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A free lunch in the commons

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ABSTRACT

We derive conditions under which raising costs through a regulatory constraint or a fully expropriated tax can increase the profits arising from a common-pool resource. The basic model assumes a fixed number of identical agents with linear costs selling in a single period at an exogenous price. A necessary and sufficient condition for a cost increase to be profitable is that aggregate output from the resource be locally convex in aggregate effort. We also show that cost increases can be profitable even if price is endogenous, agents are heterogeneous, entry is costless, or agents are playing a Markov-perfect equilibrium of a dynamic game. We also discuss more general welfare implications of the result along with its relation to existing results for a Cournot oligopoly.

1. Introduction

Common-pool resources give rise to an important source of market failure. A large economics literature investigates both positive and normative aspects of the common-pool resource problem. Fundamental insights are most frequently made through a comparison of two extreme cases of property rights: sole ownership and open access. Under sole ownership, externalities are nonexistent and, in the absence of market power, management of the resource is efficient because rents are maximized. Under open access, individual incentives result in such excessive production that congestion externalities completely dissipate all rents, giving rise to the so-called "Tragedy of the Commons."[1] Comparison of these two polar cases provides the conceptual foundation for understanding a range of policy instruments designed to manage the commons, including, but not limited to, taxes, harvest limits, entry restrictions, technology constraints, and individual transferable quotas. In our basic model, we consider the intermediate case in which a fixed number of agents is active in the commons.[2]

We focus in particular on the ways in which policy instruments that increase marginal costs—including taxes and regulatory constraints—affect strategic incentives and payoffs. We identify what heretofore has been an unrecognized opportunity for a Pareto improvement that does not require redistribution and hence should be politically attractive. Under conditions we delineate, we find, for example, that a tax imposed on effort can increase producer profits, while not reducing and possibly increasing consumer surplus, even when the tax revenue is fully expropriated. We find, in other words, a veritable "free lunch" in the commons.

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[1] See Gordon [10] for the first economics treatment of the problem, and see Hardin [11] for the description that gave the "Tragedy" its name.

[2] Existing studies that take a similar approach to the study of common-pool resources such as fisheries include Cheung [5], Dasgupta and Heal [8], Wilen [20], and Heintzelman et al. [12]. Other analyses of contest games, which are isomorphic, include studies by Nitzan [13], Chung [6], Baik and Lee [1], and Baye and Hoppe [3].

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Our treatment of an exogenous increase in marginal costs is consistent with at least two different types of policy instruments. The first is a tax on each unit of a single input. The second is a regulatory constraint that reduces the efficiency of the input. In the context of wildlife extraction or fishing, for example, a tax might take the form of a licensing fee, whereas the regulatory constraint might consist of a technology restriction, size limit, or seasonal and area closures. In what follows, we investigate how policies such as these affect equilibrium profits of each agent and consumer surplus, in addition to overall social welfare.

The main result that a cost-increasing measure will always raise equilibrium profits if production is locally convex in aggregate effort. Intuitively, profits increase because the higher costs induce a sufficiently large, coordinated contraction of production effort that mitigates the negative congestion externality. This result, as we show, is analytically similar to Seade's [17] result for cost increases in a Cournot oligopoly, but we also discuss how the underlying mechanism is fundamentally different. We also show how the result can be generalized to account for price endogeneity, agent heterogeneity, entry and exit, and dynamics.

2. The commons under restricted access

We begin with the case in which there are n identical agents indexed $i=1,\ldots,n$. Agent i chooses to exert effort level x_i at cost cx_i. Aggregate effort is $X=\sum_{i=1}^{n} x_i = X_{-i}+x_i$ and yields total product $F(X)$. Average product is defined as $A(X)=F(X)/X$. We assume $A(X)$ is continuous, twice differentiable, $A'(X)<0$ and finite, $A(0)-c>0$, and $\lim_{X\to\infty}A(X)=0$. We also assume initially that price is exogenous and normalized to unity. In this case, the functions $F(X)$ and $A(X)$ represent, respectively, the value of the total product and the value of the average product.

We assume that an agent exerting k percent of the total effort receives k percent of the total product. Conditional on effort level x_i, agent i earns payoff

$$\pi_i = F(X)\frac{x_i}{X} - cx_i.$$

Each agent i thus chooses x_i to solve

$$\max_{x_i} \pi_i = A(x_i+X_{-i})x_i - cx_i. \tag{1}$$

The assumption $A(0)-c>0$ implies that, in any equilibrium, every agent must be active ($x_i>0$). For if $x_i=0$ is optimal for some i, then it must hold that $A(X)-c\le 0$. But under this circumstance, it would be optimal for every other identical agent to be inactive as well, requiring that $A(0)-c\le 0$, which contradicts an assumption. Accordingly, the following first-order condition must hold for each of the n agents:

$$A(X)+x_iA'(X)-c=0. \tag{2}$$

This condition implies that, in any equilibrium, all n agents exert the same level of effort, denoted $x=X/n=(A(X)-c)/-A'(X)>0$.

