Towards a genuine exchange value of nature: interactions between humans and nature in a principal-agent-framework

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Received 2 April 2001; received in revised form 21 June 2002; accepted 21 June 2002

Abstract

This paper discusses the potential for modeling nature and man in an exchange economy. We will firstly be outlining the need for exchange values in addition to the usual human evaluation of nature. Secondly, we will be reviewing some basic exchange economy ideas, arguing that these ideas can be adopted to a mutually beneficial exchange between humans and nature. Thirdly, in a formal model, we will show how the assumption that a 'civic society' can be adapted to a principal agent approach, whereby humans are the principal and nature is the agent. Issues such as property rights—an objective concerning nature—and services to be exchanged will be introduced. This will include the derivation of a behavioral equation for nature as anticipated by humans. Fourthly, a principal-agent framework delivers a mutually beneficial exchange; such as land for labor, and given property rights. Derived genuine exchange values are interpreted as relative prices reflecting 'human and natural objectives'. Fifthly, the aforementioned problem will be extended to a world with undefined property rights, and hints will be given to how this world can be modeled. Potential applications, conflicting questions, such as human welfare versus fitness of nature, and the distribution of rights will be discussed.

Keywords: Exchange model; Political economy; Simultaneous optimization and exchange of man and nature; Fitness of nature as objective; Principal agent approach

1. Introduction

There is extended literature questioning the evaluation of nature on the premise of human preferences, and whether nature has a distinct value of its own (Pearce and Turner, 1990). Furthermore, in environmental economics, it is widely debated whether direct or indirect, observable or hypothetical, theoretical or ad-hoc-based methods, etc., are best suited for the evaluation of nature (Freeman, 1993). These questions are not merely academic. If nature is to become better represented in human planning, many conflicting areas (maximal bio-diversity or selective extinction; natural or cultural landscapes; natural or human shaped habitats, etc.) require a 'market' or
exchange value for nature. A deeper insight into values and value generation is urgently needed for decision making. So far the evaluation of nature can be predominantly described by assigning human-values to resources used by humans (monetary value of bio-diversity; Pearce and Moran, 1994). Although there are some talks about non-use values, humans are still the only evaluators.

Human evaluation leads, according to many ecological economists, to an over-exploitation of ecosystems (Martinez-Alier, 1987): so, why not get nature to determine its own values (Hannon, 1998)? Moreover, there is a distinction between the acceptance of such value categories as teleological, teleonomic, or telenomatic (Lockwood, 1997). Even if we accept that higher level values of nature (teleological values) are unperceivable, unobservable or unretrievable—because evolution has raised nature as a causal construct or value neutral—lower functional value categories are important. Teleological values may be confined to humans; but humans assign values to the functioning of ecosystems (McGrady-Steed et al., 1997; Chapin et al., 2000). Primarily for the reason of acquiring an adequate description and easy access to understanding ecosystems, humans have a tendency to perceive nature as a human-like organism. Fitness and function are categories. However, ‘fitness and well-functioning’ are already normative or value concepts. Henceforth, it may be reasonable to look for measures to infer medium level (teleonomic), or functional ‘values’. Nevertheless, these must come from a concept that artificially introduces teleological values, notably as a research hypothesis. However, philosophical insight might not be needed to talk about nature-values, though values like human-values may never appear.

It is the objective of this paper to broaden the debate about nature-value with respect to a ‘genuine exchange’ of services between nature and man in a reasonable way. Instead of pursuing the common perspective of evaluating nature by a benevolent expropriator—this being man—we will refer to an exchange between ‘equal’ creatures. Human expropriators have a tendency towards evaluating nature as a ‘free’ good, if it is not already owned by other humans. Hence, institutions play an important role in evaluation, which we will further explore, though from a different angle than human rights only. We will shift the perspective and we will ask what happens to the pricing of nature if we pursue the idea of an exchange between humans and nature: one that is similar to an exchange between humans, that follows the concept of a principal and an agent, and that is based upon some property rights of nature. The property rights component should assure that nature will not be exploited, at least in terms of nature having basic rights.

2. Background to an exchange between humans and nature

2.1. Use of the term ‘value’

In standard literature, the dominant theme in the evaluation of nature is obtaining monetary or ‘user’ values (so to say, the human utility perspective). It should be observed, however, that almost every study on the evaluation of nature in environmental economics has a reference to monetarization or ‘non-use’, as opposed to ‘use’ values. Nevertheless, it is not clear what ‘utility’ and ‘use’ are. Since humans are willing to pay for something, it means they receive or increase utility (Freeman, 1993). Anyhow, non-use values are considered values for humans because humans derive utility from nature: thus, nature can be evaluated in monetary terms. Note: real monetarization of nature with respect to non-use values requires a human being that is very conscious about nature being his/her living support system. Yet, is he/she capable and willing to care about nature on the basis of good will; hence being a ‘naturi-tarian’? In contrast: “What are ‘self’-use aspects of nature?” Only rarely, for example, if they consider themselves to be ‘ecological’, do humans ask: “How might nature value man?” (Hannon, 1998). From a philosophical point of view, there seem to be trenches involved in the debate on values that are not easy to bridge. Arguing that evaluation can only be attributed to man is standard reasoning against ‘nature-values’.
Perhaps this is only obscured by the phrasing of ‘value’.

However, it is not the objective of this paper to enter into a deep philosophical debate. On the one hand, we will pursue a more simplistic view of nature-values, utilizing the economic idea of humans being the principal and nature being the agent for value detection. On the other hand, we accept that the well-functioning of ecosystems implies a category of teleonomic values which go beyond the valuation of a being that only observes his/her counterpart. These two aspects already enable us to draw interesting conclusions about the evaluation of nature in the case of an exchange economy between actors. The main idea is: Humans assign values to goods acquired from nature, which are based on human utility and which are intrinsic to human nature, e.g. the taste of good food, health benefits from plants with medical properties, etc. Nature assigns ‘values’ to services delivered by humans, which are based on the fitness of nature and which are retrievable from behavior, i.e. response to service. Values, in this context, are defined as derivatives from objective-functions, and are thus revealed by exchange. Though, in the case of nature and for clarification, these quasi or narrow values are called ‘nature’s’ values; they are admittedly not classical human-values.

