Effects of the Concern for Status on the Exploitation of Common Pool Renewable Resources.

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Abstract

(This version: April 8, 2015) We examine the impact of social status in a common pool renewable resource oligopoly. A small number of players share access to a common pool resource and sell their production in a common market where they are oligopolists.

We depart from the main literature on common pool resource oligopolies by considering that each player cares about her social status. We allow for two channels to impact a player's welfare: harvest and profits. Under the first channel, a player has a bump in her utility when her harvest is larger than the average harvest of the rest of the players. In this case we show that the presence of this channel exacerbates the tragedy of the common and in a symmetric game all agents are worse off than if they did not compare their harvest to the harvest of the other players. Under the second channel, a player enjoys a bump in her utility if she manages to earn more profits than the average profits of the other players. In this case we show that social status may **temporarily** alleviate the tragedy of the commons: it results in a decrease of extraction (over an interval of stock sizes). **Welfare comparisons remain to be explored.**

1 Introduction

The utility that an economic agent derives from her consumption, income, or wealth tends to be affected by how these compare to other economic agents' consumption, income or wealth. This has been established in different contexts. Some authors label this as envy, others as status conscious behavior, or keeping up with the Joneses (Veblen, 1899; Pollack,1976; Frank; 1985, 1990, 2007). Veblen (1899) emphasizes the pervasiveness of emulation, which he defines as 'the stimulus of an invidious comparison which prompts us to outdo those with whom we are in the habit of classing ourselves.' He claims that 'with the exception of the instinct for self-preservation, the propensity for emulation is probably the strongest and most alert and persistent of economic motives proper.' Emulation can lead to direct contests, and to wasteful use of efforts and other real resources.

The main finding in the context of a common pool resource extraction problem is that envy tends to exacerbate the tragedy of the commons; i.e. a more aggressive depletion of the resource, and this leads to lower welfare for all. This welfare consequence has been noted by the evolutionary biologist Richard Dawkins (1986, p.184):

> Why, for instance, are trees in the forest so tall? The short answer is that all the other trees are tall, so no one tree can afford not to be. It would be overshadowed if it did... But if only they were all shorter, if only there could be some sort of trade-union agreement to lower the recognized height of the canopy in forests, all the trees would benefit. They would be competing with each other in the canopy for exactly the same sun light, but they would all have "paid" much smaller growing costs to get into the canopy.

Because of envy, private decisions on consumption or asset accumulation generate externalities, and as a result one can no longer presume that a competitive equilibrium is Pareto efficient. A number of papers have studied the effects of envy on saving behavior, bequest and inequality (e.g., Alvarez-Cuadrado, et al. 2004; Liu and Turnovsky, 2005; Alvarez-Cuadrado and Long, 2012), and also on labor supply choices in a dynamic context (Fisher and Hof; 2000). There are also a few studies that analyze the question of envy when the other forms of intertemporal externalities are also present (e.g., Brekke and Howarth, 2002).[1]

In the case of a common pool renewable resource the effect of harvesting on the net rate of renewal of the resource plays an important role in the future availability of the resource. The effect of envy on resource depletion needs to be examined within the context of a dynamic model that accounts for biological reproduction. Long and McWhinnie (2012) examine this question in a dynamic game with a logistic growth function.[2] They show that envy or status seeking results in a decrease of the stock of the resource and the catch in the steady state. They find that this result robust to changes in the source of envy; i.e. whether fishermen are affected by the relative consumption, or relative profits compared to the rest of the fishermen sharing access to the resource, envy results in a more agressive depletion of the resource in the long-run. The analysis of Long and McWhinnie (2012) relies on two key assumptions: first, each agent takes as given the time paths of resource exploitation of other agents (i.e., the authors restrict attention to open-loop strategies); and second, the agents take the market price of the extracted resource as given (i.e., the goods markets are perfectly competitive).

[1] Brekke and Howarth (2002) show that concerns for status may lead agents to underestimate non-market environmental services. Extending the work of Stokey (1998), they show that consumption interdependence exacerbates the rate of environmental degradation.

[2] Alvarez-Cuadrado and Long (2011) examine the impact of envy on resource depletion, but they abstract from strategic behavior. Katayama and Long (2010) investigate the role of status-seeking in a dynamic game with a non-renewable natural resource and physical capital accumulation. Long and Wang (2009) modify the linear-growth model of Tornell and Lane (1999) to account for the impact of status concerns on the rate of resource grabbing.