Building on (2), it is useful to define the function

$$J(X)=A(X)+\frac{X}{n}A'(X)-c. \tag{3}$$

It follows from the assumptions on $A(X)$ that $J(X)$ is continuous, differentiable, $J(0)>0$, and $J(X)$ is strictly negative for sufficiently large X. Hence the intermediate value theorem ensures the existence of one or more values of X satisfying $J(X)=0$. The only candidates for a Nash equilibrium are these roots, as only they satisfy the first-order condition for each agent. We further assume that $J'(X)<0$ at every root.[3] This is sufficient for existence of a unique root, denoted X^*, and hence a unique candidate for the Nash equilibrium.[4] Finally, assume that when $X_{-i}=(n-1)X^*/n$, agent i's profit function in (1) is pseudoconcave in x_i; that is, whenever the agent's first-order condition holds, the second-order condition for a maximum is satisfied as well. This insures that every agent's payoff is globally maximized at $x_i=X^*/n$ and thus guarantees that the strategy profile $x_i^*=X^*/n$ for $i=1,\ldots,n$ defines the unique, pure-strategy equilibrium.

3. The effect of costs on profits

We now consider how a change in the common marginal cost affects equilibrium profits. After establishing our main result—the necessary and sufficient condition for a cost-increasing measure to increase profits—we contrast it with other results in the literature on oligopoly and the commons.

[3] It is easily verified that $J'(X)=[F''(X)+(n-1)A'(X)]/n$. From this formulation, it is clear that $J'(X)<0$ does not require concavity of $F(X)$. The importance of permitting convexity will become clear in the next section.

[4] This corresponds to the standard assumption in models of Cournot oligopoly used to insure uniqueness of the equilibrium [18]. In some cases, the assumption is referred to as the stability condition (see [9,17]).

3.1. The main result

Consider changes in the marginal cost that may arise from either a tax on effort or a regulation that requires use of a less efficient technology. To capture both possibilities, we decompose the marginal cost of the previous section into two terms: $c=\overline{c}+\tau$, where $\overline{c}$ is the marginal cost associated with the most efficient technology, and τ represents either a per unit tax on effort or an additional marginal cost from a technology restriction.

The first step is to determine how a change in τ affects equilibrium effort for each agent. Totally differentiating (2) at the equilibrium yields

$$\frac{dx^*}{d\tau}=\frac{1}{(n+1)A'(X^*)+X^*A''(X^*)}=\frac{1}{nJ'(X^*)}<0. \quad (4)$$

This implies, for example, that an increase in the marginal cost of effort will always decrease equilibrium effort.

Now to determine how a change in τ affects profits, we use the fact that each agent's equilibrium profit can be written as

$$\pi^*=A(x^*+X^*_{-i})x^*-(\overline{c}+\tau)x^*.$$

After totally differentiating and substituting in the first-order condition, we solve for

$$\frac{d\pi^*}{d\tau}=(n-1)x^*A'(X^*)\frac{dx^*}{d\tau}-x^*. \quad (5)$$

The first term reflects the *strategic effect* and the second term reflects the *direct effect*. The direct effect is negative because a cost increase reduces a given agent's profits in the absence of any response by other agents. The strategic effect is strictly positive, assuming $n>1$, because a cost increase causes other agents to decrease their aggregate effort, and this effect alone, because it attenuates the negative externality, would increase the given agent's profits. An interesting—and somewhat counterintuitive—possibility arises if the strategic effect *outweighs* the direct effect, in which case all agents would benefit from the cost increase. This can never happen if $n=1$, however, since there is no strategic effect under sole-ownership.

We now consider in more detail the conditions necessary and sufficient for the sign of (5) to be positive. Substituting (4) into (5) and rearranging yields

$$\frac{d\pi^*}{d\tau}=x^*(E^*-2)\frac{A'(X^*)}{nJ'(X^*)}, \quad (6)$$

where

$$E^*=-\frac{X^*A''(X^*)}{A'(X^*)}.$$

If $E^*<2$, we have what is perhaps the more intuitive case in which the sign of (6) is negative, meaning that profits are decreasing in the marginal cost of effort.

