Anticipatory Effects of Taxation in the Commons: *When do taxes work, and when do they fail?*[*]

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Abstract

This paper considers a common-pool resource where a regulator announces a new policy curbing appropriation (usage fee). While firms respond reducing their appropriation once the fee is in effect, we identify under which conditions firms choose to increase their appropriation before the fee comes into effect. We demonstrate that this policy-induced appropriation increase is more likely when: (1) several firms compete for the resource; (2) firms sustain some market power; (3) firms impose significant cost externalities on each other; and (4) the resource is scarce. Our results, therefore, indicate that policy announcements can trigger increases in resource exploitation before the policy comes into effect.

Keywords: Common-pool resources, Environmental policy, Anticipatory effects.
JEL classification: H23; L13; Q5.

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1 Introduction

Usage fees are often suggested as a tool to curb the excessive appropriation that firms exploiting a common-pool resource choose if left unregulated. Fees can help firms internalize the cost externality that their appropriation imposes on other firms operating in the same commons, ultimately leading them to exploit the resource at the socially optimal level. While this analysis yields first-best outcomes once the policy comes into effect, it overlooks the potential anticipatory effects that the policy triggers in firms' appropriation decisions before the policy comes into effect. If firms choose to increase their resource exploitation —anticipating a loss in future payoffs once regulation is implemented— the policy becomes less effective since overall appropriation does not decrease as expected, and may even increase. If, instead, firms choose to decrease their exploitation, the policy becomes effective even before coming into force. While the empirical literature has extensively evaluated the potential increase or decrease in pollution before an environmental policy comes into effect, we examine how firms' anticipatory behavior is affected by industry characteristics.

Our model considers a polluting industry with N firms exploiting a common pool resource (CPR) which does not have a close substitute, implying that the regulator cannot subsidize a clean alternative to affect the CPR exploitation.[1] Our setting allows for different types of industries as special cases. First, when firms are price takers and generate a cost externality on their rivals, our model resembles a standard CPR. Second, when firms face a downward sloping demand curve in the output market and do not generate cost externalities on each others' profits, our setting coincides with a standard Cournot model of quantity competition. Third, when firms face a downward sloping demand curve and generate cost externalities, our model includes features of the two extreme settings described above. Allowing for different types of industries helps us predict the anticipatory effects of taxation in different CPRs.

As expected, when firms exploit a CPR with large cost externalities and are price takers in the product market, our results show that firms increase their exploitation of the resource before the policy comes into effect. This setting is, however, rather stylized. When we relax the above assumptions, allowing for firms to face a downward sloping demand curve, our findings suggest that firms may reduce their appropriation in anticipation of the future policy. This is a positive result for regulators since the policy not only entails efficiency gains at the period when it is implemented, but potentially in previous periods, as firms' exploitation approaches the social optimum. Specifically, we show that appropriation is more likely to decrease in anticipation of future taxes when: (1) few firms compete for the resource, (2) firms are not price takers in the market where they sell their appropriation, (3) firms do not impose significant cost externalities on each other, and (4) the resource is abundant and/or grows across periods.[2] If some of these conditions do not hold, our

[1] Instead, we focus on CPRs where appropriation levels is socially excessive, such as several fishing grounds and acquifers. According to FAO (2018), the percentage of stocks fished at biologically unsustainable levels increased from 10 percent in 1974 to 33.1 percent in 2015, with the largest increases in the late 1970s and 1980s.

[2] In the context of polluting industries, Marz and Pfeiffer (2015) also identify a production and pollution decrease in the context of a monopolist extracting natural resources, but do not study settings with several firms. Similarly, Nachtigall and Rubbelke (2016) find a similar policy response in the context of resource extraction where firms benefit

findings suggest that the introduction of regulation will induce firms to respond by increasing their first-period appropriation, partially offsetting the effects of regulation during the second period.

In the context of polluting industries exploiting a non-renewable resource, the "green paradox" literature identifies a positive policy response, where firms respond by increasing pollution before the period in which the policy comes into effect.[3] For instance, in an empirical study, Di Maria et al. (2012) find a 9% increase in the amount of sulphur emitted measured in the period mediating the announcement of Title IV of the Clean Air Act affecting $CO/O_3/SO_2$, in 1990, and its final implementation, in 2000. Similar results apply to Lemoine (2017), who uses future markets data to study the American Clean Energy and Security Act, announced in 2009, planned to become into effect in 2013, but that finally was not implemented as the bill did not come up for a vote in the Senate.[4] Several papers found, instead, industries that react to new policies by reducing their pollution before the implementation of the law, or whose pollution remained unaffected. Hammar and Löfgren (2001), for instance, analyze the Swedish Sulphur Tax, finding a 59% reduction in sulphur dioxide between its announcement, in 1989, and its final implementation, in 1992.[5] Finally, Costello and Kaffine (2008) examine how an insecure property right framework affects the exploitation of a CPR, where renewal may not be granted. They find that uncertainty on renewed concession can induce to efficient exploitation. However, they do not analyze the anticipatory effect of the policy.[6]

We contribute to the debate of the anticipatory effects of taxation to industries mostly overlooked by the above literature: CPRs where every firm imposes a cost externality on its rivals and standard oligopolies with different degrees of market power. Our results help identify under which contexts we should expect appropriation reductions before regulation comes into effect, which yield unambiguous efficiency gains, and under which settings we should, instead, anticipate a more intense exploitation of the resource before the policy is implemented, yielding more ambiguous gains in this case. Our findings suggest that policy makers regulating CPRs where some of the above four conditions hold should expect that policy announcements lead to lower appropriation levels, even before the policy enactment.

Section 2 presents our model. Section 3 then analyzes equilibrium results, as well as its comparative statics. Section 4 discusses our policy implications.

