Managing multiple fishery pools: property right regimes and market structures

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ABSTRACT: Well-defined and enforceable property rights are usually seen as a prerequisite for optimal resource management. However, the interaction effects between different renewable resource pools with different ownership structures are often not well recognized. In this paper we introduce these interaction effects in the optimal fishery management theory. Various property right regimes and market structures for fisheries are analyzed. Furthermore, we perform a sensitivity analysis with respect to the carrying capacity of the lakes for the different agents. We show that an increase in the carrying capacity has an ambiguous result on the optimal catch. Furthermore, differences in carrying capacity lead to trade and that the more market power the other player has the more you start supplying yourself resulting in lower steady state stock levels.

Keywords: fisheries, market structures, property rights, renewable resources

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1 INTRODUCTION

When the property rights regime of lakes can be characterized as open access fisheries the problem of the commons will occur. This is well known for the case of closed economies. In a trade context the problem is also demonstrated by e.g. Brander and Taylor (1997 and 1998). In our analyses we also focus on the effect of property rights regimes on the world market. An example where analyses concerning trade in renewable resources can be applicable are the alkaline lakes in Tanzania and Kenya. Due to the high concentration of alkaline, only certain kinds of tilapia can grow in these lakes and these fish are not found anywhere else. In addition no other fish grows here (Ramsar, 2001 and Fishbase, 2005). Currently there a regime prevails of regulated open access, fishermen can buy permits allowing them to catch whatever they want. In the future the two countries can opt for a different strategy of assigning property rights resulting in different market structures. Another example concerns lake trout in Trout lake and Black Oak lake in Northern America. Genetic tests showed that this fish is a unique species and only lives in these two lakes. The regulating government decides on the amount of fish that can be caught (Outdoor News Network, 2003). An often heard solution to the problem of the commons is to assign well defined property rights to persons who will keep in mind the effect of their current actions on the future. The way these property rights are assigned can result in different market structures. It is the purpose of this paper to investigate those different market structures. Chichilnisky (1994) shows that if two countries are identical except for property rights there is room for trade. It is shown that due to trade the problem of overuse of the natural resources increases for the country with an open access regime. However, growth of the natural resource is independent of the stock. Levhari and Mirman (1980) consider a Nash-Cournot game where two agents are harvesting from the same common resource pool but not for spatially separated resources. Fischer and Laxminarayan (2005) look at a situation where there is interaction between a privately owned company that produces antibiotics and an open access pool of antibiotics. However, opposed to fisheries there is no restriction on the amount that can be produced as there is not a finite resource nor does the growth depend on the current stock.[2]

[2] For exhaustible resource markets extensive research has been done for different (complex) structures, for example a Nash-Cournot equilibrium (Salant, 1976), or the von Stack-

As can be seen from the two examples there are real-life situations where there will be an interaction effect between lakes. Furthermore, if one of these countries decides to introduce well defined property rights this will lead to new market structures and thus the interaction between the two countries changes. These interaction effects will be investigated for different market-structures and ownership regimes in a two-country setting. Besides differences in ownership regime the two lakes can also differ in size resulting in different carrying capacities[3] and corresponding stock and catch levels. These effects in changes of carrying capacity will also be analyzed.

In the next section we will present the model and the assumptions. In the third section the equilibrium in autarky will be analyzed as a benchmark. The fourth section will analyze equilibria when the countries start trading and section five will analyze the situation when the two countries cooperate. Section six concludes.

We show that an increase in the carrying capacity has an ambiguous effect on the optimal catch. Furthermore, differences in carrying capacity lead to trade and that the more market power the other player has the more you start supplying yourself resulting in lower steady state stock levels.

2 THE MODEL

To describe the different market structures and property rights regimes a model with two separate lakes indexed by i ($i = 1, 2$) will be considered. Fish stocks at instant of time t are denoted by $X_i(t)$. The initial stocks are $X_{i0} > 0$. The natural growth function G_i satisfies

(A.1) $G_i(0) = G_i(K_i) = 0$ for some $K_i > 0$. G_i is nonnegative and strictly concave on $[0, K_i)$. Finally, $G_i(X) = 0$ for all $X > K_i$.

By y_i we denote total catch from lake i. Hence:

$$\dot{X}_1(t) = G_1(X_1(t)) - y_1(t), \; X_1(0) = X_{10}, \; X_1(t) \geq 0, \; y_1(t) \geq 0 \quad (1)$$

elberg equilibrium (for open-loop von Stackelberg, see for example, Gilbert, 1978, Newbery, 1981, and Groot et al., 1992; for the feedback von Stackelberg equilibrium see, Groot et al., 2003).