The more interesting possibility—when profits are increasing in the marginal cost of effort, even with price held constant—requires $E^*>2$. Though we can see that strict convexity of average product at X^* is necessary for the result, it is not sufficient. A condition that is both necessary and sufficient, however, is strict convexity of the total product at X^*. To see this, recall that $F(X^*)=X^*A(X^*)$ and therefore

$$F''(X^*)=2A'(X^*)+X^*A''(X^*)=A'(X^*)[2-E^*],$$

which implies $F''(X^*)>0$ if and only if $E^*>2$. Notice that the result places no requirement on the sign of $F'(X^*)$; that is, production may be increasing in effort or, perhaps due to congestion, decreasing. This implies, for example, that when an increase in τ unambiguously reduces aggregate effort, total product can either increase or decrease, and in either case, equilibrium profits must increase.

We illustrate the result with an example using common functional forms (see [7]). Let $F(X)=10(X^{0.2}-0.5X^{0.4})$, so that for any $X>0$, $\text{sgn}F(X)=\text{sgn}(1-0.5X^{0.2})$, sgn $F'(X)=\text{sgn}(1-X^{.2})$, and sgn $F''(X)=\text{sgn}(3X^{0.2}-4)$. Hence the production function is initially increasing and concave, reaches a maximum at $X=1$ and then, as it decreases, inflects at $X=(\frac{4}{3})^5\approx 4.214$ and remains strictly convex until it descends to zero at $X=32$. We depict the associated value of the average and marginal product curves in Fig. 1. Average product is strictly positive (for $X<32$) and strictly decreasing. With $c=0.5$, socially optimal effort occurs at $X\approx 0.48$, rent dissipation occurs at $X\approx 7.5$. For sufficiently large n, therefore, the Nash equilibrium will occur in the strictly convex region of $F(X)$, where our general results imply that a marginal increase in c raises the profit of each player.

Though not the focus of our analysis here, an immediate corollary of the main result is worth mentioning. Whenever a cost-increasing measure raises profits, a cost-reducing measure must lower them. Hence per-unit cost-reducing technological progress—even if implemented costlessly—will lower the profits of common property extractors if and only if they operate in the convex region of the aggregate production function.

3.2. Relation to existing literature

Our analysis of the commons thus far is isomorphic to Seade's [17] unpublished analysis of a Cournot oligopoly. Seade considers identical oligopolists with linear costs who simultaneously choose production in a static Cournot game. He asks

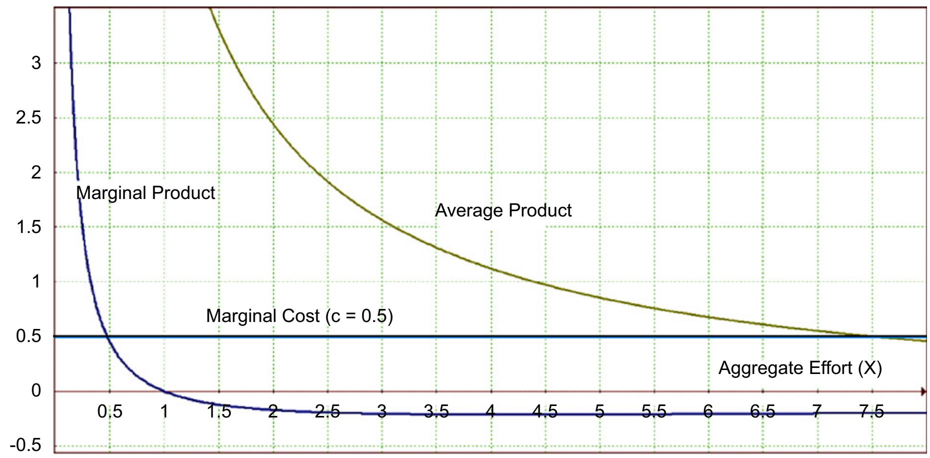

Fig. 1. Example in which a cost-increasing measure increases equilibrium profits for all agents.

whether firms can benefit from an increase in the constant marginal cost or, equivalently, from a fully expropriated tax per unit output. Formally, one can obtain his analysis from ours by reinterpreting X as aggregate output instead of aggregate effort and reinterpreting $A(X)$ as average revenue (i.e., inverse demand) instead of average product. With these alternative interpretations, maximization problem (1) is simply the standard setup of a Cournot oligopoly with identical, linear costs.