In this paper, we relax those assumptions. We model the situation where (a) each agent anticipates that at any point of time in the future, other agents will choose their harvesting levels based on their concurrent observation of the resource stock level; and (b) each agent can influence the market price in each period, by controlling her supply to the market. Our model thus displays three types of externalities. First, there is the well known common pool externality. Second, there is status externality. Third, the oligopolistic market structure is a form of externality: when one agent increases her output, the market price falls, resulting in lower revenue for other firms.

We show that when agents use feedback strategies and the transition phase is taken into account, the well established result that envy exacerbates the tragedy of the common must be seriously qualified. More specifically we show that there exists an interval of the stock size of the resource for which the extraction policy under envy is less aggressive than the extraction policy in the absence of envy. However, it remains true that starting at any common initial stock, the steady-state equilibrium stock reached in a game where agents are envious is lower than that reached in a game where agents are not envious. When agents are heterogenous (so that there are winners and losers in the race for status), the implications of envy on welfare depend, among other things, on whether the pleasure derived from outdoing others and the pain suffered by the losers should be accounted for in the measure of social welfare.[3]

2 Model

Consider a common property resource exploited by n players. Let $c_i(t) \geq 0$ denote player i's ouput (or harvest) at time t. Assume that player i's unit cost of harvesting is a constant, $b_i > 0$.The parameter b_i reflects agent i's skill level. The total harvest at t is

$$C(t) = \sum_{i=1}^{n} c_i(t)$$

The total harvest is sold in the market, and the market clearing price is

$$p_i(t) = A - C(t)$$

Player i's profit is

$$\pi_i(t) = [A - C(t)]\, c_i(t) - b_i c_i(t).$$

We assume that $A > b_i$ for all i.

If an agent's skill level is not known to the community at large, she may have an incentive to signal it. Signals of skills, health, and strength may be useful in the competition for jobs, positions in a hierarchical structure, or for marriage

[3] Rawls (1970, p. 545) wrote "Suppose...that how one is valued by others depends upon one's relative place in the distribution of income and wealth. (...) Thus, not everyone can have the highest status, and to improve one person's position is to lower that of someone else. Social cooperation to increase the conditions of self-respect is impossible. Clearly this situation is a great misfortune."

or mating partners. The importance of signalling for success in biological reproduction is abundantly documented in the literature on evolutionary biology. Dawkins (1986) reports the 'Superglue Experiment', whereby male birds whose tails were lengthened by experimenters with the help of Superglue were observed to be more successful in attracting mating partners.[4]

A readily observable signal of skills is the relative harvest, $c_i - c_{-i}$, where we define c_{-i} to be the average harvest of other agents:

$$c_{-i} \equiv \frac{1}{n-1} \sum_{j \neq i} c_j = \frac{C - c_i}{n-1}$$

Let us define

$$a_i = A - b_i > 0$$

The utility of each player is

$$\begin{aligned} u_i &= (a_i - C)\, c_i + \theta\,(c_i - c_{-i}) \\ &\quad + \beta\left((a_i - C)\, c_i - \frac{\Sigma_{j \neq i}(a_j - C)\, c_j}{n-1}\right) \end{aligned}$$

The first term corresponds to the revenue from the catch c_i. The second term corresponds to the case of other regarding preferences where players compare their catch to the average of the other players' catches and the last term captures the fact that each player compares her profits to the average profit of the other players.

The resource stock, denoted by X, evolves according to the following differential equation

$$\dot{X} = F(X) - \Sigma_i c_i, \ X(0) = X_0 \tag{1}$$

where, for tractability, we assume that the natural growth function $F(X)$ is 'tent-shaped'[5]

$$F(X) = \begin{cases} \delta X & \text{for} \quad X \leq X_y \\ \delta X_y \left(\dfrac{\overline{X} - X}{\overline{X} - X_y}\right) & \text{for} \quad X > X_y. \end{cases} \tag{2}$$

Here, the parameter $\delta > 0$ is the intrinsic proportional growth rate of the resource. When the resource stock reaches a critical level X_y, the proportional growth rate begins to decline. It becomes zero when the stock is at the 'carrying capacity level' $\bar{X}$. For stock level greater than $\bar{X}$, the growth rate is negative. For simplicity, we normalize $\bar{X}$ to 1.

[4] Similarly, wealth can serve as signal. For models of dynamic games where agents use absolute (rather than relative) wealth as signals, see Long and Shimomura (2004a, b).