[3] The carrying capacity of a lake is the maximum amount of fish that can sustainable live in that lake.

$$\dot{X}_2(t) = G_2(X_2(t)) - y_2(t),\ X_2(0) = X_{20},\ X_2(t) \geq 0,\ y_2(t) \geq 0 \qquad (2)$$

Fish from the two lakes is homogeneous. Local demand for fish, z_i, is given by an identical inverse demand function $P(z_i)$ that is monotonically decreasing and has the usual properties derived from a quasilinear utility function $V_i(z_i, m_i) = U(z_i) + m_i$. Here m_i represents money holdings. Note that utility from fish consumption is equal across regions. The amount of fish caught depends on the current stock and the effort e_i (see for example Clark (2005)). The cost per unit of effort is w. With constant returns to scale of effort, for a given stock, the cost of fishing is $we_i = C_i(X_i)y_i$. With regard to $C_i(X_i)$ the following assumption is made:

(A.2) C_i is decreasing and strictly convex. Moreover $P(0) = C_i(\hat{X})$ for some $\hat{X} > 0$.

The latter condition implies that fishing is not profitable for all $0 \leq X \leq \hat{X}$.

3 AUTARKY

The ownership regimes considered in autarky are open access and private ownership. In the latter regime we make a distinction between the case where the private owner can exercise market power and the case where he cannot. In the present section we omit the index i.

3.1 Open Access

With open access anyone can start fishing without restrictions and fishermen will continue fishing as long as they can make a profit. Hence, in the long run all rents dissipate (Gordon, 1954). Following the standard approach in fishery economics entry and exit do not take place instantaneously. Similar to e.g. Perman et al. (2003) we introduce some delay in the response of the catch to changes in profitability. So,

$$\dot{y}(t) = \alpha[P(y(t)) - C(X(t))]y(t)$$

$$y(t) = 0 \text{ if } P(0) < C(X(t))$$

Therefore, as long as the price exceeds the unit cost of fishing, catch will increase. However, if fishing is not profitable, fishing immediately ceases. We also have

$$\dot{X}(t) = G(X(t)) - y(t)$$

In $X - y$ space the isoclines can be drawn A typical shape of the isoclines is depicted in figure 1. There are two stable equilibria. The first is $(0, \hat{X})$, which occurs if the initial stock is smaller than or equal to $\hat{X}$. The other equilibrium is point A, where $P(y) = C(X)$ and $y = G(X)$. Below the latter curve the stock of fish is increasing. The curve $P(y) = C(X)$ is increasing. If $P(y) > C(X)$, hence for small y profits are positive and catch is increasing. This explains the phase diagram in figure 1.

We are interested in the dependence of the solution on the carrying capacity. If the carrying capacity is increased then the new locus of points for which $y = G(X)$ will lie entirely above the old one. So, if the carrying capacity does not play a role in the cost function, the steady state stock as well as the steady state catch will increase. If the costs are increasing in the carrying capacity, then the locus of points for which $p(y) = C(X)$ will move downwards. Hence, in this case the steady state stock increases as well. However, the effect on the steady state catch is ambiguous.

3.2 Private ownership

The private owner maximizes his profits over time, discounted at the constant discount rate $\rho > 0$. In the absence of foreign supply the private owner is the only supplier. Formally, the optimization problem for the private owner can be stated as follows:

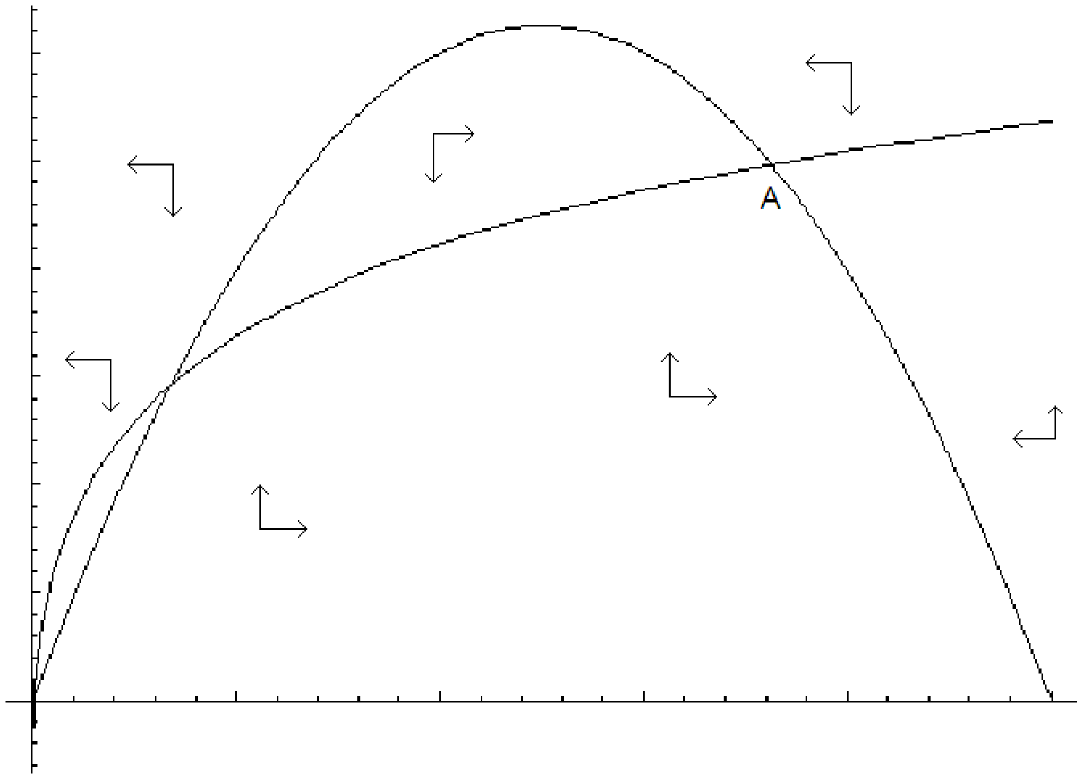

Figure 1: Phase diagram autarky

$$\max_{y} \int_{0}^{\infty} \{P(y) - C(X)\} y e^{-\rho t} dt$$

subject to (1). The current-value Hamiltonian reads:

$$H(X, y, \lambda) = P(y)y - C(X)y + \lambda[G(X) - y]$$

For an interior solution the necessary conditions read:

$$\begin{aligned} \frac{\partial H}{\partial y} &= 0 : \frac{\partial P}{\partial y} y + P(y) = C(X) + \lambda & (3) \\ \frac{\partial H}{\partial X} &= -\dot{\lambda} + \rho\lambda : \ \dot{\lambda} = C'(X)y - [G'(X) - \rho]\lambda & (4) \end{aligned}$$

Condition (3) requires that marginal revenue equals the marginal costs of harvesting ($C'(X)$) plus the marginal costs (λ) of having less fish left in the lake. The arbitrage condition (4) states that the change in the future benefits is given by the stock effect (having more stock reduces the price of catching the fish $C'(X)y$) and the difference between the growth effect of having more fish in the lake and the discount rate ($[G'(X) - \rho]\lambda$).

If the private owner is a price taker the first order conditions for an interior solution read:

$$\begin{aligned} \frac{\partial H}{\partial y} &= 0 : P(y) = C(X) + \lambda & (5) \\ \frac{\partial H}{\partial X} &= -\dot{\lambda} + \rho\lambda : \ \dot{\lambda} = C'(X)y - [G'(X) - \rho]\lambda & (6) \end{aligned}$$

In the steady state we have $\dot{y} = \dot{X} = 0$ and therefore $\dot{\lambda} = 0$. The locus of points for which $\dot{X} = 0$ is the same as under open access. If perfect competition prevails, i.e., the private owner is a price taker, we have $\lambda = P(y) - C(X)$ with $\lambda > 0$. Hence the locus of points where $\dot{y} = 0$ is below the locus for the open access. This implies that the steady state stock is now higher than in the case of open access. Moreover, it corresponds with a lower catch. For the monopolist this result is even more pronounced because $P'(y) < 0$. Note, however that the approach paths are different from the paths generated by the open access regime. The differential equation for the catch is given by

$$P'(y)\dot{y} = C'(X)G(X) - (G'(X) - \rho)(P(y) - C(X))$$

Hence, y is increasing for points above the isocline (assuming $G'(X) - \rho < 0$), whereas it was decreasing above the isocline in the open access case. The result derived for the change in the carrying capacity still holds.

4 TRADE

If the two countries decide to start trading, there are three possible situations. One where the lakes in both countries have open access, one where one country has an open access regime and the other lake is privately owned (the mixed regime) and, finally, one with both lakes privately owned. When the two countries start trading there is a single market for the fish. Recall that the price when there is trade is $P^T(y_1 + y_2) = P(\frac{1}{2}[y_1 + y_2])$. We are interested to see how the opening up to trade affects the stocks and amounts of fish being caught. We will assume here that we originate from a state were the lakes are in their autharky steady-state.