Between the two formulations, however, the underlying economic mechanism for how a cost-increasing measure can increase profits is fundamentally different. In Seade's oligopoly, an increase in marginal cost reduces output and therefore increases price, and the offsetting effect of the price increase can lead to higher profits. In our model of the commons, an increase in marginal costs reduces effort and, regardless of whether production increases or decreases, price remains constant; it is instead the inevitable increase in average product that can lead to higher profits.[5]

A further difference between the oligopoly and commons results is their potential policy relevance. In the usual antitrust context where market power results in too little production, policies that further reduce production are undesirable from an efficiency standpoint, even if they are more profitable for firms. The situation is entirely different in the commons. Policies that reduce effort are desirable from an efficiency standpoint because they mitigate the congestion externality, and the fact that profits can increase should serve to make such policies more politically attractive. From the perspective of social welfare, therefore, the result that cost-increasing measures can be profitable is more compelling in the context of common-pool resources than of non-polluting oligopolies.[6]

Our result is also related to the findings of Dasgupta and Heal [8]. In their discussion of common property under restricted access, they use the same static setup as ours (initiated by [5]) but reach the opposite conclusion:

> The question arises whether firms are better or worse off at the free access equilibrium than they are at the tax equilibrium if the entire tax revenue is expropriated from them by the government. Rather surprisingly, perhaps, it is easy to show that they are unambiguously better off at the free access equilibrium (p. 70).[7]

In other words, they conclude that a cost-increasing measure must *reduce* the profits of every agent. The reason for the difference is that Dasgupta and Heal, unlike us, confine attention to the case where production is everywhere strictly concave in effort.

4. Extensions

We now consider four extensions to the basic model and show that in each case the main result continues to hold: a cost-increasing measure can increase profits.

4.1. Endogenous price

The additional feature of the model is a monotonically decreasing, inverse demand function of aggregate output Q, written as $P(Q)$ where $Q=F(X)$. The payoff to each agent is now

$$\pi_i = P(F(X))F(X)\frac{x_i}{X} - cx_i, \tag{7}$$

[5] In the next section we extend the model to account for the possibility of price endogeneity.

[6] If the oligopoly is associated with a negative externality, then reducing production may be desirable from an efficiency standpoint.

[7] Despite Dasgupta and Heal's use of the term "free access," they are considering a model in which n is finite.

and each agent solves

$$\max_{x_i} \pi_i = P(F(x_i + X_{-i}))A(x_i + X_{-i})x_i - cx_i. \tag{8}$$

A straightforward way to see the parallel with our previous analysis is to define $\tilde{A}(X) = P(F(X))A(X)$. It follows that all of the previous results hold as long as we replace $A(X)$ everywhere with $\tilde{A}(X)$. To avoid confusion, we denote aggregate effort in the Nash equilibrium with price endogenous as $\tilde{X}$, the counterpart to X^* in the exogenous price case discussed previously. In the generalized model, aggregate effort ($\tilde{X}$) solves

$$\tilde{A}(\tilde{X}) + \frac{\tilde{X}}{n}\tilde{A}'(\tilde{X}) - c = 0.$$

As for the main result—that a cost-increasing measure can increase profits—the sufficient conditions can be written in parallel with the previous analysis. An increase in τ, as defined previously, will increase each agent's profits if and only if $\tilde{A}'(X) < 0$ and $\tilde{E} > 2$, where $\tilde{E} = -\tilde{X}\tilde{A}''(\tilde{X})/\tilde{A}'(\tilde{X})$.

We can once again interpret the condition $\tilde{E} > 2$ with an equivalent expression for strict convexity of total revenue. By definition, we have

$$P(F(X))F(X) = P(F(X))XA(X) = X\tilde{A}(X),$$

so the derivatives of the expression on the left equal the derivatives of the expression on the right, evaluated at $\tilde{X}$. The second derivative of the expression on the right is $2\tilde{A}'(\tilde{X}) + \tilde{X}\tilde{A}''(\tilde{X})$, which is positive if and only if $\tilde{E} > 2$. It follows that

$$\tilde{E} > 2 \iff \frac{d^2[P(F(\tilde{X}))F(\tilde{X})]}{dX^2} > 0. \tag{9}$$

Our earlier result can be seen as the special case where $P(\cdot) = 1$, implying that $\tilde{A}(X) = A(X)$, $\tilde{E} = E$, $\tilde{X} = X^*$, and the necessary and sufficient condition for a cost-increasing measure to increase profits is $d^2F(X^*)/dX^2 = F''(X^*) > 0$.

