Conservation Markets for Common-Pool Natural Resources: Do they sustain efficient equilibria when exclusion or alienation rights are not feasible?

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Abstract

We show that creating a Conservation Market for natural resources leads to a decentralized efficient equilibrium by using competitive markets with no need for subsidies or entry constraints. We consider a dynamic general equilibrium model in which agents have infinite lifetimes and allocate time to exploiting a common-pool natural resource, which is consumed, and to leisure. We prove that allocating ownership rights to families linked to conservation markets enables the Pareto optimal allocation to be sustained as a competitive equilibrium with free access and with no need to subsidize firms. Moreover, environmental service prices in equilibrium are positive and depend negatively on the discount factor and on household preferences for leisure relative to consumption, and positively on the growth elasticity of the resource.

Keywords: conservation markets, ownership rights, common-pool resources.
JEL codes: O1.

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1 Introduction

Schlager and Ostrom (1992) define the rights of access, withdrawal, management, exclusion and alienation as the most significant ownership rights for the use of common-pool resources. Table 1 describes these four categories of rights. Schlager and Ostrom classify individuals in ownership categories – owner, proprietor, claimant, and authorized user – depending on what rights each individual possesses. Schemes that include the right of alienation can be considered in full ownership right schemes because include all the other rights and are equivalent to private ownership (Ostrom, 2003). Some examples of this type of scheme applied to natural resource management are the individual transferable quotas (ITQs) created for avoiding the overexploitation of fisheries (Clark, 1973; Pearse, 1992)\footnote{Some authors consider that ITQs do not create full property rights in some fisheries because they include sunset clauses which mean that they are not permanent (Copes 1986, Bromley 2009).}, the tradable emission permits to prevent excessive pollution (Montgomery, 1972; Grafton and Rose, 1996) and the tradable permits to protect rare habitats and biodiversity (Wissel and Wätzold, 2010).\footnote{See Tietenberg (2006 and 2007) for surveys on the implementation and results of different programmes.}

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Source: Adapted by Ahmed et al. (2008) from Schalager and Ostrom (1992)

There is also a long tradition in natural resource economics suggesting that efficiency cannot be achieved when the privatization mechanism allows free access to the resource (Gordon, 1954; Hardin, 1968). In the terms used by Schlager and Ostrom (1992), privatization schemes without exclusion or alienation rights are not enough strong to generate efficient allocations. The economic reasoning behind this idea is twofold: on the one hand, when ownership rights are allocated to firms they tend to overexploit the resource, obtaining extraordinary profits. In this case, efficiency requires not only design ownership mechanisms designed to include exclusion rights but also adequate monitoring to prevent access to the exploitation of the resource. On the other hand, if the ownership rights are allocated to consumers a competitive market with free access dissipates profits and firms have to be subsidized to pay the rental of the common-pool resource.

In this paper we show that creating a conservation market for a common-pool resource is a fair mechanism that leads to efficient allocations by using competitive markets without the need for subsidies or entry.
constraints. We consider the creation of a conservation market in a dynamic general equilibrium model, where agents have infinite lifetime and allocate time to exploiting a natural resource, which is consumed, and to leisure.

Conservation markets were first suggested by Chichilnisky and Heal (1998) as an economic instrument to “securitize natural capital” with the goal of preserving the biosphere. Such markets traditionally are linked to the provision of environmental services. However, the system can be applied to the management of any natural common-pool resource where free access leads to the overexploitation of the resource. The main tool used for the implementation of a conservation market is Payments for Environmental Services (Wunder, 2006), which entails voluntary transactions where the environmental service provider is paid by service beneficiaries whenever the environmental service generates an externality. Payments for environmental services are the key to many conservation programmes that have been successfully implemented, e.g. the United State Conservation Reserve Program (Sullivan et al., 2004), the Mexican Payments for Hydrological Services Program (Muñoz-Piña et al., 2008) and the Zimbabwe Communal Areas Management Programme for Indigenous Resources (Frost and Bond, 2008). A good survey of the use of Payments and Environmental Services can be found in Engel et al. (2008).

In our framework, the environmental service is the service derived from the extraction of the natural resource (for instance, the resource harvested), the exploitation firms are the service providers (the firms that use the technology to extract the resource) and the families are the service beneficiaries (consumers). Consider in our benchmark economy that the ownership rights of the common-pool resource are fully assigned to the families. In this context, families are willing to invest in the future of the resource because their future revenues will depend on the state of the stock. A conservation market can be assumed in which exploitation firms negotiate with the owners (families) and obtain revenues for that part of the resource that is not exploited; this can be seen just as an example of a payment for an environmental service. We formally prove that in this set up there is a competitive equilibrium with a positive payment for the environmental service which implies that firms’ profits are zero and the allocation is efficient in the Pareto sense. Thus, the allocation of fully ownership rights to families linked to a conservation market enables the Pareto optimal allocation to be sustained with free access and with no need for subsidies. Moreover, environmental service prices in equilibrium are positive and depend negatively on the discount factor and on household preferences for leisure relative to consumption, and positively on the growth elasticity of the resource.

In spite of how widely it is used, there are few articles analyzing the theoretical economic properties of including conservation markets in the management of natural resources. Exceptions include Ferraro and
Simpson (2002), who demonstrate that paying for ecosystem protection directly can be far more cost-effective than encouraging commercial activities that indirectly generate ecosystem protection; Gulati and Vercammen (2006) show ways to overcome the time-inconsistency inherent in resource conservation contracts; and Foundi (2012) who analyzes the circumstances under which resource conservation contracts incentivise the conserving of soil services. The present article seeks to contribute to this literature by showing that the merging of a conservation market based on appropriate ownership rights leads a competitive economy with common-pool natural resources to an optimal self-sustained equilibrium.