4.1 Open access

All fishermen take the price as given. As we have seen previously the following holds in an interior equilibrium:

$$P^T(y_1^T + y_2^T) = C_1(X_1^T) = C_2(X_2^T) \tag{7}$$

$$y_1^T = G_1(X_1^T), y_2^T = G_2(X_2^T) \tag{8}$$

Several cases are to be considered.

a. If $G_1 \equiv G_2$ and $C_1 \equiv C_2$ then nothing changes compared to autarky.

b. If $G_1 \equiv G_2$ and $C_1(X) > C_2(X)$ for all $X > 0$, then the locus of points for which $P(y) = C_1(X)$ lies strictly below the locus of points where $P(y) = C_2(X)$. Hence, in the autarky case the stable equilibrium has $X_1^A > X_2^A$. For the case where trade occurs we now have $C_1(X_1^T) = C_2(X_2^T)$ so that also $X_1^T > X_2^T$.

c. If $G_1(X) > G_2(X)$ for all $X > 0$ and $C_1 \equiv C_2$, then $X_1^T = X_2^T$ and consequently $y_1^T > y_2^T$.

In order to analyze the effects of differences in growth functions as well as unit cost functions we consider the case where they have specific functional forms.

$G_i(X_i) = rX_i[1 - \dfrac{X_i}{K_i}]$. Here the constant r, assumed positive, is the intrinsic growth rate and K_i is the carrying capacity of lake i.

$U_i(z_i) = z_i\bar{p} - \frac{1}{2}z_i^2$. The corresponding inverse demand function in autarky is: $P_i(z_i) = \bar{p} - z_i$, where $\bar{p}$ is the choke price. In an autarky equilibrium $z_i(t) = y_i(t)$. When the two countries start trading there is a single market for fish. The price when there is trade is $P^T(y_1 + y_2) = P(\frac{1}{2}[y_1 + y_2])$. In the sequel autarky values and values under trade will be denoted by superscripts A and T respectively.

$C_i(X_i) = \frac{K_i}{\sqrt{x_i + a}}$, with $a > 0$. The unit cost function depends on the carrying capacity as an indicator of the size of the fishing ground, which, for a given stock of fish, is negatively related to the unit costs.

We thus have the following conditions for an interior solution:

$$\bar{p} - G_1(X_1) - G_2(X_2) = C_1(X_1) = C_2(X_2)$$

Given the specific forms of $C_1(X_1)$ *and* $C_2(X_2)$ *we can write* $X_1 = \frac{a(k_1 - k_2)^2}{k_2^2} + \frac{k_1^2}{k_2^2}x_2$ *we thus see that if* $K_1 > K_2$ *it must hold that* $X_1 > X_2$*. The lake with the highest carrying capacity must thus have the highest steady state stock. Furthermore if we compare the price function in autarky* ($p_1 = \overline{P} - G(X_1)$) *with the price function in the situation with trade* ($p = \overline{P} - \frac{1}{2}G(X_1) - \frac{1}{2}G(X_2)$) *one can notice immediately that if the two lakes are identical nothing changes. However, if the two countries have different carrying capacities things will change. If* $G(X_2) > G(X_1)$ *the equilibrium price under trade will be below that of the price when country* 1 *is in autarky. The costs of catching fish in country* 1 *thus have to decrease as well and therefore the steady state* *stock has to increase (and the catch will also change depending on where we are on the growth curve) compared to autarky. When $G(X_2) < G(X_1)$ following the same reasoning the steady state stock has to decrease compared to autarky. An increase or decrease in steady state stock under trade compared to autarky thus depends the steady state catch in country* 2 *compared to the steady state catch in country* 1*.*

4.2 Mixed regime

Here we have one country where the lake is privately owned. The other country has a lake which is characterized by open access and where the fishermen take the price as given. For the privately owned lake we consider two cases. One where the owner is a price taker, and one where the lake owner takes the supply from the other lake as given. The problem of the private owner of lake 1 reads:

$$\max_{y_1} \int_0^\infty \{P^T(y_1 + y_2)y_1 - C_1(X_1)y_1\}e^{-\rho t}dt$$

subject to (1). The current-value Hamiltonian is:

$$H_1 = P^T(y_1 + y_2)y_1 - C_1(X_1)y_1 + \lambda_1 [G_1(X_1) - y_1] \tag{9}$$

The necessary conditions for an interior solution read

$$\frac{\partial H_1}{\partial y_1} = 0 : (P^{'})^T y_1 + P^T = C_1(X_1) + \lambda_1 \tag{10}$$

$$\frac{\partial H_1}{\partial X_1} = -\dot{\lambda}_1 + \rho\lambda_1 : \dot{\lambda}_1 = C_1'(X_1)y_1 - [G_1'(X_1) - \rho]\lambda_1 \tag{11}$$