To demonstrate that satisfying (9) is still possible, first consider, as we did in the pervious section, a production for which aggregate effort in the Nash equilibrium with a price of unity occurs in its convex region. Now assume inverse demand of the form $P(F(X)) = 1 - \theta F(X)$, from which the equilibrium level of aggregate effort can be written as a continuous function of the slope parameter, $X(\theta)$.[8] When $\theta = 0$, we have the case in which price is exogenous, that is, $P = 1$ and $X(0) = X^*$. More generally, total revenue is $TR(X(\theta)) = [1 - \theta F(X(\theta))]F(X(\theta))$, and solving for the second derivative with respect to effort yields

$$TR''(X(\theta)) = F''(X(\theta)) - 2\theta[F(X(\theta))F''(X(\theta)) + F'(X(\theta))^2]. \tag{10}$$

To see that this expression can be strictly positive with $\theta > 0$, and thereby satisfies (9), note that at $\theta = 0$ the condition collapses to $F''(X^*) > 0$. It follows by continuity that (10) must be strictly positive over some nonempty interval of $\theta > 0$. We have thus proved that a cost-increasing measure can increase profits in the commons even if price is endogenous.

4.2. Heterogeneity

We return, for simplicity, to the base-case model in which price is exogenous and normalized to unity. Building on the previous decomposition of marginal costs, $c = \overline{c} + \tau$, we assume there are two agents: one with low costs $c_l = \overline{c} + \tau - \kappa$ for $\kappa > 0$, and one with high costs $c_h = \overline{c} + \tau + \kappa$. Notice that this formulation includes homogeneity as a special case with $\kappa = 0$. Denote the equilibrium level of effort for the two agents as x_l^* and x_h^*. Because the sum of the marginal costs is $2c$ in both the homogeneous and heterogeneous cases, aggregate effort remains the same X^* either way and is therefore independent of κ.[9] For the same reason, any change $d\tau$ will induce a different level of aggregate effort that is also independent of κ.

Following the steps in Section 3, we use the first-order conditions to solve for the change in the effort of agent $i = l,h$ given a change in τ:

$$\frac{dx_i^*}{d\tau} = \frac{A' + [x_{-i}^* - x_i^*]A''}{[2A' + x_i^*A''][2A' + x_{-i}^*A''] - [A' + x_{-i}^*A''][A' + x_i^*A'']}. \tag{11}$$

Though it involves a bit of tedium, one can verify that with homogeneity, which requires $\kappa = 0$ and implies $x_i^* = x_{-i}^*$, this expression reduces for both agents to

$$\frac{dx_i^*}{d\tau} = \frac{1}{3A'(X^*) + X^*A''(X^*)} < 0,$$

which is simply Eq. (4) for the case of $n = 2$, and we have already shown that it must be strictly negative. Then, since $dx_i^*/d\tau$ is a continuous function of κ, it must also be true that (11) is strictly negative for both $i = l,h$ over some nonempty interval of $\kappa > 0$. It follows in this case that, even with heterogeneity of agents, a cost-increasing measure decreases the equilibrium level of effort for both agents.

[8] We omit the "tilde" when writing aggregate effort as a function of θ.

[9] This result is a special case of the theorem proved in Bergstrom and Varian [4].

A similar line of reasoning can demonstrate the possibility that profits will increase as well. The change in profit for agent $i = l,h$ given a change in τ, the counterpart to Eq. (5), is

$$\frac{d\pi_i^*}{d\tau} = x_i^* A'(X^*) \frac{dx_{-i}^*}{d\tau} - x_i^*, \tag{12}$$

which consists, once again, of the strategic effect and the direct effect, respectively. We know, in the case of homogeneous agents, that (12) simplifies to (5) for the case of $n=2$, and we have already shown that (5) can be strictly positive. By continuity of $d\pi_i^*/d\tau$ in κ, therefore, there exists a nonempty interval of $\kappa > 0$ over which (12) is strictly positive as well. We thus conclude that—even with heterogeneity of agents—a cost-increasing measure can increase equilibrium profits for all agents.

4.3. *Entry and exit*

We now investigate the consequences of allowing costless entry and exit. Consider a general setup in which each of a fixed number of players $N > n$ simultaneously decides whether to be active in the commons or to engage in an alternative activity. Assume the payoff per player in the alternative activity is an exogenous weakly decreasing function of the number of players engaged in it. Each agent who chooses the commons receives the equilibrium payoff discussed in the base-case model. Note this payoff, as is the standard Cournot result, is decreasing in the number of agents choosing the commons. In a Nash equilibrium, the N players would allocate themselves between the two activities so that no player could unilaterally switch activities and earn a strictly greater payoff. In the absence of an integer problem, therefore, profits per player would equalize across the two activities.

