Resource and Energy Economics 33 (2011) 1028–1053

Contents lists available at ScienceDirect

Resource and Energy Economics

journal homepage: www.elsevier.com/locate/ree

Relative consumption and renewable resource extraction under alternative property-rights regimes

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A R T I C L E I N F O

Article history:
Received 25 June 2007
Received in revised form 28 September 2010
Accepted 28 September 2010
Available online 8 October 2010

JEL classification:
D62
Q20
Q50

Keywords:
Consumption externalities
Status seeking
Renewable resources

A B S T R A C T

This paper presents a simple model of resource extraction where preferences are defined over the individual's consumption level, her effort and the comparison of her consumption with that of other members of the community. Our specification captures the intuition that lies behind the growing body of empirical evidence that places interpersonal comparisons as a key determinant of well-being. We consider the effect of consumption externalities under two alternative property-rights regimes: perfect property rights and open access. We identify two dimensions along which consumption externalities distort the efficient exploitation of resources, or, in the case of open access, aggravate the over-exploitation of resources: (i) the static trade-off between consumption and leisure, and (ii) the dynamic trade-off between current and future consumption. In general, envious agents over-exploit the natural resource stock, resulting in a steady-state stock lower than the efficient level chosen by a central planner. We propose a tax mechanism to induce the first-best outcome.

1. Introduction

The assumption that preferences are independent across households is standard in the economic literature, although it is not particularly appealing.[1] Indeed, social scientists and philosophers have

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[1] As a referee points out, apart from status corncerns, there are many other factors that can create interdependencies of preferences. Among these are altruism, reciprocity, inequality aversion, and spitefulness. In this paper, we focus on the effects of status concerns.

0928-7655/$ – see front matter
doi:10.1016/j.reseneeco.2010.09.003

long stressed the relevance of status seeking as being an important characteristic of human behavior (see Aristotle, 1941, Rhetoric, Book II, Chapter 10; Kant, 1960, Chapter 6; Rawls, 1971, Sections 80–82; Schoeck, 1966). In economics, it has also been long recognized that the overall level of satisfaction derived from a given level of consumption depends not only on the consumption level itself but also on how it compares to the consumption of other members of society. Though origins of this proposition can be traced as far back as Smith (1776)[2] and Veblen (1899), it was not until the work of Duesenberry (1949), Pollak (1976), and Boskin and Sheshinski (1978) that the idea was subjected to systematic analysis. The subsequent literature has often referred to this type of interdependence as "catching up with the Joneses" as in Abel (1990), "keeping up with the Joneses" as in Gali (1994), "status" as in Fisher and Hof (2000) or Corneo and Jeanne (2001), "jealousy" as in Dupor and Liu (2003), or "envy" as in Varian (1974).

There is a growing body of empirical evidence that confirms the importance of preference interdependence. A subset of this empirical literature focuses on behavior, such as work/leisure choice, or determinants of expenditure share of positional goods. Neumark and Postlewaite (1998) propose a model of relative income to rationalize the striking rise in the employment of married women in the U.S. during the past century. Using a sample of married sisters, they find that married women are 16–25% more likely to work outside the home if their sisters' husbands earn more than their own husbands. Another approach relies on questionnaires and reported levels of happiness.[3] Clark and Oswald (1996), using a sample of 5000 British workers, find that workers' reported satisfaction levels are inversely related to their comparison wage rates, supporting the hypothesis of positional externalities. Luttmer (2005) matches individual-level panel data on well-being from the U.S. National Survey of Families and Households to census data on local average earnings. After controlling for income and other own characteristics, he finds that local average earnings have a significantly negative effect on self-reported happiness.

Research on status concerns has also been applied to environmental economics. Ng and Wang (1993) argue that relative income effects may lead to excessive levels of consumption and environmental degradation. Howarth (1996) examines the implications of status effects for the design of efficient policies for the environment, in a static, competitive economy. Howarth (2000, 2006) finds that ignoring the role of consumption externalities can lead analysts to substantially overstate the optimal levels of GHG emissions; he concludes that, accounting for relative consumption effects, optimal carbon dioxide emissions taxes should be higher that those obtained under the base model in which preferences are independent of social context. Brekke and Howarth (2002) point out that the importance of social identity and relative economic status may lead individuals to significantly underestimate the full social benefits of public goods and non-market environmental services. They also extend the work of Stokey (1998) on the environmental Kuznets curve by incorporating status concerns. They show that consumption externalities exacerbate the rate of environmental degradation, because status signalling biases trade-offs between pollution abatement and consumption.

In contrast with the attention paid to the impacts of status concerns in environment economics, there is a lack of analysis of their impacts on the exploitation of renewable natural resources. Do concerns for relative consumption lead to a lower stock of renewable resource compared with the efficient solution? Would that necessarily lead to lower steady-state consumption and welfare? What tax-transfer schemes would ensure an efficient exploitation path? These questions, and others, can be explored under two different settings: a perfect property-rights scenario and a common property (or open access) scenario.

Resource economists have traditionally focused in the "common property" characteristics of many resources. Gordon (1954) presents a lucid treatment of the economics of common property resources.

[2] Adam Smith (1776, Book V, Ch. 2) pointed out that the Englishmen of his day would be "ashamed to appear in public" without wearing items such as leather shoes and linen shirts.

[3] Easterlin (2001) offers a unified theory that explains why cross-sectional happiness–income correlation is consistent with the absence of any time-series relationship between happiness and income. According to this theory, aspiration grows with income, and individual actions are based on false expectations. At a more fundamental level, Rayo and Becker (2007) advance the view that evolutionary forces favor a happiness function that rewards successes in relative terms.

Smith (1968) focuses on the steady-state inefficiency while Plourde (1971), Brown (1974) and Smith (1975) explicitly consider models that exhibit transitional dynamics. Brown (1974) points out that a harvest tax, which must change over time as the stock level evolves, should be introduced to correct for congestion externalities. Smith (1975) reviews the debate on the cause of the extinction of many animal species in prehistoric time, and assesses the role of "over-hunting" by primitive human societies.[4]

In this paper we connect these two streams of literature: envy and over-exploitation of renewable natural resources. Our goal is to explore the effects of relative consumption concerns on the exploitation of renewable resources.

In order to focus on the role of relative consumption, we begin our analysis by abstracting from the common property problem. As a first step, we present results derived under the assumption that the stocks of resources are privately owned. This assumption allows us to clearly identify the specific distortions associated with consumption externalities, abstracting from other external effects, such as the ones caused by congestion or common property.

We modify a standard model of renewable resource exploitation by specifying that preferences are defined over the individual's consumption level, her effort and the comparison of her consumption with that of other members of the community.[5] We identify two dimensions along which consumption externalities distort the efficient extraction of resources. First, when effort is costly, envy distorts the marginal rate of substitution between consumption and leisure. We call this the static/steady-state distortion. Since status-seeking individuals overvalue consumption, their willingness to exert effort in order to achieve additional consumption is higher than the efficient level. As a consequence, they over-exploit the resource, resulting in a steady-state stock level that is lower than the efficient level chosen by a central planner. Second, even when effort is costless, consumption externalities might distort the willingness to shift consumption through time, resulting in an inefficient path of extraction. We call this the dynamic distortion. We explore the conditions under which these two distortions arise and we show that there exists an optimal tax scheme which induces the competitive agents to replicate the choices of the planner. The tax rate is positive and, in general, time-varying. We calibrate our model under widely used functional forms and find that, under consumption externalities, the competitive steady-state resource stock is close to three quarters of the efficient stock. Moreover the welfare costs associated with this over-exploitation are very large, about one fifth of the laissez-faire steady-state level of consumption.

Once we have explored the distortions introduced by relative consumption under perfect property rights we extend our results to an environment where the resource is extracted under the open access regime. This case is perhaps more relevant in poorer countries, where property rights to many natural resource stocks are not well defined or enforced.[6] The intuition developed under private property readily extends to this framework where concerns for relative consumption only reinforce the over-exploitation that characterizes imperfect property-rights arrangements. In our benchmark calibration the laissez-faire steady-state resource stock is not even one third of the efficient stock. Consumption externalities account for roughly one third of this decrease while the remaining two thirds are the result of over-exploitation due to common property.

Our analysis of static and dynamic distortions is related to Fisher and Hof (2000) and Liu and Turnovsky (2005). These authors explore the effects of relative consumption on the rate of capital accumulation and growth. They show that, when labor is endogenous, the concerns for relative consumption lead to the over-accumulation of capital. In contrast, in our context, consumption externalities lead to the under-accumulation of the stock of natural resources.[7]

[4] We provide a model of extinction induced by relative consumption concerns in Appendix B.

[5] In our model, the consumption good is positional, and leisure is a non-positional good. As a referee points out, it may be desirable to introduce an additional consumption good that is non-positional, as in Brekke et al. (2003). We refrain from doing so at this stage to keep the analysis simple.

[6] Brekke and Howarth (2002) and Brekke et al. (2003) point to various historical and anthropological studies that show that status-seeking behavior is common in societies with comparatively low consumption levels.

[7] Our welfare results are closely related to the recent literature that explores the determinants of (self-reported) well-being such as Frank (1985), Easterlin (1995), Frey and Stutzer (2002) and Layard (2005). This literature highlights the importance of interpersonal comparisons as a key determinant of self-reported happiness.

The paper is organized as follows. Section 2 sets out the basic model under perfect property rights, compares the laissez-faire outcome and the centrally planned solution, explores the distortions associated with envy and characterizes the optimal fiscal policy. Section 3 deals with the effects of status concerns in the common property case. The conclusions are summarized in Section 4, while the appendices provide some technical details and revisit two important topics in the natural resource literature, amenities and extinction, in the presence of consumption externalities.

2. Consumption externalities and resource extraction under the perfect property-rights regime

2.1. Economic environment

Consider an economy populated by a continuum of identical infinitely lived individuals distributed uniformly along the unit interval with a total population mass of 1. Each individual privately owns a resource stock, S, fully internalizing the effects of her harvesting choices on the evolution of her stock. Each resource stock is extracted according to the following harvesting function,

$$y = F(S, L) \tag{1}$$

that satisfies $F_L > 0$, $F_S \geq 0$ and $F(0, L) = F(S, 0) = 0$, where L is the representative individual's harvesting effort. The change in the stock at any point in time is the difference between the natural growth rate of the resource, $G(S)$, and the amount harvested:

$$\dot{S} = G(S) - y \tag{2}$$

where $G(.)$ is a strictly concave function, with $G(0) = 0$ and $G'(0) > 0$. Assume $G(S)$ reaches a global maximum at $S_M > 0$. We call S_M the maximum-sustainable-yield stock level. The quantity harvested is consumed.[8] We denote by c the consumption of the representative individual, and use y and c interchangeably.