The paper comprises 5 sections. Section 2 describes the model and characterizes the Pareto efficient allocation that is used as a reference to assess the results obtained in the following sections. Section 3 shows that resource privatization is efficient but it requires subsidies for firms or entry constraints. Section 4 shows how a conservation market enables free access competitive equilibrium (without subsidies) to be efficient. Section 5 concludes.

2 Efficient allocation

At the beginning of each period there is a stock of a natural resource, $X_t$, which is available for exploitation by the members of the economy. This resource grows according to a Cushing function (Cushing, 1973), thus the gross growth function is given by $F(X_t) = AX_t^\alpha$, where $\alpha \in [0, 1]$ represents the growth elasticity of the stock and $A > 0$ can be interpreted as the productivity of the resource.

There are a number of identical firms that exploit the resource with an extraction technology that uses labor, $l$, and the gross stock as inputs to obtain the extraction yield. In particular the production function considered is $h_t = F(X_t)l_t$, which $h_t$ represents the extraction yield.

The assumptions made in regard to the natural behavior of the resource and the technology used to exploit it define the dynamics of the resource, which are shown in the following functions:

$$X_{t+1} = AX_t^\alpha - h_t,$$

$$h_t = AX_t^\alpha l_t. \quad (1)$$

On the other hand, the economy consists of a number of families with infinite lifetimes. In each period $t$ each of them is endowed with one unit of time, a fraction of which, $l_t$, is dedicated to exploiting the resource and the remaining $1 - l_t$ to leisure or to producing goods at home. These families thus obtain utility from
the consumption of the natural resource extracted, \( c \), and from leisure. In particular we consider that the preferences of the families are represented by the following strictly concave and monotonically increasing utility function

\[
u(c_t, 1 - l_t) = \log c_t + e \log(1 - l_t),
\]

where \( e \) represents the weight of leisure relative to the consumption.

Assume a benevolent social planner who takes into consideration that his/her decisions on current consumption affect the future size of the stock. It is well known that in this context, without markets, the allocation that results from the process of maximizing the discounted life utility of the representative family subject to what is feasible is efficient in the Pareto sense. Families choose their optimal consumption path, \( \{c_t\}_{t=1}^{\infty} \), and the allocation of their time endowment, \( \{l_t\}_{t=1}^{\infty} \), by solving the following dynamic problem,

\[
\max_{\{c_t, l_t, X_{t+1}\}_{t=1}^{\infty}} \sum_{t=0}^{\infty} \beta^t \left[ \log c_t + e \log(1 - l_t) \right],
\]

\[
\text{s.t.} \begin{cases}
  c_t & = h_t \\
  h_t & = AX_t^p l_t, \\
  X_{t+1} & = AX_t^p - h_t, \\
  X_{t+1}, l_t & \geq 0, X_{t+1} \geq 0,
\end{cases}
\]

where \( \beta \in (0, 1) \) is the subjective discount factor.

The first constrain in problem (3) is the resource constraint of the economy in period \( t \), which means that the total supply of the resource extracted provides for the consumption of the families. The second and third constrains show the extraction technology, (2), and the dynamics of the natural resource, (1), respectively.

In the dynamic optimization problem (3), the stock of the resource can be seen as the state variable. Therefore, rewriting the control variables, \( c_t \) and \( l_t \), as functions of the state variable:

\[
\begin{align*}
  c_t &= AX_t^p - X_{t+1}, \\
  1 - l_t &= \frac{X_{t+1}}{AX_t^p},
\end{align*}
\]

we can be simplified the dynamic problem. Then the Pareto optimal allocation can be obtained by solving
the following problem:

\[
\max_{\{X_{t+1} \in \mathbb{R}^+\}} \sum_{t=0}^{\infty} \beta^t \left[ \log AX_t^\alpha - X_{t+1} + \epsilon \log \left( \frac{X_{t+1}}{AX_t^\alpha} \right) \right].
\]

The first order conditions for solving this dynamic problem are given by the following Euler equation:

\[
\frac{X_{t+1}}{AX_t^\alpha - X_{t+1}} = \frac{\alpha \beta AX_{t+1}^\alpha}{AX_{t+1}^\alpha - X_{t+2}} + e(1 - \alpha \beta), \tag{4}
\]

and the transversality condition for the resource, by the following:

\[
\lim_{t \to \infty} \beta^{t-1} \frac{X_{t+1}}{AX_t^\alpha - X_{t+1}} = 0.
\]

Notice that the Euler equation (4) can also be written as:

\[
\frac{c_{t+1}}{c_t} = AX_{t+1}^{1-\alpha} \left[ \alpha \beta + e(1 - \alpha \beta) \right] - \frac{X_{t+2}}{X_{t+1}} e(1 - \alpha \beta).
\]

This expression helps to interpret the optimal condition of the dynamic problem (3). It indicates that in the efficient allocation consumption in every period is chosen such that the marginal rate of substitution between present and future consumption (left hand side) is equal to the net marginal product of the natural resource (right hand side). Notice that the marginal product of the resource is the balance between two effects: i) the increase in production in the next year (first sum on the left hand side); and ii) the negative effect on the stock in future periods (second sum on the left hand side).

The Euler equation (4) is a two-order differential equation on the resource variable, \(X_t\). It can be reduced to a first order differential equation by defining \(z_t = X_{t+1}^{1-\alpha} \). Taking this into account, the equation to be solved is:

\[
\frac{z_t}{1 - z_t} = \frac{\alpha \beta}{1 - z_{t+1}} + e(1 - \alpha \beta).
\]

It is straightforward to see that the stationary Pareto optimal allocation is given by

\[
z_{t+1} = z_t = z = \frac{\alpha \beta + e(1 - \alpha \beta)}{1 + e(1 - \alpha \beta)} < 1. \tag{5}
\]

Notice that \(z_t\) represents the fraction of the growth resource that is not depleted in period \(t\), i.e. that is the savings of the resource kept for the future. Moreover \(z_t = 1 - l_t\). Therefore, the fraction of the growth resource that is not depleted is equal to the optimal fraction of time that is devoted to leisure and in the stationary solution that fraction is constant.
We prove in the appendix (in Proposition 3) that \( z_t = 1 - l_t \) depends positively on the parameters \( \alpha, \beta \) and \( \epsilon \). These results are quite intuitive. When households care more about the future (higher \( \beta \)) they save more resources for the future. When \( \alpha \) increases, the economy is able to produce the same amount with less labor, thus increasing leisure and the saving rate in equilibrium. Also, when households value leisure relatively more than consumption (higher \( \epsilon \)) they consume less, thus increasing the savings of resources for the future.