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from learning-by-doing.

[3] As initially suggested by Sinn (2008), the "green paradox" refers to the possibility that climate policies, such as emission fees, which are aimed at reducing carbon emissions, instead lead to an increase in emissions; see Jensen et al. (2015) for a detailed literature review.

[4] For other contributions to this literature considering price-taking firms, see Strand (2007), Hoel (2010), Werf and Di Maria (2011), Di Maria et al. (2014), Smulders et al. (2012), Ploeg (2013), and Di Maria et al. (2012). Other contributions include Grafton et al. (2012) and Van der Ploeg and Withagen (2012).

[5] Other empirical studies reporting significant reductions in pollutants after the policy announcement and before its implementation include Malik and Elrod (2017) in the pulp, paper, and paperboard industries; Agnolucci and Ekins (2004) for CO_2 emissions; and the Swedish Environmental Protection Agency Report (2000) for shulphur dioxide. Di Maria et al. (2014) finds no significant change in coal use after the announcement of the Acid Rain Policy, affecting the coal industry and SO_2 emitting firms, between its announcement in 1990 and its enactment in 1995.

[6] Riekhof and Bröcker (2017), using a general equilibrium model, examine the effect of the announcement of a carbon emissions tax on generation of emissions. However, they do not explicitly examine the strategic effects of this announcement on firms' appropriation level in a CPR and do not identify which specific industry characteristics generate more significant policy responses.

2 Model

Consider an industry where $N \geq 2$ firms compete in quantities, facing a linear inverse demand $p(X) = 1 - bX$, where $b \geq 0$ and X denotes aggregate first-period appropriation. Every firm i faces cost function

$$C(x_i, x_{-i}) = \frac{x_i(x_i + \lambda x_{-i})}{\theta}$$

during the first period, where θ represents the total stock, x_i denotes firm i's appropriation, and $x_{-i} \equiv \sum_{j \neq i} x_j$ represents the aggregate appropriation by all other $N-1$ firms. Total cost is, therefore, increasing and convex in firm i's appropriation, x_i. Firm i's cost is also linearly increasing in its rivals' appropriation x_{-i} if $\lambda > 0$. Therefore, parameter $\lambda \geq 0$ indicates the extent of the cost externality that every firm's appropriation imposes on its rival, e.g., exploitation becomes more costly for firm i as firm j increases its appropriation. When $\lambda = 0$, total cost collapses to $\frac{x_i^2}{\theta}$, thus being independent on firm j's appropriation, whereas when $\lambda = 1$, the cost function becomes $\frac{x_i(x_i + x_{-i})}{\theta}$.

Finally, total and marginal costs are decreasing in the stock's abundance, θ, and we assume that aggregate appropriations cannot exceed the total stock, $\theta > X$. Since price becomes zero at aggregate appropriation $X = \frac{1}{b}$, our setting allows for the case in which the stock is relatively abundant, $\theta > \frac{1}{b}$, and thus imposes no capacity constraint on firms' appropriation decisions. That is, even if aggregate appropriation is $X = \frac{1}{b}$, yielding a zero price for the product, the resource is not depleted. Our model also allows for the case in which the stock is relatively scarce, $\theta \leq \frac{1}{b}$, implying that firms face a limited resource before reaching a zero price, which is a more natural assumption in CPRs.[7]

In the second period, every firm faces a similar cost function as in the first period

$$C(q_i, q_{-i}) = \frac{q_i(q_i + \lambda q_{-i})}{\theta(1+g) - X}$$

where q_i denotes firm i's second-period appropriation, and q_{-i} represents aggregate appropriation by firm i's rivals. The available stock at the beginning of the second period is $\theta(1+g) - X$, where $g \geq 0$ denotes the growth rate of the initial stock, θ. When $g = 0$, the initial stock θ does not grow at all, entailing that firms face an available stock of $\theta - X$ at the beginning of the second period. In contrast, when $X = g\theta$, the stock is fully recovered, so the initial stock θ is available again at the beginning of the second period. In this case, the second-period cost function becomes $C(q_i, q_j) = \frac{q_i(q_i + \lambda q_{-i})}{\theta}$, thus being symmetric to that in the first period.

Our model thus embodies standard CPR models as a special case when $b = 0$ and $\lambda > 0$. In this setting, firms take price as given, but their appropriation generates a negative externality on their rivals' costs, who experience a higher appropriation cost since the resource became more depleted.

[7] When $\theta > \frac{1}{b}$, the initial assumption $\theta > X$ holds for all levels of aggregate appropriation X in inverse demand function $p(X) = 1 - bX$. However, when $\theta \leq \frac{1}{b}$, the initial assumption $\theta > X$ implies that aggregate appropriation X lies in the left segment of the inverse demand curve.

Our model also embodies standard Cournot competition as a special case when $b > 0$ and $\lambda = 0$. In this context, every firm's sales affect market prices, but its appropriation does not entail a cost externality on other firms. Finally, we allow for mixed settings where prices are not given, $b > 0$, and externalities are present, $\lambda > 0$.

The time structure of the sequential-move game is the following:

1. **First period.**
   (a) The regulator announces a fee t that will come into effect at the beginning of the second period.
   (b) Every firm $i \in N$ simultaneously and independently chooses its first-period appropriation x_i not subject to fees.

2. **Second period.**
   (a) Fee t comes into effect.[8]
   (b) Observing both fee t and the profile of first-period exploitation $(x_1, x_2, ..., x_N)$, every firm i simultaneously and independently chooses its second-period appropriation q_i.