Now consider the case in which a cost-increasing measure increases profits for all of the initial players in the commons. With the measure in place, the profit per player in the commons would be higher than the profit per player in the alternative activity unless more of the N players migrate from the alternative activity to the commons. This follows because profits per player in the commons are monotonically decreasing in the number of players. It must be the case, therefore, that the cost-increasing measure induces a new Nash equilibrium with more players in the commons and fewer players pursuing the alternative activity.

The effect on profits then depends on the underlying structure of the alternative activity. If the migration of players out of the alternative activity raises the payoff per person of those who remain, then payoffs for both activities will equalize at a higher level, making all N players better off. If instead the alternative activity has a constant payoff per person independent of the number pursuing the activity, then the entry of players into the commons would drive profits back to the initial level, with no change in the payoff to any of the N players. In this case, the paradoxical result about profits does not hold, but as long as $E^* > 2$, a new paradoxical result about entry emerges: a cost-increasing measure in the commons promotes entry.

4.4. *Dynamics*

Many resources that are harvested as common property, such as fish and wildlife, are renewable. It is therefore appropriate to ask whether a cost-increasing measure can be profitable in a dynamic game. Writing before the era of dynamic games, Dasgupta and Heal [8, p. 143] assume that each player's payoff from an effort profile is the steady-state profit induced by that effort profile. They then determine the Nash equilibrium profiles and investigate comparative statics. While analytically tractable, their approach takes no account of the transition to the new steady state.[10] Nevertheless, if one regards Dasgupta–Heal's approach as a "first approximation," one can use our previous results to show that fishermen can benefit from a cost-increasing measure. In dynamic problems, it is no longer necessary for our result that the aggregate production function has a strictly convex region. Even if it is strictly concave throughout, the curvature of the growth function can insure our result.[11]

Cost increases may also be profitable in the *Markov-perfect equilibria* of common property games. Suppose that in every period n fishermen simultaneously choose their effort levels after observing the stock of fish. Each fisherman maximizes the discounted value of his profit from the current period onward given the current stock of fish and the anticipated current and future extraction rules of the other players. As in the static game, we continue to normalize price to unity and assume that each period's aggregate harvest is split among fishermen in proportion to their efforts.

While this game is straightforward to formulate, a Markov-perfect equilibrium cannot be solved analytically under the conventional assumption that biological growth is logistic. We can, however, deduce the implications of any example using numerical simulation. Consider an example in which the biological growth is $G(S_t) = S_t(1 - S_t/10)$ per period and the harvest is $H(X_t, S_t) = X_t^2 S_t/3$ per period, which is strictly concave in aggregate effort (see [7]). Hence, at the environmental carrying

[10] Moreover, the steady state of this approach differs subtly from the steady state of the Markov-perfect equilibrium since in the latter case each fisherman realizes that by increasing his current effort, he will reduce the stock of fish in the next period and hence the fishing effort of the other players in that period.

[11] For example, assume that in the absence of fishing, the stock grows at rate $dS/dt = 2S(1-S/10)$, and the harvest function is $H(X,S) = X^{.2}S$, which is strictly concave in aggregate fishing effort (X). Then the steady-state stock can be expressed as a strictly convex function of fishing effort, $S(X) = 10(1 - .5X^{.2})$, and the amount harvested in the steady-state can be written entirely as a function of effort, $H(X,S(X)) = 10(X^{.2} - .5X^{.4})$. This function, however, is precisely $F(X)$ in the example of Section 3.1 with its strictly convex region. Hence, the cost increase in this example raises steady-state profits.

capacity of 10, there would be no net biological growth, and fishing always exhibits diminishing returns to fishing effort. Denote the initial stock size as $\overline{S} \in (0,10)$, the common marginal cost of effort as c, and the common discount factor as β. Given a T-period time horizon, one can now solve numerically for the symmetric Markov-perfect equilibrium using backward induction and compare the present discounted value of profits under different values of c.

Simulation results indicate that a cost-increasing measure can be profitable provided that β is sufficiently high.[12] To build intuition, consider first the polar opposite case where $\beta = 0$. In this case, every fisherman ignores the future, and the value of the initial stock in the Markov-perfect equilibrium coincides with the value of playing the Nash equilibrium of a static game where the extraction function and initial stock are the same as in the dynamic game. Hence, our results about the change in equilibrium profits in the static model carry over to the change in discounted profits in the dynamic equilibrium, as concavity of the production function ($E^* < 2$) implies that a cost increase must decrease profits. Simulation results confirm that this result continues to hold in the Markov-perfect equilibrium if instead β is small but nonzero.