If the lake owner takes the world market price as given the steady state is characterized by

$$P(\frac{1}{2}[y_1 + y_2]) = C_2(X_2) \tag{12}$$

$$y_1 = G_1(X_1) \tag{13}$$

$$y_2 = G_2(X_2) \tag{14}$$

$$P(\frac{1}{2}[y_1 + y_2]) = C_1(X_1) + \lambda_1 \tag{15}$$

with

$$\lambda_1 = \frac{C_1'(X_1)}{G_1'(X_1) - \rho} y_1 \tag{16}$$

which is the same expression as under autarky. The steady state lake stock of the private owner is larger than in autarky. To see this suppose that $X_1^T < X_1^A$. Then $y_1^T > y_1^A$ and $C_1(X_1^T) > C_1(X_1^A)$. We also have

$$d\lambda_1 = \left[\{C_1''(X)G_1(X) + G_1'(X)C'(X)\}\{G'(X) - \rho\} - G''(X)c'(X)G(X)\right] dX < 0 \tag{17}$$

Therefore $\lambda_1^T > \lambda_1^A$. It follows that $\frac{1}{2}[y_1^T + y_2^T] < y_1^A$. Hence, since $y_1^T > y_1^A$,we have $y_2^T < y_2^A$. So, $X_2^T > X_2^A$ because of $y_2 = G_2(X_2)$. But also $X_2^T < X_2^A$ from the zero profit condition. This yields a contradiction. We conclude that the private owner now has a higher stock in the steady state. He supplies less than in autarky.

a. $G_1 \equiv G_2$ and $C_1 \equiv C_2$. Now $C_2(X_2) = C_1(X_1) + \lambda_1$, which implies that $X_1^T > X_2^T$. Therefore, the private owner has a higher resource stock in equilibrium.

b. If $G_1 \equiv G_2$ and $C_1(X) > C_2(X)$ for all $X > 0$, then $X_1^T >> X_2^T$ in equilibrium as the following must still hold $C_2(X_2) = C_1(X_1) + \lambda_1$

c. $G_1(X) > G_2(X)$ for all $X > 0$ and $C_1 \equiv C_2$, then $C_2(X_2) = C_1(X_1) + \lambda_1$ still holds and thus $X_1^T > X_2^T$, as $G_i' < 0$ (in equilibrium we are on the right part of the curve) it is undetermined if $G_1(X_1)$ is bigger then $G_2(X_2)$ or the other way around. If $G_1(X) < G_2(X)$ for all $X > 0$ and $C_1 \equiv C_2$ then $G_2(X_2)$ is unambiguously bigger then $G_1(X_1)$

In the second case the private owner is not a price taker, but he takes the supply by the open access lake as given. The equations of movement are then given by

$$\dot{X}_1 = G_1(X_1) - y_1 \tag{18}$$

$$\dot{X}_2 = G_2(X_2) - y_2 \tag{19}$$

$$\dot{y}_1 = [\overline{p} - y_1 - \frac{1}{2}y_2 - C_1(X_1)][G_1'(X_1) - \rho] - \frac{1}{2}[a[P(\frac{1}{2}[y_1 + y_2])] - C_1'(X_1)[G_1(X_1)] \tag{20}$$

$$\dot{y}_2 = a[P(\frac{1}{2}[y_1 + y_2]) \tag{21}$$

The derivation of $\dot{y}_1$ is given in appendix A.

Using the equations of movement we can find the path towards equilibrium when countries open up to trade while being in their steady state equilibrium. We take a catch slightly off the equilibrium and let time run back until we reach the moment the stocks equal the steady state stocks in autarky. This gives the period of time needed to go from the autarky steady state towards the steady state under trade and with this period of time we can also calculate the amount that needs to be caught when opening up to trade to follow the equilibrium path.[4]

4.3 Private owners

In this regime we have a private owner for each of the two lakes and the owners play a Nash game against each other, each one taking the quantities offered by the other as given. The optimization problem for the social planner of lake 1 can be stated as follows:

$$\max_{y_1} \int_0^\infty \{P(y_1 + y_2)y_1 - C_1(X_1)y_1\}e^{-\rho t}dt$$

subject to (1). The time path of y_2 is taken as given. The corresponding current-value Hamiltonian is:

[4] Formally we are saying that the transversality condition $\lambda(t)X_1(t)e^{-\rho t}$ has to go to 0 as $t \to \infty$. This only holds along the equilibrium path towards the saddle point

$$H_1 = P^T(y_1 + y_2)y_1 - C_1(X_1)y_1 + \lambda_1 \left[G_1(X_1) - y_1\right] \tag{22}$$