[5] This formulation was first proposed in Benchekroun (2008), for tractability. This tent-shaped growth function approximates the usual logistic growth function described in standard textbooks, such as Tietenberg and Lewis (2012), Perman et al. (2011), and used in Long and McWhinnie (2012).

The highest feasible rate of harvest consistent with keeping the stock level stationary occurs at the stock level X_y. We call X_y the 'maximum-sustainable-yield' stock level, and δX_y the 'maximum sustainable yield' (MSY).

Each player takes as given the exploitation strategies of other players. We assume that agents use feedback strategies, i.e., each agent conditions her action (catch level) on the current stock level, $c_j = \phi^j(X)$. For simplicity, we focus on the case where agents are symmetric, so that at a symmetric equilibrium, $c_i = c_j = \phi(X)$, for all i, j. The objective function of agent i is to choose the time path c_i to maximize

$$\max \int_0^\infty e^{-rt} u(c_i, C) dt$$

where $C = c_i + (n-1)\phi(X)$. The maximization is subject to the transition equation, $\dot{X} = F(X) - C$, and the non-negativity constraints $c_i \geq 0$ and $X \geq 0$. The feedback strategies of other players, $c_j(t) = \phi(X(t))$, imply that player i's profit at any time t depends on the concurrent stock level. Therefore, even when exploitation cost is zero, at the equilibrium steady state, in contrast to the monopoly case (Long, 1977) the firm does not equate the rate of time preference, r, with the marginal biological rate of reproduction, $F'(X)$, net of marginal grabbing rate of her rivals, $(n-1)\phi'(X)$: the firm's revenue function itself is dependent on $(n-1)\phi(X(t))$.[6]

We solve for a symmetric Markov perfect Nash Equilibrium extraction strategy and use it to examine the impact of other-regarding preferences on the equilibrium extraction policy.[7] We separately consider the case where agents use solely relative catch as signal (i.e., $\theta > 0$ and $\beta = 0$) and the case where they use solely relative profit as signal (i.e., $\theta = 0$ and $\beta > 0$). We show that the impacts of status signal on the equilibrium extraction policy differ sharply between the two cases. In contrast with the standard result in literature, we show that for a range of stock levels, envy with respect to relative profits can result in smaller extraction than in the absence of envy.

3 Relative output as the only signal of status: $\theta \geq 0$ and $\beta = 0$

This section deals with the case where the relative output, $c_i - c_{-i}$, is the only signal of status, i.e. $\theta \geq 0$ and $\beta = 0$. We will focus on the symmetric equilibrium, such that all agents use the same exploitation strategy. In the following lemma, we show that the equilibrium strategy has the following properties. Exploitation is a continuous, non-decreasing, and piece-wise linear function of the

[6] The Hamiltonian is $H = u(c, c + (n-1)\phi(X)) + \psi\left[F(X) - c - (n-1)\phi(X)\right]$. Thus

$$\dot{\psi} = \psi\left[r - (F' - (n-1)\phi')\right] - u_C(n-1)\phi'$$

[7] For a definition of Markov perfect Nash equilibrium, see e.g., Dockner et al. (2000).

stock. There are two endogenously determined threshold levels of stock, denoted by $X_1(\theta)$ and $X_2(\theta)$, where $0 < X_1(\theta) < X_2(\theta)$, such that

(a) For all $X \in [0, X_1(\theta)]$, all agents refrain from exploitation, allowing the resource stock to grow. They are in fact 'investing' in the resource by waiting. We call X_1 the '*waiting threshold.*'

(b) For all $X \in [X_1(\theta), X_2(\theta)]$, the exploitation is a linear and increasing function of the resource stock.

(b) For all $X \geq X_2(\theta)$, the agents behave as if the resource stock had no value: beyond the stock level $X_2(\theta)$, they are effectively 'static oligopolists.' We call $X_2(\theta)$ the '*upper threshold.*'

In order to focus on the interesting cases, we make the following assumption.

Assumption A1: *The intrinsic growth rate δ is sufficiently great, such that*

$$\delta > \max\left\{\frac{(1+n^2)}{2}r, \frac{a\left(1+n^2\right)+(n-1)\,n\theta}{X_y\,(1+n)^2}\right\} \tag{3}$$

and the coefficient of importance of relative output is rather low, such that

$$\theta \leq \frac{a}{n}\left[\frac{2\delta-(1+n^2)r}{2\delta+(n-1)r}\right] \tag{4}$$

The first part of inequality (3) ensures that no one has an incentive to drive the resource to extinction, because the intrinsic rate of growth is sufficiently high relative to the rate of discount, r. The second part of the inequality ensures that the 'upper threshold' X_2 is smaller than the maximum-sustainable-yield stock, X_y.