2.2. The concept of scarcity, evaluation using objective functions, and a genuine price

In order to really preserve our surrounding ecosystems, human users have to be confronted with the real costs or prices of those exploitative human activities that threaten nature. These costs or prices should reflect scarcity in both the human and natural sphere (Pearce and Turner, 1990). The measuring of scarcity or pricing of nature by scarcity is a concept that requires objective functions, not only for man. We need a research concept that is capable of establishing quantifiable objective functions for conflicting parties, and that should assure consecutively and concisely derived marginal values (genuine prices). In this paper, the introduction of objective functions will help us to apply the scarcity concept to the human and the natural sphere as done elsewhere (Gutierrez and Regev, 1983). Our basic assumption is that there are two complementary instruments, causality and goals, and using these together will provide us insight into nature and man’s behavior in a genuine exchange economy (Latour, 1999).

To be practical, we take fitness as nature’s objective function. The reason for the depiction of the functioning of ecosystems as fitness is that it has already been frequently used (Chapin et al., 2000). Fitness shall be translated into a measurable concept which has to be explicitly specified as a treatable variable. Functioning and fitness are normative categories, and they are categories comparable to economic and human categories, such as utility and welfare. We will also use fitness most generically as a teleonomic category for nature (other possible categories are, for instance, entropy: Hannon et al., 1992, etc.). Note further: explicit objectives of nature are also requested in nature preservation to make alternatives comparable on an opportunity cost basis (Montgomery et al., 1999); so their use is not unique in ecology.

3. Search for paradigms and notational approaches to specific nature exchange values

3.1. The need for a concept of nature-values, limitations and notational problems

Ecosystem values which are to be newly delineated, and should go beyond classical concepts of human-values, having the property to include known procedures as special cases¹, are difficult to perceive and are confronted with epistemological barriers. From a non-academic point of view, these values should be as ‘competitive’ as monetary values, i.e. have normative power, though they are distinct. Competitive also means that those favoring strong protection of nature from human influence should search for alternative concepts of environmental evaluation which put

¹ i.e. monetary evaluation from a standpoint of nature users, not to say, standpoint of a parasite (Hannon, 1998; Faber et al., 1998).
nature in a far fairer position to express its interests in remaining functionality (Chapin et al., 2000). ‘Fair position’ implies that nature becomes recognizable by ‘objective’ criteria as derived from ‘subjective’ values, norms, rights, functional interests, etc. (Hannon et al., 1992). Seemingly a paradox, this can only be solved by the criteria of an exchange value, as proved in the theory of market economy (Smith, 1776). Theoretically, nature-values must most prominently qualify as objective exchange values and, in particular, they must be empirically retrievable. Another similarity to monetary values should be that nature-values are to be based on visible transactions (Bateman and Willis, 1999).

3.2. Philosophical concerns

Apparently, there is a strong philosophical debate as to whether nature can actually have a value of its own (Faber et al., 1998). Maybe, following the tradition of classical philosophers and founders of economic theory (Mill, 1857), we have to restrict the term ‘values’ to humans. But we are less strict about the term ‘nature value’. Let us assume that ecosystems follow, and can be described by, a concept of functionality and scarcity (see above), and that this concept shall be the norm-value and objective provided. Hence, we speak of genuine nature-values in contrast to human values. If ecosystems reveal a kind of optimization in finding strategies for survival (fitness), the genuine values are derived values from such strategies. Note: this further raises the question: “What is life in the context of evolution, scarcity, system objectives, system values, etc.” (Schrödinger, 1944)?

From another angle, an appropriate approach to genuine nature values can refer to the basic concept of a civic society (Rawls and Herman, 2000). In this context, the consideration of rights is the basic idea when determining ‘fair’ pricing and exchange in an economy. Rights are established as property rights. Previous philosophers did not explicitly recognize nature because in their time nature was not scarce. But philosophers and philosophically oriented economists (Mill, 1857) tried to establish whether exchanges of goods and prices are fair (Locke, 1823). Hence, questions of genuine exchange values are also questions of fairness.

3.3. Basic assumptions on the economic framework

First of all, we have to specify some institutional features of a potential exchange situation between man and nature. For this we use the principal–agent framework. In the principal–agent framework one has to reason from an institutional point of view what the property agents are assigned, and what they bring into the ‘exchange’ economy (Richer and Furubotn, 1997). In a hypothetical experiment, we will first define land as nature’s property and labor as man’s property. Later we will alter this. Next, we have to look at types of games. We will apply a cooperative game (Nash, 1953). Note: if we pursue the idea of a cooperative game (principal–agent model, Richter and Furubotn, 1997), we depart from the notion of nature being exploited!

Furthermore, it should be noted that economists are in general not particularly concerned with objective-functions which are too concrete. Economists use utility merely as a substitute for something subjective and unknown. If ‘fitness and utility’ help explain behavior, it could be a sufficient concept (the philosophy in principal–agent theory! See Richter and Furubotn, 1997). Finally, we will determine the optimal exchange conditions, internally, in a game similar to a share cropping arrangement (a game being frequently analyzed in agricultural economics; Zusman and Bell, 1989). Following this, exchange values become optimal at the point when voluntary exchange ceases, and gains of cooperation are shared.

4. Framing nature exchange in a principal–agent model

4.1. Nature as agent

Our model is based upon the analogy of a human agent maximizing his/her utility in exchange for money with a principal who offers
money in return for labor, whereby the principal maximizes revenues from sales of services which are provided by the agent, minus the money spent for labor acquisition (Richter and Furubotn, 1997). With respect to the nature–human interface, we modify this setting and assume now that the ‘nature maximizes something’ is ‘fitness’—i.e. increased fitness from exchange: nature’s land for human labor. Note, the corresponding super-organism approach of ecosystems (nature) is only followed as a research hypothesis for management (Simberloff, 1998). How big communication problems for ecosystem management are, and how urgently a goal is needed, can also be inferred from Bunnel (1998). For the moment, we will simply use the stated goal, ‘fitness’ (as a research hypothesis), take nature as super-organism (as the agent) and look for the logical consequence (as reasonable for humans dealing with nature).