It is convenient to invert the harvesting function to get the "effort requirement" function

$$L = L(c, S) \tag{3}$$

with $L_c > 0$ and $L_S \leq 0$.

Let C denote the average per capita consumption in our economy,

$$C \equiv \int_0^1 c_i \, di \tag{4}$$

Following Abel (1990) and Carroll et al. (1997), we assume that the utility function of our representative individual depends not only on her own level of consumption and effort, but also on the average consumption level in the economy: $U(c, C, L)$. This specification captures the intuition that lies behind the growing body of empirical evidence reviewed earlier that places interpersonal comparisons as a key determinant of individual well-being. We denote the marginal utility of own consumption, average consumption and effort by U_1, U_2, and U_L, respectively. The level of utility achieved by our representative individual is increasing in her own consumption but at a decreasing rate, $U_1 > 0$ and $U_{11} < 0$, and decreasing in effort, $U_L < 0$. In addition we assume that the utility function is jointly concave in individual consumption and effort with $U_{1L} \leq 0$, so the marginal utility of consumption decreases with effort. The crucial aspect of our preference specification concerns the externality imposed by average consumption on the well-being of the individual agent. In the terminology of Dupor and Liu (2003) our agents are jealous, i.e., $U_2 < 0$.

Furthermore we make the following assumption to impose some restrictions on the consumption externality for symmetric increases in individual and average consumption, i.e., at $C = c$.

[8] For simplicity, we assume that there is only one consumption good. For a model with two consumption goods, see Brekke et al. (2003) who evaluated the Hirsch hypothesis that the share of income devoted to the purchase of status goods should rise in the face of economic growth.

Assumption 1. The utility function, evaluated at symmetric consumption, satisfies the following properties

$$U_1 + U_2 > 0, \qquad U_{11} + U_{12} < 0, \qquad U_{L1} + U_{L2} \leq 0. \tag{5}$$

These inequalities guarantee that along a symmetric equilibrium the direct effects (i.e., effects through the individual's own consumption), always dominate the indirect effects (i.e., effects through average consumption).

Finally, it is useful to define the following measure of the strength of envy, denoted by ξ, evaluated at symmetric consumption:

$$\xi \equiv \frac{-U_2(c,c,L)}{U_1(c,c,L) + U_2(c,c,L)} \tag{6}$$

Example 1. Consider the following functions that are increasing in the ratio c/C:

(i)

$$U(c,C,L) = \frac{1}{1-\theta}\left[\left(\frac{c}{C}\right)^{\beta} cL^{-\mu}\right]^{1-\theta},$$
$$\text{where } \theta > 0,\ \theta \neq 1,\ \beta > 0,\ \theta + \beta(\theta - 1) > 0,\ \mu > 0,\ (\theta - 1) > 1/\mu. \tag{7}$$

(ii)

$$U(c,C,L) = \frac{1}{1-\theta}\left[\left(\frac{c}{C}\right)^{\beta} c\right]^{1-\theta} - \frac{\chi}{1+\varepsilon}L^{1+\varepsilon},$$
$$\text{where } \theta > 0,\ \theta \neq 1,\ \beta > 0,\ \theta + \beta(\theta - 1) > 0,\ \varepsilon \geq 0,\ \chi \geq 0. \tag{8}$$

(iii)

$$U(c,C,L) = \left[\left(\frac{c^{\beta+1}}{C^{\beta}}\right)^{-1} + \left(\frac{1}{L}\right)^{-1}\right]^{-1} \quad \text{with } \beta > 0. \tag{9}$$

For (i),(ii), and (iii), it is easy to verify that the strength of envy is a constant; in fact using (6), $\xi = \beta$.

Example 2. The following function also has a constant strength of envy

$$U(c,C,L) = \ln(c - \delta C) - \frac{\chi}{1+\varepsilon}L^{1+\varepsilon} \quad \text{with } 0 < \delta < 1,\ \varepsilon \geq 0 \text{ and } \chi \geq 0 \tag{10}$$

The strength of envy is, using (6),

$$\xi = \frac{\delta}{1-\delta}$$

Notice that this utility function can be expressed as dependent of the ratio C/c, too, since

$$\ln(c - \delta C) = \ln\left[c\left(1 - \delta\frac{C}{c}\right)\right] = \ln c + \ln\left(1 - \delta\frac{C}{c}\right).$$

2.2. Model solution: decentralized versus centralized exploitation

Each individual chooses consumption and effort to maximize the present value of her intertemporal utility,

$$\Omega = \int_0^\infty U(c, C, L)e^{-\rho t}\, dt, \quad \rho > 0, \tag{11}$$

subject to the resource constraint, (2), the effort requirement function, (3) and $S(0)=S_0$. In a decentralized (laissez-faire) solution each individual ignores the effects of her own consumption choices on average consumption and therefore takes the path of C as given. Denoting by ψ^d the private shadow value of the resource, the optimality conditions associated with this program, where the superscript d denotes decentralized choices, are

$$U_1(c^d, C^d, L(c^d, S^d)) + U_L(c^d, C^d, L(c^d, S^d))L_c(c^d, S^d) = \psi^d \tag{12}$$

$$\rho - \frac{\dot{\psi}^d}{\psi^d} = G'(S^d) + \frac{U_L(c^d, C^d, L(c^d, S^d))L_S(c^d, S^d)}{U_1 + U_L L_c} \tag{13}$$

together with (2) and the transversality condition, $\lim_{t\to\infty} \psi^d S^d e^{-\rho t} = 0$. Eq. (12) indicates that at the margin the utility of a unit of consumption, net of the effort cost required to extract it, must be equated to the private shadow value of the resource. Eq. (13) is the standard intertemporal allocation condition that requires the equalization of the consumption rate of interest and the rate of return of the unextracted resource. The latter consists of two terms: the marginal reproduction rate of the resource and the reduction in the required effort cost when the stock is marginally more abundant.

In contrast to the optimization problem of private agents, the central planner acknowledges that each individual's consumption choice creates distortions through its effects on average consumption. Therefore he perceives the following utility specification for the representative individual, $U(c, c, L)$. The planner chooses the levels of consumption and effort to maximize the present value of the flow of utility subject to (2), (3), and $S(0)=S_0$. The first order conditions for this program, where the superscript p denotes the planner's choices, are

$$U_1(c^p, c^p, L(c^p, S^p)) + U_2(c^p, c^p, L(c^p, S^p)) + U_L(c^p, c^p, L(c^p, S^p))L_c(c^p, S^p) = \psi^p \tag{14}$$

$$\rho - \frac{\dot{\psi}^p}{\psi^p} = G'(S^p) + \frac{U_L(c^p, c^p, L(c^p, S^p))L_S(c^p, S^p)}{U_1 + U_2 + U_L L_c} \tag{15}$$

together with (2) and the transversality condition, $\lim_{t\to\infty} \psi^p S^p e^{-\rho t} = 0$. The difference between the two solutions arises because the planner internalizes the negative impact of average consumption on individual welfare by adjusting the marginal utility of private consumption to take into account its marginal social cost. In a general set-up, with endogenous consumption and effort choices, consumption externalities can introduce distortions along two margins: (a) the trade-off between consumption and effort at any given time, the *static/steady-state distortion*, and (b) the trade-off between consumption at different points in time, the *dynamic distortion*. We will explore the effects of both distortions along a symmetric equilibrium where $c=C$.[9]

2.3. The steady-state distortion

Since status-seeking individuals overvalue consumption, their willingness to exert effort in order to achieve additional consumption is higher than the efficient level. As a result, at any given stock

[9] The optimality conditions presented in this section are necessary for an interior optimum path. Under well-behaved preferences and reproduction functions, these conditions are also sufficient. In our analysis we assume that our necessary conditions are also sufficient.

level, competitive agents choose levels of consumption and effort above the efficient levels chosen by the central planner. Let us find out if this necessarily leads to an inefficiently low steady-state stock level. The first immediate result is that, comparing (13) and (15), it is clear that the steady-state stock level, and therefore steady-state consumption, achieved in the decentralized solution coincides with the efficient solution if and only if either effort is costless (i.e., $U_L=0$) or the stock does not enter the harvest function (i.e., $L_S=0$). Now, assuming that the resource stock enters the harvesting function and effort is costly, let us compare the decentralized steady state with the efficient steady state. For this purpose, we use linear approximations of the first system, given by (12), (13) and (2), around the second, given by (14), (15) and (2) evaluated at $(c_\infty^p, S_\infty^p, \psi_\infty^p)$, where the subscript ∞ denotes steady-state values. Our results, proved in the appendix, show that the laissez-faire steady-state stock of resources, S_∞^d, is lower than the efficient level, S_∞^p. Using the steady-state versions of (2) and (13), we can see that deviations in the stock of resources imply deviations in consumption and effort. Our findings are summarized in the following proposition:

Proposition 1.

(i) *In a decentralized economy where* (*a*) *either effort is costless*, *or* (*b*) *the harvest function is independent of the stock*, *the steady-state resource stock and consumption are efficient.*
(ii) *In a decentralized economy where effort is endogenous* ($U_L<0$) *and the effort requirement function is decreasing in the stock* ($L_S<0$), *the steady-state resource stock is lower than the efficient stock chosen by a central planner. If* $G'(S_\infty^d)<0$ (*i.e.*, S_∞^d *is greater than the maximum sustainable yield stock*), *the laissez-faire outcome is associated with over-consumption in the steady state and an inefficiently high level of effort. If* $G'(S_\infty^d)>0$ *the laissez-faire outcome is associated with an inefficiently low level of steady-state consumption and its effects on steady-state effort is ambiguous.*

Proof. See Appendix A. □

Remark. In the special case where $G(S)$ is quadratic, say $G(S)=bS(1-(S/K))$, and the harvesting function takes the familiar Schaefer specification, $c=\gamma SL$ (Schaefer, 1957; Brander and Taylor, 1998), where b, K and γ are positive parameters, it is easy to verify that steady-state effort is monotonically decreasing in steady-state stock, $L_\infty=\gamma^{-1}G(S_\infty)/S_\infty=(b/\gamma)(1-(S_\infty/K))$, hence steady-state effort in a decentralized economy is bigger than under the social planner, regardless of whether S_∞^d is greater or smaller than the maximum sustainable yield stock.