Therefore, firm i's first-period profit is

$$\pi_i(x_i, x_{-i}) = (1 - bX)x_i - \frac{x_i(x_i + \lambda x_{-i})}{\theta} \tag{1}$$

where $X \equiv x_i + x_{-i}$ represents first-period aggregate appropriation. Similarly, second-period profit is

$$\pi_i(q_i, q_{-i}) = (1 - bQ)q_i - \frac{q_i(q_i + \lambda q_{-i})}{\theta(1 + g) - X} - tq_i \tag{2}$$

where $Q \equiv q_i + q_{-i}$ indicates second-period aggregate appropriation. For simplicity, we consider that demand does not change across periods. Relative to expression (1), the profit in (2) indicates that firm i faces a more depleted resource and a per-unit fee $t \geq 0$. As described below, this is a usage fee that the regulator sets to control the appropriation of the resource.[9]

Social planner. Social welfare in the first period, when fees are absent, is given by

$$SW_1(x_i, x_{-i}) \equiv CS_1(X) + PS_1(x_i, x_{-i})$$

[8] If, instead, the regulator considered the sum of first- and second-period welfare, the fee that he announces in the first period would not be credible since he could change it at the beginning of the second period. We then assume, for tractability purposes, that the regulator cannot credibly commit to an emission fee at the beginning of the game.

[9] We consider that firms are symmetric in their cost function. For completeness, Appendix 5 analyzes how our model is affected if one of the firms exhibits a cost advantage. For simplicity, the appendix considers two firms.

thus accounting for consumer surplus, $CS_1(X) \equiv \frac{1}{2}bX^2$, and producer surplus, $PS_1(x_i, x_{-i}) \equiv \sum_{i=1}^{N} \pi_i(x_i, x_{-i})$. In the second period firms face fee t, and welfare becomes

$$SW_2(q_i, q_{-i}) \equiv CS_2(Q) + PS_2(q_i, q_{-i}).$$

3 Equilibrium analysis

We solve the above sequential-move game by backward induction.

3.1 Second stage

In the second period, every firm i solves

$$\max_{q_i \geq 0} \; [1 - b(q_i + q_{-i})]\, q_i - \frac{q_i(q_i + \lambda q_{-i})}{\theta(1+g) - X} - tq_i \tag{3}$$

as described in the next lemma.

Lemma 1. *Equilibrium second-period appropriation is*

$$q_i(t) = \frac{(1-t)\,[\theta(1+g) - X]}{2 + b(N+1)\,[\theta(1+g) - X] - (N-1)\lambda}$$

which yields second-period profits of $\pi_i(t) = \pi_i(t) = \frac{(1-t)^2[\theta(1+g)-X][1+b[\theta(1+g)-X]]}{[2+b(N+1)[\theta(1+g)-X]-(N-1)\lambda]^2}$.

The socially optimal appropriation solves

$$\max_{Q} SW_2(q_i, q_{-i}) = CS_2(Q) + PS_2(q_i, q_{-i}) \tag{4}$$

At first glance, one could think that the regulator had to maximize the welfare from both periods, rather than that from the second period alone. Such a fee, however, would not be credible, i.e., sequentially rational. For the fee to be sequentially rational, it must maximize social welfare from this point forward, and thus coincides with the above program. Lemma 2 reports the result to problem (4).

Lemma 2. *The socially optimal appropriation is*

$$Q^{SO} = \frac{N\,[\theta(1+g) - X]}{2 + bN\,[\theta(1+g) - X] + 2(N-1)\lambda}$$

which is weakly increasing in the initial stock, θ, and its growth rate, g; but weakly decreasing in first-period appropriation, X, and in the cost externality, λ, for all parameter values. In addition, Q^{SO} is weakly decreasing in the number of firms, N, if $\lambda > 1$.

Therefore, the social planner seeks a larger second-period aggregate appropriation when the stock at the beginning of the second period, $\theta(1+g)-X$, is abundant, which occurs when the initial stock, θ, is large, the growth rate, g, is high, and first-period appropriation, X, is not severe. In contrast, the planner seeks a lower second-period appropriation when firms impose large cost externalities on each other (high λ) and several firms compete for the resource.

The above socially optimal appropriation Q^{SO} can be induced by setting a fee t^* that solves $Q^{SO}=Q(t)$, where $Q(t)\equiv\sum_{i=1}^{N}q_i(t)$ denotes aggregate second-period appropriation, as found in Lemma 1. Solving for fee t, yields the following result.

Proposition 1. *The socially optimal fee is*

$$t^*=\frac{b\left[\theta(1+g)-X\right]+\lambda(N-1)}{2\lambda(N-1)+2+bN\left[\theta(1+g)-X\right]}$$

which is positive for all $\lambda>\overline{\lambda}\equiv\frac{b[\theta(1+g)-X]}{N-1}$*. In addition,* t^* *is weakly increasing in aggregate first-period appropriation,* X*, and the number of firms competing for the resource,* N*, but weakly decreasing in the growth rate,* g*, in the available stock,* θ*, and the cost externality,* λ*.*

Intuitively, when the cost externality that firms impose on each other is sufficiently severe (high values of λ), t^* is a tax that discourages appropriation while otherwise t^* becomes a subsidy.[10] As described in Lemma 2, when the resource is more heavily used in the first period and/or more firms compete for it, aggregate appropriation becomes socially excessive, inducing a more stringent fee. In contrast, when the resource regenerates faster across periods, first-period appropriation produces a smaller welfare loss in the second period (when policy becomes effective), implying that aggregate appropriation is not different from the social optimum, and thus a lax fee is in order.