Apparently, land as the property held by nature is a further issue that could be challenged. To be as clear as possible in the beginning, from the perspective of model construction/portrayal, property rights have to be made explicit but must not be generally agreed upon. Moreover, what is the given technology? How is the further endowment situation characterized, and how does land use translate into the objective of nature? For the sake of an introductory outline expressing the problem in a principal–agent framework, we will assume that our ‘nature’ initially lives without man on a piece of land, ‘B’ (a natural reserve), and has full ‘rights’ to this land. Later we will modify land ‘ownership’. To comply with a given current occupation of land between man and nature, a property-right description is sufficient. Finally, the model is deterministic and not dynamic; not because we believe that this is ‘reality’, rather because we want to clarify points. Extensions to the dynamics of models are steps that can follow.

Regarding functional relationships, let us check what a principal–agent theory requires: as mentioned before, there is no chance to avoid the use of an objective-function for an agent (nature). As a matter of fact, explicit objectives are needed in value detection: but how general can they be? Human-values are normally not given by utility in inter-personal communication. Instead, money, which is a specific numeraire good, is given. We have already elaborated on the objective-function of nature with respect to what it ‘might’ maximize. Now we look for revealed preferences. Like utility, fitness is a broad specification. But the term ‘fitness’ is sufficient; we do not really need to specify it, rather we need to look for revealing preferences.

As an analogy, we assume that nature maximizes ‘composed fitness’ (N as a variable in Eq. (2)), which is a weighted vector of contribution to bio-mass acquisition and bio-diversity (interestingly enough, this outline corresponds to McGrady-Steed et al., 1997). We will consider achieving maximal fitness as a strategy of evolution, and use fitness as a definition function (Regev et al., 1998). To transcend the language barrier, in economic terms it means that nature has a preference for higher biomass and diversity, and those eco-systems that produce higher bio-mass and diversity are more fit (apparently the background of fitness is to make it synonymous with utility). We will show, using certain properties, that such an objective-function can be retrieved from observation, and that it offers a linear response function of nature with respect to incentives. For further clarification, nature, just as humans, is considered goal-oriented and land-constrained. Thus, the task firstly is to explain composition of nature. Keeping in mind that composition of nature can be considered a revealed preference function of fitness, we have to show how revelation works. From revealed preference investigations (in ecology), we hope to establish coefficients in behavioral equations (for empirical application: the argument runs from the results of habitat occupation to the weighting of species).

To build the model around this baseline concept, we look at the relationship between a composed set of habitats (land allocated to habitats which are characterized by a vector ‘b’) and species appearance ‘s’ (vector). For ecologists, habitats may be organized most easily and appropriately in a grid system (Baker, 1994), which enables a depiction of the problem of species presence in a cellular automata model (Balzer et al., 1998). For economists, with an appropriate...
subdivision of land in habitats, ‘b’, a ‘production function of nature’ is introduced that reflects nature’s potential to accomplish a set of species as a vector, ‘s’.

\[ s = \Omega_1 b \] (1)

Eq. (1) uses ‘\( \Omega_1 \)’ as the transition from habitats (‘design’) to species (‘composition’). The transition is measured in matrix notation and associated with cellular automata modeling (Balzer et al., 1998); i.e. ‘\( \Omega_1 \)’ contains probabilities. It refers to our ‘knowledge’ of nature, inferable as probabilities to ‘achieve’ a certain vector of species if a certain habitat ‘design’ is chosen. Species occupancy (nature designs in the territory) occurs in such a way that multiple habitats exist, with these habitats supporting the particular species composition.

The next step is, as intended for the revelation of preferences, to ‘design’, at least mathematically, a practical objective-function Eq. (2). In this function ‘N’ should reflect ‘nature’s fitness’. Fitness should be related to diversity of nature, ‘D’, and is considered a mean, not an end (teleonomic). The function should also incorporate the respective species vector Eq. (1) in such a way that relevant elements of a maximizing process resume. Assuming nature is quasi optimizing (i.e. an ex-post simulation of evolution and building the first derivative), the objective-function becomes directly linked to ‘nature productions’ in Eq. (1). When observing the results of apparent species (the constructivist’s view of revelation) we can think of a weighted objective-function between bio-mass ‘M’ and diversity ‘D’. Hence, we state nature’s objective-function explicitly containing two elements, ‘M’ and ‘D’, and being linear given a weight \( \omega \) as:

\[ N = \omega M - [1 - \omega]D \] (2)

Next, we have to delineate the objective Eq. (2) as dependent on a specified species vector ‘s’. In doing so we might use a quasi ‘evaluation’, for instance, a physical weight ‘p’; then \( M = ps \). For further explanation: a weight ‘p’ given to ‘s’ is not a utility derived value (a price), though it measures the partial contribution of one creature as species in ‘s’ to bio-mass. It expresses current species’ appearance in a ‘physical’ way (for instance, the body weight of an elephant in contrast to a mouse; alternatively to physical weights, the vector ‘\( \rho \)’ might be a measure of the metabolic body weight, if energy efficiency is an objective in evolution). But if we interpret this economically, ‘\( \rho \)’ will represent a price in the evaluation of nature: the assignment of ‘\( \rho \)’ is only ‘as if’ a price (a ‘fitness’-derived marginal value) is given. However, assuming a linear relationship between bio-mass and fitness, it is logically fitting to categorize bio-mass as being teleonomic. We argue that nature has ‘designed’ the scaling of species in such way that numerical appearance and specific body weight coincide (for instance, 10 000 mice at the weight of 50 g is equal to ten elephants at 5 t). So what is the gain? As will be shown, we will be capable of inferring substitution conditions in a concept of nature’s preferences. In other words, specific weight is a revealed preference of nature.