3 Resource Privatization

The efficient allocation obtained in the previous section serves as a reference point for assessing the consequences of privatizing the natural resource in terms of allocation. The subsections below compare the efficient allocation obtained above with the competitive equilibria obtained in market economies by privatizing the resource. This comparison enables conclusions to be drawn concerning the degree of efficiency and sustainability of the results achieved by privatization.

Assigning ownership to the firms.

The first step is to analyze the behavior of the economy under the assumption that the resource ownership rights are fully assigned to firms. In the terms used by Schlager and Ostrom (1992), firms can be considered as the owners of the resource.

Assume that in period \( t \) there are \( T_t \) firms endowed with the right to exploit the resource. In this context, each firm \( i = 1, \ldots, T_t \) decides how much labor to hire, \( n^i_t \), and how much resource to extract, \( h^i_t \), taking as given resource prices, wages and the number of firms accredited. Since firms are the owners of the resource they take into account the effect of current extraction by all firms on the future size of the stock. Firms therefore introduce stock dynamics, (1), into their maximization calculations. Formally, firm \( i \) maximizes the present value of future profits by solving the following dynamic problem:

\[
\max_{\{h^i_t, n^i_t, X_{t+1}\}_{t=1}^\infty} \sum_{t=0}^\infty \beta^t \Pi^i_t = \sum_{t=0}^\infty \beta^t \left( h^i_t - w_t n^i_t \right),
\]

s.t.

\[
\begin{align*}
    h^i_t &= AX^\alpha_t n^i_t, \\
    X_{t+1} &= AX^\alpha_t - \sum_{i=1}^{T_t} h^i_t, \\
    h^i_t, n^i_t, X_t &\geq 0, \\
    X_0 &\text{ is given},
\end{align*}
\]

(6)

where \( w_t \) is the real wage in period \( t \) and superscript \( i \) stands for the variables of the firm \( i \).
With respect to families, we assume, with no loss of generality that there is a single representative family that obtains income from two sources.\(^3\) Wage income is obtained by offering their initial time endowment in the labor market, \(w_t l_t^w\), and asset income is obtained from firms’ profits, \(\Pi_t\). This income is used to purchase consumption of the resource extracted, \(c_t\). Given that families are not the owners of the resource, they do not take into account the effect of current extraction on the future size of the stock. Therefore families maximize their utility function taking wages and profits as given but not considering the dynamics of the resource. Formally the representative family solves the following static problem:

\[
\begin{align*}
\max_{\{c_t, l_t^w\}} & \quad \left[ \log c_t + e \log(1 - l_t^w) \right], \\
\text{s.t.} & \quad c_t = w_t l_t^w + \Pi_t, \\
& \quad c_t, l_t^w \geq 0, \\
& \quad \Pi_t \text{ is given.}
\end{align*}
\]

Note that in this scenario the economy consists of two competitive markets: a factor market where labor is negotiated between firms and workers (families) and a good market where the resource extracted is sold by firms to families. A competitive equilibrium in this economy is given by an allocation that solves the optimization problems of firms, (6), and families, (7), and where the goods and factor markets clear, i.e. \(c_t = \sum_{i=1}^{T_t} h_i^t, l_t^w = \sum_{i=1}^{T_t} n_i^t\) and \(\Pi_t = \sum_{i=1}^{T_t} \Pi_i^t\).

The competitive allocation of this economy where the ownership rights of the resource are assigned to the firms is efficient in the Pareto sense whenever the ownership rights are assigned to an adequate number of firms in each period. In particular, we prove that the number of firms with the right to exploit the resource must be adjusted period by period in such a way that the aggregate resource extracted is constant over time. The proof of this result is shown in the Appendix, in Proposition 1. Moreover, even if the number of firms accredited to exploit the resource guarantees efficiency of the competitive allocation, those firms may happen to obtain extraordinary profits. This implies that firms not accredited to do so have incentives to break the rules and illegally exploit the resource. This means that this efficient allocation can only be sustained with the aid of non-market mechanisms such as access constraints or perfect enforcement. The following proposition formalizes these results.

**Proposition 1.** When firms fully own the common-pool resource of the economy they obtain extraordinary profits and the competitive allocation is efficient whenever the assignment of ownership rights are assigned to an adequate (and non-constant) number of firms in each period.

\(^3\)Notice that in this economy firms have decreasing returns to scale while families have constant returns to scale. This means that in the case of families the optimal decisions do not depend on the number of families.
Proof: See Appendix.

The results in this section thus show that granting ownership to firms does not suffice to ensure the self-sustainability of an efficient competitive allocation. On the one hand, the ownership right assignment system has to be designed in a sophisticated way that enables the number of firms accredited for the exploitation of the resource to be changed period by period. On the other hand, a monitoring system that guarantees perfect enforcement is required to assure that non accredited firms cannot access to the resource. It can therefore be concluded that allocating ownership of the resource to firms is not an effective way of implementing a self-sustaining competitive equilibrium.

Assigning ownership to the families.

Assume that the resource is fully owned by families. In this case, firms have to rent the right to exploit the resource from families.