Lemma 1: *Consider the following piece-wise linear exploitation strategy ϕ_c : $[0,\infty) \to [0,\infty)$,*

$$\phi_c\left(X;\theta\right) = \begin{cases} 0 & \text{for } X \leq X_1(\theta) \\ \left(X - X_1(\theta)\right)\frac{c_s(\theta)}{X_2(\theta)-X_1(\theta)} & \text{for } X \in [X_1(\theta), X_2(\theta)] \\ c_s(\theta) & \text{for } X \geq X_2(\theta) \end{cases}$$

where c_s is the output level that representative oligopolist subject to output envy would choose if the game were a static game (when the future is irrelevant):

$$c_s(\theta) = \frac{a+\theta}{1+n}.$$

The 'waiting threshold' $X_1(\theta)$ is given by

$$X_1(\theta) = \frac{a\left(2\delta - \left(1+n^2\right)r\right) - \left(2\delta + (n-1)\,r\right)n\theta}{\delta\,(1+n)^2\,(2\delta - r)} \geq 0$$

The upper threshold $X_2(\theta)$ is given by

$$X_2(\theta) = \frac{a\left(1+n^2\right)+(n-1)\,n\theta}{\delta\,(1+n)^2}$$

If Assumption A1 is satisfied, the symmetric strategy profile $(\phi_c, .., \phi_c)$ is a Marko-perfect Nash Equilibrium.

The proof of Lemma 1 is omitted. It is straightforward to verify that given that the above equilibrium strategy is chosen by $n-1$ players, the remaining player will find that her optimal extraction will satisfy that strategy. This is the standard approach for establishing that a candidate strategy profile is a MPNE. See, e.g., Dockner et al. (2000). In the case where $\theta = 0$, this equilibrium is the same as the one obtained in Benchekroun (2008).

Discussion: The equilibrium strategy displays plausible properties. When the resource stock is so large that $X \geq X_2$ the agents behave as if the resource stock is not affected by their exploitation, and we obtain static Cournot equilibrium output which is increasing in the envy parameter θ, i.e., $\frac{dc_s}{d\theta} > 0$. When the resource stock is very small, such that $X < X_1$, no exploitation will take place, because agents are willing to wait for stock to grow (even though the stock has no direct influence on the harvesting cost). Waiting is a form of investment. We find that thw waiting threshold X_1 becomes smaller as θ increases:

$$\frac{dX_1}{d\theta} = \frac{-\left(2\delta+(n-1)\,r\right)n}{\delta\,(1+n)^2\,(2\delta-r)} < 0$$

This means that an increase in envy leads agents to stop waiting sooner, a very intuitive result. Everyone tries to grab a piece of the resource before the others start grabbing; but of course in equilibrium they start their grabbing at the same time. (It would be interesting to study the case of heterogeneous agents.) Concerning the upper threshold level X_2, we find that

$$\frac{dX_2}{d\theta} = \frac{(n-1)\,n}{\delta\,(1+n)^2} > 0$$

Thus an increase in θ raises threshold stock level at which extraction proceeds as if agents were playing a static game.

Remarks (i) The distance between the upper threshold and the waiting threshold, $X_2(\theta) - X_1(\theta)$, is increasing in θ. **(ii)** In the interior of the interval (X_1, X_2), the slope of the equilibrium strategy is independent of θ :

$$\frac{d\phi(X)}{dX} = \frac{c_s(\theta)}{X_2(\theta)-X_1(\theta)} = \frac{(2\delta-r)\,(n+1)}{2n^2} < \delta \text{ for } X \in (X_1, X_2).$$

It follows that at any given X such that $0 < \phi(X;\theta) < c_s(\theta)$, an increase in θ to $\theta' > \theta$ will shift uniformly the upward-sloping section of the graph of $\phi(X;\theta)$

by the same amount:

$$\begin{aligned}\phi(X;\theta') - \phi(X;\theta) &= \left[X_1(\theta) - X_1(\theta')\right] \frac{(2\delta - r)(n+1)}{2n^2} \\ &= \left[\frac{(\theta' - \theta)}{1+n}\right] \frac{(2\delta + (n-1)r)}{2\delta n^2} > 0\end{aligned}$$

This vertical shift is smaller than the vertical shift in the horizontal part of the exploitation strategy

$$c_s(\theta') - c_s(\theta) = \frac{(\theta' - \theta)}{1+n}$$

The disparity between the two shifts is consistent with the continuity of the exploitation strategy, because $X_2(\theta)$ increases with θ.