We use the following numerical example to illustrate the results stated in Proposition 1. We consider the utility function (10) where $\chi\geq 0$ is the *effort cost* parameter. We assume the growth function $G(S)=bS(1-(S/K))$ and the Schaefer harvesting function. Notice that the maximum-sustainable-yield stock is $S_M=K/2$. Setting $\varepsilon=0$, $\rho=0.05$, $K=1$, $b=\gamma=10$ and $\delta=0.3$, we consider three cases (a) effort is costless (i.e., $\chi=0$), (b) effort cost is low, $\chi=0.1$, and (c) effort cost is high, $\chi=3$.

In case (a), the steady-state stock under the decentralized economy is identical to that under the planner, $S^d=S^p=0.0455$, which is below the maximum-sustainable-yield stock. Effort is $L^p=L^d=0.9545$. Consumption is at $c^d=c^p=bS(1-S)=0.4303$.

In case (b), the steady-state stock under the decentralized economy is $S^d=0.1368$, smaller than that under the planner, $S^p=0.1570$, which is again below the maximum-sustainable-yield stock. The level of consumption is $c^d=1.1808<c^p=1.3235$, and effort is $L^d=0.8632>L^p=0.8430$. Therefore steady-state utility in the decentralized economy is lower than under the planner.

In case (c), the steady-state stock under the decentralized economy is $S^d=0.6802$, smaller than that under the planner, $S^p=0.7512$. Both are greater than the maximum-sustainable-yield stock. The level of consumption is $c^d=2.1749>c^p=1.8686$, and effort is $L^d=0.3197>L^p=0.2487$. The steady-state utility in the decentralized economy is $U^d=-0.5388<U^p=-0.4776$.

Intuitively, relative consumption concerns trigger a process of excessive extraction of the natural resource. If the effort cost parameter is high, then at the steady state, the stock level will exceed the maximum-sustainable-yield stock, i.e., the natural reproduction rate is locally decreasing in the stock, and over-consumption can be maintained but only at the expense of an inefficiently high level of effort. On the other hand, if the effort cost parameter is low (but still positive) the steady-state stock of resources will be below the maximum-sustainable-yield stock, i.e., the reproduction rate is locally increasing in the stock, then the laissez-faire solution provides a permanently lower level of consumption relative to the efficient solution.

So far we have assumed that the steady-state stock is positive. This is plausible if the resource good is the only consumption good and the marginal utility of consumption tends to infinity as c tends to zero. If there are other consumption goods, and the marginal utility of consuming the resource good is bounded, then extinction of the resource is a definite possibility. In fact, in Appendix B.2, we show that in this case, under certain range of parameter values, the steady-state stock under the social planner is positive, while under decentralized choices, a sufficiently strong degree of envy can lead to extinction of the resource.

2.4. The dynamic distortion

The dynamic distortion arises when concerns for relative consumption cause a deviation of the private willingness to shift consumption through time from the efficient rate of change of consumption chosen by a central planner. Differentiating (12) and combining the result with (13), along a symmetric equilibrium where $c=C$, we obtain the following system of differential equations for the decentralized solution,

$$\frac{\dot{c}^d[U_{11}+U_{12}+U_{1L}L_c+(U_{L1}+U_{L2}+U_{LL}L_c)L_c+U_LL_{cc}]}{U_1+U_LL_c}+\frac{\dot{S}^d[U_{1L}L_S+U_{LL}L_SL_c+U_LL_{cS}]}{U_1+U_LL_c}$$
$$=\rho-G'(S^d)-\frac{U_LL_S}{U_1+U_LL_c} \tag{16}$$

$$\dot{S}^d=G(S^d)-c^d \tag{17}$$

Proceeding similarly with (14) and (15) we obtain the following pair of differential equations for the efficient solution

$$\frac{\dot{c}^p[U_{11}+2U_{12}+U_{1L}L_c+U_{2L}L_c+U_{22}+(U_{L1}+U_{L2}+U_{LL}L_c)L_c+U_LL_{cc}]}{U_1+U_2+U_LL_c}$$
$$+\frac{\dot{S}^p[U_{1L}L_S+U_{2L}L_S+U_{LL}L_SL_c+U_LL_{cS}]}{U_1+U_2+U_LL_c}=\rho-G'(S^p)-\frac{U_LL_S}{U_1+U_2+U_LL_c} \tag{18}$$

$$\dot{S}^p=G(S^p)-c^p \tag{19}$$

By definition, the dynamic distortion is limited to the transitional path and therefore it is better illustrated using a simpler variant of the model where relative consumption does not introduce steady-state distortions. From Proposition 1, both steady states coincide if $L(c,S)=L(c)$, and for the sake of exposition we shall make this assumption throughout Section 2.4. Then the transitional path of the competitive solution is efficient if and only if

$$\frac{U_{11}+U_{12}+U_{1L}L_c+(U_{L1}+U_{L2}+U_{LL}L_c)L_c+U_LL_{cc}}{U_1+U_LL_c}$$
$$=\frac{U_{11}+2U_{12}+U_{1L}L_c+U_{2L}L_c+U_{22}+(U_{L1}+U_{L2}+U_{LL}L_c)L_c+U_LL_{cc}}{U_1+U_2+U_LL_c} \tag{20}$$

At this stage is convenient to define the following function, called the “reduced-form utility function”

$$V(c,C)\equiv U(c,C,L(c)) \tag{21}$$

Let us define $k(x)$ as the marginal rate of substitution of the reduced-form utility function on a point on the 45 degree line, where $c=C$:

$$k(x) \equiv \frac{V_C(x,x)}{V_c(x,x)} \equiv \frac{V_2(x,x)}{V_1(x,x)} \tag{22}$$

Proposition 2. *There are no dynamic distortions if and only if the reduced-form utility function $V(c, C)$ displays "scale-independent" marginal rate of substitution along the 45 degree line ($c=C$ line), i.e., iff $k(x)$, as defined by (22), is a constant (independent of x).*

Proof. Using (21) we can express condition (20) as follows □

$$\frac{V_{11}+V_{12}}{V_1} = \frac{V_{11}+V_{12}+(V_{21}+V_{22})}{V_1+V_2}$$

where all derivatives are evaluated at $(c, C)=(x, x)$, for any $x>0$. This equality holds if and only if

$$(V_1+V_2)(V_{11}+V_{12}) = (V_1)(V_{11}+V_{12}) + (V_1)(V_{21}+V_{22})$$

i.e.,

$$-\left[\frac{V_{22}}{V_1} - \frac{V_2 V_{12}}{(V_1)^2}\right] = \frac{V_{21}}{V_1} - \frac{V_2 V_{11}}{(V_1)^2}$$

which is equivalent to

$$-\frac{\partial}{\partial C}\left[\frac{V_2}{V_1}\right] = \frac{\partial}{\partial c}\left[\frac{V_2}{V_1}\right]$$

i.e.,

$$\frac{d}{dx}\left[\frac{V_2(x,x)}{V_1(x,x)}\right] = 0$$

Under exogenous effort, this condition reduces to the result presented by Fisher and Hof (2000) in the context of a growing economy.[10]

Let us illustrate the results of Proposition 2 by a few examples:

Example 3. Assume preferences are given by (7) and $L=c^{\gamma}$, with $\gamma>0$. Then, assuming $1>\mu\gamma$ and $0<(1+\beta-\mu\gamma)(1-\theta)<1$,

$$V(c,C) = \frac{1}{1-\theta}\left[\left(\frac{1}{C}\right)^{\beta} c^{\beta+1-\mu\gamma}\right]^{1-\theta}$$

[10] We refer our readers to Turnovsky and Liu (2004) for an extensive analysis of the effects of the dynamic distortion. Under costless effort their results are readily applicable to our context.

This function is concave and homogeneous of degree $(1-\mu\gamma)(1-\theta)$ in (c, C). Thus the marginal rate of substitution is constant along any ray through the origin, i.e., any line $C=bc$ where $b>0$. Using Proposition 2, there are no dynamic distortions.

Example 4. Assume preferences are given by (9) and $L=c^{\gamma}$, with $\gamma>0$. Then

$$V(c,C) = \left[\left(\frac{c^{\beta+1}}{C^{\beta}}\right)^{-1} + (c)^{\gamma}\right]^{-1}$$

$V(c, C)$ is not homogeneous in (c, C), and the marginal rate of substitution is not constant along the 45 degree line $c=C$, so consumption externalities distort the transition.

What is the direction of dynamic distortions? To simplify, let us continue to assume that $L(c, S)=L(c)$ so that there are no steady-state distortion. In the (S, c) space, let $c^d(S)$ denote the stable branch of the saddle path under decentralized choices. How does it compare with $c^p(S)$, the stable branch of the saddle path under the social planner? The following proposition supplies a partial answer.

Proposition 3. *Suppose there are dynamic distortions, but no steady-state distortions. Then in the steady state, the stable branch of the saddle path under decentralized choices has a flatter (respectively, steeper) slope then that under the social planner if the marginal rate of substitution, $k(x)$, is an increasing (respectively, decreasing) function of x.*

Proof. See Appendix A. □

2.5. Optimal policy intervention

In the presence of consumption externalities the decentralized allocation of resources is not Pareto efficient. We now show that the government can restore efficiency by means of corrective taxation. Consider the decentralized economy described in Section 2.2, with a government that imposes a time varying tax, $\tau(t)$, on resource extraction. The government is assumed to run a balanced budget, returning at each instant in time the amount raised through taxes as a lump sum transfer, $T(t)$. Under this tax-and-transfer program, the individual, taking T as given, perceives the following relationship between her level of extraction and her consumption

$$c = (1-\tau)y + T$$

i.e., she takes it that $dc/dy=1-\tau$. The consumer chooses the time path y^r, where the superscript r denotes variables under the scenario with tax or regulations, to maximize

$$\Omega = \int_0^{\infty} U((1-\tau)y^r + T, C, L(y^r, S^r))e^{-\rho t}\,dt$$

subject to

$$\dot{S}^r = G(S^r) - y^r \tag{23}$$

The necessary conditions for the representative consumer are

$$(1-\tau)U_1 + U_L L_y = \psi^r \tag{24}$$

$$\frac{\dot{\psi}^r}{\psi^r} = (\rho - G'(S^r)) - \frac{U_L L_S}{(1-\tau)U_1 + U_L L_y} \tag{25}$$

Differentiate (24) with respect to time

$$(1-\tau)\left[\frac{d}{dt}(U_1)\right] - (U_1)\left[\frac{d}{dt}\tau\right] + \left[\frac{d}{dt}(U_L L_y)\right] = \dot{\psi}^r \tag{26}$$

Combining Eqs. (26) and (25), we get

$$\frac{(1-\tau)[d(U_1)/dt] - (U_1)[d\tau/dt] + [d(U_L L_y)/dt]}{(1-\tau)U_1 + U_L L_y} = (\rho - G'(S^r)) - \frac{U_L L_S}{(1-\tau)U_1 + U_L L_y} \tag{27}$$

Suppose the government set $\tau(t)$ as follows:

$$\tau(t)U_1(c^r, c^r, L(c^r, S^r)) = -U_2(c^r, c^r, L(c^r, S^r)) \tag{28}$$

then, differentiating both sides of (28) with respect to t

$$U_1\left[\frac{d}{dt}\tau\right] + \tau(t)\left[\frac{d}{dt}(U_1)\right] = -\left[\frac{d}{dt}(U_2)\right] \tag{29}$$

Substituting (28) and (29) into (27), we obtain the following differential equation that together with (23) describes the dynamics of the competitive solution under our tax scheme:

$$\frac{[d(U_1)/dt] + [d(U_2)/dt] + [d(U_L L_y)/dt]}{U_1 + U_2 + U_L L_y} = (\rho - G'(S^r)) - \frac{U_L L_S}{U_1 + U_2 + U_L L_y}$$

This equation coincides with (18) and therefore achieves the social optimum. Our results are summarized in the following proposition.[11]

Proposition 4. *Along a symmetric path, $c = C$, the efficient equilibrium can be decentralized by setting a tax on resource extraction at each point in time equal to*

$$\tau = -\frac{U_2(c^r, c^r, L(c^r, S^r))}{U_1(c^r, c^r, L(c^r, S^r))}$$

In general τ will be time-varying along the transitional path converging to a positive constant at the steady state. Furthermore our restrictions on preferences (Assumption 1) imply that $0 < \tau < 1$.