3.2 First period

In the first period, every firm i solves

$$\max_{x_i\geq 0}\quad\left[1-b(x_i+X_{-i})\right]x_i-\frac{x_i(x_i+\lambda X_{-i})}{\theta}+\delta\pi_i(t^*) \tag{5}$$

where $\delta\in[0,1]$ denotes the discount factor. The profit function in the above profit-maximization problem, $\pi_i(t^*)$ —the value function of firm i's second-period problem we obtained in Lemma 1— is evaluated at the optimal fee t^* found in Proposition 1, since the firm can anticipate the fee effective in the subsequent stage of the game, that is,

$$\pi_i(t^*)=\frac{\left[(1+g)\theta-(X_{-i}+x_i)\right]\left[1+b\left(\theta(1+g)\right)-(x_i+X_{-i})\right)]}{\left[2\lambda(N-1)+2+bN\left[\theta(1+g)-(x_i+X_{-i})\right]\right]^2}.$$

Before solving problem (5), we describe how its result can help us understand firms' policy response.

[10] Appendix 1 provides a more detailed analysis of this result.

Policy response (PR). Consider the firm's optimal first-period appropriation that solves problem (5), $x_i(t)$, and evaluate at $t = 0$ to obtain the firm's appropriation when fees are absent, $x_i(0)$, and then at the second-period fee t^* that the regulator selects in equilibrium, t^*, to find the firm's appropriation when fees are present. We can then define the firm's "policy response" (PR), as follows

$$PR \equiv x_i(t^*) - x_i(0),$$

When $PR > 0$, first-period appropriation increases from $x_i(0)$, when fees are absent, to $x_i(t^*)$, evaluated at the second-period fee t^*. A positive value for PR would indicate that firms, anticipating the future CPR policy during the second period, increase their first-period production, hence depleting the resource more intensively than when the policy is absent. In contrast, a negative PR suggests that firms respond to policy announcements by decreasing their current production in order to reduce their future taxes.

Differentiating with respect to first-period appropriation, x_i, in problem (5) yields a highly non-linear equation which does not allow for an analytical expression of $x_i^*(t^*)$. Table I numerically evaluates $x^*(t^*)$ at different (b, λ)-pairs, where $\theta = \delta = 1$, $N = 2$ and $g = 1/4$. (For more details, see tables A1-A3 in Appendix 2, which consider other parameter values.)

b	λ	$x_i^*(t^*)$	$x_i^*(0)$	PR
0	0	0.375	0.375	0
0	1	0.312	0.296	0.016
0	2	0.243	0.234	0.008
0.5	0	0.248	0.262	−0.015
0.5	1	0.209	0.209	−0.0004
0.5	2	0.176	0.174	0.001
1	0	0.185	0.194	−0.008
1	1	0.158	0.161	−0.002
1	2	0.138	0.139	−0.001

Table I. First-period appropriation and firms' policy response.

Specifically, Table I provides first-period appropriation with and without regulation, $x_i^*(t^*)$ and $x_i^*(0)$, respectively. The value of $x_i^*(0)$ is found by evaluating second-period appropriation $q_i(t)$ from Lemma 1 at $t = 0$, $q_i(0)$, as well as second-period profit $\pi_i(0)$, which can then be inserted into (5) to obtain $x_i^*(0)$. Finally, the table also reports the policy response $PR = x_i^*(t^*) - x_i^*(0)$, measuring the increase in appropriation that results from the introduction of the policy (if $PR > 0$) or the policy-induced reduction in appropriation (if $PR < 0$). For illustration purposes, Table II considers those (b, λ)-pairs in Table I, as well as other (b, λ) combinations, and reports the PR next to each point.[11]

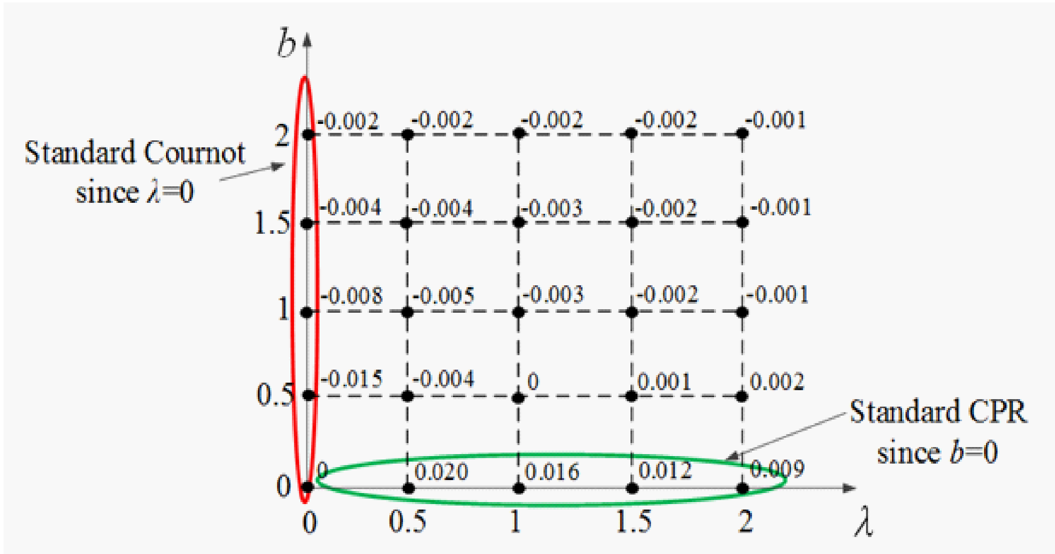

Table II. Policy response under different settings.