We conclude that an increase in θ results in an increase in extraction. When relative output is the signal for status, envy exacerbates the tragedy of the commons.

The slope of the aggregate exploitation function is steeper than the slope δ of the tent-shaped biological growth function

$$\frac{dn\phi(X)}{dX} = \frac{(2\delta - r)(n+1)}{2n} > \delta$$

where the strict inequality follows from $\delta > (1+n^2)r/2$ (Assumption A1). This, together with the fact that $nc_s(\theta) > \delta X_2(\theta)$, shows that there is a locally stable steady-state stock X_L to the *left* of the maximum-sustainable yield stock X_y, where, at X_L, the upward-sloping part of the graph of $n\phi(X)$ cuts the line δX from below. If, in addition, $nc_s < \delta X_y$, then there are two other interior steady-state stocks, denoted by X_M and X_R, generated by the intersection of the horizontal line nc_s with the tent-shaped graph of $F(X)$, such that $X_L < X_M < X_y < X_R$. The steady-state equilibrium at stock level X_M is unstable, and steady-state equilibrium at stock level X_R is stable. Thus an increase in θ always decreases the stable steady-state stock levels.

Proposition 1:

The equilibrium extraction strategy under envy in relative output is never below the equilibrium extraction strategy in the absence of envy. It is strictly above the no-envy equilibrium extraction strategy when for $X > X_1$. Locally stable steady-state stock levels fall as θ increases.

4 Relative profit as the only signal of status: $\theta = 0$ and $\beta \geq 0$

In the following lemma, we show that the equilibrium strategy has the following properties. Exploitation is a continuous, non-decreasing, and piece-wise linear function of the stock. There are two endogenously determined threshold levels of stock, denoted by $X_{1p}(\beta)$ and $X_{2p}(\beta)$, where $0 < X_{1p}(\beta) < X_{2p}(\beta)$, such that

(a) For all $X \in [0, X_{1p}(\beta)]$, all agents refrain from exploitation, allowing the resource stock to grow. They are in fact 'investing' in the resource by waiting. We call $X_{1p}(\beta)$ the '*waiting threshold*.'

(b) For all $X \in [X_{1p}(\beta), X_{2p}(\beta)]$, the exploitation is a linear and increasing function of the resource stock.

(b) For all $X \geq X_{2p}(\beta)$, the agents behave as if the resource stock had no value: beyond the stock level $X_{2p}(\beta)$, they are effectively 'static oligopolists.' We call $X_{2p}(\beta)$ the '*upper threshold*.'

In order to focus on the interesting cases, we make the following assumption.

Assumption A2: *The intrinsic growth rate δ is sufficiently great, such that*

$$\delta > \left\{ \frac{\left(1 + (1+\beta)^2 n^2\right) r}{2}, \frac{a\left(1 + (1+\beta)^2 n^2\right)}{X_y \left(1 + (1+\beta) n\right)^2} \right\} \tag{5}$$

The first part of inequality (5) ensures that no one has an incentive to drive the resource to extinction, because the intrinsic rate of growth is sufficiently high relative to the rate of discount, r. The second part of the inequality ensures that the 'upper threshold' $X_{2p}(\beta)$ is smaller than the maximum-sustainable-yield stock, X_y.

Lemma 2:

Let

$$\phi_p(X;\beta) = \begin{cases} 0 & \text{for } X \leq X_{1p}(\beta) \\ (X - X_{1p}(\beta)) \frac{c_{sp}(\beta)}{X_{2p}(\beta) - X_{1p}(\beta)} & \text{for } X \in [X_{1p}(\beta), X_{2p}(\beta)] \\ c_{sp}(\beta) & \text{for } X \geq X_{2p}(\beta) \end{cases}$$

where

$$c_{sp}(\beta) = \frac{a(1+\beta)}{1 + n(1+\beta)}$$

and

$$X_{1p}(\beta) = \frac{a\left(2\delta - \left(1 + (1+\beta)^2 n^2\right) r\right)}{\delta \left(1 + (1+\beta) n\right)^2 (2\delta - r)}$$

and

$$X_{2p}(\beta) = \frac{a\left(1 + (1+\beta)^2 n^2\right)}{\delta \left(1 + (1+\beta) n\right)^2}$$

The vector $\left(\phi_p, .., \phi_p\right)$ is a MPNE.