Now consider the opposite extreme of β near unity. An increase in the common cost of effort can increase profits if fishermen are sufficiently patient. For, in this model, a steady state is eventually reached in which the stock is larger because the cost increase reduces fishing effort. Although the profit flow is initially lower because costs have increased and the stock has had no time to expand, the profit flow in the simulations soon becomes larger than before the cost increase and eventually stabilizes at a higher level as the stock of fish approaches its new steady state. If $\beta = 1$, the loss in profits during the transition phase can always be outweighed by the subsequent gain in profits if sufficient time is spent in the phase where the profit flow is strictly larger. In simulations, the present value of profits is greater under the higher cost for sufficiently high discount factors and sufficiently long time horizons.[13]

5. Welfare implications

We now discuss welfare implications of our finding that higher marginal costs can increase profits. To begin, recall that two different interpretations are consistent with our treatment of increased marginal costs: a tax on each unit of effort and a regulatory constraint that reduces the efficiency of effort. In terms of welfare implications, one obvious difference between the two interpretations is that a tax generates tax revenue, whereas a regulatory constraint does not.

Our result for the common-pool resource model identifies a new opportunity to produce a Pareto improvement, even without redistribution. In the base case, price is constant and a regulatory constraint can increase profits at no cost to consumers. Note that this scenario is equivalent to one in which a tax is imposed and the revenue completely discarded. But with a tax, of course, the revenue can be used in socially beneficial ways and is therefore typically treated as neutral from a social welfare perspective.

The most intriguing possibility, however, occurs when price is endogenous. Because we have shown that higher marginal costs can increase output, despite reducing effort, price may fall if it is endogenous. This implies that consumer surplus can increase as well. It follows that cost-increasing measures in the commons have the potential to make both producers and consumers better off, in addition to raising distortion-free tax revenue. A corollary, however, is that a cost-saving measure can make both producers and consumers worse off, thereby providing an example where technological progress is immiserizing.

While our analysis thus far has focused on local results in the neighborhood of the Nash equilibrium, we now consider the question of whether the same results can hold if a cost-increasing measure were imposed to implement the first-best level of effort. This would be consistent with an optimal Pigouvian tax where none of the tax revenue is returned to the agents in the commons. Considering the same question, Baumol and Oates [2] conclude that

> ... wherever a common-property resource is subject to rising costs of congestion, the imposition of the optimal Pigouvian tax will reduce the welfare of the users of that resource so long as they are excluded from the benefits accruing from the tax revenues. We may see here why opposition to "optimal" taxes is to be expected, unless special provisions are made to assist the losers (p. 240).

In what follows, we show, once again, that convexity of total revenue can reverse the conclusion.

We begin with consideration of a tax and then contrast the findings to that of a regulatory constraint. We also focus on our base-case model in which price is exogenous and normalized to unity. The first observation is that our main result cannot hold locally in the neighborhood of the socially optimal (i.e., sole-owner) level of effort. To see this formally, define $\hat{X} = \text{argmax}\{F(X) - cX\}$. Satisfying the second-order condition thus requires $F''(\hat{X}) \leq 0$. If the equilibrium occurs where aggregate production is strictly (weakly) concave, an increase in the per-unit cost would always strictly (weakly) reduce the sole owner's profit.

But the question still remains about whether, with $n \geq 2$, profits can ever be higher with a fully expropriated tax at the socially optimal level than without a tax. Fig. 2 is useful to demonstrate the mechanism at work. The sole owner's level of effort occurs at the intersection of marginal product ($F'(X)$) and marginal cost, yielding profits $\hat{X}(A(\hat{X}) - c)$. The open-access level of effort, denoted $\overline{X}$, occurs at the intersection of average product ($A(X)$) and marginal cost, yielding zero profits. The new

[12] The simulation results are contained in a technical appendix, authored by Zach Stangebye, that is available at *JEEM*'s online archive of supplementary material, which can be accessed at http://aere.org/journals.

[13] For purposes of replication, the configuration of parameters is $T = 300$, $c = 0.5/3$, $c' = 1.2c$, and $\beta \geq 0.85$.

