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Abstract

This paper shows that, after the announcement of a new environmental policy, firms respond reducing their output and pollution under large parameter combinations, which yields a reversal of the green paradox. In addition, we demonstrate that pollution reduction is more severe when the market is highly concentrated. Our results, therefore, indicate that policy announcements can trigger a decrease in pollution before the law comes into effect, thus rationalizing recurrent empirical observations.

KEYWORDS: Green paradox, Pollution, Environmental policy.
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1 Introduction

The "green paradox" states that, after the announcement of an environmental policy, such as the imposition of an emission fee on a polluting industry, firms respond by increasing pollution before the time period in which the law comes into effect.[1] Intuitively, firms seek to maximize their current profits anticipating a loss in future payoffs once regulation comes into force. Empirically, however, few studies have supported the green paradox, often restricted to firms exploiting natural resources.[2] 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.[3]

While the green paradox has been extensively studied in the extraction of fossil fuel resources, it has been overlooked in polluting industries that do not exploit natural resources. Our model focuses on this type of industry, helping rationalize the above empirical findings. In particular, our results show that the green paradox cannot be positive under any parameter combinations. Instead, it is negative when the market is highly concentrated, or zero otherwise. Intuitively, a monopoly internalizes the tax-savings effect of reducing its current pollution, since such reduction can lead to less accumulated pollution in future periods, ultimately reducing emission fees in subsequent periods. A firm competing in an oligopoly, however, does not internalize the above tax-savings effect of reducing its current output, and thus has less incentives to alter its production decisions before and after the policy announcement. Therefore, our results indicate that, if few firms compete, the policy announcement per se, and the strategic effects it triggers, reduces first-period output and pollution even *before* firms become subject to the new policy.[4]

The green paradox literature has warned against the potential effects of environmental policy, as it could aggravate global warming. Our findings, in contrast, suggest that policy makers should not hesitate when regulating polluting industries that do not exploit natural resources, such as the automotive and construction sectors, since the announcement of future environmental policies can lead to lower pollution levels before its enactment.

Section 2 presents our model. Section 3 then analyzes equilibrium results, first, in a monopolistic market, and then in an oligopoly.

[1] See Sinn (2008). For a literature review on the green paradox, see Jensen et al. (2015).

[2] Di Maria et al. (2012) finds 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 and implemented in 2013.

[3] Other 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; Dewees et al. (2016) affecting water pollutings firms across 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.

[4] Marz and Pfeiffer (2015) also identify a reversal of the green paradox but in the context of a monopolist extracting natural resources, and do not study settings with several firms. Similarly, Nachtigall and Rubbelke (2016) find a reversal in the context of resource extraction and rely on firms benefiting from learning-by-doing.

2 Model

Consider a market where all firms face constant marginal cost $c > 0$ and a linear inverse demand $p(x) = a - bx$, where x denotes aggregate output in the first period of the game, where $a > c$ and $b > 0$. Similarly, firms face demand $p(q) = a - bq$ in the second period, and the same marginal cost of production c, where q denotes aggregate second-period output. We assume that, before the beginning of the game, the regulator announced the implementation of an emission fee $t \geq 0$ that firms must comply with during the second period. The time structure of the game is the following:

1. **First period.** Every firm $i \in N$ simultaneously and independently chooses its first-period output x_i not subject to fees.
2. **Second period.**
   (a) Emission fee t comes into effect at the beginning of the second period.
   (b) Observing both fee t and the profile of first-period output $(x_1, x_2, ..., x_N)$, every firm i simultaneously and independently chooses its second-period output q_i.

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

$$SW_1(x) \equiv CS_1(x) + PS_1(x) - Env_1(x)$$

thus accounting for consumer surplus, $CS_1(x) \equiv \frac{1}{2}bx^2$; producer surplus, $PS_1(x) \equiv (a - bx)x - cx$; and environmental damage, where the latter is linear in output $Env_1(x) = dx$ and $d > \frac{a-c}{2}$, which guarantees positive emission fees. In the second period firms face fee t, and welfare becomes

$$SW_2(q(t)) \equiv CS_2(q(t)) + PS_2(q(t)) + tq(t) - Env_2(q(t))$$

which now includes tax revenue to guarantee that emission fees are revenue neutral. Environmental damage is now given by $Env_2(q) = d_2 q = [d + \beta(dx)]\, q$, where parameter $d_2 \equiv d + \beta(dx)$ denotes the effective amount of environmental damage in the second period. In particular, β captures how the pollution from first-period output, dx, persists into the environment during the second period. When $\beta = 0$, second-period damage collapses to $Env_2(q) = dq$, entailing that first- and second-period pollution are independent (i.e., first-period pollution does not persists into the second period); whereas when $\beta > 0$ a positive share of first-period pollution generates second-period environmental damage. We refer to parameter β as "pollution persistence" and, for simplicity, we consider that it is not excessive, $\beta < \frac{1}{d}$.[5]

Green paradox. In the next section, we seek to measure the "green paradox,"

$$GP \equiv x(t^*) - x(0),$$

[5] This entails that $\beta < \frac{1}{d} < 1$ since $d > \frac{a-c}{2}$ by definition. Therefore, $\beta < 1$, which implies that we do not consider the case in which every unit of first-period pollution fully persists into the second-period game.