Proof: Omitted.

The distance betwen X_{2p} and X_{1p} is

$$\begin{aligned}
& \frac{(2\delta - r)\, a \left(1 + (1+\beta)^2 n^2\right)}{(2\delta - r)\, \delta\, (1 + (1+\beta)\, n)^2} - \frac{a\left(2\delta - \left(1 + (1+\beta)^2 n^2\right) r\right)}{(2\delta - r)\, \delta\, (1 + (1+\beta)\, n)^2} \\
= & \frac{2\delta a n^2 (\beta+1)^2}{(2\delta - r)\, \delta\, (n + n\beta + 1)^2} \\
= & \frac{2an^2}{(2\delta - r)\left(n + \frac{1}{(\beta+1)}\right)^2}
\end{aligned}$$

This distance is increasing in the envy parameter β.

The slope of the exploitation function in the interior of the interval $[X_{1p}, X_{2p}]$ is

$$\frac{(2\delta - r)\,(n(1+\beta)+1)}{2n^2\,(\beta+1)} \text{ long ok}$$

or

$$\frac{1}{2n}(2\delta - r)\left(1 + \frac{1}{n(1+\beta)}\right)$$

i.e., it becomes flatter as β increases. The slope of the aggregate exploitation function is

$$\frac{dn\phi(X)}{dX} = \frac{1}{2}(2\delta - r)\left(1 + \frac{1}{n(1+\beta)}\right)$$

i.e.

$$(2\delta - r)\left(\frac{1}{2n(1+\beta)} + \frac{(1+\beta)}{2}\right)$$

We show below that this slope is greater than δ.

We use A2

$$\left(1 + (1+\beta)^2 n^2\right) r < 2\delta$$

Then

$$2\delta - r > 2\delta\left(1 - \frac{1}{1 + (1+\beta)^2 n^2}\right)$$

$$\frac{1}{2}(2\delta - r) > \delta\left(1 - \frac{1}{1 + (1+\beta)^2 n^2}\right)$$

$$\frac{1}{2}(2\delta - r)\left(1 + \frac{1}{n(1+\beta)}\right) > \delta\left(1 - \frac{1}{1 + (1+\beta)^2 n^2}\right)\left(1 + \frac{1}{n(1+\beta)}\right)$$

where

$$\left(1 - \frac{1}{1 + (1+\beta)^2 n^2}\right)\left(1 + \frac{1}{n(1+\beta)}\right) =$$

$$\frac{n^2\beta^2 + 2n^2\beta + n^2 + n\beta + n}{n^2\beta^2 + 2n^2\beta + n^2 + 1} > 1$$

Thus Assumption A2 implies that the slope of the aggregate exploitation function is greater than δ. Thus the line $n\left(X-X_{1p}\right)\frac{c_{sp}}{X_{2p}-X_{1p}}$ cuts the line δX from below. The intersection occurs at the point X_{ss} defined by

$$X_{ss}=\frac{n\frac{c_{ps}}{X_{2p}-X_{1p}}X_{1p}}{n\frac{c_{ps}}{X_{2p}-X_{1p}}-\delta} \tag{6}$$

The second part of Assumption A2 implies that $X_{ss}<X_{y}$, and $\delta X_{ss}<nc_{sp}$. Thus X_{ss} is a steady state stock level.

Proposition 2: *Assume $n\geq 3$. Then there exist X'_{β} and $X''_{\beta}\in\left(X_{1p},X_{2,p}\right)$ such that*

$$\phi_{p,\beta=0}\left(X\right)>\phi_{p}\left(X\right)\ \text{ for all } X\in\left(X'_{\beta},X''_{\beta}\right)$$

That is, at any stock level inside the interval $\left(X'_{\beta},X''_{\beta}\right)$, envy results in a smaller extraction than under the absence of envy.

Proof:

We will make use of the following facts:

(i) The horizontal part of the exploitation function $\phi_p(X)$ is increasing in β.

(ii) The slope of the equilibrium exploitation function $\phi_p(X)$ is a decreasing function of β.