First, when firms compete in a standard CPR (taking prices as given, $b = 0$, but generating external effects on each other, $\lambda > 0$), our results show a positive PR. This is illustrated in the horizontal axis, confirming the finding in the green paradox literature, namely, that firms increase their first-period appropriation anticipating the loss in future profits they will experience in the second period under regulation. When $b = 0$, the first-order condition from problem (5) yields an analytical expression for the optimal first-period appropriation with regulation, $x_i^*(t^*)$, and without regulation, $x_i^*(0)$. This is the only case in which an analytical solution can be found. In particular, $x_i^*(t^*) = \frac{\theta\left[4-\delta+8\lambda(N-1)+4\lambda^2(N-1)^2\right]}{4[1+(N-1)\lambda]^2(2+(N-1)\lambda)}$ and $x_i^*(0) = \frac{\theta\left[(2+(N-1)\lambda)^2-\delta\right]}{[2+(N-1)\lambda]^3}$, thus yielding a policy response

$$PR = \frac{(N-1)\delta\theta\lambda(4+3(N-1)\lambda)}{4\left[1+(N-1)\lambda\right]^2\left[2+(N-1)\lambda\right]^3},$$

which is positive since $N \geq 2$ by definition.

Second, when firms compete a la Cournot ($b > 0$ and $\lambda = 0$), we show a negative PR, as depicted in the points along the vertical axis. Third, the table reports (b, λ)-pairs with positive PR when the market structure is relatively similar to a standard CPR —low values of b and high values of λ— but a negative PR when firms do not take prices as given.

Intuitively, for a given value of λ, a first-period appropriation reduction entails no change in market prices when firms are price takers (as in standard CPRs where $b = 0$). However, when $b > 0$,

[11] For instance, when $b = 0.5$ and $\lambda = 0$, as described in the fourth row of Table I, $PR = -0.015$, as depicted next to point $(b, \lambda) = (0.5, 0)$ on the vertical axis of Table II. Appendix 2 provides tables listing first-period appropriation with and without regulation in each of these cases, and its associated policy response PR.

this appropriation reduction produces an increase in market prices, making it more attractive for the firm than when $b = 0$. Therefore, regulation not only decreases second-period appropriation, but can also reduce first-period appropriation (before coming into effect) if firms face a downward sloping demand curve. Table II also suggests that, for a given $b > 0$ (such as $b = 0.50$), a more severe cost externality (higher λ) produces a nil or positive PR. In words, this indicates that regulation yields either a negligible decrease (or even an increase) in first-period appropriation when firms generate a severe externality on each others' costs. In this setting, firms anticipate a more stringent fee in the second period, responding with a larger appropriation with than without regulation to partially compensate for their future profit loss.

3.3 Comparative statics

Table IIIa illustrates PRs with a more abundant initial stock, $\theta = 2$, keeping all other parameter values unchanged. Relative to Table II, Table IIIa shows that PR becomes negative under larger (b, λ)-pairs. Intuitively, a more abundant resource (higher θ) leads to a less stringent fee (since t^* and θ move in opposite directions, as shown in Proposition 1), inducing firms to increase their first-period appropriation when regulation is present, $x_i(t^*)$, but increasing their first-period appropriation even more significantly when regulation is absent, $x_i(0)$. As a result, policy response PR becomes negative (positive) under more (less) parameter combinations. Table IIIb confirms this comparative statics by evaluating PR at a more abundant resource ($\theta = 3$).

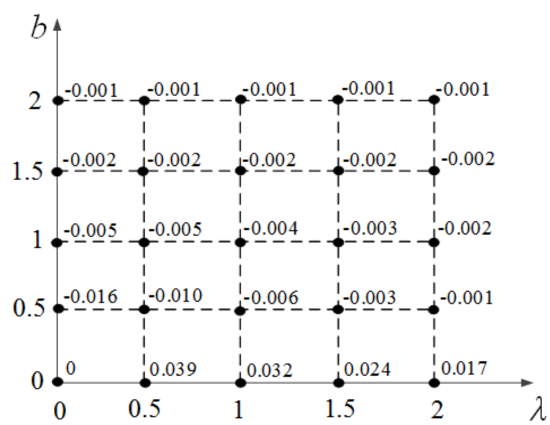

Table IIIa. PR with θ= 2 (abundant stock).

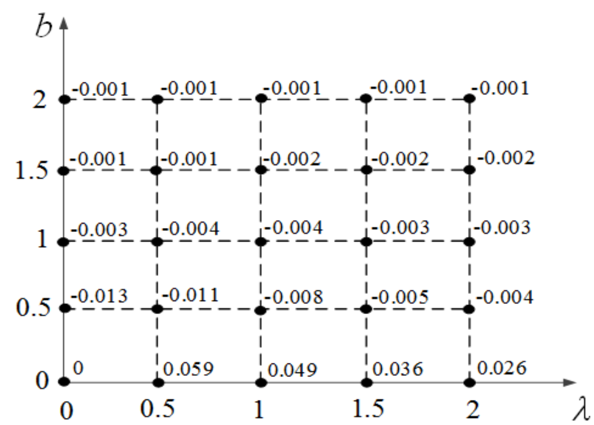

Table IIIb. PR with θ= 3 (more abundant stock).

Table IVa illustrates similar findings as in tables IIIa-IIIb when the growth rate is larger, $g = 1/2$, since in this case the fee also becomes less stringent. For completeness, table IVb depicts the case in which g further increases to $g = 1$.

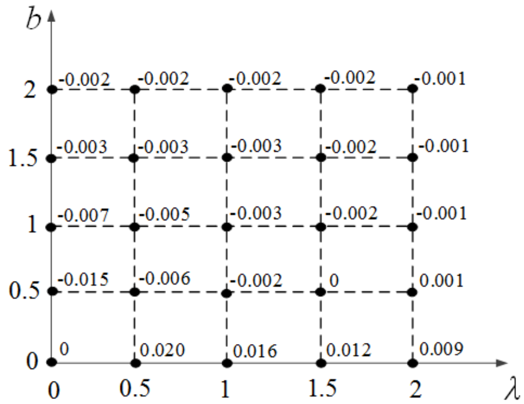

Table IVa. PR with $g = 1/2$.

