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Short communication. Economics of natural resources: in search of a unified theoretical framework

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Abstract

This paper proposes a unified theoretical framework for dealing with the optimum economic use of any type of natural resource. After formulating and economically interpreting the unified framework, the basic rules governing the economic exploitation of the different natural resources can be easily obtained by particularizing the different values of its basic parameters. Taking this approach, it is easy to understand what commonalities there are, in terms of economic logic, between the different types of natural resources. This considerably increases the amount of consilience and understanding about the discipline.

Additional key words: economic logic; environmental economics; Jevons principle.

Resumen

Comunicación corta. Economía de los recursos naturales: en busca de un marco teórico unificado

En este trabajo se propone un marco teórico para el análisis unificado del uso óptimo de cualquier tipo de recurso natural. En primer lugar, dicho marco unificado se formula y se interpreta desde un punto de vista económico. A continuación, se demuestra cómo las reglas básicas que determinan la explotación óptima de los diferentes recursos naturales se pueden establecer, de una manera directa por simple particularización de los valores de los parámetros que caracterizan el modelo unificado. Este tipo de enfoque permite un mayor entendimiento de los aspectos comunes que subyacen a los diferentes recursos naturales, lo que incrementa la coherencia y la comprensión de esta disciplina económica.

Palabras clave adicionales: economía ambiental; lógica económica; principio de Jevons.

The economics of natural resources is a relatively new applied economics discipline, which is now growing at an impressive rate. A common practice in teaching and research within this disciplinary field is to present the economic analysis of natural resources separately and independently as if it were a pigeonhole system. In any academic course, book or research paper in this field, the optimal depletion of exhaustible resources, the optimal exploitation of renewable resources like fisheries and forestry, etc., are usually addressed in a totally disconnected way. This is an understandable tradition, since it is the strategy underlying the pioneering books written about this field (*e.g.,* Fisher, 1981; Neher, 1990; Pearce & Turner, 1990; etc.).

The above strategy can give the wrong impression that the different natural resources are totally unconnected entities. This paper takes the opposite view, *i.e.* we argue that the different natural resources are economically connected within a single common framework. We also argue that there are a significant number of benefits to be gained from establishing a logical bridge between the economic use of different natural resources.

A unified framework for the economic analysis of any type of natural resources is now presented. Later on, we will see how the key economic rules on the exploitation of the different natural resources can be derived by particularizing the analytical framework to different values of its basic parameters. The fol-

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lowing three functions are basic ingredients of our analysis:

$$q = q(t),\ q'(t) \geq 0\ q''(t) \leq 0 \qquad [1]$$

$$p = p(t),\ p'(t) \geq 0\ p''(t) \leq 0 \qquad [2]$$

$$h = h(t),\ h'(t) \geq 0\ h''(t) \leq 0 \qquad [3]$$

Function [1] is a growth curve measuring the amount of available homogeneous resource (*e.g.,* a single species for forests and a fisheries) q as a function of time *t*. Function [2] is a price function that describes the evolution of the price of the resource *p* over time *t*. Function [3] measures the possible flow of non-commercial services from the stock of a natural resource of age t [*i.e.* a Hartman function (1976)].

The following simplifying assumptions are introduced:

— *Assumption 1*. Resource owners want to exploit the resource at a rate at which they will earn maximum profits.

— *Assumption 2*. The amount of resource extracted or harvested does not influence the price of the resource.

— *Assumption 3*. The quality of the resource is uniform over time.

— *Assumption 4*. The marginal cost of extracting or harvesting the resource c is constant.

— *Assumption 5*. Resource owners know the exact figures for the discount rate i and for land rent *R*. The discount rate will be estimated by a interest rate when the resource is of private property or by a social discount rate when the resource is of public property.