(iii) The upper threshold, X_{2p}, is increasing in β

$$\frac{\partial X_{2p}}{\partial\beta}=\frac{\partial\left(\frac{a\left(1+(1+\beta)^{2}n^{2}\right)}{\delta(1+(1+\beta)n)^{2}}\right)}{\partial\beta}=\frac{2an(n+n\beta-1)}{\delta\left(n+n\beta+1\right)^{3}}>0$$

and

(iv) The lower threshold is decreasing in β

$$\frac{\partial X_{1p}}{\partial\beta}=\frac{\partial\left(\frac{a\left(2\delta-\left(1+(1+\beta)^{2}n^{2}\right)r\right)}{\delta(1+(1+\beta)n)^{2}(2\delta-r)}\right)}{\partial\beta}=-\frac{2an\left(2\delta-r+nr\left(1+\beta\right)\right)}{\delta\left(2\delta-r\right)\left(n\left(1+\beta\right)+1\right)^{3}}<0$$

This implies that the extraction strategy under envy and without envy must either intersect twice (once in the linear increasing phase of the extraction policy and once in the phase where the no-envy policy is flat) or not at all.

We now examine if the two policies intersect on the interval $[X_{1p},X_{2p}]$. Let $\phi_p\left(X,\beta\right)$ to denote the equilibrium strategy under envy. We seek to determine the sign of the gap

$$H\left(X\right)=\phi_{p}\left(X,\beta\right)-\phi_{p}\left(X,0\right)$$

at the stock level $X_{2p}(\beta=0)$, i.e., at

$$X=\left.X_{2p}\right|_{\beta=0}=\frac{a\left(1+n^{2}\right)}{\delta\left(1+n\right)^{2}}.$$

After some algebraic manipulations, we obatin

$$H\left(X_{2p}|_{\beta=0}\right) = \frac{a}{n}\frac{\beta\Delta}{\delta\left(\beta+1\right)\left(n+1\right)^{2}\left(n+n\beta+1\right)}$$

where

$$\Delta = \left(n\left(1+\beta\right) - n^{2}\left(1+\beta\right)+2\right)\delta + r\left(n^{2}\left(1+\beta\right)-1\right)$$

The term $\left(n\left(1+\beta\right) - n^{2}\left(1+\beta\right)+2\right)$ is negative for $n \geq 2$ and $\beta \geq 0$. Therefore, using Assumption A2, we have

$$\Delta \leq \left(n\left(1+\beta\right) - n^{2}\left(1+\beta\right)+2\right)\frac{\left(1+\left(1+\beta\right)^{2}n^{2}\right)r}{2} + r\left(n^{2}\left(1+\beta\right)-1\right)$$

i.e.,

$$\Delta \leq \frac{1}{2}nr\left(\beta+1\right)P\left(\beta\right)$$

where

$$P\left(\beta\right) \equiv n^{2}\left(1-n\right)\beta^{2} + 2n\left(n-n^{2}+1\right)\beta + \left(n^{2}-n^{3}+3n+1\right)$$

Notice that $P\left(\beta\right)$ is a polynomial of degree in 2 in β with each coefficient negative for $n \geq 3$. Therefore we have $P\left(\beta\right) < 0$ for all $\beta \geq 0$. This implies that for $n \geq 3$ we have

$$\phi_{p}\left(X_{2p}|_{\beta=0}, \beta\right) - \phi_{p}\left(X_{2p}|_{\beta=0}, 0\right) < 0$$

which implies that $\phi_{p}\left(X,\beta\right)$ and $\phi_{p}\left(X,0\right)$ intersect twice for all δ that satisfies Assumption 2. This along with (i)-(iii) completes the proof.

Remark Proposition 2 was established using $n \geq 3$. What can we say in the case where $n = 2$?

For $n = 2$, Δ reduces to $\Delta = 3r + 4r\beta - 2\beta\delta$. Thus, $\Delta < 0$ iff δ is greater than a critical value δ_1

$$\delta > \frac{(3+4\beta)r}{2\beta} \equiv \delta_{1}$$

Let use define

$$\delta_{2} = \frac{r}{2}\left(1+\left(1+\beta\right)^{2}4\right)$$

Using Assumption A2, we have $\delta > \delta_2$. Note that

$$\delta_{2} - \delta_{1} = \frac{1}{2}\frac{r}{\beta}\left(2\beta+3\right)\left(2\beta-1\right)\left(\beta+1\right)$$

Thus, if $\beta > 1/2$, then Assumption A2 yields $\Delta < 0$. Since condition $\beta > 1/2$ is too strong, we state a weaker sufficient condition for Δ to be negative in the case $n = 2:$

$$\delta > \max\left(\delta_{1}, \delta_{2}\right)$$

Thus Proposition 2 extends to the case $n = 2$ for $\delta > \max(\delta_1, \delta_2)$.