The necessary conditions for an interior solution read

$$\begin{aligned}
\frac{\partial H_1}{\partial y_1} &= 0 : (P')^T y_1 + P^T = C_1(X_1) + \lambda_1 && (23)\\
\frac{\partial H_1}{\partial X_1} &= -\dot{\lambda}_1 + \rho\lambda_1 : \dot{\lambda}_1 = C_1'(X_1)y_1 - [G_1'(X_1) - \rho]\lambda_1 && (24)
\end{aligned}$$

Similarly for the second lake owner:

$$\begin{aligned}
\frac{\partial H_2}{\partial y_2} &= 0 : (P')^T y_2 + P^T = C_2(X_2) + \lambda_2 && (25)\\
\frac{\partial H_2}{\partial X_2} &= -\dot{\lambda}_2 + \rho\lambda_2 : \dot{\lambda}_2 = C_2'(X_2)y_2 - [G_2'(X_2) - \rho]\lambda_2 && (26)
\end{aligned}$$

The equations of movement are given by:

$$\begin{aligned}
\dot{X}_1 &= G_1(X_1) - y_1 && (27)\\
\dot{X}_2 &= G_2(X_2) - y_2 && (28)\\
\dot{y}_1 &= \frac{4}{3}\{[\overline{p} - y_1 - \frac{1}{2}y_2 - C_1(X_1)][G_1'(X_1) - \rho] - \frac{1}{2}[\overline{p} - \frac{1}{2}y_1 - y_2 - C_2(X_2)][G_2'(X_2) - \rho] && (29)\\
&\quad -C_1'(X_1)G_1'(X_1) + \frac{1}{2}C_2'(X_2)G_2'(X_2)\}\\
\dot{y}_2 &= \frac{4}{3}\{[\overline{p} - \frac{1}{2}y_1 - y_2 - C_2(X_2)][G_2'(X_2) - \rho] - \frac{1}{2}[\overline{p} - y_1 - \frac{1}{2}y_2 - C_1(X_1)][G_1'(X_1) - \rho] && (30)\\
&\quad -C_2'(X_2)G_2'(X_2) + \frac{1}{2}C_1'(X_1)G_1'(X_1)\}
\end{aligned}$$

The steady state solutions given by

$$\begin{aligned}
p &= \overline{p} - y_1 - y_2 = \overline{p} - G_1(X_1) - G_2(X_2) && (31)\\
\rho &= G_1'(X_1) - \frac{C_1'(X_1)G_1(X_1)}{(P')^T y_1 + P^T - C_1(X_1)} && (32)\\
\rho &= G_2'(X_2) - \frac{C_2'(X_2)G_2(X_2)}{(P')^T y_2 + P^T - C_2(X_2)} && (33)
\end{aligned}$$

Using the equations of movement we are able to show the transition for the autarky steady-state towards the steady state in trade using the same method as the previous section.

If both owners are price takers, the steady state follows from

$$y_1 = G_1(X_1) \tag{34}$$

$$y_2 = G_2(X_2) \tag{35}$$

$$P^T(y_1 + y_2) = C_1(X_1) + \frac{C_1'(X_1)G_1(X_1)}{G_1'(X_1) - \rho} \tag{36}$$

$$P^T(y_1 + y_2) = C_2(X_2) + \frac{C_2'(X_2)G_2(X_2)}{G_2'(X_2) - \rho} \tag{37}$$

When we compare the private owner situation with the mixed regime we can conclude that a private owner will have a lower stock and a higher supply of fish when the other lake is also privately owned. To see this assume equal carrying capacities for both lakes. We then know there is no reason for trade if everything is equal (in this case with equal property rights) thus the autarky and trade equilibrium is equal. While in the previous section we saw that the private owner will keep a higher stock and will supply less.

5 Cooperation

In this scenario both lakes are privately owned and the owners are allowed to cooperate thereby forming a monopoly. It can thus be seen as a problem where there is one owner for the two lakes who acts as a monopolist.

The optimization problem is:

$$\max_{y_1, y_2} \int_0^{\infty} \{P\,(y_1 + y_2)\,[y_1 + y_2] - C_1(X_1)y_1 - C_2(X_2)y_2\}e^{-\delta t}dt \quad (38)$$

subject to (1) and (2)

The corresponding current-value Hamiltonian is the following:

$$\begin{aligned} H &= P(y_1 + y_2)[y_1 + y_2] - C_1(X_1)y_1 - C_2(X_2)y_2 + \qquad (39) \\ &\quad +\lambda_1(t)\,[G_1(X_1) - y_1] + \lambda_1(t)\,[G_1(X_1) - y_1] + \lambda_2(t)\,[G_2(X_2) - y_2] \end{aligned}$$