When $GP > 0$, this expression indicates that first-period output increases from $x(0)$, when emission fees are absent, to $x(t^*)$, evaluated at the second-period fee t^* that the regulator selects in equilibrium. A positive value for GP would indicate that firms, anticipating the future environmental policy during the second period, increase their first-period production, hence increasing pollution. In contrast, a negative GP suggests that firms respond to policy announcements by decreasing their current production in order to reduce their future taxes.

3 Equilibrium analysis

We solve the above sequential-move game by backward induction. For presentation purposes, we start by examining the case of a monopoly, and then extend our analysis to oligopolies.

3.1 Monopoly

Stage 2b, optimal q. In the second period, the monopolist solves

$$\pi(t) \equiv \max_{q} \ (a - bq)q - (c + t)q$$

where $t \geq 0$ denotes the emission fee per unit of output. Differentiating with respect to output q and solving for q, we obtain profit-maximizing output $q(t) = \frac{a-(c+t)}{2b}$, which yields second-period profits of $\pi(t) = \frac{[a-(c+t)]^2}{4b}$.

Stage 2a, optimal fee. The social planner anticipates the above output function $q(t)$ and inserts it in the following problem

$$\max_{t} \ SW_2(q(t))$$

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. However, at this point of the game, the regulator's fee is sequentially rational, i.e., it maximizes social welfare from this point forward, and thus coincides with the above program. Solving for fee t, yields $t^* = 2d_2 - (a - c)$, or

$$t^* = 2d\,(1 + \beta x) - (a - c)$$

after using $d_2 \equiv d + \beta\,(dx)$. The optimal fee is thus increasing in environmental damage d; and on first-period output, x, when $\beta > 0$. In words, when a share of first-period output persists in the form of pollution during the second period, the optimal fee that the regulator imposes on the second period must increase to compensate for this additional pollution. However, when $\beta = 0$, emission fees become independent of first-period output, as the effect of x does not persist into the second-period game.[6]

[6] Emission fee t^* is positive only if environmental damage d is sufficiently high, i.e., $d > \frac{a-c}{2(1+\beta x)}$, which holds since $d > 1/2$ by definition. Emission fees are, therefore, positive under all admissible parameter values, and for all first-period output x.

Stage 1, optimal x. In the first period, the monopolist solves

$$\max_{x}\ (a-bx)x-cx+\delta\pi(t^{*})$$

where $\delta\in[0,1]$ denotes the discount factor. The profit function $\pi(t)$ —the value function of the monopolist's second-period problem— is evaluated at the optimal fee t^{*} found above, since the monopolist can anticipate the fee that the regulator sets in the subsequent stage of the game. Differentiating with respect to output x and solving for x, we obtain a profit-maximizing output of

$$x^{*}\left(t^{*}\right)=\frac{b(a-c)-2d(a-c-d)\beta\delta}{2(b^{2}-d^{2}\beta^{2}\delta)}$$

which collapses to the standard monopoly output $\frac{a-c}{2b}$ when the monopolist does not assign a positive weight to future profits, $\delta=0$. Intuitively, current pollution may affect future fees and thus profits, but when the monopolist does not care about the latter, it chooses $\frac{a-c}{2b}$. A similar argument applies when the pollution from first-period output does not persist into the second period, i.e., $\beta=0$. Intuitively, future emission fees are unaffected by the monopolist's current production, and thus second-period profits become independent of the choice of x. Last, it is easy to check that first- and second-period output are positive in equilibrium if pollution persistence is not excessive, i.e., $\beta<\overline{\beta}\equiv\frac{2(a-c-d)b}{(a-c)d}$.[7]

Green Paradox. As discussed in the previous section, the increase in first-period output due to future taxes is measured by $GP\equiv x^{*}(t^{*})-x^{*}(0)$, where $x^{*}(0)=\frac{a-c}{2b}$ denotes first-period output when emission fees are absent, and yields

$$GP=\frac{d\beta\delta\left[(a-c)d\beta-2b(a-c-d)\right]}{2(b^{3}-b\delta d^{2}\beta^{2})}.$$

Following our above analysis of first-period output, $GP=0$ when no share of first-period pollution persists into the second-period, $\beta=0$. A similar argument applies when firms assign no weight to future payoffs, $\delta=0$, which also yields $GP=0$. This can be the case, for instance, of firms expecting to exit the industry.

