached to date concerning both the identification of a significant biological unit for conservation and the question of prioritisation (Kraaijeveld, 2000; Bruford, 2003).

Uncertainty about using genetic distance as a basis for a diversity measure is particularly substantial in the case of livestock breeds (Bruford, 2003). Distances for breeds may be mediated by demographical factors, such as the founder effect, inbreeding and admixture. The use of the inbreeding coefficient, $?F$, to estimate changes in extinction probabilities has also been questioned (Bruford, 2003; Frankham *et al.*, 2002; Keller and Waller, 2002).

Moreover, this approach does not take into account the genetic variation within units. This is also an important drawback. In the case of livestock breeds, for instance, it has been estimated

that within-breed diversity account for 50 to 70% of total diversity (Hammond and Leitch, 1996).

The second important assumption is that "it is not possible to conserve everything". The reason that is explicitly given is that "budget and other resources are limited". While it is clear that resources in general, hence budget too, *are* limited, the actual meaning of this statement is that resources are *too* limited to conserve everything. This is a widely accepted *dogma* that remains yet to be proven. Implications of taking a wider view on the causes of biodiversity loss and conservation policies will be addressed in the following chapter.

V. Conclusions

This handbook has tackled the complex issue of livestock biodiversity evaluation and conservation. A series of values having wider scope than direct use values and than those captured by markets have been thoroughly investigated and methods to estimate them have been discussed.

Some theory underlying the methods used for evaluation have been recalled. An important issue having been raised is linked to utility, where satisfaction about conservation compensates partly the loss of profit (Chapter II.4.*iii*). Some important research has been cited, showing that farmers do not exclusively base their choices on profit-maximising motives. This is also important in relation to the public policy approach to the allocation of conservation funds.

As relating to the latter, Chapter IV has presented the Weitzman approach and discussed its limitations. The reference set of assumptions in this approach includes the concept of an exogenous budget constraint, perfect knowledge of diversity and rational choices. It is clear that nothing in Weitzman's approach precludes taking into account breed utility apart from profit or productivity. However, it explicitly measures the contribution to diversity as distinct from the contribution of the individual breed because diversity depends by its very definition on the set of breeds surviving. A major challenge for future research is to measure the contribution to diversity and to utility in a commensurate manner. Only in this way can the often cited trade-offs among these two aspects be formally considered in the setting of conservation priorities.

Conservation through *ad hoc* policy funds is one way to preserve breeds. In addition other means could be used, for instance voluntary approaches developing market niches and special marketing channels that have on some occasions proved effective (e.g. Verhaegen and Van Huylenbroeck, 2001).

Turning back to the introduction and the underlying causes for biodiversity loss in farm AnGR, there is yet another aspect that deserves discussion. Contrary to what is assumed as a given in Weitzman (1992; 1993; 1998) and Simianer *et al.* (2003), the budget constraint is not necessarily exogenous to the larger problem of AnGR biodiversity conservation. Particularly in 'developed' countries, agricultural policies have allocated considerable budget to support measures that cause market distortions and that in many cases are an important factor enhancing the loss of AnGR.

For instance, in the EU agricultural policies have favoured certain types of crops. Caraveli (2000) has studied the impact of the EU Common Agricultural Policy (CAP) on mainly mountainous less-favoured areas (LFAs) of the Mediterranean regions. According to this study, there is evidence that "the CAP has been a major factor for the strengthening of [the] process" of abandonment of traditional low-intensity farming systems in LFAs, "reinforcing market forces in this respect." CAP incentives have both favoured intensification, causing an expansion of arable land at the expense of permanent grassland, and extensification, causing the abandonment of many LFAs. This has largely led to a decline in transhumance. Small ruminant production has been affected by shifts to more sedentary systems and in some cases farmers have switched from sheep and goat to cattle, and often from livestock to arable crops as maize or wheat.

A thorough assessment of policies would be necessary to measure the overall effect on agricultural and related activities. This argument gains particular relevance in the recent context of global agricultural policy reforms. The effective quantitative impact of these reforms might be questioned. In relation to the agreements of the 'Uruguay Round', developed countries committed to a reduction of 20% in the period 1995-2000 compared to the base year 1986. Yet, domestic support as a share of farm receipts was still 31% in 2001, down from 38% on average in 1986-88[5]. Policies hence continue to engender important distortions in markets and the effect of this on local breeds is probably important though hard to determine.

Moreover, public funds are allocated to other activities and policy choices made in other fields than agriculture sometimes have an indirect impact on agriculture. A systemic approach would allow taking a broader perspective. Multi-agent systems (cf. e.g. Kirman and Vriend, 2001; Macy and Willer, 2002; Berger, 2001) are being further developed as useful modelling tools in a system analysis perspective, thanks to larger calculating power of computers. There is scope for further research in this field.

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[5] Source: OCDE statistical database, online at : http://www.ocde.org

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