In this context, families obtain income from three sources. In each period they obtain it from just income from work, \( w_tl_t \), and profits, \( \Pi_t \), but also from renting their capital (natural capital) to firms, \( r_tK_t \), where \( r \) represents the rental price and \( K \) is the resource to be exploited. Since families are the owners of the resource they take into account the effect of current extraction on the future size of the stock. Families therefore introduce the dynamics of the stock, (1), into their optimization calculations. Formally, families maximize the present value of their future utility by solving the following dynamic problem:

\[
\max_{\{c_t, l_t, K_{t+1}\}} \sum_{t=0}^{\infty} \beta^t \left( \log c_t + \epsilon \log (1 - l_t^*) \right),
\]

\[
s.t. \\
\begin{align*}
 c_t &= w_tl_t^* + r_tK_t + \Pi_t, \\
 K_{t+1} &= AK_t^\alpha - c_t, \\
 c_t, l_t, K_{t+1} &\geq 0, \\
 K_0 \text{ and } \Pi_t \text{ are given.}
\end{align*}
\] (8)

The first constraint of this dynamic problem is the family budget constraint. The second represents the dynamics of the resource from the point of view of the owner: their capital tomorrow is the current capital taking into account its natural growth less the extraction used for consumption.

On the other hand, firms take decisions on labor hired, \( n \), the use of the resource rental, \( X \), and the amount extracted, \( h \), in such way that their profits are maximized, taking the price of the factors as given. Since firms are not the owners of the resource, they do not take into account the effect of current extraction on
the future size of the stock. Formally they solve the following static problem:

\[
\max_{\{h_t, n_t, X_t\}} \Pi_t = h_t - w_t n_t - r_t X_t,
\]

\[
\begin{align*}
\text{s.t.} & \quad h_t = a X_t, \\
& \quad h_t, n_t, X_t \geq 0.
\end{align*}
\] (9)

Note that in this scenario the economy consists of three competitive markets: two factor markets where labor and use of the resource are negotiated between firms and families (workers and owners of the resource) and a goods market where the resource extracted is sold by the firms to the families. A competitive equilibrium in this economy is given by an allocation that solves the optimization problems of families (8), and firms, (9), and where the goods and factor markets clear, i.e. \(h_t = c_t, l_t^s = n_t\) and \(K_t = X_t\).

We prove that the competitive allocation of this economy where resource ownership rights are assigned to families is efficient on the transitional path without adding any further constraints. Moreover we prove that the competitive allocation leads firms to make negative profits. The following proposition states the results.

**Proposition 2.** When families fully own the common-pool resource of the economy and no additional markets are created, then the competitive allocation is efficient if firms are subsidized.

**Proof:** See Appendix.

When families own the resource the competitive allocation is always efficient. This differs from the scenario in which ownership rights are assigned to firms; in this set up the efficiency of the competitive allocation does not require additional constraints on the design of ownership right assignation. However, as occurred in the previous subsection, the consequences of the solution in terms of distribution play a determinant role. To achieve this efficient allocation it is necessary to compensate firms for their losses by means of a system of subsidies. Thus, the results of this section show that granting ownership to families does not suffice to assure a competitive allocation. Even though the resource is privatized this market system still does not have all the elements required to sustain a competitive equilibrium. It can be concluded that allocating ownership to families is not an effective way of implementing a self-sustaining competitive equilibrium.

### 4 Conservation markets

As shown in the previous section, assigning ownership rights either to firms or to families without adding additional markets leads the competitive economy to efficient allocations which are costly to implemented.
On the one hand, when rights are assigned to firms the number of firms accredited for the exploitation of the resource has to be changed period by period. Moreover, enforcement mechanisms that can assure that non accredited firms cannot access to the exploitation of the resource are necessary. On the other hand, when ownership rights are assigned to families the sustainability of the efficient solution requires firms to be subsidized for their losses. In this section we show that creating a conservation market for the resource may solve these faults.

In the context where families are the full owners of the resource, the existence of a conservation market is based on the assumption that families will be willing to invest part of their income in conserving the resource whenever this improves their future utility. This enables the economy to be completed with a further market: the resource conservation market. Now firms, which pay families a rental at the commencement of the period for the right to exploit the resource, $r_t X_t$, have the possibility of selling that part of the resource that is not extracted at the end of the period for a price $q_t$.

This assumption generates a perfectly competitive context with complete markets. Now there are four different markets involved in the allocation process: a goods market where firms sell the resource extracted to families, two factor markets where labor and the use of the resource are negotiated between firms and families (workers and owners of the resource) and the conservation market, where firms sell to families the future resource that has not been depleted.

The assumption that families invest in the future of the resource has implications for their budget constraint. Now the income of families - wages, $w_t l_t$, the revenues generated by rental on the use of the resource, $r_t K_t$ and the profits of firms, $\Pi_t$- is used to pay for the consumption of the resource, $c_t$, and to invest in improving their future resource endowment, $i_t$. Formally the family’s budget constraint is:

$$c_t + i_t = w_t l_t + r_t K_t + \Pi_t.$$  

In this complete market economy families determine their optimal behavior by solving the following dynamic
maximization problem:

\[
\max \left\{ c_t, i_t, K_{t+1} \right\} \quad \sum_{t=0}^{\infty} \beta^t \left[ \log c_t + \epsilon \log (1 - l_t^i) \right],
\]

\[
\begin{aligned}
&\quad c_t + i_t = w_t l_t^i + r_t K_t + \Pi_t, \\
&\quad i_t = q_t K_{t+1}, \\
&\quad K_{t+1} = A K_t^\alpha - c_t, \\
&\quad c_t, i_t, K_{t+1} \geq 0, \\
&\quad K_0 \text{ and } \Pi_t \text{ are given.}
\end{aligned}
\]

(10)