More generally, $GP>0$ for all $\beta>\overline{\beta}$, while $GP\leq0$ otherwise. Condition $\beta>\overline{\beta}$, however, is incompatible with a positive second-period output. In this setting, the monopolist anticipates a stringent fee during the second-period game, which forces the firm to shut down in the second period. As a consequence, second-period profits are nil, and the monopolist's optimal first-period output remains at the standard monopoly market without taxes. Hence, when $\beta>\overline{\beta}$, first-period output satisfies $x^{*}(t^{*})=x^{*}(0)$ which yields $GP=0$.[8] In contrast, when $\beta<\overline{\beta}$ the firm reduces

[7] To see this point, first note that second-period output $q(t)=\frac{a-(c+t)}{2b}$ is positive as long as the emission fee satisfies $t^{*}<a-c$. Evaluating fee $t^{*}=2d\left(1+\beta x\right)-(a-c)$ at the above output $x^{*}\left(t^{*}\right)$, condition $t^{*}<a-c$ yields $\beta<\overline{\beta}\equiv\frac{2(a-c-d)b}{(a-c)d}$. In addition, first-period output is positive if $\beta<\widehat{\beta}\equiv\frac{b(a-c)}{2d\delta(a-c-d)}$. However, cutoff $\widehat{\beta}$ satisfies $\widehat{\beta}>\overline{\beta}$ for admissible parameter values, implying that condition $\beta<\overline{\beta}$ is sufficient for both first- and secon-period output to be positive.

[8] In other words, the firm anticipates a stringent fee during the second-period game even if it were to produce

its first-period output as a response to future taxes, i.e., $GP < 0$. In this context, future taxes are lax, and can become more moderate if the firm cuts its current production, thus increasing future profits. Interestingly, the announcement per se, and the strategic effects that the future tax triggers, reduces first-period output and pollution when firms are not yet subject to the tax.

3.2 Oligopoly

Following a symmetric approach as in the previous section, the green paradox in an oligopoly market with $N \geq 2$ firms, $GP \equiv x^*(t^*) - x^*(0)$, becomes[9]

$$GP(N) = \frac{b\left[(a-c)b - 2d\beta\delta(a-c-d)\right]}{b^2(1+N) - 2d^2\beta^2\delta} - \frac{a-c}{(1+N)b}.$$

where $x^*(0) = \frac{a-c}{(1+N)b}$ denotes first-period output without second-period taxes. In this context, $GP(N)$ becomes nil when: (1) $\beta = 0$; or (2) $\delta = 0$; or (3) $\beta = \overline{\beta}(N)$, where $\overline{\beta}(N) \equiv \frac{(1+N)(a-c-d)b}{(a-c)d}$.[10] Therefore, our results confirm that $GP(N) < 0$ emerges in equilibrium when $0 < \beta < \overline{\beta}(N)$; whereas $GP(N) = 0$ holds otherwise. However, $GP(N) > 0$ cannot be sustained in equilibrium under any parameter combinations; as in our analysis of monopoly markets.

Differentiating $GP(N)$ with respect to N, we obtain

$$\frac{\partial GP(N)}{\partial N} = -b\left(b\frac{b\left[(a-c)b - 2d\beta\delta(a-c-d)\right]}{\left[b^2(1+N) - 2d^2\beta^2\delta\right]^2} - \frac{a-c}{\left[(1+N)b\right]^2}\right)$$

which is weakly positive given that $GP(N) \leq 0$. Therefore, $GP(N)$, despite being negative under all parameter values, increases in N (i.e., becomes closer to zero). This result indicates that, while the announcement of a future tax decreases first-period output, such a decrease is more severe for a monopolist, who fully internalizes the tax-saving effect of reducing its first-period production, than for a firm competing in an oligopoly, which free-rides its rivals' reduction in first-period output. Indeed, if firm j reduces its own output x_j^*, the pollution that reaches the second period decreases, and thus emission fees also decrease, benefiting all firms in the second-period game. We should therefore observe that firms, after the announcement of a future emission fee, respond by reducing their current pollution more intensively when operating in highly concentrated markets, where they can appropriate most of the tax-saving benefits, than in competitive industries. Indeed, the limit of $GP(N)$ when $N \to \infty$ is zero, indicating that firms do not alter their production behavior after the announcement of future emission fees, i.e., free-riding incentives are extreme.

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a small amount of output in the first period. Therefore, the monopolist shifts its output decision towards the first period.

[9] We first obtain the second-period profit-maximizing output $q_i(t) = \frac{a-(c+t)}{(1+N)b}$, the optimal fee set by the regulator $t^* = d(1+N)(1+x\beta) - (a-c)N$, and the resulting first-period profit-maximizing output $x_i^* = \frac{b(a-c)-2d(a-c-d)\beta\delta}{b^2(1+N)-2d^2\beta^2\delta}$.

[10] In the case of a monopoly market, $N = 1$, cutoff $\overline{\beta}(N)$ becomes $\frac{2(a-c-d)b}{(a-c)d}$, thus coinciding with the cutoff we found in Section 3.

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