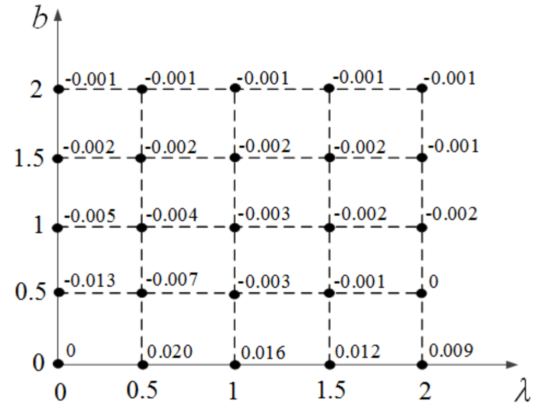

Table IVb. PR with $g = 1$.

Table Va reports PRs using the same parameters as Table II, but allowing for $N = 3$ firms. Table Va shows that PR decreases in absolute value, becoming closer to zero for all (b, λ)-pairs, which occurs both when the PR was positive and when it was negative in Table II. Results are emphasized when $N = 4$ firms compete; see table Vb.

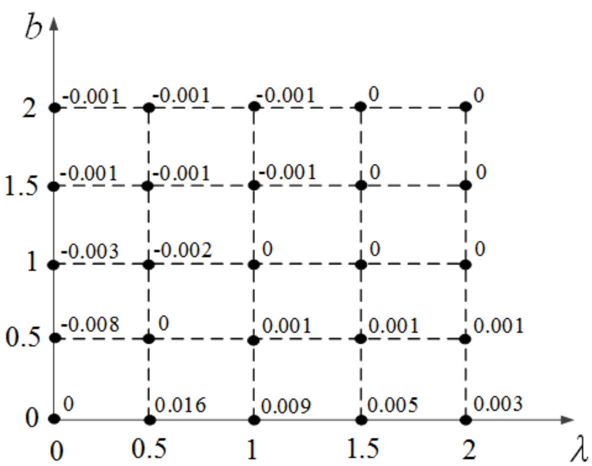

Table Va. PR with $N = 3$ firms.

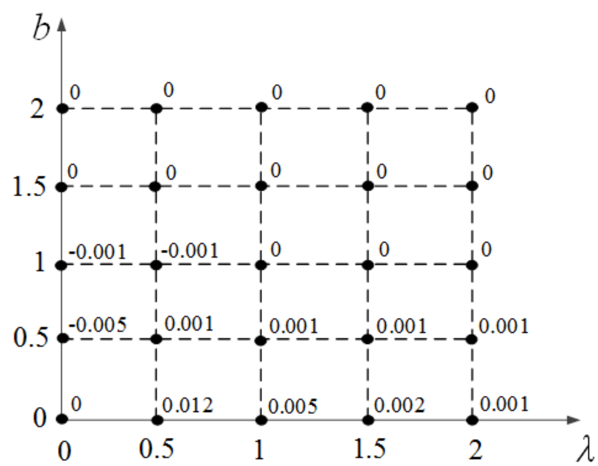

Table Vb. PR with $N = 4$ firms.

A similar argument applies when firms discount future profits more significantly ($\delta = 1/2$ rather than $\delta = 1$), as depicted in Table VI. Intuitively, future taxation produces in this setting a smaller change in first-period appropriation, relative to that when taxes are absent. It can be easily shown that further reductions in discount factor δ decrease PR, becoming $PR = 0$ under all (b, λ)-pairs when firms assign no value to future profits, since first-period appropriation satisfies $x_i^*(t^*) = x_i^*(0) = \frac{\theta}{2+\theta(N+1)b+(N-1)\lambda}$ when $\delta = 0$.

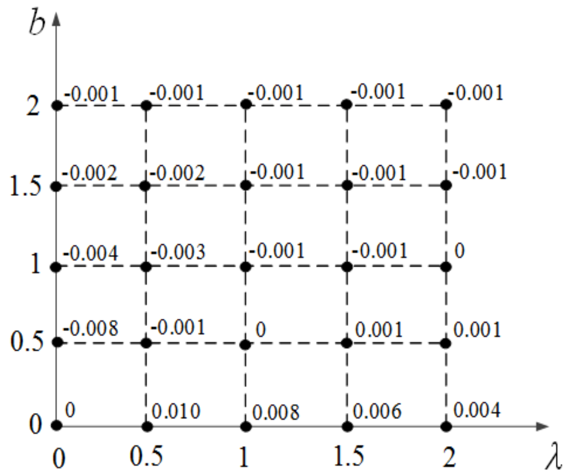

Table VI. PR with $\delta = 1/2$.

4 Extensions

4.1 Cartel behavior

For completeness, Appendix 3 studies appropriation decisions when firms operate as a cartel, seeking to maximize their joint profits during the first and second periods. Table VII summarizes first-period appropriation with and without regulation, and the resulting PR^C, where the C superscript denotes cartel. For comparison purposes, we evaluate these expressions at the same parameter values as Table I,[12] showing that when firms operate as a cartel, they internalize the cost externality (when $\lambda > 0$), the price effects (when $b > 0$) or both, and thus exploit the resource less intensively, a result that holds under all parameter combinations, with and without regulation. The cartel, however, produces a smaller reduction in first-period appropriation when firms face regulation, $x_i^C\left(t^C\right)$, than when they do not, $x_i^C(0)$, ultimately yielding a larger PR^C. Intuitively, regulation serves as coordination tool for firms when they do not form a cartel, helping them approach to cartel appropriation levels, which implies that regulating a cartel does not alter exploitation decision so significantly. In conclusion, the pollution reduction effects that can arise when firms do not act as a cartel, $PR < 0$, are less likely to emerge when firm operate as such.