On the other hand firms introduce into their calculations the fact that their income does not come solely from the sale of their extractions, \( h_t \), but that they can also sell that part of the stock that has not been depleted in the conservation market, at a price \( q_t \). Thus, in each period they pay \( r_t X_t \) for the right to access to the resource, hire \( n_t \) units of labor at a wage of \( w_t \) and decide how much to extract, \( h_t \), considering they can sell on the conservation market that part of the resource which is not depleted. Thus, firms solve the following static maximization problem:

\[
\max \left\{ h_t, n_t, X_t \right\} \quad h_t + q_t X_{t+1} - w_t n_t - r_t X_t,
\]

\[
\begin{aligned}
&\quad h_t = A X_t^\alpha n_t, \\
&\quad X_{t+1} = A X_t^\alpha - h_t, \\
&\quad h_t, X_{t+1}, n_t, X_t \geq 0, \\
&\quad X_t \text{ is given.}
\end{aligned}
\]

(11)

From the first order conditions of this problem, the prices of the factors can be written as follows:

\[
w_t = (1 - q_t) A X_t^\alpha,
\]

(12)

\[
r_t = \alpha A X_t^{\alpha-1} \left[ (1 - q_t)n_t + q_t \right].
\]

(13)

As usual, conditions (12) and (13) indicate that firms hire labor and resource use until their marginal products equal their factor prices. But notice that now the marginal products of both inputs, labor and use of the resource, reflect that hiring an additional unit of input will reduce the future stock and therefore the income that the firm can obtain in the conservation market.

A competitive equilibrium in this economy is given by an allocation that solves the optimization problems of families (10), and firms, (11), and where the good, factor and conservation markets clear, i.e. \( h_t = c_t \).
\[ l_t^n = n_t, K_t = X_t \text{ and } i_t = X_{t+1}. \]

The following proposition characterizes the competitive equilibrium of this economy under the assumption that families own the natural resource and there is a conservation market. In particular, we prove that the competitive equilibrium is efficient in the Pareto sense and can be sustained without the need to subsidize firms. Furthermore, we obtain the price for the environmental service in the conservation market. The proposition below formalizes the results.

**Proposition 3.** With a conservation market the free entry competitive equilibrium is efficient and firms make zero profits. Moreover, environmental service prices are positive at the following figures:

\[
q = \frac{\alpha l}{1 - \alpha (1 - l)} = \frac{\alpha (1 - \alpha \beta)}{1 - \alpha^2 \beta + e(1 - \alpha \beta) (1 - \alpha)} > 0.
\]

Furthermore, environmental service prices in equilibrium depend negatively on the discount factor, on household preferences for leisure relative to consumption, and positively on the growth elasticity of the resource (\( \partial q/\partial \alpha > 0, \partial q/\partial \beta < 0 \) and \( \partial q/\partial e < 0 \)).

**Proof:** See Appendix.

Notice that the price for the environmental service depends negatively on the labor rate. Since in this economy the optimal fraction of time devoted to leisure is equals to the share of resources saved for the future \( (z = 1 - l) \), then any increase in labor brings down the stock in the future. This depletion of the future stock implies an increase in the the price of the conservation service.

Moreover, we find that the more households care about the future (higher \( \beta \)) the lower the environmental service price, \( q \), is. The reasoning is the following: an increase in the discount factor increases the savings of the resource for the future \( (\partial z/\partial \beta > 0) \) and the larger the stock of the resource is in the future the lower the price is that households are willing to pay firms for the environmental service. The same reasoning applies to the weight of leisure relative to consumption in the utility function, \( e \). The more households care about leisure relative to consumption, the lower consumption and the time devoted to production are \( (\partial l/\partial e < 0) \), and the more time is devoted to leisure. This increases the resource savings for the future and this abundance leads to a reduction in the price for conserving the resource. Finally, any change in the growth elasticity of the stock, \( \alpha \), affects the environmental service price, \( q \), in two ways. First, an increase in growth elasticity increases the savings of the resource for the future \( (\partial z/\partial \alpha > 0) \) and this abundance reduces the price paid to firms for the environmental service. Second, an increase in growth elasticity lowers the price that firms have to pay to rental the resource for exploitation, \( r \); this reduction in input prices increases the current harvest,
lowering the future stock of the resource. Again, this scarcity leads the price of the conservation service to fall. The two effects go in opposite directions but we prove that the positive effect dominates the negative one.

In summary, if the families who own the resource are willing to invest in its conservation then firms may possibly negotiate with the part of the stock that is left unharvested in each period. Adding this conservation market to the existing markets avoids the distribution problems that could arise from privatization. An efficient competitive equilibrium with zero profit and free access is self-sustaining and therefore needs neither enforcement nor subsidies.

5 Discussion

The relationship between ownership rights and the conservation of natural resources has long concerned economists (Gray, 1913). Since Coase (1960), we know that the allocation of ownership rights is a mechanism that may solve some of the inefficiencies caused by externalities such as those that arise in the exploitation of common-pool natural resources.

In this paper we consider a dynamic general equilibrium model where agents have infinite lifetimes and allocate time to exploiting a natural resource, which is consumed, and to leisure. In this context, firstly, we first analyze the consequences of assigning full ownership rights either to firms or to families. On the one hand, we prove that if the privatization of the resource assigns the ownership rights to firms then the allocation system has to enable the number of firms accredited to exploit the resource to be change period by period; otherwise the efficiency of the competitive equilibrium is not assured. Moreover, a monitoring system that guarantees perfect enforcement is necessary to assure that non accredited firms cannot access to the resource. That is, regardless of the ownership rights used, control and enforcement are necessary to ensure that firms without access privileges are excluded from the exploitation (Grafton et al., 2006; Strandlund and Dhanda, 1999; Österblom et al., 2010; Nestbakken 2013; Da Rocha et al., 2013).