2.6. Calibrating the effects of the externality under the perfect property-rights regime

Consider an economy populated by a representative individual endowed with preferences given by (7). Multiplicative relative consumption has been widely used, see for example Abel (1990), Gali (1994), Solnick and Hemenway (1998) and Alvarez-Cuadrado et al. (2004). In the competitive solution the individual takes C as given and chooses c to maximize

$$\int_0^\infty e^{-\rho t}\left\{\frac{1}{1-\theta}\left[c\left(\frac{c}{C}\right)^\beta [L(c,S)]^{-\mu}\right]^{1-\theta}\right\}dt$$

[11] Our proposition on the optimal consumption tax is in line with the existing literature. See for example Brekke and Howarth (2002).

subject to (2) and $S(0)=S_0$. Evaluating the optimality conditions along a symmetric equilibrium path where $C=c$, we obtain

$$(1+\beta)c^{-\theta}L^{-\mu(1-\theta)} - \mu c^{1-\theta}L^{-\mu(1+\theta)-1}L_c - \psi = 0 \tag{30}$$

$$\dot{\psi} = \psi[\rho - G'(S)] + \mu c^{1-\theta}L^{-\mu(1+\theta)-1}L_S \tag{31}$$

Consider the following harvesting and natural resource reproduction functions,[12]

$$c = F(S,L) = S^{\alpha}L^{\gamma} \tag{32}$$

$$G(S) = S^{\lambda} \tag{33}$$

with $(1-\gamma) \le \alpha \le 1$, $(1-\alpha) \le \gamma \le 1$ and $0<\lambda<1$. Our harvesting function nests the popular Schaefer harvesting function, where $\gamma=\alpha=1$, and the constant returns to scale Cobb–Douglas function, where $\alpha+\gamma=1$ (Brown, 1974; Smith, 1975) as special cases. Inverting (32) the necessary conditions become[13]

$$S^{(\mu(1-\theta)\alpha)/\gamma}c^{(-(\mu(1-\theta)+\theta\gamma))/\gamma}\left[(1+\beta) - \frac{\mu}{\gamma}\right] - \psi = 0 \tag{34}$$

$$\dot{\psi} = \psi\left[\rho - \lambda S^{\lambda-1}\right] - \mu S^{(\mu(1-\theta)\alpha/\gamma)-1}c^{(-(\mu(1-\theta)+\theta\gamma)/\gamma)+1} \tag{35}$$

Combining (34), (35), (33) and (2) we get a system of two differential equations that together with the initial stock of resources and the transversality condition fully describes the dynamic behavior of our model. In the unique steady state, the stock of natural resources satisfies

$$\rho - \lambda\left(S^d_{\infty}\right)^{\lambda-1} = \frac{\alpha\mu}{\gamma(1+\beta)-\mu}\left(S^d_{\infty}\right)^{\lambda-1} \tag{36}$$

It is straightforward to show that the steady-state stock of natural resources, S^d_{∞}, is decreasing in the importance of relative consumption captured by β. Furthermore if effort is costless (i.e., $\mu=0$) the steady-state level of the natural resource is not affected by relative consumption concerns. Finally it is worth noticing that the efficient steady state satisfies (36) with $\beta=0$ and therefore in line with our analytical results, $S^d_{\infty} < S^p_{\infty}$ and $C^d_{\infty} < C^p_{\infty}$.

We calibrate our model to illustrate the quantitative effects of relative consumption in the steady-state stock of resources, consumption, effort, and welfare. Our measure of the welfare cost of the distortion is standard: we denote by φ the negative of the percentage increase in individual (and average) steady-state consumption that an agent living in the competitive world must receive in order to enjoy the same welfare level as that of an agent living in the steady state of the planned economy. Notice that given this definition welfare losses are represented by negative values of φ and gains by positive ones.[14] In our benchmark calibration, we use the Schaefer harvesting function, we set the rate of time preference to the standard value in the literature $\rho=0.05$, the stock elasticity of the reproduction function $\lambda=.5$, and the parameter that governs the disutility of effort $\mu=0.2$. Fig. 1 conducts extensive sensitivity analysis around these parameter choices.

[12] Our numerical results are based on a reproduction function strictly increasing in the resource stock. Although this specification is more restrictive than our previous analytical results, we believe that in the resource extraction context the increasing range of this function is the empirically relevant one.

[13] In order to ensure that the planner's optimization problem is strictly concave in c we impose the restriction $\mu/\gamma<1$.

[14] The steady state level of welfare achieved by the planned economy is given by $\Omega^p(c^p_{\infty}, L^p_{\infty}) = \int_0^{\infty} e^{-\rho t}\{1/(1-\theta)[c^p_{\infty}(L^p_{\infty})^{-\mu}]^{1-\theta}\}\,dt$, the corresponding measure for the decentralized economy is given by $\Omega^m(c^m_{\infty}, L^m_{\infty}) = \int_0^{\infty} e^{-\rho t}\{1/(1-\theta)[c^m_{\infty}(L^m_{\infty})^{-\mu}]^{1-\theta}\}\,dt$. We define our welfare cost as the negative of the value of φ that satisfies $\Omega^p(c^p_{\infty}, L^p_{\infty}) = \Omega^m((1+\varphi)c^p_{\infty}, L^m_{\infty})$. Admittedly, φ overstates the true welfare cost since it ignores the welfare effects along the transition. Nonetheless given the size of the welfare costs associated with the steady state distortion we believe our measure is a good proxy for the overall welfare costs of the distortion from any set of initial conditions. See Alvarez-Cuadrado (2007) for an analysis of the welfare costs along the transitional path in the context of a growing economy.

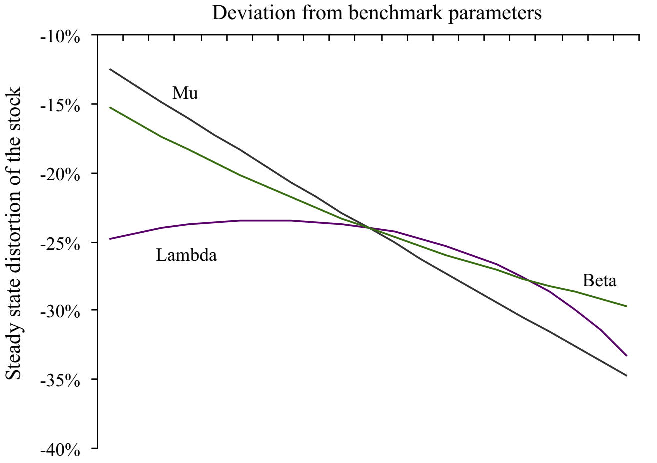

Fig. 1. Sensitivity analysis around benchmark calibration parameters.

Table 1
Schaefer extraction technology under private property of the stock: steady state distortion for different parameter configurations (μ and β govern the utility importance of effort and envy respectively).

	$\mu=0.2$					$\beta=0.5$			
	$\beta=0$	$\beta=0.2$	$\beta=0.5$	$\beta=1$	$\beta=5$	$\mu=0$	$\mu=0.1$	$\mu=0.3$	$\mu=0.4$
Stock of resources	0%	−13%	−**24%**	−34%	−49%	0%	−13%	−35%	−45%
Consumption	0%	−7%	−**13%**	−19%	−29%	0%	−6%	−19%	−26%
Effort	0%	7%	**15%**	23%	40%	0%	7%	24%	35%
Welfare, φ	0%	−9%	−**18%**	−28%	−50%	0%	−8%	−32%	−52%
Optimal tax rate	0%	16%	**33%**	50%	83%	0%	33%	33%	33%

Since we restrict our analysis to steady-state outcomes our results are independent of the value of θ. Direct evidence on the importance of relative consumption, captured by β is sparse. The literature on the equity premium puzzle suggests that only relative consumption matters; see Abel (1990), Gali (1994) and Campbell and Cochrane (1999). Easterlin (1995) and Frey and Stutzer (2002) evaluate the time series and cross-sectional properties of several measures of self-reported happiness. Their findings are consistent with preference specifications that again place most of the weight on relative consumption. Alpizar et al. (2005) conduct several experiments to assess the importance of relative consumption. In the case of cars and housing their median estimate for the weight of relative consumption lies between 0.5 and 0.75. Finally, Howarth (2000), exploring the impact of relative consumption on climate change, suggests a weight on status in the order of one third. A similar value is chosen by Wendner and Goulder (2008) after a review of the empirical literature. In our context, this is equivalent to $\beta=0.5$. We use this value for our benchmark calibration and explore its sensitivity to the range of reported estimates.

As reported in Table 1, at the steady state of our benchmark calibration (in bold numerals), the competitive stock of resources is three fourths of the efficient stock. As a result, there is a shortfall in consumption equal to one eighth of the efficient level and the laissez-faire level of effort exceeds the efficient level by approximately 15%. This combination of lower consumption and higher effort is associated with a welfare cost, expressed in units of permanent consumption, close to one sixth of the competitive level of consumption. Table 1 presents some robustness checks for our benchmark results. As we increase the weight of relative consumption (i.e., $\beta/(1+\beta)$) from

Table 2
Constant returns to scale technology under private property of the stock: steady state distortion for different parameter configurations (μ and β govern the utility importance of effort and envy respectively).