The basic equation for deriving the optimal economic policy for any type of natural resource will be given by maximizing the following net present value (NPV) associated with the exploitation of the resource:

$$\text{Max NPV}(t) =$$
$$= p(t)\, q(t)\, e^{-it} + \int_0^t h(t) e^{-it} dt - R\int_0^t e^{-it} dt \qquad [4]$$

The first term on the right-hand side of [4] [*i.e.* $p(t)\, q(t)\, e^{-it}$] represents the present value of the amount of resource extracted or harvested. The second term

$$(i.e.\ \int_0^t h(t) e^{-it} dt)$$

represents the present value of the accumulated flow of possible non-commercial services provided by the resource across its planning horizon. Finally, the last term

$$(i.e.\ R\int_0^t e^{-it} dt)$$

represents the present value of the accumulated flow of possible land rents (opportunity costs) that a particular use of the natural resource entails.

By calculating the first derivative of [4], the following first-order condition necessary to maximize the NPV is obtained:

$$p'(t)\, q(t) + p(t)\, q'(t) + \text{h}(t) - R = i\, p(t)\, q(t) \qquad [5]$$

Equation [5] represents the basic rule for the optimal economic exploitation of every type of natural resource. Eq. [5] should be interpreted as a Jevonsian equilibrium between the two possible resource uses: extraction/harvest or conservation. In fact, the left-hand side of [5] represents the benefits to resource owners if they decide to postpone its exploitation, while the right-hand side of [5] represents the benefits to resource owners if they decide to exploit the resource immediately.

Thus, if resource owners postpone resource exploitation they will benefit from an increase in the price [$p'(t)$], from an increase in the stock of the resource [$q'(t)$] and from the possible flow of non-commercial services from the stock [$h(t)$]. However, they will, at the same time, incur an opportunity cost given by the land rent R. Now let us interpret the left-hand side of [5] as the benefit to resource owners associated with the immediate exploitation of the resource. Thus, if we now multiply the stock of resource $q(t)$ by its net price $p(t)$, we obtain the economic value of the resource. Therefore, the respective financial return of the resource is obtained by multiplying this figure by the discount interest rate *i*. Therefore, if the left-hand side of Eq. [5] is larger than the right-hand side, then it is economically better to conserve the resource. Otherwise, the rational economic decision is to exploit the resource. In short, Eq. [5] represents a typical Jevonsian equilibrium.

In what follows, the classic rules for the optimal exploitation of any type of natural resource will be straightforwardly derived from [5] by implementing different particularizations of the parameter values.

Some specifications in the proposed theoretical framework are:

— For *exhaustible resources,* we have the following specifications in our general equilibrium condition:

$$q(t) = \bar{q} \Rightarrow q'(t) = 0 \quad h(t) = R = 0$$

where $\bar{q}$ is the initial stock of the resource. For an exhaustible resource the growth of the stock of the resource is actually so slow that it can be considered negligible. Additionally, it is sensible to accept that there is no opportunity cost or land rent R to consider in this case, nor does the existence of a proper stock of the resource generate a flow of non-commercial services. By implementing the above specifications in [5], the following first-order condition is obtained:

$$\bar{q}\, p'(t) - i\, \bar{q}\, p(t) = 0 \qquad [6]$$

Equation [6] can be expressed as

$$\frac{p'(t)}{p(t)} = i \qquad [7]$$

The equilibrium condition [7] is known as Hotelling's rule or the "golden rule" of economic exploitation of exhaustible resources, as this outstanding economist proposed in 1931 (Hotelling, 1934).

— For *forest resources (plantation case)*, we have the following specifications in our basic equilibrium equation [5]:

$$p(t) = p \Rightarrow p'(t) = 0 \quad h(t) = 0$$

We assume initially that the timber price is constant, and the flow of non-commercial services derived from the plantation are negligible. By implementing the above specifications in [5], the following first-order condition is obtained:

$$pq'(t) - i\, p\, q(t) - R = 0 \qquad [8]$$

Equation [8] can be expressed as:

$$\frac{q'(t)}{q(t)} = i + \frac{R}{pq(t)} \qquad [9]$$

Equation [9] represents the well-known Faustmann formula, proposed by this renowned German forester in 1849 using a completely different analytical procedure (Faustmann, 1849). This formula is nowadays considered to be a basic foundation of the forest economics discipline.