A further note: the weights ‘\( \omega \)’ and ‘\( 1 - \omega \)’ are particular weights. Figures can be correspondingly inferred. Next, diversity ‘D’ shall be measured as a type of a Shannon–Wiener index, which is normally the sum of the product of a relative appearance multiplied by the logarithm of that appearance. This is approximated by ‘\( s(1+s) \)’ and scaled to the body weight of the species. Then, these deliberations are represented in a re-specified objective-function of nature (in vector notation) such as:

\[ N = \omega \rho s - [1 - \omega]s(1 + s) \] (2a)

Since we are interested in the translation of habitats into species as a revelation of the ‘allocation structure’ of nature (in terms of reproducing species appearance), one can translate the objective-function to habitat levels and the following function is a first building block, so that:

\[ N = \omega \rho \Omega_1 b + [1 - \omega]b \Omega_1(1 + \Omega_1 b) \] (2b)

Moreover, land for habitats is constrained, \( B_n \). This aspect is important since the way we have ‘constructed’ nature shall also explore the analogy of scarcity in nature and human land occupation. In vector notation this is:

\[ B_n = 1'b \] (3)

Optimization of Eq. (2b) given Eq. (3) provides
a representation of habitats in a natural situation of:
\[
\omega \Omega_1 \rho + [1 - \omega] \Omega_1 + \lambda [1 - \omega] \Omega_1 \Omega_1 b + I \lambda = 0
\]
\(1 \, \hat{b} = B_n \) \hspace{1cm} (4)

Solvable for habitats ‘\( \hat{b}^* \)’ (a vector) in a system Eq. (4a), as a reference, ‘natural’ land use is:
\[
[b^*] = \begin{bmatrix} \Omega_1 \Omega_1 & 1 \\ 1' \end{bmatrix}^{-1} \begin{bmatrix} [1 - \omega] \Omega_1 1 + \omega \Omega_1 \rho \end{bmatrix}
\]
(4a)

Our result Eq. (4a) needs further explanation: firstly, nature is ‘constructed’ by given species, and it is site specific. It differs in species numbers occupying a certain territory. Secondly, a mixture of habitats and multiple-occupation is possible. Thirdly, we are primarily interested in the revelation of nature’s ‘habitat design’ with respect to species composition in quantitative terms. Fourthly, for establishing an exchange, we assume nature optimally figures out how to use habitats under a given land constraint, and the potentially offered compensation. Since we will model the ‘invasion’ of humans in these habitats, scarcity of land and the capability to occupy territories is the important issue. Fifthly, habitats and land occupation are research categories because, in our model, nature is habitat-oriented and a causality runs from a predetermined habitat design to an obtainable species composition. Sixthly, we recognize two elements in the maximized objective-function, bio-mass and bio-diversity. There may be other components such as resilience, etc., but we have omitted them for simplification.

4.2. Specifying the exchange of nature as agent

Next, we have to answer questions such as: What could be the potential exchange? Would nature ‘give-up’ land and reduce its habitat occupation in exchange for services provided by humans? Humans occupy land out of necessity, with the conflict being over ‘Lebensraum: the German word for living space’. In particular, land for an increasing human population that needs food is the biggest challenge to nature’s land. But what are potential services? Services for exchanges can be considered on two levels, and services as well as goods have to be ‘valuable’ for both sides. We can justify human services offered to nature with an ‘inference on scarcity and demand’. Once more, in order not to be misperceived from the perspective of the natural sciences, nature may be purely determined by laws of causality (ecological). Hence, an objective of nature (teleonomic) is an artifact. Nature makes no ‘deliberate’ decisions, for instance, in negotiating with humans over the exchange of services for land, but intelligent humans may observe nature’s ‘behavior’ (from a philosophical, or more narrowly, Kantian perspective, causality is a category of thinking about what drives nature; therefore, causality can be considered a paradigm (Kuhn, 2000); paradigms are flexible and their success to predict is the criteria for best choices on paradigms). Our position is: ‘As with an agent from whom you want a good performance, nature has to be treated well’! If it is treated well by man (principal), and it can be encouraged to provide services, then this is to our (man’s) benefit (simply speaking: the slave ‘nature’ must become a servant before one can exploit him more perfectly, and he must be paid!).

So what is the solution to the exchange question? Primarily, human labor shall positively affect species’ prevalence and composition (the gardeners’ view). Secondarily, we can supplement labor with nutrients, such as organic matter equivalents, which can be applied on a habitat level. Nutrients shall alleviate shortages in nature. Organic matter including nitrogen from outside (human sphere) shall be injected into the bio-mass circulation of ecosystems (natural sphere). Organic matter given back to nature by humans can be humus, compost, etc. Note: the items to be exchanged are not waste matters; on the contrary, they have positive values for humans and nature. An injection of nutrients into the natural sphere is accompanied by a loss of valuable material for humans. The organic matter injection aspect implies a circular economy for nature, with over-injection (fertilization) being like inflation.

Human labor services should have an impact on nature’s production function Eq. (1) and should augment the potential for the occurrence of species; but not every species will benefit. We should receive a function that caters for the two
aspects of mutual exchange: Firstly, land ‘b’ for farmers from nature and labor ‘\(L_n\)’ for nature from farmers (the component in the first brackets in Eq. (5)). Secondly, ‘nitrogen’ as a basic ‘payment’ for nature on a habitat level (this component is additive and serves as compensation in Eq. (5) if labor is in deficit). Labor is organized into a matrix which means that specific labor is especially intended to single species. Nitrogen is the general medium to augment species’ appearance (it reduces scarcity by making land ‘more nutritious’). It takes the position of a currency then:

\[
s = \Omega_1[E + L \Omega_0][b^* - b] + \Omega_2 n_0
\]

\[= \Omega_1[b^* - b] + \Omega_1 L_n \Omega_0[b^* - b] + \Omega_2 n_0 \tag{5}\]

substitutes Eq. (1).

For explanation: in Eq. (5), as an example, imagine that the planting of additional willow trees for nesting birds creates better habitats for those birds using this habitat. This requires labor for planting, perhaps also water, etc., i.e. on the level of the relationship between a bird species ‘j’ (a Chickadee) and a habitat ‘I’ (a willow tree woodland). Note further: the ‘\(b_i\)’s in the vector ‘\(b’ = [b_1, \ldots, b_i, \ldots, b_n]\’, i.e. the habitats, can be organized in a raster (for technical purposes in a cellular automata or geographical information system, GIS), and the ‘sacrifice’ of particular land in the vector ‘\(b’ by nature is defined as land deduction from a naturally optimal habitat raster ‘\(b^*’). There are two ways to imagine this: Firstly, looking at it from the angle of nature: humans will cultivate strips in that raster. Secondly, looking at it from a human perspective: nature is given buffer strips.