	μ = 0.2					β = 0.5			
	β = 0	β = 0.2	β = 0.5	β = 1	β = 5	μ = 0	μ = 0.1	μ = 0.3	μ = 0.4
Stock of resources	0%	−19%	**−33%**	−44%	−59%	0%	−15%	−56%	−82%
Consumption	0%	−10%	**−18%**	−25%	−36%	0%	−8%	−33%	−57%
Effort	0%	0%	**0%**	0%	0%	0%	0%	0%	0%
Welfare, φ	0%	−11%	**−22%**	−33%	−56%	0%	−8%	−50%	−133%
Optimal tax rate	0%	16%	**33%**	50%	83%	0%	33%	33%	33%

zero to more than eight tenths, the competitive stock of resources falls to one half of the efficient stock. The diminishing returns in the resource reproduction function limit the drop in consumption that remains close to two thirds of the efficient level, but despite this, the associated welfare costs, as a result of diminishing marginal utility, more than double relative to our benchmark calibration. Finally, in line with Brekke and Howarth (2002, p. 80) the optimal tax rate in our benchmark calibration, which is equal to the weight of relative consumption, is one third. Since relative consumption concerns affect the steady-state allocation of resources through the trade-off between consumption and effort, the distortion is very sensitive to changes in μ. As effort becomes more costly, μ = 0.4, the planner reduces both consumption and effort to reach a steady state with a relatively high stock of resources. Since competitive agents overvalue consumption they exert an inefficiently high level of effort that eventually runs the stock of resources down to only one half of the efficient level. The negative welfare figures are of course welfare costs. They are quite large, equivalent to a consumption loss of 52% of the steady state laissez faire level. Fig. 1 explores the sensitivity of the distortion in the stock of resources to percentage changes in our benchmark parameters. In line with the results reported in Table 1 the size of the distortion increases quickly both on the importance of relative consumption and on the disutility of effort.

The steady-state results for the constant returns to scale extraction function are presented in Table 2. Under our benchmark calibration, α = 0.5, the competitive stock of resources and the level of consumption are only two thirds and four fifths of their efficient counterparts respectively. Since under our benchmark parameter values steady-state effort is not distorted, this lower level of consumption is associated with a welfare cost close to one fourth of the laissez-faire level of consumption. As in the constant returns to scale case, increases in the weight of relative consumption, β, or increases on the disutility of effort, μ, exacerbate the effects of the distortion and its welfare costs.

3. Consumption externalities under open access

We now turn to the other extreme and assume that the resource is exploited under the open access regime. We model open access by assuming that the resource is extracted by a continuum of individuals; they are indexed by i, where i is a real number in the interval $[0, 1]$. Individuals are identical in all respects. There is only one resource stock, denoted by S. Let $y_i(t)$ denote individual i's rate of resource extraction at time t. Aggregate extraction at time t is $Y(t)$ where

$$Y(t) = \int_0^1 y_i(t)\, di$$

The evolution of the resource stock is $\dot{S}(t) = G(S(t)) - Y(t)$. Thus the harvest y_i of any agent i has a negligible impact on the resource stock. Consequently, agent i takes the time path $Y(t)$ as given and independent of her actions. We maintain the same assumptions on preferences and harvesting technology introduced in the private property rights section.

3.1. Laissez-faire outcome under open access

We assume that all output is consumed. Then $c^i = y^i$, and $C = Y$. Inverting the harvesting function we obtain the effort requirement of the i th individual, $L_i = L^i(y_i, S)$. This agent takes the time path $Y(t)$ as given and chooses the time path $y_i(t)$ to maximize her life-time utility

$$\int_0^\infty e^{-\rho t} U(c^i, C, L^i(c_i, S))\, dt$$

subject to $\dot{S}(t) = G(S(t)) - C(t)$. Pointwise maximization gives the first order condition

$$U_1(c, C, L) + U_L L_c = 0 \tag{37}$$

Remark. Eq. (37) has a solution $c \in (0, \infty)$ if we use the functions (8) or (10), but does not have a solution if we use (7).

The second order condition is

$$\Delta \equiv U_{11} + U_{1L}L_c + L_c[U_{L1} + U_{LL}L_c] + U_L L_{cc} < 0$$

In a symmetric equilibrium, $C = c$, and thus the laissez-faire harvest level c satisfies

$$U_1(c, c, L(c, S)) + U_L(c, c, L(c, S))L_c(c, S) = 0 \tag{38}$$

Eq. (38) determines the equilibrium current extraction $c(t)$ under open access as a function of the current stock level $S(t)$. Differentiate Eq. (38) totally, we get

$$[\Delta + U_{12} + U_{L2}L_c]dc + [U_{1L}L_S + U_{LL}L_c L_S + U_L L_{cS}]dS = 0$$

As before, we assume that $\Delta + U_{12} + U_{L2}L_c < 0$. Assuming $L_{cS} \leq 0$, we obtain $U_{1L}L_S + U_{LL}L_cL_S + U_LL_{cS} > 0$, hence $dc/dS > 0$. Thus we obtain a curve $c = c(S)$ which shows that the (open-access) equilibrium consumption at any time as an increasing function of the concurrent stock level. The intersection of the curve $c(S)$ and the curve $G(S)$ yields the steady-state stock S^{oa} (here oa stands for "open access") under open access. In general there can be many such intersections. Since $G(S)$ is by assumption strictly concave with $G(0) = 0$, if $c(S)$ is convex or linear with $c(0) = 0$ and $c'(0) < G'(0)$ then there is a unique positive steady state S^{oc}.

Let us specialize this result by using the functional form (10) for the utility function, and (32) for the harvest function. Then Eq. (38) becomes

$$\frac{1}{c - \delta c} = \chi (L(c, S))^{\varepsilon} \left[\frac{1}{\gamma} c^{(1/\gamma)-1} S^{-\alpha/\gamma} \right]$$

$$\frac{c^{-1}}{1 - \delta} = \frac{\chi}{\gamma} c^{((1+\varepsilon)/\gamma)-1} S^{-(\alpha(1+\varepsilon))/\gamma}$$

hence

$$c = \left[\frac{\gamma}{(1 - \delta)\chi} \right]^{\gamma/(1+\varepsilon)} S^{\alpha}$$

In the case $\alpha = 1$, this gives a linear and increasing function $c(S)$. Then its intersection with the curve $G(S)$ gives a unique interior steady state stock level S^{oa}, provided that

$$c'(0) \equiv \left[\frac{\gamma}{(1 - \delta)\chi} \right]^{\gamma/(1+\varepsilon)} < G'(0) \tag{39}$$

Proposition 5. *Assume the functional forms (10) and (32) with $\alpha = 1$. Then, provided inequality (39) holds, there is a unique interior steady state $S^{oa} > 0$. An increase in the strength of envy (an increase in δ) will shift the* *curve $c(S)$ up, reducing the steady-state stock level. If envy is very strong, then (39) cannot be satisfied, and the only steady state is extinction of the resource stock.*

Remark. If $\alpha \in (0, 1)$, there may exist many interior steady state stock levels. Suppose there are two. Then the smaller one is unstable and the bigger one is stable. An in the strength of envy (an increase in δ) will shift the curve $c(S)$ up, reducing the stable steady-state stock level, and raising the unstable one.

3.2. Comparing steady states under alternative regimes

The following proposition compares the steady-state stock under open access with that under the perfect property-rights regime.

Proposition 6. *The steady-state stock under open access is smaller than the steady-state stock of the representative individual under the perfect property-rights regime.*

Proof. Under open access, the steady-state stock is obtained by solving the following pair of equations

$$G(S) - c = 0$$

$$U_1(c, c, L(c, S)) + U_L L_c(c, S) = 0$$

Under the perfect property-rights regime, the two equations are

$$G(S) - c = 0$$

$$U_1(c, c, L(c, S)) + U_L L_c(c, S) = \psi^d_\infty$$

where ψ^d_∞ is the positive shadow price at the steady state. □

Let us define the function

$$K(c, S, \phi) \equiv U_1(c, c, L(c, S)) + U_L L_c(c, S) - \phi$$

where ϕ is a parameter. When $\phi = 0$ (respectively, ψ^d_∞) we have the open access (resp. perfect property rights) case. The equation $K(c, S, \phi) = 0$ defines c as a function of S and ϕ. We now show that the curve $c = c(S, \phi)$ shifts down as ϕ moves from 0 to ψ^d_∞. To see this, apply the implicit function theorem to eq $K(c, S, \phi) = 0$. For any given S, we can compute

$$\frac{\partial c(S, \phi)}{\partial \phi} = -\frac{K_\phi}{K_c} = \frac{1}{K_c} < 0$$

since by assumption the social planner's objective function is concave in c.

It follows that the open-access regime results in a lower steady-state stock level.

3.3. Efficiency-inducing taxes

In order to induce competitive agents under a common property arrangement to replicate the planner's solution, we propose two taxes $\tau_1(t)$ and $\tau_2(t)$ that follow different dynamics. In principle in the presence of two external effects, over-exploitation of the resource resulting from relative consumption and from the absence of perfect property rights, we will need two tax instruments with different dynamics to mimic the efficient solution.

Recall that the central planner's solution satisfies the equations

$$U_1 + U_2 + U_L L_c = \psi^p \tag{40}$$

$$\rho - \frac{\dot{\psi}^p}{\psi^p} = G'(S) + \frac{U_L L_S}{U_1 + U_2 + U_L L_c} \tag{41}$$

These two equations imply that

$$\frac{1}{U_1 + U_2 + U_L L_c} \frac{d}{dt}[U_1 + U_2 + U_L L_c] = \rho - G'(S) - \frac{U_L L_S}{U_1 + U_2 + U_L L_c} \tag{42}$$

Consider the decentralized economy with a government that imposes a time varying tax, $\tau(t) = \tau_1(t) + \tau_2(t)$, on resource extraction. The government runs a balanced budget, returning at each instant in time the amount raised through taxes as a lump sum transfer, $T(t)$. Under this scheme, the individual, taking T as given, perceives the following relationship between her level of extraction and her consumption

$$c = (1 - \tau_1 - \tau_2)y + T$$

i.e., she takes it that $dc/dy = 1 - \tau_1 - \tau_2$. The consumer chooses the time path y^r, where the superscript r denotes variables under the scenario with government tax or regulations, to maximize

$$\int_0^\infty U((1 - \tau_1 - \tau_2)y^r + T, C, L(y^r, S^r))e^{-\rho t}\, dt$$

This gives the first-order condition

$$(1 - \tau_1)U_1 + U_L L_y = \tau_2 U_1 \tag{43}$$

Let us choose $\tau_1(t)$ by

$$\tau_1(t) = -\frac{U_2(c^p(t), c^p(t), L(c^p(t), S^p(t)))}{U_1(c^p(t), c^p(t), L(c^p(t), S^p(t)))} \tag{44}$$

and choose $\tau_2(t)$ such that

$$\tau_2(t)U_1(c^p(t), c^p(t), L(c^p(t), S^p(t))) = \psi^p(t) \tag{45}$$

The first tax, τ_1, induces competitive agents to internalize the negative impact of their harvesting choices on the welfare of other agents through their contribution to average consumption while second tax, τ_2, induces competitive agents to internalize the impact of their choices on the evolution of the stock of resources.