On the other hand, we prove that when the privatization mechanism assigns the ownership rights to families the competitive allocation is always efficient but firms have to be compensated for their losses by means of a system of subsidies. Experience and theory have shown that it is difficult to maintain efficiency when operating firms have to be subsidized (Arnason et al., 2008; Schroeer et al., 2011).

From these findings, we conclude that allocating full ownership to firms or families does not provide an
efficient, self-sustaining competitive equilibrium when exclusion or alienation rights are not feasible.

On the other hand it is well established that even resource privatization designed with ownership mechanisms that include the rights of exclusion and alienation are report to have negative effects on the conservation of the resource. For instance ITQs detail negative effects on sustainability due to grading and discarding (Vestergaard, 1996; Turner, 1997), biological losses because of the concentration of quotas in particular types of vessel (Amstronf and Sumaila, 2001) or the concentration of ITQs in a few large fishing companies (Pinkerton and Edwards, 2009). Along the same lines, tradable emission permit mechanisms may lead to adverse effects including higher emissions due to cheating (Egteren and Weber, 1996), noncooperative equilibrium settings (Helm, 2003) or the lack of precise formulation of moral concerns (Eyckmans and Kverndokk, 2010). Also the use of tradable permits to protect rare habitats and biodiversity may have negative effects if they are designed without including a spatial and temporal characterization in each individual permit (Dreschsler and Harting, 2011). All these issues could be addressed in future research in the context of a conservation market where the part of the resource not depleted in each period can be negotiated between economic agents.

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References


A Appendix

Proof of Proposition 1:

We start by characterizing the solution of the firms’ maximization problem (6). Note that from the first and the second restriction of the problem we can write

\[ h_i^t = A X_t^{\alpha} - X_{t+1} - \sum_{j=1, i \neq j}^{T_t} h_j^t, \]

\[ n_i^t = 1 - \frac{X_{t+1}}{A X_t^{\alpha}}. \]

Substituting both expressions into the maximizing function,

\[ L = \sum_{t=0}^{\infty} \beta^t (h_i^t - w_t n_t^i) = \sum_{t=0}^{\infty} \beta^t \left[ A X_t^{\alpha} - X_{t+1} - \sum_{j=1, i \neq j}^{T_t} h_j^t - w_t + w_t \frac{X_{t+1}}{A X_t^{\alpha}} \right]. \]

Therefore the first order condition is given by

\[ \beta^{\alpha} A X_t^{\alpha-1} - \beta w_t \frac{X_{t+1}}{A X_t^{\alpha}} - 1 + w_{t-1} \frac{X_{t-1}}{A X_{t-1}^{\alpha}} = 0. \]  

(14)

Moreover, the first order conditions for solving the families’ maximization problem (7) is given by the following equation,

\[ \frac{e c_t}{(1 - l_t^i)} = w_t. \]  

(15)

Considering the symmetry of the equilibrium, \( n_i^t = n_t \), the market clear conditions \( c_t = \sum_{i=1}^{T_t} h_i^t \) and \( l_t^i = \sum_{i=1}^{T_t} n_i^t = T_t n_t = l_t \), and the production function we can prove that

\[ c_t = \sum_{i=1}^{T_t} h_i^t = \sum_{i=1}^{T_t} A X_t^{\alpha} n_i^t = A X_t^{\alpha} \sum_{i=1}^{T_t} n_i^t = A X_t^{\alpha} T_t n_t = A X_t^{\alpha} l_t, \]

\[ X_{t+1} = A X_t^{\alpha} - \sum_{i=1}^{T_t} h_i^t = A X_t^{\alpha} (1 - T_t n_t) = A X_t^{\alpha} (1 - l_t). \]

(16)

Substituting these into the optimal (15) we can express

\[ \frac{w_t}{A X_t^{\alpha}} = e \frac{T_t n_t}{1 - T_t n_t} = e \frac{l_t}{1 - l_t} = e \frac{\sum_{i=1}^{T_t} h_i^t}{X_{t+1}}. \]
Plugging this into equation (14) and forward one period ahead

$$\beta \alpha \left( AX_{t+1}^{\alpha-1} - e \frac{\sum_{i=1}^{T_t} h_{i+1}^t}{X_{t+1}^n} \right) = 1 - e \frac{\sum_{i=1}^{T_t} h_i^t}{X_{t+1}^n},$$

$$1 = \beta \alpha AX_{t+1}^\alpha + e \frac{\sum_{i=1}^{T_t} h_i^t}{X_{t+1}^n} - \beta \alpha e \frac{\sum_{i=1}^{T_t} h_{i+1}^t}{X_{t+1}^n},$$

$$X_{t+1} = \beta \alpha AX_{t+1}^\alpha + e \frac{\sum_{i=1}^{T_t} h_i^t - \beta \alpha e \sum_{i=1}^{T_t} h_{i+1}^t}{X_{t+1}^n},$$

$$\frac{X_{t+1}}{AX_{t+1}^\alpha - X_{t+1}} = \beta \alpha AX_{t+1}^\alpha + e \left[ 1 - \beta \alpha \left( \frac{\sum_{i=1}^{T_t} h_{i+1}^t}{\sum_{i=1}^{T_t} h_i^t} \right) \right].$$

Notice that this expression coincides with the Euler equation of the efficient problem, (4), whenever the aggregate production is constant; that is, whenever $X_t^\alpha T_t n_t = X_{t+1}^\alpha T_{t+1} n_{t+1}$. This proves the statement i) of the Proposition 1.