The necessary conditions are

$$\begin{aligned} \frac{\partial H}{\partial y_1} &= 0 : (P')^T[y_1 + y_2] + P^T = C_1(X_1) + \lambda_1 \qquad (40) \\ \frac{\partial H}{\partial X_1} &= -\dot{\lambda}_1 + \delta\lambda_1 : \dot{\lambda}_1 = C_1'(X_1)y_1 - [G_1'(X_1) - \delta]\lambda_1 \qquad (41) \\ \frac{\partial H}{\partial y_2} &= 0 : (P')^T[y_1 + y_2] + P^T = C_2(X_2) + \lambda_2 \qquad (42) \\ \frac{\partial H}{\partial X_2} &= -\dot{\lambda}_2 + \delta\lambda_2 : \dot{\lambda}_2 = C_2'(X_2)y_2 - [G_2'(X_2) - \delta]\lambda_2 \qquad (43) \end{aligned}$$

The catch in one lake affect the catch in the other lake. Clearly, an increase of the catch in lake 1 not only reduces the price of fish in the first lake but also of fish in the second lake.

The steady state is characterized by:

$$\begin{aligned} p &= \overline{p} - y_1 - y_2 = \overline{p} - G_1(X_1) - G_2(X_2) \qquad (44) \\ \delta &= G_1'(X_1) - \frac{C_1'(X_1)G_1(X_1)}{(P')^T[y_1 + y_2] + P^T - C_1(X_1)} \qquad (45) \\ \delta &= G_2'(X_2) - \frac{C_2'(X_2)G_2(X_2)}{(P')^T[y_1 + y_2] + P^T - C_2(X_2)} \qquad (46) \end{aligned}$$

With equal carrying capacities (and everything else equal) we know opening up to trade has no effect on the stock or supply levels. Thus it also means that compared to the private owner regime the levels of stock and supply will be higher.

6 CONCLUSION

We have addressed several issues concerning trade and property rights regimes of lakes as well as the resulting market structures. We have found that when the carrying capacity increases in a lake the steady stock of that lake always increases and that there is an ambiguous effect on the catch. A difference in the carrying capacity also gives an incentive to start trading when countries open up to trade.

We also see that with a decline in market power the stock decreases and the supply increases (the monopolist had a higher stock compared to the private owner who had more compared to the amount of fish left in the lake in open access). This does not only hold in autarky but we also that in trade the market power of the other player affects the stock size. A private owner will keep a higher stock when there is an open access regime in the other lake compared to a private owner who has market power.

For further research, the dynamics will be analyzed further. Using the equations of movement and numerical examples the equilibrium path from one equilibrium towards the other can be found and the resulting changes in welfare effect can be measured to make a further comparison between the different structures.

Furthermore a Stackelberg game can be explored including the reaction of another private owner in the optimization process of the Stackelberg leader. From the exhaustible resource literature we know this can lead to a dynamic time-inconsistency (for example Newbery (1981)). Besides this one could think of investigating different costs structures. Private owners might harvest cheaper than open-access fishermen. One could also think of the private owner buying better machineries when the carrying capacities increases thereby changing the cost function.

REFERENCES

Brander, J. and Taylor, M., 1997. International trade and open access renewable resources; the small open economy case. Canadian Journal of Economics 30 (3), 526-552.

Brander, J. and Taylor, M., 1998. Open access renewable resources: Trade and trade policy in a two-country model. Journal of International Economics 44 (2), 181-209.

Chichilnisky, G., 1994. North-South trade and the global environment. The American Economic Review 84 (4), 851-874.

Clark, C., 2005. Mathematical Bioeconomics: Optimal Management of Renewable Resources, 2nd edition. New Jersey, John Wiley & Sons inc.

Fischer, C. and R. Laxminarayan, 2005. Managing partially protected resources under uncertainty: an application to antibiotic resistance. Working paper.

Fishbase, 2005. Oreochromos alealicus. http://ichtyonb1.mnhn.fr/Summary/SpeciesSummary.php?id=2034

Gilbert, R.J., 1978. Dominant firm pricing policy in a market for an exhasutible resource. The Bell Journal of Economics 9 (2), 385-395.

Gordon, S., 1954. The economic theory of a common-property resource: The fishery. The Journal of Political Economy 62 (2), 124-142.

Groot, F., C. Withagen and A. de Zeeuw, 1992. Note on the open-loop von Stackelberg equilibrium in the cartel versus fringe model. The Economic Journal 102, 1478-1484.

Groot, F., C. Withagen and A. de Zeeuw, 2003. Strong time-consistency in the cartel-versus-fringe model. Journal of Economic Dynamics & Control 28, 387-306.

Levhari, D. and L. Mirman, 1980. The great fish war: an example using a dynamic Cournot-Nash solution. The Bell Journal Journal of Economics 11 (1), 322-334.