Combining (41) with (45) we reach,

$$\frac{1}{\tau_2 U_1^p} \frac{d}{dt}\left[\tau_2 U_1^p\right] = \rho - G'(S^p) - \frac{U_L L_S}{U_1 + U_2 + U_L L_c} \tag{46}$$

Then Eq. (43) gives

$$(1 - \tau_1)\frac{d}{dt}(U_1) - U_1\dot{\tau}_1 + \frac{d}{dt}\left[U_L L_y\right] = \frac{d}{dt}[\tau_2 U_1] \tag{47}$$

Dividing the left-hand side of (47) by $(1 - \tau_1)U_1 + U_L L_y$ and the right-hand side by $\tau_2 U_1$, and making use of (44) and (46), we get

$$\frac{(1 - \tau_1)(d(U_1)/dt) - U_1\dot{\tau}_1 + d[U_L L_y]/dt}{U_1 + U_2 + U_L L_y} = \rho - G'(S^p) - \frac{U_L L_S}{U_1 + U_2 + U_L L_c} \tag{48}$$

Now, from (44)

$$\tau_1 \frac{d}{dt}(U_1) + U_1\dot{\tau}_1 = -\frac{d}{dt}[U_2] \tag{49}$$

Table 3
Steady state distortion for different parameter configurations under Schaefer extraction technology: private property vs. common property (δ governs the utility importance of envy).

	Private property				Common property			
	δ=0	δ=0.15	δ=0.33	δ=0.5	δ=0	δ=0.15	δ=0.33	δ=0.5
Stock of resources	0%	−12%	**−24%**	−37%	−53%	−61%	**−69%**	−77%
Consumption	0%	−6%	**−13%**	−21%	−32%	−37%	**−44%**	−52%
Effort	0%	6%	**15%**	26%	47%	60%	**79%**	107%
Welfare, φ	0%	−10%	**−23%**	−45%	−91%	−130%	**−199%**	−346%
τ_1	0%	16%	**33%**	50%	0%	16%	**33%**	50%
τ_2	0%	0%	**0%**	0%	53%	45%	**36%**	27%

Substituting (49) into (48) we get

$$\frac{d(U_1)/dt + d(U_2)/dt + d[U_L L_y]/dt}{U_1 + U_2 + U_L L_y} = \rho - G'(S^p) - \frac{U_L L_S}{U_1 + U_2 + U_L L_c}$$

which shows that the open access extraction path under corrective taxation mimics the central planner's path, as given by (42).

3.4. Numerical results

Consider an economy populated by a continuum of identical individuals endowed with preferences given by (10). These agents have access to the same Schaefer harvesting technology and we assume the reproduction of the resource is given by (33). We calibrate our model to compare the effects of relative consumption in the steady-state stock of resources, consumption, effort, and welfare under private and common property arrangements. We set the rate of reproduction of the resource, λ = .5, and the rate of time preference, ρ=0.05, equal to our previous calibration. Under our preferences specification (10), the value suggested by Brekke and Howarth (2002) for the relativity concerns implies δ=0.33. Finally, we choose the effort parameters to obtain steady-state distortions under private property of the resource stock that are equal to the ones obtained with multiplicative relative consumption in Section 2. Table 3 summarizes our results and explores its sensitivity to variations of the importance of relative consumption.

As in Section 2, in the steady state under private property the competitive stock of resources and consumption are respectively three fourths and one eighth of their efficient counterparts, while effort is 15% above the efficient level. When the resource is harvested under open access the competitive stock of resources is barely one third of the efficient stock. Consumption externalities account for roughly one third of this decrease while the remaining two thirds are the result of over-exploitation due to common property. The level of consumption associated with the steady state competitive stock of resources is barely half of the efficient level while effort exceeds by almost 80% the efficient level. The introduction of the tragedy of commons only exacerbates the distortions associated with relative consumption. In our benchmark calibration, the welfare losses associated with both external effects are huge, equivalent to a consumption loss three times as large as the steady state laissez faire level. As we increase the importance of relativity concerns, as measured by δ, both the stock of resources and consumption fall while effort increases. Finally, since both externalities are complementary, increases in the first tax rate, τ_1, in response to increases in the importance of relative consumption, reduce the external effect associated with open access and therefore are associated with decreases in the second tax rate, τ_2.

4. Conclusions

The negative welfare consequences of competitive consumption have been long noted by social and natural scientists. In the words of 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.

Only recently has the economic profession begun to pay closer attention to the welfare consequences of consumption externalities. In this paper we have presented a simple model of resource extraction where preferences are defined over the individual's consumption level, her effort, and the comparison of her consumption with that of other members of the community. Our specification captures the intuition that lies behind the growing body of empirical evidence that places interpersonal comparisons as a key determinant of well-being. We find that envious individuals ignore the negative effects that their extraction choices impose on the welfare of their neighbors; as a result they over-exploit the natural resource, resulting in an inefficiently low steady-state stock.

We have identified two dimensions along which consumption externalities distort the efficient extraction of resources. In the case where effort is endogenous, envy distorts the marginal rate of substitution between consumption and effort, the *static/steady state distortion*. Even when effort is costless, consumption externalities might distort the willingness to shift consumption through time and therefore the path of extraction displays a *dynamic distortion*. These distortions provide a new rationale for the increasing concerns about over-exploitation of resources, possible extinction, and the general deterioration of the environment caused by human activities. Our results highlight an important scope for government intervention even in the absence of the externalities associated with common property arrangements. In a world where agents envy the consumption of their neighbors, an appropriately chosen harvesting tax must be imposed to induce the preservation of the natural resource and improve welfare. Our results are particularly important for developing economies because they have greater macroeconomic dependence on renewable resources.

Appendix A. Proofs of Propositions 1 and 3

A.1. Proof of Proposition 1

The steady-state values of the symmetric competitive solution, denoted by $(c^d_\infty, \psi^d_\infty, S^d_\infty)$, satisfy the following system of equations

$$U_1(c, c, L(c, S)) + U_L L_c - \psi = 0$$

$$\psi[\rho - G'(S)] - U_L(c, c, L(c, S))L_S(c, S) = 0$$

$$G(S) - c = 0$$

The steady-state values of the social planner's solution, denoted by $(c^p_\infty, \psi^p_\infty, S^p_\infty)$, satisfy the following system of equations

$$U_1(c, c, L(c, S)) + U_2(c, c, L(c, S)) + U_L L_c - \psi = 0$$

$$\psi[\rho - G'(S)] - U_L(c, c, L(c, S))L_S(c, S) = 0$$

$$G(S) - c = 0$$

We assume that the planner's steady state has the usual saddlepoint property. We wish to compare $(c^p_\infty, S^p_\infty, \psi^p_\infty)$ with $(c^d_\infty, S^d_\infty, \psi^d_\infty)$.

Proof of Part (i): Assume either $U_L = 0$ or $L_S = 0$. Then the steady-state stock satisfies $G'(S) = \rho$ under the social planner, and also under the laissez-faire regime. Since $G(S)$ is strictly concave, this condition implies $S^p_\infty = S^d_\infty$. This in turn implies $c^p_\infty = c^d_\infty$.

Proof of Part (ii): Assume that $U_L < 0$ and $L_S < 0$. Then, since the shadow price ψ is positive, at the steady state $\rho - G'(S) = \psi^{-1} U_L L_S > 0$. We now show that this implies $S^d_\infty < S^p_\infty$. For this purpose, we define the following vector-valued function

$$\mathbf{J}(c, S, \psi, \phi) \equiv \begin{bmatrix} J^{(1)}(c, \psi, S, \phi) \\ J^{(2)}(c, \psi, S, \phi) \\ J^{(3)}(c, \psi, S, \phi) \end{bmatrix}$$

where

$$J^{(1)}(c, \psi, S, \phi) \equiv U_1(c, c, L(c, S)) + (1 - \phi) U_2(c, c, L(c, S)) + U_L L_c - \psi$$

$$J^{(2)}(c, \psi, S, \phi) \equiv \psi\left[\rho - G'(S)\right] - U_L(c, c, L(c, S)) L_S(c, S)$$

$$J^{(3)}(c, \psi, S, \phi) \equiv G(S) - c$$

By construction, when we set $\phi = 0$, we obtain the social planner's system of equations, i.e., $\mathbf{J}(c^p_\infty, \psi^p_\infty, S^p_\infty, 0) = \mathbf{0}$. Similarly, setting $\phi = 1$, we obtain the market outcome $\mathbf{J}(c^d_\infty, \psi^d_\infty, S^d_\infty, 1) = \mathbf{0}$. Applying Taylor expansion around the point $(c^p_\infty, \psi^p_\infty, S^p_\infty, 0)$, we get

$$\mathbf{0} = \mathbf{J}(c^p_\infty, \psi^p_\infty, S^p_\infty, 0) - \mathbf{J}(c^d_\infty, \psi^d_\infty, S^d_\infty, 1) = \begin{bmatrix} J^{(1)}_c & J^{(1)}_\psi & J^{(1)}_S & J^{(1)}_\phi \\ J^{(2)}_c & J^{(2)}_\psi & J^{(2)}_S & J^{(2)}_\phi \\ J^{(3)}_c & J^{(3)}_\psi & J^{(3)}_S & J^{(3)}_\phi \end{bmatrix} \begin{bmatrix} c^p_\infty - c^d_\infty \\ \psi^p_\infty - \psi^d_\infty \\ S^p_\infty - S^d_\infty \\ 0 - 1 \end{bmatrix}$$

where we have ignored the higher order terms. Now, since $J^{(1)}_\phi(c^p_\infty, S^p_\infty, \psi^p_\infty, 0) = -U_2\left(c^p_\infty, c^p_\infty, L\left(c^p_\infty, S^p_\infty\right)\right) \equiv -U^p_2$, $J^{(3)}_c = -1$, $J^{(3)}_\psi = 0$, $J^{(2)}_\psi = \rho - G'(S^p_\infty) > 0$, and $J^{(2)}_\phi = 0 = J^{(3)}_\phi$, we get

$$\begin{bmatrix} J^{(1)}_c & J^{(1)}_\psi & J^{(1)}_S \\ J^{(2)}_c & \rho - G'(S^p_\infty) & J^{(2)}_S \\ -1 & 0 & G'(S^p_\infty) \end{bmatrix} \begin{bmatrix} c^p_\infty - c^d_\infty \\ \psi^p_\infty - \psi^d_\infty \\ S^p_\infty - S^d_\infty \end{bmatrix} = \begin{bmatrix} -U^p_2 \\ 0 \\ 0 \end{bmatrix}$$

Let D denote the determinant of the matrix on the left-hand side. It can be shown (see Lemma 1) that $D > 0$. Then, using Cramer's Rule,

$$S^p_\infty - S^d_\infty = \frac{-(U^p_2)(\rho - G'(S^p_\infty))}{D} > 0$$

This shows that the market outcome results in a lower steady-state stock level as compared with the outcome under the social planner. Similarly

$$c^p_\infty - c^d_\infty = \frac{-(U^p_2)(\rho - G'(S^p_\infty)) G'(S^p_\infty)}{D}$$

This expression is positive iff $G'(S^p_\infty) > 0$.