Next, response Eq. (5) will be used in a reformulation of nature’s objective-function. Now, the formulation of the new objective-function Eq. (6) includes explicit exchange modes as ‘agreed’.

\[
N = \omega \rho \Omega_1[b^* - b] + \Omega_1 L_n \Omega_0[b^* - b] + \omega \rho \Omega_2 n_0 - [1 - \omega][b^* - b] \Omega_1(1 + \Omega_1[b^* - b]) \tag{6}
\]

Formulation Eq. (6) can be understood two-fold. In economic terms, it is an ‘interest’ function by nature for exchange. Hence, it can also be interpreted in game theory terms (Zusman and Bell, 1989; we will later refer to the underlying aspects of such a game). In technical terms it is an easy way to represent an ‘interest’ function of nature in a principal–agent framework (Richter and Furubotn, 1997). The ‘task of nature’ as agent is to respond to the will of the farmer, who provides labor and organic matter in return for sacrificed land whilst maintaining the ecosystem.

Newly maximizing the function Eq. (6), we get a response function that opens the eyes of a human principal to nature’s willingness to accept ‘contracts’ on a mutually beneficial basis (utility and fitness improvement). For instance, a farmer notices that he has to ‘pay’ for land with labor if he wants to maintain the ecosystem. The success criteria is the ‘fitness’ of nature. Furthermore, a willingness to pay for land with labor by humans is an indicator of nature’s marginal values, i.e. an explicit respect towards the property right of nature. ‘Values’ are derivatives from objective-functions, i.e. marginal values to pursue fitness are ‘nature-values’, nothing more and nothing less!

In Eq. (7) newly optimized habitats (which determine the modified composition of species) include a voluntary waiver on land (exchange) to the ‘benefit/(fitness) of nature (payment). Since labor and nutrients compensate losses, a type of a constraint on incentives prevails. Optimization is a matter of endogenous vectors ‘\(b’ and ‘\(\lambda’). The first gives the waiver of land, and the second the shadow price associated with scarcity of habitats.

\[
\omega \Omega_1 \rho + \omega \Omega_2 \Omega_0 L_n \rho - [1 - \omega][\Omega_1 b^* + \Omega_1 \Omega_0[b^* - b]] + I \lambda = 0 \tag{7}
\]

The solution for vectors ‘\(b’ and ‘\(\lambda’, the Eq. (8), is an ‘offer’ function, as dependent on \(B_n, b^*, \) and \(\rho\), which represents the endowment and starting conditions for our now flexible ‘nature’. Importantly, the inclusion of \(L_n\) in Eq. (8) reflects the incentive component which will be optimized later by the principal.

\[
\begin{pmatrix}
\begin{bmatrix}
\hat{b}
\end{bmatrix} \\
\hat{\lambda}
\end{pmatrix} = 
\begin{pmatrix}
\Omega_1 \Omega_1 & I \\
I & 0
\end{pmatrix}^{-1} 
[1 - \omega][\Omega_1 b^* + \omega \Omega_1 + \Omega_2 \Omega_0 L_n] \rho \tag{8}
\]

As a result of the voluntary (i.e. fitness related)
nature response, we get a linear system Eq. (8):

$$b = \psi B_n + \Psi^* b^* + \Psi^* L_n \rho$$  

(8a)

The response function Eq. (8a) reflects the constructed exchange of land for labor Eq. (5), and it can be recognized as an ‘incentive constraint’. This type of wording needs re-phrasing in ecological terms: Due to labor provided by farmers, nature develops in a specific direction, i.e. towards a new vector of habitats which is favorable to the old one. Nature is no longer ‘natural’, but rather becomes symbiotic with humans: a cultural landscape perspective. Admittedly, it is difficult to speak of greater ‘fitness’ of nature since nature was already ‘optimal’ without humans. But, since nature’s constraints (scarcity of habitats) are now relaxed, nature should be better off. At least nature is no longer harmed by human land expansion.

4.3. Humans as principals

Firstly, humans, for instance as farmers, maximize economic returns from a specific vector of species ‘f’ (human-owned species, different from natural ones and considered as farm species or non-free). Again we assume a kind of production function Eq. (9) that calculates the relationship between land occupation in habitats b (notice as the waivers of nature) but now occupied by humans for use of ‘f’. Furthermore, in production function Eq. (9), labor devoted to care for farm species are included, and the production function depends on natural components ‘s’. This recognition of natural biological activity, ‘s’, in Eq. (9), constitutes the live support aspect of eco-systems: for instance, services from natural predators.

Hence, the farmer’s production function consists of three components, one is necessary land; a second is labor; and the third is the quality of nature. This reflects a double dependency on nature.

$$f = \Theta_1 [E + \Theta_2 L_n b + \Theta_3 s]$$

$$= \Theta_1 b + \Theta_1 \Theta_2 L_n b + \Theta_1 \Theta_3 s$$

(9)

Now inserting Eq. (5) for ‘s’ gives:

$$f = \Theta_1 [E + \Theta_2 L_n b + \Theta_3 L_n b^* + \Theta_3 L_n \rho]$$

(9a)

and if coefficients in matrices and vectors are recalculated in order to simplify, we get Eq. (9b):

$$f = \Theta_1 [E + \Theta_2 L_n b + \Theta_3 L_n b^* + \zeta_0 \rho]$$

(9b)

For further simplification we assume humans are farmers; they are primarily concerned with food production, and a food market exists. A farmer sells food (wheat, cows, etc.) as species ‘f’ at prices ‘p’ on a market, and has to recognize the recycling of organic matter (nutrients) to nature at costs ‘r’. Note: in general, the analysis is not confined to farmers, rather farmers represent the human need for food as a prime service of nature. In Eq. (10), the price ‘p’ gives the marginal utility of food. Now monetary values enter the debate as marginal utility, since the farmer’s objective-function Eq. (10) is profit maximization, and is composed of human-wise prices. Moreover, there is a constraint on labor.

$$F = p'f - r' n_0 - \mu [L - l' [L_n + L_a]]$$

$$- g'_L n' L_n g$$  

(10)

Secondly, labor costs are modeled on the basis of a Lagrange formulation and in the mode of adding up several constraints on a vector basis. This is necessary because we have labor devoted to nature and farming.