Newbery, D., 1981. Oil prices, cartels, and the problem of dynamic inconsistency. The Economic Journal 91, 617-646.

Outdoor News Network, 2003. Genetic tests show Trout Lake fish unique. http://www.outdoorcentral.com/mc/pr/03/06/10e11.asp

Ramsar, 2002. Information sheet on Ramsar wetlands (RIS) - United Republic of Tanzania, Lake Natron Basin, 2001. http://www.ramsar.org/ris/ris_tanzania_natron.htm

Salant, S., 1976. Exhaustible resources and industrial structure: a Nash-Cournot approach to the world oil market. Journal of Political Economy 84, 1079-1904.

Appendix A

The first order conditions of the problem where the following

$$\frac{\partial H_1}{\partial y_1} = 0 : (P')^T y_1 + P^T = C_1(X_1) + \lambda_1 \quad (47)$$

$$\frac{\partial H_1}{\partial X_1} = -\dot{\lambda}_1 + \rho\lambda_1 : \dot{\lambda}_1 = C_1'(X_1)y_1 - [G_1'(X_1) - \rho]\lambda_1 \quad (48)$$

Using the functional form of the marginal revenue 47 reads

$$[\overline{p} - y_1 - \frac{1}{2}y_2] = C_1(X_1) + \lambda_1 \quad (49)$$

From (49) we get $\lambda_1 = [P - y_1 - \frac{1}{2}y_2 - C_1(X_1)]$, differentiating this with respect to time we get

$$\frac{\partial \lambda_1}{\partial t} = -\dot{y}_1 - \frac{1}{2}\dot{y}_2 - C_1'(X_1)\dot{X}_1 \quad (50)$$

Equating 49 and 50 with each other and solving for $\dot{y}_1$ we get

$$\dot{y}_1 = [\overline{p} - y_1 - \frac{1}{2}y_2 - C_1(X_1)][G_1'(X_1) - \rho] - \frac{1}{2}\dot{y}_2 - C_1'(X_1)[\dot{X}_1 + y_1]$$

Which leads to

$$\dot{y}_1 = [\overline{p} - y_1 - \frac{1}{2}y_2 - C_1(X_1)][G_1'(X_1) - \rho] - \frac{1}{2}[a[P(\frac{1}{2}[y_1 + y_2])] - C_1'(X_1)[G_1(X_1)]$$

Appendix B

The first order conditions for the first private owner read

$$\frac{\partial H_1}{\partial y_1} = 0 : MR_1(y_1, y_2) = C_1(X_1) + \lambda_1 \quad (51)$$

$$\frac{\partial H_1}{\partial X_1} = -\dot{\lambda}_1 + \rho\lambda_1 : \dot{\lambda}_1 = C_1'(X_1)y_1 - [G_1'(X_1) - \rho]\lambda_1 \quad (52)$$

Which equal the first order conditions in Appendix A, we thus also have for $\dot{y}_1$

$$\dot{y}_1 = [\overline{p} - y_1 - \frac{1}{2}y_2 - C_1(X_1)][G_1'(X_1) - \rho] - \frac{1}{2}\dot{y}_2 - C_1'(X_1)[\dot{X}_1 + y_1] \quad (53)$$

Due to symmetry we also have the following expression

$$\dot{y}_2 = [\overline{p} - \frac{1}{2}y_1 - y_2 - C_2(X_2)][G_2'(X_2) - \rho] - \frac{1}{2}\dot{y}_1 - C_2'(X_2)[\dot{X}_2 + y_2] \quad (54)$$

Substitution of (53) and (54) and rewriting leads to

$$\begin{aligned}
\dot{y}_1 &= \frac{4}{3}\{[\overline{p} - y_1 - \frac{1}{2}y_2 - C_1(X_1)][G_1'(X_1) - \rho] - \frac{1}{2}[\overline{p} - \frac{1}{2}y_1 - y_2 - C_2(X_2)][G_2'(X_2) - \rho] \quad (55)\\
&\quad -C_1'(X_1)G_1'(X_1) + \frac{1}{2}C_2'(X_2)G_2'(X_2)\} \\
\dot{y}_2 &= \frac{4}{3}\{[\overline{p} - \frac{1}{2}y_1 - y_2 - C_2(X_2)][G_2'(X_2) - \rho] - \frac{1}{2}[\overline{p} - y_1 - \frac{1}{2}y_2 - C_1(X_1)][G_1'(X_1) - \rho] \quad (56)\\
&\quad -C_2'(X_2)G_2'(X_2) + \frac{1}{2}C_1'(X_1)G_1'(X_1)\}
\end{aligned}$$