Some extensions of the above formula can be easily implemented. Thus, we have admitted that the price of the resource is constant, since for a plantation scarcity does not necessarily increases with extraction. However, if we now consider that the timber price p is a function of time [*i.e.* $p = p(t)$], the new equilibrium is:

$$\frac{q'(t)}{q(t)} + \frac{p'(t)}{p(t)} = i + \frac{R}{p(t)q(t)} \qquad [10]$$

— For *Forest resources (a natural forest case)* the specifications to be implemented in Eq. [5] are:

$$p(t) = p \Rightarrow p'(t) = 0$$

Again we assume initially that the timber price is constant and that there is a significant flow of non-commercial services from the forest. Equation [5] turns now into the following new equilibrium:

$$pq'(t) - ipq(t) + h(t) - R = 0 \qquad [11]$$

Equation [11] can be expressed as:

$$\frac{q'(t)}{q(t)} = i + \frac{R - h(t)}{pq(t)} \qquad [12]$$

Equation [12] represents Hartman's well-known formula, proposed by this economist in 1976 (Hartman, 1976). It is interesting to note from Eq. [12] that the condition for the forest conservation is as follows:

$$\text{if } h(t) > ipq(t) + R \ \forall t$$

that is, the economic logic indicates that if the above inequality holds, then the forest should not be harvested. For instance, within a context where carbon sequestration plays a primary role, if the value of the flow of carbon captured by the forest is larger than the financial value of the timber [$ipq(t)$] plus the land rent R for every age of the forest, then the respective stands should not be harvested (Romero *et al.,* 1998).

Expression [12] admits several simple variants. Thus, if the timber price is a function of time [*i.e.* $p = p(t)$], then Hartman's expression given by [12] becomes:

$$\frac{q'(t)}{q(t)} + \frac{p'(t)}{p(t)} = i + \frac{R - h(t)}{p(t)q(t)} \qquad [13]$$

— A sensible set of specifications of Eq. [5] for *commercial fisheries* resources is:

$$p(t) = p \Rightarrow p'(t) = 0, \ h(t) = R = 0$$

that is, we assume again that the price of fish is constant and that the flow of non-commercial services provided by fish stock, as well as due to the characteristics of the resource there is not anything like a land rent. By implementing the above specifications in [5], the following first-order condition is obtained:

$$p\,q'(t) - i\,p\,q(t) = 0 \qquad [14]$$

Equation [14] can be expressed as:

$$\frac{q'(t)}{q(t)} = i \qquad [15]$$

The equilibrium condition [15] matches the classic equilibrium defined by Gordon in 1954 for a fisheries management problem (Gordon, 1954). It is interesting to note that Faustmann's formula given by [9] and Eq. [15] coincide, provided that the land rent *R* is zero. Hence, the key difference in terms of economic logic between forestry and fisheries resources is the consideration of an opportunity cost or land rent *R* derived from covering the soil with a specific timber stand.

— For the case of *non-commercial fisheries* or for a fishery (e.g. *case of the blue whale*) with important capture constraints for environmental reasons, the following specifications seem sensible:

$$q(t) = \bar{q} \Rightarrow q'(t) = 0 \;\; \mathrm{R} = 0$$

For the above specifications the equilibrium condition [5] is:

$$\bar{q}\,p'(t) + h(t) - i\,\bar{q}\,p(t) = 0 \qquad [16]$$

Equation [16] can be expressed as:

$$\frac{p'(t)}{p(t)} = i - \frac{h(t)}{\bar{q}p(t)} \qquad [17]$$

Another point worthy of note is the fact that from Eq. [17] the following condition is obtained:

$$\text{If } h(t) > i\,\bar{q}\,p(t)\;\forall t$$

then economic logic dictates that the fish considered (*e.g.,* blue whale) should never be captured.