[12] Other parameter values produce similar results, and can be provided by the authors upon request.

b	λ	$x_i^C\left(t^C\right)$	$x_i^C\left(0\right)$	PR^C
0	0	0.438	0.438	0.000
0	1	0.234	0.188	0.047
0	2	0.160	0.139	0.021
0.5	0	0.225	0.212	0.012
0.5	1	0.157	0.148	0.010
0.5	2	0.120	0.113	0.007
1	0	0.156	0.157	−0.001
1	1	0.119	0.117	0.002
1	2	0.097	0.094	0.002

Table VII. First-period appropriation and the policy response under cartel.

4.2 Introducing pollution damages

In this section, we allow for appropriation to generate pollution, such as water discharges from vessels or other pollutants that firms exploiting a CPR emit in their activities. Specifically, in the first period, when fees are absent, social welfare is

$$SW_1(x_i, x_{-i}) \equiv CS_1(X) + PS_1(x_i, x_{-i}) - dX^2$$

where the last term, dX^2, represents the convex environmental damage from aggregate first-period appropriation, X, and $d > 0$. In the second period, firms face fee t, and welfare becomes

$$SW_2(q_i, q_{-i}) \equiv CS_2(Q) + PS_2(q_i, q_{-i}) - d(Q + \gamma X)^2$$

where parameter $\gamma \in [0, 1]$ denotes the damage persistence of first-period appropriation, X. When $\gamma = 0$, second-period environmental damage collapses to dQ^2, but when $\gamma = 1$ every unit of first-period appropriation, X, also generates damages in the second period.

For compactness, Appendix 4 solves our sequential-move game again in this context. Table VIII summarizes first-period appropriation and the firms' policy response in this setting, comparing it against that when pollution was not considered in Table I. For comparison purposes, we evaluate all variables at the same parameter values as in Table I.[13]

[13] The only new parameters relative to Table I are d and γ, which are evaluated at $d = 1/2$ and $\gamma = 0$ in Table VIII. Other parameter values yield qualitatively similar results.

b	λ	$x_i^*(t^*)$	$x_i^*(0)$	PR with pollution	PR without pollution
0	0	0.463	0.375	0.088	0
0	1	0.329	0.296	0.033	0.016
0	2	0.249	0.234	0.014	0.008
0.5	0	0.280	0.263	0.017	−0.014
0.5	1	0.219	0.210	0.009	−0.0004
0.5	2	0.180	0.174	0.006	0.001
1	0	0.197	0.194	0.003	−0.008
1	1	0.164	0.162	0.003	−0.002
1	2	0.141	0.139	0.002	−0.001

Table VIII. Firms' policy response with/without pollution.

Table VIII indicates that policy responses are more likely to become positive when firms are subject to a tax seeking to curb pollution (i.e., emission fee) than when appropriation does not yield environmental damages (i.e., usage fees). Intuitively, the emission fee is more stringent than the usage fee, as the former seeks to alleviate two market failures, a socially excessive pollution and appropriation, while the latter only seeks to curb a socially excessive appropriation. In anticipation of a more stringent fee in the second period, firms are more likely to increase their first-period appropriation. Therefore, a positive PR, and the associated resource depletion, are more substantial when regulators use emission fees to reduce pollution in CPRs than when they use usage fees.

Table IX reports PR when first-period appropriation generates a larger second-period damage ($\gamma = 1/2$ in table IX as opposed to $\gamma = 0$ in table VIII), illustrating that policy response decreases for most parameter combinations, becoming negative (i.e., reduction in first-period appropriation due to future taxes) under larger conditions. Intuitively, this occurs because, as environmental damages persist more significantly over time (higher γ), the regulator sets a more severe tax (see Appendix 4 for more details), which firms anticipate in the first period, decreasing their appropriation relative to the setting without regulation.

b	λ	$x_i^*(t^*)$	$x_i^*(0)$	PR with pollution
0	0	0.469	0.375	-0.046
0	1	0.329	0.296	-0.048
0	2	0.248	0.234	0.039
0.5	0	0.274	0.263	-0.045
0.5	1	0.218	0.210	-0.030
0.5	2	0.180	0.174	0.018
1	0	0.193	0.194	-0.031
1	1	0.163	0.162	-0.021
1	2	0.141	0.139	0.002

Table IX. Firms' policy response with severe second-period damage, $\gamma = 1/2$.

5 Discussion

Anticipatory effects of taxation. Our above results indicate that firms respond to future regulation by altering their first-period appropriation decisions, that is, fees are effective even before they are implemented. In addition, we showed that the PR, understood as how much firms increase their first-period appropriation in anticipation of future fees, is not necessarily positive, as suggested by the literature, but can also be negative, or zero, depending on the market structure where firms interact. Our findings then indicate that regulators should carefully consider industry characteristics when designing policy. In particular, the environmental outcomes are better (negative PRs) if the following characteristics are met when regulation starts: (1) firms are not price takers in the market where they sell their appropriation (relatively high b); (2) firms do not impose significant cost externalities on each other (relatively low λ); (3) the stock is abundant (relatively high θ); (4) the resource grows across periods (high g); and (5) few firms compete for the resource (low N). If some of these conditions do not hold, our findings suggest that the introduction of fees will induce firms to respond by increasing their first-period appropriation under larger parameter values, ultimately inducing a positive PR. This partially offsets the efficiency gains from regulation during the second period. In contrast, when the above conditions hold, we showed that a negative PR is more likely. In other words, this entails that the introduction of policy can yield not only benefits during the second period, when the regulation comes into effect, but also during the first period since firms respond to the future policy by reducing their first-period appropriation.