Lemma 1. *Consider any autonomous optimal control problem with one state variable, c, and one control variable, S. Assume the Hamiltonian is concave in (c, S), and strictly concave in c, and the existence of a steady state that displays saddlepoint stability. Let D be the determinant of the* 3×3 *matrix*

$$\begin{bmatrix} H_{cc} & H_{c\psi} & H_{cS} \\ -H_{Sc} & \rho - H_{S\psi} & -H_{SS} \\ H_{\psi c} & H_{\psi\psi} & H_{\psi S} \end{bmatrix}$$

evaluated at that steady state. Then $D > 0$.

A.2. Proof of Proposition 3

Under decentralized choices, we have the following system of equations

$$\frac{(V_{11} + V_{12})\dot{c}}{V_1} = \rho - G'(S)$$

$$\dot{S} = G(S) - c$$

Assume $V_{11}(c_\infty, c_\infty)$+$V_{12}(c_\infty, c_\infty)$ (in the same spirit as Assumption 1). Then the steady state S_∞ is stable in the saddlepoint sense. The stable branch of the saddlepoint can be described by a function $c_d(S)$ where $c_d'(S) > 0$, i.e., the slope of the stable branch of the saddlepoint is positive. It can be shown that this slope, evaluated at S_∞, is

$$c_d'(S_\infty) = \frac{1}{2}\left(\rho - \sqrt{\rho^2 - 4K^d G''(S_\infty)}\right) > 0$$

where

$$K^d \equiv \frac{V_1(c_\infty, c_\infty)}{V_{11}(c_\infty, c_\infty) + V_{12}(c_\infty, c_\infty)} < 0$$

Similarly, under the social planner, we have the system

$$\frac{(V_{11} + V_{12} + V_{21} + V_{22})\dot{c}}{V_1 + V_2} = \rho - G'(S)$$

and

$$\dot{S} = G(S) - c$$

Again, assuming $V_{11}(c_\infty, c_\infty)$+$V_{12}(c_\infty, c_\infty)$+$V_{21}(c_\infty, c_\infty)$+$V_{22}(c_\infty, c_\infty) < 0$. Then the stable branch of the saddlepoint under the social planner is upward sloping, with slope

$$c_p'(S_\infty) = \frac{1}{2}\left(\rho - \sqrt{\rho^2 - 4K^p G''(S_\infty)}\right) > 0$$

where

$$K^p \equiv \frac{V_1(c_\infty, c_\infty) + V_2(c_\infty, c_\infty)}{V_{11}(c_\infty, c_\infty) + V_{12}(c_\infty, c_\infty) + V_{21}(c_\infty, c_\infty) + V_{22}(c_\infty, c_\infty)} < 0$$

It is clear that

$$\begin{aligned} c_p'(S_\infty) \quad &> c_d'(S_\infty) \;\Leftrightarrow\; \rho^2 - 4K^p G''(S_\infty) < \rho^2 - 4K^d G''(S_\infty) \\ &\Leftrightarrow\; K^p < K^d \;\Leftrightarrow\; (V_1 + V_2)(V_{11} + V_{12}) < (V_1)(V_{11} + V_{12}) + (V_1)(V_{21} + V_{22}) \end{aligned}$$

i.e.,

$$-\left[\frac{V_{22}}{V_1}-\frac{V_2V_{12}}{(V_1)^2}\right]<\frac{V_{21}}{V_1}-\frac{V_2V_{11}}{(V_1)^2}$$

which is equivalent to

$$-\frac{\partial}{\partial C}\left[\frac{V_2}{V_1}\right]<\frac{\partial}{\partial c}\left[\frac{V_2}{V_1}\right]$$

i.e.,

$$\frac{d}{dx}\left[\frac{V_2(x,x)}{V_1(x,x)}\right]>0.$$

Appendix B. Additional results with consumption externalities under the perfect property-rights regime

B.1. A model with amenity values

In addition to being consumption goods or production inputs, some natural resources generate a variety of amenity services that include, for instance, the recreational and aesthetic values associated with a well-preserved environment.[15] Following Krautkraemer (1985) we assume that the owner of a resource stock not only earns income from extraction, but also enjoys other amenities from the preservation of the stock. To capture this idea, we adopt the following preference specification for our representative individual,

$$U=\left[\alpha\left(\left(\frac{c}{C}\right)^{\beta}c\right)^{\omega}+(1-\alpha)S^{\omega}\right]^{\mu/\omega}=\left[\alpha C^{-\beta\omega}c^{(1+\beta)\omega}+(1-\alpha)S^{\omega}\right]^{\mu/\omega} \tag{50}$$

where $-\infty<\omega<1$, $0<\alpha<1$ and $0<\mu\leq 1$. Here, in order to focus on the role of amenities, we assume that extraction does not require effort: $\dot{S}=G(S)-c$. Define $Z=\alpha C^{-\beta\omega}c^{(1+\beta)\omega}+(1-\alpha)S^{\omega}$. In a decentralized setting the representative individual chooses the path of c to maximize the intertemporal value of (50) subject to (2) and $S(0)=S_0$. The necessary conditions for this program are

$$\frac{\mu}{\omega}Z^{(\mu/\omega)-1}(1+\beta)\alpha C^{-\beta\omega}\omega c^{(1+\beta)\omega-1}-\psi=0 \tag{51}$$

$$\dot{\psi}=\psi(\rho-G')-\frac{\mu}{\omega}Z^{(\mu/\omega)-1}(1-\alpha)\omega S^{\omega-1} \tag{52}$$

together with (2) and the transversality condition, $\lim_{t\to\infty}\psi Se^{-\rho t}=0$. Differentiating (51) with respect to time and combining the result with (51) and (52), we obtain the following differential equation

$$\frac{\dot{\psi}}{\psi}=(\rho-G'(S))-\frac{(1-\alpha)S^{\omega-1}}{(1+\beta)\alpha C^{-\beta\omega}c^{(1+\beta)\omega-1}}$$

[15] The experimental literature on relative consumption highlights important differences in the degree of comparison among different consumption goods. In general, easily observable goods or services, such as housing or cars, are subject to stronger externalities than unobservable ones, such as medical insurance or leisure. In line with this evidence, we make the extreme assumption that interpersonal comparisons do not involve comparing the amenity services provided by the stock of natural resources.

A symmetric steady state is reached when $C=c=G(S_\infty)$ and $\dot{\psi}=0$ and therefore the steady-state stock of resources satisfies

$$\rho - G'(S_\infty) = \frac{1-\alpha}{(1+\beta)\alpha}\left[\frac{G(S_\infty)}{S_\infty}\right]^{1-\omega} \tag{53}$$

It is straightforward to show that the steady-state stock of natural resources, S_∞, is unique. Furthermore, increases in the importance of relative consumption, captured by β, decrease the steady-state stock of resources. Intuitively increases in the importance of relative consumption increase the willingness of the competitive agent to increase extraction at the cost of lowering the amenity services provided by the unexploited resource. This process of over-extraction is associated with a lower steady-state stock of the natural resource. Finally, it is worth noticing that the efficient stock of resources is given by (53) with $\beta=0$ and therefore is always larger than the laissez-faire solution.

B.2. A model with extinction of privately owned resource stocks

If the marginal utility of consumption, evaluated at $c=0$, is infinite, then given our assumption that each agent has perfect property rights over her own resource stock it is not possible that the market outcome, with agents maximizing over an infinite horizon, will result in the extinction of the resource.[16]

We now show that if the marginal utility of consumption from harvested resources, evaluated at $c=0$, is finite, then under certain parameter values, the social planner would want to maintain a positive stock level, but the market outcome results in extinction, even though each individual has full control of her own resource stock.

Assume the utility function is a function of a basic good x, and a resource good (e.g. timber furniture), the consumption of which is denoted by c. We posit in the case where envy applies only to the consumption of the resource good. We specify the utility function $U(x,c,C,L)=v(x)+\ln\left[1+c^{\beta+1}C^{-\beta}L^{-\mu}\right]$ where $v(x)$ is a concave and increasing function, and $0<\beta<\mu<1, 0<1+\beta-\mu<1$. 1. The harvesting function is $y=LS$, and as before the resource harvested is consumed, $c=y$. Then $L=cS^{-1}$. Substitution yields

$$U = v(x) + \ln\left[1 + c^{\beta+1}C^{-\beta}c^{-\mu}S^{\mu}\right] \tag{54}$$

Assume that at each point of time, each agent is endowed with a fixed flow $\bar{x}>0$ of a non-storable basic good, so her consumption of this good is equal to $\bar{x}$.

Assume $G(S)$ is strictly concave, with $G(0)=0=G(\bar{S})$ for some $\bar{S}>0$. Then $G(S)/S$ is a decreasing function, and

$$\lim_{S\to 0}\frac{G(S)}{S} = G'(0) \equiv a > 0$$

We shall prove the following:

Proposition 7. *Assume that the parameter values satisfy the following inequalities*

$$\frac{(1+\beta-\mu)}{\mu}(\rho - G'(0)) \geq G'(0) > \frac{1-\mu}{\mu}(\rho - G'(0)) > 0 \tag{55}$$

Then under laissez-faire, there exists no positive steady-state stock, while the social planner's problem has a unique positive steady-state stock level.