We have illustrated the potential of the proposed model by deriving from Eq. [5], the classic rules of exploitation of five types of illustrative natural resources. These findings are summarized in Table 1. However, it is quite clear that by making other changes to the values of the parameters appearing in Eq. [5], more real rules of rational exploitation of natural resources can be derived.

Different policy implications can be derived from the proposed unified framework, valid for any type of natural resource. To analyze a crucial policy implication, we will determine the influence of the value of the interest rate on the temporal process underlying to the optimal economic exploitation of any type of natural resource. To do this, note that the basic Eq. [5] is actually a function *Z*(*t*,*i*) of the planning horizon *t* and of the discount rate *i*. By calculating the total differential of Z(t,i), we have:

$$\left[pq''(t) + h'(t) - ipq'(t)\right]dt = pq(t)di \qquad [18]$$

Notice that, without loss of generality and in order to avoid unnecessary algebraic complications, the price of the resource has been assumed to be constant. Eq. [18] is equivalent to:

$$\frac{dt}{di} = \frac{pq(t)}{pq''(t) + h'(t) - ipq'(t)} \qquad [19]$$

It is straightforward to check that, according to the specifications given above, the sign of [19] is negative. That is, there is an opposing relationship between the discount rate i and the planning horizon *t*. Therefore, high interest rates lead to resources of private property to short planning horizons (*e.g.* short rotation age, short economic exhaustion periods for a non-renewable resource, etc.). This can imply high risks of collapse for any resource whatsoever. Monetary policies and conservation policies are clearly linked!

The analytical framework presented in this paper is very elementary. It is intended as a first step in the search for a unified framework for the economic analysis of natural resources. However, the proposed framework represents the fundamental underpinning of more advanced ways of dealing with this type of problem. Additionally, some important conclusions have been drawn from the analysis. Although there are wide-ranging resources, their similarities are stronger than their differences from the viewpoint of the economic logic underlying their exploitation.

We can move on to more realistic models by eliminating or weakening the set of assumptions established above. However, it is now clear that there are substantial likenesses between all the natural resources (be they non-renewable, forestry, fisheries, etc.) from the viewpoint of economic logic.

Although the different parts of this paper are themselves well-known approaches, their integration into a common framework serves to clarify the close relationship between the economic aspects of the different natural resources. The literature has tended to neglect this kind of integration. However, its theoretical con-

Table 1. Type of resource, parameter specification and basic rules of exploitation.

Natural resource	Parameter specification	Basic rule of exploitation
Exhaustible	$q(t) = \bar{q} \Rightarrow q'(t) = 0 \quad h(t) = R = 0$	$\frac{p'(t)}{p(t)} = i$
Forestry (plantation)	$p(t) = p \Rightarrow p'(t) = 0 \quad h(t) = 0$	$\frac{q'(t)}{q(t)} = i + \frac{R}{pq(t)}$
Forestry (natural forest)	$p(t) = p \Rightarrow p'(t) = 0$	$\frac{q'(t)}{q(t)} + \frac{p'(t)}{p(t)} = i + \frac{R - h(t)}{pq(t)}$
Commercial fisheries	$p(t) = p \Rightarrow p'(t) = 0 \quad h(t) = R = 0$	$\frac{q'(t)}{q(t)} = i$
Non-commercial fisheries	$q(t) = \bar{q} \Rightarrow q'(t) = 0 \quad R = 0$	$\frac{p'(t)}{p(t)} = i - \frac{h(t)}{\bar{q}p(t)}$

sideration has the following advantages: i) the proposed unified framework stresses economic similarities between different natural resources; this can increase understanding, clarity and precision in future dialogues; ii) it is important to understand that all the basic rules (Faustmann, Gordon, Hartman, Hotelling, etc.) for the optimal economic exploitation of a natural resource derive from a common framework; iii) the economic logic underlying the optimal exploitation of any type of natural resource is the same, the differences are due exclusively to the empirical facts about the resource; for instance, the fixedness or variability of the stock of the resource depending on a particular natural growth rate.

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