How many steady-state stocks are there for each given β? How do they compare with those corresponding to $\beta = 0$?

We consider three cases.

Case 1: (Small MSY). Assume that the maximum-sustainable yield, δX_y, is small, in the sense that

$$nc_{sp}(\beta) > \delta X_y \text{ for all } \beta \geq 0$$

In this case, there is exactly one interior steady state, and it is stable. An increase in β will result in a smaller steady state stock.

Case 2: (Intermediate MSY)

$$nc_{sp}(\beta = 0) < \delta X_y$$

and

$$nc_{sp}(\beta) > \delta X_y \text{ for all } \beta > \beta_L$$

where β_L satisfies Assumption A2. In this case, starting at $\beta = 0$, a sufficiently large increase in β chnages an economy with three steady states to one with a unique (and lower) steady state.

SEE FIGURE A and B for the case of small and intermediate MSY

Case 2: Three interior steady-state stocks.

Consider the stock level $X_{ss}(\beta)$ defined by equation (6). Assume that the following three conditions hold: (i) $X_{ss}(\beta) < X_y$; (ii) $\delta X_{ss}(\beta) < c_{ps}(\beta)$; and (iii) $\delta X_y > c_{ps}(\beta)$. Then, given β, there exist three interior steady-state stock levels, $X_{1,\infty}^{(\beta)} < X_{2,\infty}^{(\beta)} < X_{3,\infty}^{(\beta)}$, where

$$X_{1,\infty}^{(\beta)} = X_{ss}(\beta)$$

$$X_{2,\infty}^{(\beta)} = \frac{c_{ps}(\beta)}{\delta}$$

$$\left(\frac{X_y}{\overline{X} - X_y}\right)\left(\overline{X} - X_{3,\infty}^{(\beta)}\right) = \frac{c_{ps}(\beta)}{\delta}$$

The steady state $X_{2,\infty}^{\beta}$ is unstable, and the other two are stable. Figure 3 shows that an increase in β results in a decrease of the steady stock $X_{1,\infty}^{(\beta)}$ of the resource. This is in line with the results obtained in Long and McWhinnie (2012). However in our framework, a new possibility arises, as depicted in Figure 4. Suppose that in the absence of envy there are three steady states and that the initial stock is $X = X_{2,\infty}^{\beta=0} + \varepsilon$. The stock will converge in the long-run to the steady state $X_{3,\infty}^{\beta=0}$. However in the case where agents experience envy, with the same initial stock $X = X_{2,\infty}^{\beta=0} + \varepsilon$, the stock will converge to the small steady state $X_{1,\infty}^{\beta}$. Envy causes a bifurcation.

In all cases, we can show that the smallest interior steady state $X_{1,\infty}^{(\beta)} = X_{ss}(\beta)$ is a decreasing function of β, i.e., an increase in envy results in a decrease of the steady state stock of the resource.

We compute the smallest interior steady state. It can be shown that

$$X_{ss} = \frac{n\frac{c_{ps}}{X_{2p}-X_{1p}}X_{1p}}{n\frac{c_{ps}}{X_{2p}-X_{1p}} - \delta} \tag{7}$$

$$X_{ss} = \frac{a}{\delta}\frac{rn^2\beta^2 + 2rn^2\beta + rn^2 - 2\delta + r}{(n + n\beta + 1)(r - 2\delta + nr + nr\beta)}$$

and

$$\frac{\partial X_{ss}}{\partial \beta} = -2a\frac{n}{\delta}\frac{(\delta - r)\left(rn^2\beta^2 + 2rn^2\beta + rn^2 + 2\delta - r\right)}{(n + n\beta + 1)^2(r - 2\delta + nr + nr\beta)^2} < 0$$

5 Conclusion

We have shown that when agents have oligopoly power in the goods market, the effect of status seeking on common-property resource exploitation depends on whether the signal of status is relative output or relative profit. In the former case, the result is standard: more envy means more aggressive exploitation and lower steady-state output. In the latter case, the results are much more nuanced. There is a range of stock levels where an increase in envy in relative profit will result in lower exploitation, however, in the case of a unique interior steady state, eventually when the lower limit of that range is reached, exploitation under envy is greater than under non-envy, and the long run outcome is a lower steady state stock and lower exploitation.

Welfare implications remain to be explored.

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