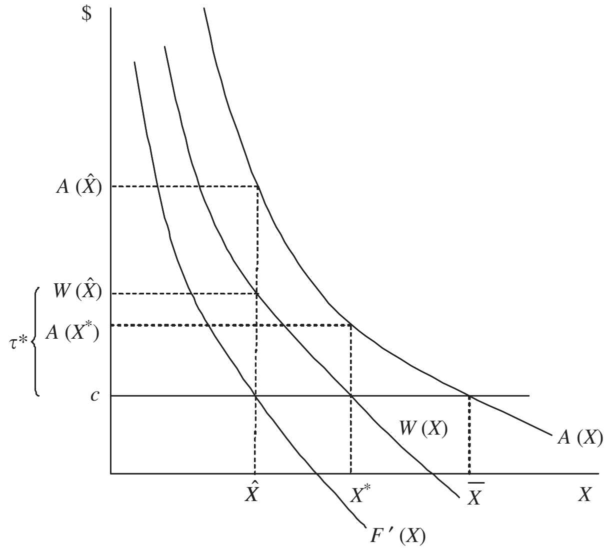

Fig. 2. The effect of an optimal tax on profits.

feature on the graph is the curve

$$W(X) = \frac{F'(X)}{n} + \frac{n-1}{n} A(X) \tag{13}$$

which is simply a rearranged expression for $J(X) + c$. Essentially, $W(X)$ is a weighted average of the marginal product and the average product, and its intersection with marginal cost determines the Nash equilibrium level of aggregate effort for any n, with corresponding aggregate profits equal to $X^*(A(X^*)-c)$.

The other useful implication of (13) is that $W(\hat{X})-c=\tau^*$ is the tax that implements the first-best level of effort. If imposed, we can see from Fig. 2 that profits remain even after the tax revenue is paid, as indicated by the area $\hat{X}(A(\hat{X})-c-\tau^*)$. The question of interest, therefore, is whether these profits can be greater than the initial profits at the Nash equilibrium. The general answer is that this is certainly possible, as the reader can verify using $F(X)$ from the example in Section 3.1, along with $c=0$ and $n=2$.

Clearly the effects on profits are unchanged regardless of whether the cost-increasing measure arises from a tax or a regulatory constraint. But the two policy instruments do differ from a social welfare perspective, because fully expropriated tax revenue can be used to generate benefits elsewhere in the economy, whereas regulatory constraints generate no such benefits. The fact that a tax raises revenue implies that a social planner—one that seeks to maximize the sum of agent profits and tax revenue—would always seek to impose a tax that implements the first-best level of effort. With a regulatory constraint, however, the social planner would never target the first-best level of effort. This follows because the social planner would only seek to impose further cost-increasing measures as long as profits increase on the margin, because there is no offsetting tax revenue if profits begin to fall. But profits cannot be increasing all the way down to the first-best level of effort since the social optimum must occur in a concave region of the production function. Accordingly, with a regulatory constraint, if the social planner would ever impose a cost-increasing measure, the resulting level of aggregate effort would still exceed the first-best. Hence the difference between the two policy instruments of a tax and a regulatory constraint is that agents' costs due to the tax are not social costs (they are tax revenue), but with the regulatory constraint they are.

6. Conclusion

This paper focuses on the potential for a veritable "free lunch" in the commons. We derive conditions under which raising costs through a regulatory constraint or a fully expropriated tax can increase the profits arising from a common-pool resource. The basic model assumes a fixed number of identical agents with linear costs selling in a single period at an exogenous price. A necessary and sufficient condition for a profitable cost increase is that aggregate output from the resource be locally convex in aggregate effort. We also show that cost increases can be profitable even if price is endogenous, agents are heterogeneous, entry is costless, or agents are playing a Markov-perfect equilibrium of a dynamic game.

One way to see the importance of the result is to consider the standard policy instrument of imposing a tax to manage the commons. The results of this paper show how producers (and sometimes consumers) can be made better off, compared to a situation with no tax, even if the tax revenue is fully expropriated. In such cases, our analysis suggests that agents operating in the commons should not oppose implementation of the tax if the alternative is no tax. Similarly, when such conditions hold, they should welcome other forms of regulation that increase the costs of all agents, as each stands to earn greater profits when compared to situations with no regulation.

The main result also contributes to the literature on decentralized forms of governance in the commons. Recent papers have shown that cooperation in the form of effort reduction is sustainable in dynamic games because of the potential threat of punishment if players deviate from the cooperative solution (see [16,19]). More generally, an extensive literature investigates the emergence of various self-governing institutional arrangements for managing the commons (e.g., [14,15]). One such example that applies even in a static game is the formation of partnerships, or profit-sharing rules, which create free-riding incentives that offset incentives for over-exploitation [12]. The present paper identifies a further mechanism for addressing the Tragedy of the Commons: the possibility that profitable cost increases can provide the basis for self-governance, in addition to promoting the political feasibility of externally imposed regulations or taxes.

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