On the other hand, we know that any efficient allocation is characterized by a constant ratio $z = \frac{X_{t+1}^\alpha}{AX_{t+1}^\alpha}$. Moreover $z = 1 - l$ is given by expression (5). Therefore, in any efficient solution

$$l = \frac{1 - \beta \alpha}{1 + e (1 - \beta \alpha)} < 1.$$

The efficient competitive allocation is fully described by

$$c_t = h_t = l AX_t^\alpha = \frac{1 - \beta \alpha}{1 + e (1 - \beta \alpha)} AX_t^\alpha,$$

$$w_t = e \frac{l}{1 - l} AX_t^\alpha = \frac{e (1 - \beta \alpha)}{\beta \alpha + e (1 - \beta \alpha)} AX_t^\alpha,$$

$$\Pi_t = c_t - w_t l = l \left[ 1 - e \frac{l}{1 - l} \right] AX_t^\alpha = \frac{\beta \alpha + (e + \beta \alpha) (1 - \beta \alpha)}{[1 + e (1 - \beta \alpha)] [\beta \alpha + e (1 - \beta \alpha)]} AX_t^\alpha.$$

Therefore profits are strictly positive in the stationary equilibrium. \( \blacksquare \)

**Proof of Proposition 2**

We start by characterizing the solution of the families’ maximization problem (8). The Lagrangian associated to this maximization problem is

$$\mathbb{L} = \sum_{t=0}^{\infty} \beta^t \left\{ \log c_t + e \log (1 - l_t^t) + \lambda_t [w_t l_t^t + r_t K_t + \Pi_t - c_t] + \mu_t [AK_t^\alpha - c_t - K_{t+1}] \right\},$$
where $\lambda_t$ and $\mu_t$ are the Lagrange multiplier associated to the restrictions of the maximization problem (8).

The first order conditions that solve this optimization problem are, $\forall t \geq 0$:

\[
\frac{\partial L}{\partial c_t} = 0, \quad \Rightarrow \quad \frac{1}{c_t} = \lambda_t + \mu_t, \tag{17}
\]

\[
\frac{\partial L}{\partial l_t} = 0, \quad \Rightarrow \quad \frac{e}{1 - l_t} = w_t \lambda_t, \tag{18}
\]

\[
\frac{\partial L}{\partial K_{t+1}} = 0, \quad \Rightarrow \quad \beta \{\lambda_{t+1} r_{t+1} + \mu_{t+1} \alpha AK_{t+1}^{\alpha-1}\} = \mu_t. \tag{19}
\]

On the other hand, the first order conditions of solving the firms’ maximization problem (9) are given by the following equations,

\[
w_t = AX_t^\alpha, \tag{20}
\]

\[
r_t = \alpha AX_t^{\alpha-1} n_t. \tag{21}
\]

Plugging equation (20), into equation (18) and taking into account that in equilibrium $K_t = X_t$ and $l_t = n_t = l_t$, we can write

\[
\frac{e}{1 - l_t} AX_t^\alpha = \lambda_t. \tag{22}
\]

Substituting this into equation (17), we have

\[
\mu_t = \frac{1}{c_t} - \frac{e}{1 - l_t} AX_t^\alpha = \frac{1}{c_t} - \frac{e}{X_{t+1}}. \tag{23}
\]

Plugging the first order condition of the firms maximization problem, (21), into equation (19) we can write

\[
\beta \alpha AX_{t+1}^{\alpha-1} \{\lambda_{t+1} r_{t+1} + \mu_{t+1}\} = \mu_t. \tag{24}
\]

Substituting expressions (22) and (23) into (24), we have

\[
\beta \alpha AX_{t+1}^{\alpha-1} \left\{\frac{1}{c_{t+1}} - \frac{e}{AX_{t+1}^\alpha}\right\} = \frac{1}{c_t} - \frac{e}{X_{t+1}}. \tag{25}
\]

Taking into account the restriction of the problem $c_t = AX_t^\alpha - X_{t+1}$, this expression can be rewritten after some manipulation as

\[
\frac{X_{t+1}}{AX_t^\alpha - X_{t+1}} = \frac{\alpha e AX_{t+1}^{\alpha-1}}{AX_{t+1}^\alpha - X_{t+2}} + e(1 - \alpha \beta),
\]

which is the Euler equation (4) that solves the efficient solution. Therefore, this proves that the competitive
equilibrium of this economy is efficient in the Pareto sense.

On the other hand, taking into account the production function and equations (20) and (21), the profits of the firms are given by

\[
\Pi_t = h_t - w_t n_t - r_t X_t
= AX_t^\alpha n_t - AX_t^\alpha n_t - \alpha AX_t^{\alpha-1} n_t X_t
= -\alpha AX_t^{\alpha} n_t < 0
\]

Therefore, when families are the owners of the resource firms make negative profits. ■

Proof of Proposition 3

We start by characterizing the solution of the families’ maximization problem when there exists a conservation market, problem (10). The Lagrangian associated to this maximization problem is

\[
L = \sum_{t=0}^{\infty} \beta^t \left\{ \log c_t + e \log(1 - l_t^*) + \lambda_t [w_t l_t^* + r_t K_t + \Pi_t - c_t - q_t K_{t+1}] + \mu_t [AK_t^{\alpha} - c_t - K_{t+1}] \right\},
\]

where \( \lambda_t \) and \( \mu_t \) are the Lagrange multiplier associated to the restrictions of the maximization problem (10).