Thirdly, a specific negative discomfort for humans working for nature is introduced in Eq. (10) in the mode of a quadratic vector presentation (at the end of Eq. (10)). Insertion of function Eq. (9b) into the objective-function Eq. (10) then provides the criteria Eq. (11) for the decision making of a representative farmer as principal:

$$F = p' [\Theta_1 E + \Theta_2 L_n + \Theta_3 L_n]$$

$$\times [\psi B_n + \Psi^* b^* + \Psi^* L_n \rho] + \Theta_4 L_n b^* + \zeta_0 \rho$$

$$- \mu [L - l' [L_n + L_a]]$$

$$- r' n_0 - g'_L n' L_n g$$

(11)

Fourthly, ‘n_0’, the non-species-specific exchange criteria, as a type of a generic compensation, is still
undetermined. Determining it from Eq. (6) results in a participation constraint which is a recalculation of Eq. (6) given the pre-exchange criteria for fitness $N^*$:

$$
n_0 = [\omega \Omega]^{-1} \times \left[ \omega \rho \Omega_1 + \Omega_2 L_n \right] [b^* - b] - [1 - \omega] \times [b^* - b] \Omega_1 (1 + \Omega_2 [b^* - b]) - N^* \right]

(6a)

In Eq. (6a), we have to insert the response function Eq. (8a), giving us:

$$
n_0 = [\omega \rho \Omega]^{-1} \left[ [b^* - b] \Omega_1 (1 + \Omega_2 [b^* - b]) - N^* \right]

(6b)

Taking into consideration this criteria of participation in Eq. (11), the production function Eq. (9b) and incentive Eq. (8a) give an overall objective-function of farmers Eq. (11a). The function Eq. (11a) is based upon farmers’ ‘knowledge’ of production conditions and nature. It represents their own disutility, matrices $\Theta$, and the ‘response’ of nature to labor provision for exchange: the $\Psi$:

$$
F = p \left[ \Theta \left[ E + \Theta_2 L_n + \Theta_3 L_n \right] \times [\psi B_n + \Psi_0 b^* + \Psi L_n \rho] + \Theta_4 L_n b^* + n_0 \right] - \mu L - 1[L_n + L_a] 3 \Phi L_n L_a \Phi \Psi - [\Theta \left[ E + \Theta_2 L_n + \Theta_3 L_n \right] \times [\psi B_n + \Psi_0 b^* + \Psi L_n \rho] + \Theta_4 L_n \theta N^* \right]

(11a)

The remaining explicit decision variables are labor for nature and labor for farm. Implicitly, the farmer decides on land which he occupies from nature and he recognizes initial nature fitness. The fitness of nature is important for humans since it is vital for exchange. After a simplification and sorting of matrices in front of $L_n$ and $L_a$, a quadratic objective-function Eq. (11b) is identified as:

$$
F = p \Psi L_n b^* + p \Psi L_n b^* + \Psi L_n \rho - \rho \Psi L_n b^* - \rho \Psi L_n \rho

\left[ L_n \Phi L_n \Phi \Psi - \Psi L_n b^* - \Psi L_n \rho \right] - \mu L - 1[L_n + L_a] 3 \Phi L_n L_a \Phi

(11b)

The optimization of Eq. (11b) gives the optimal labor allocation and, hence, recursively determines the exchange between nature and the human principal. The optimization is for the two types of labor and a shadow price vector. Mathematically, Eqs. (12a), (12b) and (12c) are first order derivatives of Eq. (11a).

$$
p \Psi L_n b^* + p \Psi L_n b^* + \Psi L_n \rho - \rho \Psi L_n b^* - \rho \Psi L_n \rho

\left[ L_n \Phi L_n \Phi \Psi - \Psi L_n b^* - \Psi L_n \rho \right] - \mu L - 1[L_n + L_a] 3 \Phi L_n L_a \Phi

= 0

(12a)

$$
p \Psi L_n b^* + p \Psi L_n b^* + \Psi L_n \rho - \rho \Psi L_n b^* - \rho \Psi L_n \rho

\left[ L_n \Phi L_n \Phi \Psi - \Psi L_n b^* - \Psi L_n \rho \right] - \mu L - 1[L_n + L_a] 3 \Phi L_n L_a \Phi

= 0

(12b)

$$
\left[ L_n \Phi L_n \Phi \Psi - \Psi L_n b^* - \Psi L_n \rho \right] - \mu L - 1[L_n + L_a] 3 \Phi L_n L_a \Phi

= 0

(12c)

Using Eqs. (12a), (12b) and (12c), a system of 2n+1 equations prevails from which we can endogenously calculate individual contributions of labor, measure the shadow price, and use recursively obtained optimal variables for determining land use, plant nutrient injection, and objective-function values. This can be done easily using a matrix inversion of Eqs. (12a), (12b) and (12c) in Eq. (13):

$$
\begin{bmatrix}
L_n \\
L_a \\
\mu
\end{bmatrix}
= \begin{bmatrix}
0 & \Psi L_n & 1 \\
0 & \Psi L_n & 1 \\
0 & \Psi L_n & 1 \\
\end{bmatrix}^{-1}
\begin{bmatrix}
\Psi L_n \rho + \Psi L_n b^* + \Psi L_n \rho \\
\Psi L_n \rho + \Psi L_n b^* + \Psi L_n \rho \\
\Psi L_n \rho + \Psi L_n b^* + \Psi L_n \rho \\
\end{bmatrix}

(13)

Next, writing the results of $L_n$ in separate
functions, the determination labor provision can be isolated as:

$$L_n = \phi_0^* + \Phi_1^* p + \Phi_2^* p + \Phi_3^* x$$  \hspace{1cm} (13a)

Finally, we see that labor devoted to nature is determined by exogenous ecological and economic variables such as human exchange values (prices) ‘p’, ecological preferences (weighting of species) ‘ρ’, and other constrained variables ‘x’. Note: discomfort preferences are included in the matrices, and variables such as land cleared by humans ‘b’ are endogenous to the system because we use the result $L_n$ from Eq. (13) in Eq. (8a).