[16] Of course with common property resources, extinction is a definite possibility even if the marginal utility of consumption at zero consumption is infinite. For a model with extinction under the regime of common-property resources, see Dutta and Rowat (2006).

Proof. (i) Market outcome (extinction):

In a decentralized setting the representative individual chooses the path of c, taking C as given, to maximize the intertemporal value of (54) subject to (2) and $S(0)=S_0$. The necessary conditions for this program are[17]

$$\frac{C^{-\beta}S^{\mu}(1+\beta-\mu)c^{\beta-\mu}}{1+c^{\beta+1-\mu}C^{-\beta}S^{\mu}}-\psi=0$$

$$\dot{\psi}=\psi(\rho-G')-\frac{\mu c^{\beta+1-\mu}C^{-\beta}S^{\mu-1}}{1+c^{\beta+1-\mu}C^{-\beta}S^{\mu}}$$

Along a symmetric equilibrium, $c/C=1$. Furthermore, let $z(t)\equiv c(t)/S(t)$. Then we have the following system

$$\frac{(1+\beta-\mu)[z(t)]^{-\mu}}{1+S(t)[z(t)]^{1-\mu}}-\psi(t)=0$$

$$\dot{\psi}(t)=\psi(t)(\rho-G')-\frac{\mu[z(t)]^{1-\mu}}{1+S(t)[z(t)]^{1-\mu}}$$

$$\dot{S}(t)=G(S(t))-z(t)S(t)$$

Assume $\rho>G'(0)$. Then it is easy to verify that the following triple is a steady state, where the steady-state stock is zero,

$$(S^d_\infty,\psi^d_\infty,z^d_\infty)=\left(0,(1+\beta-\mu)\left[\frac{(1+\beta-\mu)(\rho-a)}{\mu}\right]^{-\mu},\frac{(1+\beta-\mu)(\rho-a)}{\mu}\right)$$

Furthermore, let us show there are no steady states with a positive stock. Suppose there was one, denoted by $\widehat{S}>0$. Then $\widehat{z}=G(\widehat{S})/\widehat{S}$ and

$$\frac{(1+\beta-\mu)\widehat{z}^{-\mu}}{1+\widehat{S}\widehat{z}^{1-\mu}}(\rho-G'(\widehat{S}))=\frac{\mu(\widehat{z})^{1-\mu}}{1+\widehat{S}\widehat{z}^{1-\mu}}$$

i.e.,

$$\frac{1+\beta-\mu}{\mu}(\rho-G'(\widehat{S}))=\frac{G(\widehat{S})}{\widehat{S}} \tag{56}$$

But, from assumption (55) and the strict concavity of $G(S)$, for all $S>0$, the following inequalities hold:

$$\frac{1+\beta-\mu}{\mu}(\rho-G'(S))>\frac{1+\beta-\mu}{\mu}(\rho-G'(0))\geq G'(0)>\frac{G(S)}{S}$$

It follows that there is no $\widehat{S}>0$ that satisfies condition (56).

(ii) Social planner (non-extinction):

The social planner internalizes the negative impact of individual consumption, c, on average consumption, C, and therefore the optimality conditions for his program, where $z=c/S$, are

$$\frac{(1-\mu)z^{-\mu}}{1+Sz^{1-\mu}}=\psi$$

[17] The second order condition is satisfied because $\mu-\beta>0$.

$$\dot{\psi} = \psi(\rho - G') - \frac{\mu z^{1-\mu}}{1 + Sz^{1-\mu}}$$

Then the steady state stock S_{∞}^{p} must satisfy

$$\frac{1-\mu}{\mu}(\rho - G'(S)) = \frac{G(S)}{S} \tag{57}$$

The right-hand side of (57) starts, when $S = 0$, at $G'(0)$ and falls as S rises, and eventually becomes negative. The left-hand side starts at $(\rho - G'(0))(1-\mu)/(\mu)$ and rises as S rises. It follows that a unique steady state $S_{\infty}^{p} \in (0, \bar{S})$ exists if $(\rho - G'(0))(1-\mu)/\mu < G'(0)$. □

References

Abel, A., 1990. Asset prices under habit formation and catching up with the Joneses. American Economic Review 80, 38–42.
Alpizar, F., Carlsson, F., Johansson-Stenman, O., 2005. How much do we care about absolute versus relative income and consumption? Journal of Economic Behavior and Organization 56, 405–421.
Alvarez-Cuadrado, F., 2007. Envy, leisure and restrictions on working hours. Canadian Journal of Economics 40 (4), 1286–1300.
Alvarez-Cuadrado, F., Monteiro, G., Turnovsky, S.J., 2004. Habit formation, catching up with the Joneses, and economic growth. Journal of Economic Growth 9, 47–80.
Aristotle, 1941. In: McKeon, R. (Ed.), The Basic Works of Aristotle. Random House, New York.
Boskin, M.J., Sheshinski, E., 1978. Optimal redistributive taxation when individual welfare depends on relative income. Quarterly Journal of Economics 92, 589–601.
Brander, J.A., Taylor, M.S., 1998. The simple economics of Easter Island: a Ricardo–Malthus model. American Economic Review 88, 119–138.
Brekke, K.A., Howarth, R.B., 2002. Status, Growth and the Environment. Edward Elgard, Cheltenham, UK.
Brekke, K.A., Howarth, R.B., Nyborg, K., 2003. Status-seeking and material affluence: evaluating the Hirsch hypothesis. Ecological Economics 45, 29–39.
Brown, G., 1974. An optimal program for managing common property resources with congestion externalities. Journal of Political Economy 82 (1), 163–173.
Campbell, J.Y., Cochrane, J.H., 1999. By force of habit: a consumption-based explanation of aggregate stock market behavior. Journal of Political Economy 107, 205–251.
Carroll, C.D., Overland, J.R., Weil, D.N., 1997. Comparison utility in a growth model. Journal of Economic Growth 2, 339–367.
Clark, A.E., Oswald, A.J., 1996. Satisfaction and comparison income. Journal of Public Economics 61, 359–381.
Corneo, G., Jeanne, O., 2001. Status, the distribution of wealth, and growth. Scandinavian Journal of Economics 103, 283–293.
Dawkins, R., 1986. The Blind Watchmaker. Oxford University Press, Oxford, UK.
Dupor, B., Liu, W.-F., 2003. Jealousy and equilibrium overconsumption. American Economic Review 93, 423–428.
Duesenberry, J.S., 1949. Income, Saving and the Theory of Consumer Behavior. Harvard University Press, Cambridge, MA.
Dutta, J., Rowat, C., 2006. The commons with capital markets. Economic Theory 31, 225–254.
Easterlin, R.A., 1995. Will raising the incomes of all increase the happiness of all? Journal of Economic Behavior and Organization 27, 35–47.
Easterlin, R.A., 2001. Income and happiness: toward a unified theory. Economic Journal 111, 465–484.
Fisher, W., Hof, F., 2000. Relative Consumption and Endogenous Labour Supply in the Ramsey Model: Do Status-Conscious People Work Too Much? Institute for Advance Studies, Vienna.
Frank, R.H., 1985. Choosing the Right Pond. Oxford University Press, New York and Oxford.
Frey, B.S., Stutzer, A., 2002. What can economists learn from happiness research? Journal of Economic Literature 40, 402–435.
Gali, J., 1994. Keeping up with the Joneses: consumption externalities, portfolio choice, and asset prices. Journal of Money, Credit and Banking 26, 1–8.
Gordon, H.S., 1954. Economic theory of common property resources. Journal of Political Economy 62 (2), 124–142.
Howarth, R.B., 1996. Status effects and environmental externalities. Ecological Economics 16, 25–34.
Howarth, R.B., 2000. Climate Change and Relative Consumption. In: Jochem, E., Bouille, D., Sathaye, J. (Eds.), Society, Behavior, and Climate Change Mitigation. Kluwer, Dordrecht, pp. 191–206.
Howarth, R.B., 2006. Optimal environmental taxes under relative consumption effects. Ecological Economics 58, 209–219.
Kant, I., 1960. Education, translated by Annette Churton. University of Michigan Press, Ann Arbor.
Krautkraemer, J.A., 1985. Optimal growth, resource amenities and preservation of natural environments. Review of Economic Studies 85 (1), 153–170.
Layard, R., 2005. Happiness: Lessons from a New Science. Penguin Press, New York.
Liu, W.-F., Turnovsky, S.J., 2005. Consumption externalities, production externalities, and long-run macroeconomic efficiency. Journal of Public Economics 89, 1097–1129.
Luttmer, E., 2005. Neighbors as negatives: relative earnings and well-being. Quarterly Journal of Economics 120 (3), 963–1002.
Neumark, D., Postlewaite, A., 1998. Relative income concerns and the rise in married women's employment. Journal of Public Economics 70, 157–183.
Ng, Y.K., Wang, J., 1993. Relative income, aspiration, environmental quality, individual and political myopia: why may the rat race for material growth be welfare reducing? Mathematical Social Sciences 26, 3–23.
Plourde, G.C., 1971. Exploitation of common property renewable natural resources. Economic Inquiry 9, 256–261.
Pollak, R.A., 1976. Interdependent preferences. American Economic Review 66 (3), 309–320.
Rawls, J., 1971. A Theory of Justice. Belknap Press, Cambridge, MA.

Rayo, L., Becker, G.S., 2007. Evolutionary efficiency and happiness. Journal of Political Economy 115, 302–337.
Schoeck, H., 1966. Envy: A Theory of Social Behavior, Glenny and Ross (trans.) Harcourt, Brace, New York.
Schaefer, M.B., 1957. Some considerations of population dynamics and economics in relation to the management of marine fisheries. The Fisheries Research Board of Canada 14, 669–681.
Smith, A., 1776. An Inquiry into the Nature and Causes of the Wealth of Nations. Strhan and Cadell, London.
Smith, V.L., 1968. Economics of production from natural resources. American Economic Review 58, 409–431.
Smith, V.L., 1975. The primitive hunter culture, pleistocene extinction and the rise of agriculture. Journal of Political Economy 83, 727–755.
Solnick, S., Hemenway, D., 1998. Is more always better? A survey on positional concerns. Journal of Economic Behavior and Organization 37, 373–383.
Stokey, N., 1998. Are there limits to growth? International Economic Review 39, 1–31.
Varian, H.R., 1974. Equity, envy, and efficiency. Journal of Economic Theory 9, 63–91.
Veblen, T.B., 1899. The Theory of the Leisure Class: An Economic Study of Institutions. Modern Library, New York.
Wendner, R., Goulder, L.H., 2008. Status effects, public goods provision and excess burden. Journal of Public Economics 92, 1968–1985.