The first order conditions that solve this optimization problem are, \( \forall t \geq 0 \):

\[
\frac{\partial L}{\partial c_t} = 0, \quad \implies \quad \frac{1}{c_t} = \lambda_t + \mu_t, \tag{25}
\]

\[
\frac{\partial L}{\partial l_t^*} = 0, \quad \implies \quad \frac{e}{1 - l_t^*} = w_t \lambda_t, \tag{26}
\]

\[
\frac{\partial L}{\partial K_{t+1}} = 0, \quad \implies \quad \beta \left\{ \lambda_{t+1} r_{t+1} + \mu_{t+1} \alpha AK_t^{\alpha-1} \right\} = q_t \lambda_t + \mu_t. \tag{27}
\]

Plugging the first order condition of the firms maximization problem, equation (12), into equation (26) and taking into account that in equilibrium \( K_t = X_t \) and \( l_t^* = n_t = l_t \), we can write

\[
\frac{e}{1 - l_t} \frac{1}{(1 - q_t) AX_t^\alpha} = \lambda_t, \tag{28}
\]

Substituting this into equation (26), we have

\[
\mu_t = \frac{1}{c_t} - \frac{e}{1 - l_t} \frac{1}{(1 - q_t) AX_t^\alpha} = \frac{1}{c_t} - \frac{e}{(1 - q_t) X_{t+1}}. \tag{29}
\]
Plugging the first order condition of the firms maximization problem, equation (13), into equation (27) we can write

$$\beta \alpha X_{t+1}^{\alpha - 1} \{ \lambda_{t+1} [(1 - q_{t+1}) l_{t+1} + q_{t+1}] + \mu_{t+1} \} = q_t \lambda_t + \mu_t. \quad (30)$$

Substituting expressions (28) and (29) into (30), we have

$$\beta \alpha X_{t+1}^{\alpha - 1} \left\{ \frac{e}{1 - l_{t+1} (1 - q_t)} X_{t+1}^{\alpha} - \frac{1}{1 - l_{t+1} (1 - q_t) AX_t^{\alpha}} \right\} = \frac{e}{1 - l_t (1 - q_t) AX_t^{\alpha}} + \frac{1}{c_t} - \frac{e}{1 - l_t (1 - q_t) AX_t^{\alpha}}.$$

$$\Rightarrow \quad \beta \alpha X_{t+1}^{\alpha - 1} \left\{ \frac{1}{c_{t+1}} - \frac{e}{AX_{t+1}^{\alpha}} \right\} = \frac{1}{c_t} - \frac{e}{X_{t+1}}. \quad (31)$$

Taking into account the restriction of the problem $c_t = AX_t^{\alpha} - X_{t+1}$, this expression can be rewritten after some manipulation as

$$\frac{X_{t+1}}{AX_t^{\alpha} - X_{t+1}} = \frac{\alpha \beta AX_{t+1}^{\alpha}}{AX_{t+1}^{\alpha} - X_{t+2}} + e(1 - \alpha \beta),$$

which is the Euler equation (4) that solves the efficient solution. Therefore, this proves that the competitive equilibrium of this economy is efficient in the Pareto sense.

On the other hand, taking into account the production function and first order conditions of the firms maximization problem, equations (12) and (13), the profits of the firms are given by

$$\Pi_t = h_t + q_t X_{t+1} - w_t l_t - r_t X_t$$

$$= AX_t^{\alpha} l_t + q_t AX_t^{\alpha} (1 - l_t) - (1 - q_t) AX_t^{\alpha} l_t - \alpha AX_t^{\alpha - 1} [(1 - q_t) l_t + q_t] X_t$$

$$= AX_t^{\alpha} [q_t (1 - \alpha) - \alpha l_t (1 - q_t)]. \quad (32)$$

Notice that the competitive equilibrium allocation is independent of the price in the conservation market (see that equation (31) does not depend on $q_t$). However, profits, equation (32), do depend on the price in the conservation market, $q_t$.

On the other hand, since the competitive equilibrium is Pareto efficient, then leisure and labor are constant in equilibrium and are given by expression (5),

$$z = 1 - l = \frac{\alpha \beta + e(1 - \alpha \beta)}{1 + e(1 - \alpha \beta)}, \quad \Rightarrow \quad l = \frac{1 - \alpha \beta}{1 + e(1 - \alpha \beta)}.$$
After some calculation we find that

\[
\begin{align*}
\frac{\partial l}{\partial \alpha} &= -\frac{\beta}{[1 + e(1 - \alpha\beta)]^2} < 0, \\
\frac{\partial l}{\partial \beta} &= -\frac{\alpha}{[1 + e(1 - \alpha\beta)]^2} < 0, \\
\frac{\partial l}{\partial e} &= -\frac{(1 - \alpha\beta)^2}{[1 + e(1 - \alpha\beta)]^2} < 0.
\end{align*}
\] (33) (34) (35)

This proves the statement mentioned at the end of Section 2.

Therefore if the price for the conservation market is constant and equal to

\[
q = \frac{\alpha l}{1 - \alpha (1 - l)} = \frac{\alpha (1 - \alpha\beta)}{1 - \alpha^2 \beta + e(1 - \alpha\beta)(1 - \alpha)} < 1,
\]

then profits expressed in (32) are zero. Moreover, we can see that

\[
\frac{\partial q}{\partial l} = \frac{\alpha (1 - \alpha)}{[1 - \alpha (1 - l)]^2} > 0.
\] (36)

On the other hand, taking into account (33), (34), (35) and (36) we can calculate after some manipulation

\[
\begin{align*}
\frac{\partial q}{\partial \alpha} &= \frac{l (1 - \alpha)}{[1 - \alpha (1 - l)]^2} + \frac{\partial q}{\partial l} \frac{\partial l}{\partial \alpha} = \frac{(1 - \alpha\beta) (1 + \alpha)}{[1 - \alpha (1 - l)]^2 [1 + e(1 - \alpha\beta)]^2} > 0, \\
\frac{\partial q}{\partial \beta} &= \frac{\partial q}{\partial l} \frac{\partial l}{\partial \beta} = -\frac{\alpha^2 (1 - \alpha)}{[1 - \alpha (1 - l)]^2 [1 + e(1 - \alpha\beta)]^2} < 0, \\
\frac{\partial q}{\partial e} &= \frac{\partial q}{\partial l} \frac{\partial l}{\partial e} = -\frac{\alpha (1 - \alpha) (1 - \alpha\beta)^2}{[1 - \alpha (1 - l)]^2 [1 + e(1 - \alpha\beta)]^2} < 0.
\end{align*}
\]