Note, more generally, labor to be provided to nature can be concisely determined by human preferences (positive for products, i.e. marginal utility as prices of food, fiber; negative for discomfort, i.e. labor, etc.) and nature’s preference (i.e. weight coefficients in the ecological preference function).

4.4. Measurement of genuine exchange values

At this point of the investigation let us return to the meaning and interpretation of a genuine exchange between nature (live support system) and humans (farmers). In a ‘normal’ principal–agent model, for instance, the one of a sharecropper, one can finally determine the ‘wage’ to be paid by the principal, even in physical terms, for example, food. The ‘wage’ consists of two elements: a payment to the agent as a share of a physical product (food, optimized and negotiated as distribution of surplus from a cooperation) and a lump sum payment. A wage appears to be monetary at first glance because it is subtracted from revenues obtained on markets, i.e. from the sale of products by the principal. However, wages also have a physical aspect. In share cropping arrangements (Singh, 1989), a wage takes on the meaning of ‘price’ in terms of fixing physical sharing conditions. When considered in more depth, prices have a distribution (physical) and an incentive (price) component. For comparison: an agent, a peasant—in the theory of share cropping—receives an allotment of additional food obtained from cooperation and accrued from the land owned by the principal. Then the price is the marginal increase of food quantity accrued from cooperation.

Given these deliberations, the genuine price of nature can be re-interpreted from the point of view of an agent, nature, as a sharer of benefits from cooperation with a human. Supposedly, nature aims at fitness, then, the ‘wage’ payment is labor: for instance, a share in the measurement of the surplus obtained from farm labor. The difference of our current setting to share cropping is that a human is the principal, i.e. nature is inferior to man in understanding the game, and physical benefits are indirect. In terms of measuring the value or ‘price’ of nature, we can quantify the exchange from the point of view of farmers ‘F’ as losses per ‘labor payment’, and then have to quantify marginal changes of the objective-functions due to cooperation to get the ‘wage, $w_n$’:

$$w_f = \frac{\Delta F}{\Delta Y L_n}$$  \hspace{1cm} (14a)

for the last (marginal) unit of labor.

Losses are measured as a financial or monetary result only, not including opportunity costs for labor. In the same vein, from the point of view of nature ‘N’, the exchange value (i.e. higher fitness of nature due to human labor acquisition in exchange for land) offers an opportunity cost measure ‘$w_n$’ on forgone land such as:

$$w_n = \frac{\Delta N}{\Delta Y b}$$  \hspace{1cm} (14b)

for the last unit of land.

Note: we do not have competitive equilibrium values, but rather game (Nash) equilibrium values. As relevant criteria, both values can be used for the project evaluation (cooperation). Exchanges (humans take land but devote labor to nature) are evaluated. Organic matter also plays an interesting role. Since it is scarce in both sectors, it can take on the role of a currency.
5. Welfare, distribution, and institution-related questions

Since the model, in its current form, is neither dynamic nor particularly system-oriented, further research is required. Especially since the fertilizing of nature for the alleviation of scarcity in nutrients and land acquisition potentials alter the strength or potential to acquire resources by nature and humans. A dynamic game would be the next step in making the model more applicable to empirical research and reality. Nevertheless, it is already fairly interesting to further explore the idea of having a ‘real equilibrium in exchange between nature and humans’ presented. Note: the principal-agent equilibrium is only a Nash equilibrium. This implies that nature is the passive ‘agent’, while humans are active, i.e. superior. With respect to superiority, humans play the decision maker’s role, exploiting the live support function of nature. Though this constellation is still in favor of humans, the property rights have changed from a pure exploitative setting in land ownership (nature as slave) to land rights of nature. Nature is an agent no longer under full human control. A less exploitative situation occurs. The welfare of humans may not decline from an actor’s perspective, but the total sum of ‘utility’ from habitat occupation should be higher, and property rights should be given. This situation is depicted in the upper left part of Fig. 1. Humans improve their utility ‘actively’, using the exchange, whereas fitness of nature increases ‘passively’, until human utility is maximized. Note: nature cannot ‘actively’ increase fitness because humans ‘control’ the exchange. However, rights can be altered if we think of more complex starting conditions for $b^*$: for instance, the situation before the invasion of a natural forest.

Secondly, we were given an exchange rate between land and labor which is mutually recognized as ‘optimal’ within a ‘socialization’ of nature to humans, i.e. we obtained a value that revealed scarcity of labor and land from the point of view of nature and humans, although their interests are diametrical. Thirdly, for empirical research, a controlled area on natural habitats may serve as a benchmark for determining the local values. However, some aspects concerning rights remain unclear.

For qualifications on rights, the given institution is thus: humans are principals and nature is an agent. We may now change the situation and regard humans as agents and nature as the principal (lower right side of Fig. 1). This means altering the sequence of decision making. Firstly, humans maximize utility based upon labor offered in exchange for land use, i.e. nature becomes the real landlord and humans have to provide labor for nature, receiving rights to plant and harvest on nature’s land. Analytically, the corresponding procedure is not different from the previous work. The results are also provided in Fig. 1. Nature ‘actively’ controls the exchange, making it superior, as can be seen in Fig. 1. Now: “What are the gains in analyzing nature-values from this angle or new institution”? Primarily, the hypothetical experiment raises the issue of: “What is a relevant initial institution for rationalizing the genuine evaluation of nature”? Note: it is not the intention of this paper to question human superiority. The reasoning behind it is merely: “We will receive another optimal point of exchange which is characterized as another corner solution (Fig. 1)”. How does this all fit into a more general exposition of a real equilibrium? Let us look at the result in Fig. 1. We recognize that the newly derived utility and fitness from the second optimal points of exchange, given initial rights, favor nature, and marginal values (prices) differ. It should be noticed that the move on the second line from zero to

![Fig. 1. Welfare distribution and institutions.](image-url)
larger fitness of nature is a mode of optimization. It means to ‘invent’ mutually improving situations from the perspective of superior nature. Identifiable as win–win situations, both corners are quasi-optima given institutions. Then, Fig. 1 represents the possible utility-fitness transformation curve, starting from initial property rights.