Comparing profits with/without taxes. Emission fees produce a strict decrease in second-period profits, and a weak reduction in first-period profits. To understand this point, note that, in the second period, firm profits are lower with than without taxes, since every firm produces a suboptimal amount.[14] In the first period, the firm increases (decreases) its production when $PR > 0$ ($PR < 0$, respectively), but deviates away from its first-period exploitation level without regulation $x_i^*(0)$, thus obtaining lower first-period profits than when firms are not subject to fees. However, when the number of firms competing for the resource is sufficiently large, PR is close to zero, entailing that firms do not change their first-period appropriation decisions because of their anticipation of future taxes. Therefore, when several firms compete, the introduction of fees produces an unambiguous decrease in second-period profits, but no change whatsoever in first-period profits.

First-period efficiency gains? During the second period (when the fee is implemented), the tax induces firms to exactly produce the social optimum. In the first period, however, fees are not enacted yet but, in anticipation of the tax, firms reduce (increase) their production thus decreasing (increasing) pollution, moving first-period appropriation closer (farther away, respectively) to the social optimum. However, when several firms compete for the resource, our results show that the PR approaches zero, indicating that the efficiency gain (loss) that the second-period regulation brings into the first-period vanish.

6 Conclusions

This paper examines how the announcement of a new policy (usage fee) affects firms' appropriation of a common-pool resource. We demonstrate that a lower exploitation of the resource is more likely to occur, as anticipation of future taxes, when: (1) competition for the resource is not intense; (2) market prices are not given; (3) cost externalities that firms impose on each other are low; and (4) CPRs are abundant or grow across periods. If some of these conditions do not hold, our results indicate that the announcement of future regulations induces firms to increase their first-period appropriation, making overexploitation of the resource more likely.

References

[1] Agnolucci, P. and P. Ekins (2004) "The announcement effect and environmental taxation," Tyndall Centre Working Paper 53, Tyndall Centre for Climate Change Research.

[2] Costello, C. and D. Kaffine (2008) "Natural resource use with limited-tenure property rights," Journal of Environmental Economics and Management, 55(1), pp. 20-36.

[3] Di Maria, C., S. Smulders, and E. Van der Werf (2012) "Absolute abundance and relative scarcity: Environmental policy with implementation lags," Ecological Economics, 74, pp. 104–119.

[14] That is, even if the emission fee is revenue neutral and the regulator returns all tax collection to the firms as a lump-sum subsidy, under regulation every firm chooses an appropriation level different from that under no regulation (which maximizes its profit function).

[4] Di Maria, C., I. Lange, and E. van der Werf (2014) "Should we be worried about the green paradox? Announcement effects of the Acid Rain Program," European Economic Review, 69, pp. 143-162.

[5] Di Maria, C., I. Lange and E. van der Werf (2014) "Going full circle: demand-side constraints to the green paradox," Chapter 10 in Karen Pittel, Frederick van der Ploeg and Cees Withagen (eds.), *Climate Policy and Exhaustible Resources – The Green Paradox and Beyond*. Cambridge: MIT Press

[6] FAO (2018) "The State of World Fisheries and Aquaculture 2018 - Meeting the sustainable development goals." Rome

[7] Grafton, Q., T. Kompas (2012) "Substitution Between Biofuels and Fossil Fuels: Is there a Green Paradox?" Journal of Environmental Economics and Management, 64, pp. 328-341.

[8] Hammar, H., and Å. Löfgren (2001) "The determinants of sulphur emissions from oil consumption in Swedish manufacturing industry 1976–1995," The Energy Journal, 22 (2), pp. 107-126.

[9] Hoel, M. (2010) "Is there a Green Paradox?" CESifo Working Paper Series No. 3168.

[10] Jensen, S., K. Mohlin, K. Pittel, and T. Sterner (2015) "An introduction to the green paradox: The unintended consequences of climate policies," Review of Environmental Economics and Policy, 9(2), pp. 246–265.

[11] Lemoine, D. (2017) "Green expectations: current effects of anticipated carbon pricing," Review of Economics and Statistics, 99(3), pp. 499-513.

[12] Malik, A.S, and A.A. Elrod (2017) "The effect of environmental regulation on plant level product mix: A study of EPA's Cluster rule," Journal of Environmental Economics and Management, 83, pp. 164-184.

[13] Marz, W. and J. Pfeiffer (2015) "Carbon Taxes, Oil Monopoly and Petrodollar Recycling," Ifo Working Paper 204, September.

[14] Nachtigall, D. and D. Rubbelke (2016) "The Green Paradox and Learning-by-Doing in the Renewable Energy Sector," Resource and Energy Economics, 43, pp. 74-92.

[15] Riekhof, M. and J. Bröcker (2017) "Does The Adverse Announcement Effect Of Climate Policy Matter?—A Dynamic General Equilibrium Analysis," Climate Change Economics, 8(2), pp. 1-34.

[16] Sinn, H.-W. (2008) "Public policies against global warming: a supply side approach," International Tax and Public Finance, 15(4), pp. 360–394.

[17] Smulders, S., Y. Tsur, and A. Zemel (2012) "Announcing Climate Policy: Can a green paradox arise without Scarcity?" Journal of Environmental Economics and Management. 64(3), pp 364-376.

[18] Strand, J. (2007) "Technology Treaties And Fossil-Fuels Extraction," Energy Journal, 28(4), pp. 129–141.

[19] Swedish Environmental Protection Agency (2000) "The Swedish charge on nitrogen oxides-cost effective emission reduction."

[20] Van der Ploeg, F. and C. Withagen (2012) "Is there really a Green Paradox?" Journal of Environmental Economics and Management, 64, pp. 342-363.

[21] Van Der Ploeg, F. (2013) "Cumulative Carbon Emissions And The Green Paradox," Annual Review of Resource Economics, 5, pp. 281-300.

[22] Werf, E. van der, and C. Di Maria (2011) "Unintended detrimental effects of environmental policy: the green paradox and beyond," CESifo Working Paper, 3466.