6. Further exploration of pricing and ‘just’ exchanges

The analysis of an exchange or ‘co-habitation’ between humans and nature on the basis of a principal–agent theory and property rights structures is only a beginning. Much more must be considered when approaching the problem of extracting exchange values from mutually agreed exchange situations, and analyzing distribution impacts on what might be called the ‘civilized treatment’ of nature by humans. Determining optimal exchange rates and aligning ‘welfare’ levels by ‘cooperating partners’ are needed. Further steps may involve the exploration of different institutional settings.

Fig. 2 extends the theoretical background of developing integrated approaches of nature’s fitness and human utility. The two corner solutions are now connected by a transformation curve, a dotted line. The dotted line in Fig. 2, that increases fitness to the detriment of utility, depicts the possibility to transfer utility into fitness. Note that, in the beginning, no intervention and norms on the weights of a unified ‘welfare’, as being derived from the exchange, were necessary. Up to the achievements of corner solutions, ‘evaluation’ depends on framing the institution of exchange! The only property rights ‘policy’ needed, until the corners (solid lines in Figs. 1 and 2) are reached, is an anticipation of ‘natural’ rights to resources. This is already an artificial presumption since humans occupy most territories. But for projects further invading natural areas, it maybe applicable.

The solid lines between corners are even more policy-dependent. For further deliberations: economists would think of ‘competitive markets’ in which the exchange could take place. However, it is difficult to imagine that such markets exist, even if economists like it, because it is unclear what competition means in the given context. Beyond observations that humans, who anticipate nature in a delivery of labor and alleviate scarcity in the struggle for land, competitive pricing can only be accomplished by experimentation (dotted line in Fig. 2). One path to explore would be the analogy of a market with those of an artificial social-planner. One might call this planner an ‘impartial planner’ (or God? Gutierrez et al., 1999, who knows the dotted line). Mathematically, the solution is simple (one has to give equal weights in a function $W$), but does a supernatural planner who pursues ‘societal’ welfare exist?

Fig. 2 provides such a point whereby the 45° preference is maximized with a given possibility to transform fitness of nature into human utility. Fig. 2 also allows the exploration of several other aspects within a frame of allocation, distribution and pricing of land and labor in favor of humans and nature. The first aspect that has to be clarified is the question of which instrument should serve for a redistribution of utilities. This may change the shape of the dotted line. The second aspect is the question of sequencing in behavior. Humans will notice that an impartial supernatural benevolent planner will charge re-distributive transfers. As a consequence, we are given and should infer a different optimization of nature, of humans, and those of a planner, including transfers. Next, transfer losses appear if the planner has to use
resources such as labor and land for redistribution. Again this opens up a dynamic debate.

Another way to proceed may involve a switch in the perception of the role of the supernatural arranger of the fitness-utility distribution (Gutierrez et al., 1999); i.e. the planner may become partial. Fig. 3 provides such a solution. In this solution, the two corners provide a reference for a bargaining process (i.e. the new dotted line in Fig. 3 is no longer a 45° line as in Fig. 2). Actually, a simulation of bargaining (game theoretical solution in Fig. 3) does not need a superficial planner; instead, the result is an endogenous solution.

In ‘normal’ cases of economic transactions between humans, bargaining is self-explanatory. With respect to nature and man, however, it gets difficult to perceive a concept of bargaining. Perhaps one can perceive ‘bargaining’ as a particular bargain between several farmers and several types of nature as well as a supernatural game where a struggle for land occupation becomes involved (Zusman and Bell, 1989). The job of the ‘authority’ would be, somehow, to assure ‘fair struggles’ resulting in equal power. Then the question of cooperation or threat (threat not to cooperate, i.e. use corner solution in Fig. 3) in the game is relevant. So what are alternatives to the given principal–agent frame? Because a principal–agent framework presumes that gains from cooperation succeed losses, both sides win, though if alternatives exist, agents seek the highest wins.

Such simple constructs of a further bargaining solution could draw the attention to alternative possibilities for nature to acquire species and humans to acquire food, e.g. from outside the given system. For instance, if one restricts the analysis to a regionally confined choice problem, such settings would enable a more rigorous formulation of exchange.

7. Summary

It was the objective of this paper to broaden the discussion on nature-values with respect to a ‘genuine exchange’. The principal–agent framework served as a concept to derive a real exchange between nature and humans on the basis of mutual respect and rights on respected property. We considered humans to be the principal and nature the agent. The exchange was specified as nature providing land to man and a live support system, and with humans providing labor to nature as payment. In addition, organic fertilizer compensates land.

Within this framework we can formulate the pricing of nature in terms of services; i.e. pricing as if inferior nature and superior humans had negotiated. Superiority refers to the human ability to anticipate the behavior of nature, and respect its preferences. As a result, we obtained relative prices of labor from humans, and land from nature as dependent on our particular exchange economy. This enabled us to specify nature-values as relative (subjectively driven) and revealed (objectively measured). Similarities are drawn between share cropping, land use and distribution of cooperative gains, as developed in the institution economics of food production. Nature’s exploitation, preservation, and revelation of prices as ‘objective’ market prices all occur simultaneously. The perceived ‘market’ for exchange is a synthetic market and, by a ‘hypothetical experiment’ which uses the principal–agent framework, we derive the genuine value of nature. However, this hypothetical experiment is based upon empirically retrievable information, and a mathematical solution is provided.
Finally, the approach was extended to alternative property situations between humans and nature. We qualified the genuine pricing of nature as depending on bargaining solutions and definitions of property, thus showing the different results. The idea can be included in dynamic and system theoretical models to make it more applicable. Subsequently, a principal—agent focus on economic and ecological interfaces provides an integrative part for value detection.

References


