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Public Disclosure Programs vs. Traditional Approaches for Environmental Regulation: Green Goodwill and the Policies of the Firm

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Department of Economics

Public Disclosure Programs vs. Traditional Approaches for Environmental Regulation: Green Goodwill and the Policies of the Firm

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Abstract

A Public Disclosure Program (PDP) is compared to a traditional environmental regulation (exemplified by a tax/subsidy) in a simple dynamic framework. A PDP aims at revealing the environmental record of firms to the public. This information affects its image (goodwill or brand equity), and ultimately its profit. In our model, this impact is endogenous, i.e., a firm polluting less than its prescribed target would win consumer's sympathy and raises its goodwill, whereas it is the other way around when the firm exceeds its emissions quota. The evolution of this goodwill is assumed to depend also on *green* activities or advertising expenditures. Within this framework, we analyse how a PDP affects the firm's optimal policies regarding emissions, pricing and advertising as compared to a traditional regulation. We show that advertising acts as a complementary device to pricing and that emissions are increasing in goodwill. We also conclude that the effects of a PDP are more pronounced than those of traditional instruments for firms with a high goodwill. Moreover, we study under which conditions a PDP may be profit improving and we connect this issue to the possibility that a PDP can induce firms to overcomply with the standard. The numerical value of the emission target is rather innocuous in a market-based setting but it turns to be a crucial variable in the presence of a PDP. The theoretical results are complemented with a numerical illustration.

Keywords: Market-based Environmental Regulation; Public Disclosure Program; Pricing; Advertising; Goodwill; Optimal Control.

1 Introduction

As noted in Tietenberg (1998), the first phase of pollution control involved mainly legal remedies such as prohibitions or emissions standards. The second wave mainly involved market-based instruments such as emission charges, subsidies or tradeable permits, which have substituted, or more commonly complemented, legal remedies to control pollution. A more recent trend in environmental regulation involves disclosing firms' environmental information to the public. This paper studies the effects of information disclosure strategies as an approach to environmental policy by comparison with traditional instruments. By *traditional instruments* we mean command-and-control policies and, specially, market-based instruments.

Typically, economists recognize that market-based instruments have some economic advantages over purely regulatory actions, such as being more cost-effective and providing more incentives for innovation, and have helped to overcome some of the limitations of the regulatory approaches. Nevertheless, market-based approaches have not fully solved the problems either since the regulatory systems remain overburdened by the sheer number of substances to be controlled and the burden of designing, implementing, monitoring and enforcing an effective pollution control system (Tietenberg 1998, pp. 587-588).

Monitoring is the process of verifying if the firm complies with environmental rules, whereas enforcement is the undertaking of punitive actions to push the firm to improve its environmental performance (Foulon et al. (2002)). Monitoring and enforcement are crucial for traditional environmental policies to work properly as it has been shown in the recent literature. As for theoretical references, Harford and Harrington (1991), Harrington (1988), and Heyes (1996) show that optimal fines need not be maximal, which diverges from the well-known result in Becker (1968). On the empirical side, Magat and Viscusi (1990), and Laplante and Rilstone (1996) show that inspections significantly reduce absolute levels of water pollution emitted by pulp and paper plants in the United States and Canada. Gray and Deily (1996) state that an increase in enforcement actions in the US steel industry reduces noncompliance in air pollution. Nadeau (1997) obtains that monitoring and enforcement actions diminish the duration of noncompliance, and Helland (1998), that inspections encourage self-reporting. Kleit et al. (1998) predict that the penalty depends essentially on the gravity of the violation and on the firm's previous record of environmental violations. Dion et al. (1998) show that regulators appear to monitor larger plants for visibility of their actions, but avoid enforcing them for electoral reasons. Dasgupta et al. (2001) demonstrate that at the plant level, the variation in frequency of inspections of industrial air- and water-pollution in China is a better determinant of the firms' environmental performance than is the variation in pollution levies. Stafford (2002) shows that a rise in the maximum penalty reduces violations for waste pollutants. More recently, Shimshack and Ward (2005) find that a fine produces a decrease of about two-thirds in violation rates and that the majority of this impact can be attributed to reputation enhancement by the regulator. For a survey, see Cohen (1998).

It has been pointed out that traditional instruments might be socially expensive and their results, in practice, are often obstructed by affected firms. According to EPA[1] ex-Administrator William Reilly, for instance, four out of every five decisions made by EPA are contested in court (see Heyes (2000)). Further, it is recognized in the literature on environmental economics, that firms do not always fully comply with the imposed regulation. For instance, Harford (1978), states that "In the case of both air and water pollution standards, it has been the case that these standards have not always been complied with." In the United Kingdom, for example, "published compliance rates with many key water quality standards are significantly below 100%, sometimes as low as 50%, and the true compliance rates are likely to be even lower" (Heyes (2000)).

Among the main difficulties for designing legal and market-based environmental policy instruments are the requirements of information collection, aggregation and dissemination. As a natural result, a subsequent stage in the evolution of pollution control involves improving information provision. In such a context, information on firms' environmental records has recently been seen as a supplement or an alternative to traditional regulation (Konar and Cohen (1997)). This objective has been put into practice by means of so-called *Public Disclosure Programs* (PDP), which basically consist in planned information strategies used by the regulator to reveal the environmental performance of firms. The rationale behind this strategy is that by making the information public, the polluters will be pushed to reduce their emissions to avoid being punished by consumers and capital markets. This idea, which assumes implicitly that consumers may prefer greener products and firms, has been put forward in the literature under different names and in different contexts. For Porter (1991), it might pay to be green. For Kriström and Lundgren (2003), green goodwill can explain why firms voluntarily reduce their emissions. It is also related to the increasing importance of Eco-labels (see Mason (2006) for a theoretical analyses or Blend and Ravenswaay (1999) for an application).

There is a recent growing literature addressing the economic and environmental effects of PDPs from an empirical point of view. The main focus of this strand of literature is on the reaction of capital markets to the release of environmental information. Konar and Cohen (1997) obtain, for instance, that firms with the largest decline in stock price when the information is made public reduce their emissions more than

[1] U.S. Environmental Protection Agency.

their industry peers. Badrinath and Bolster (1996) find that, on average, there is a loss in value of about \$14.3 million during the week of the settlement. Hamilton (1995) reports that the stock value decreases on average by \$4.1 million on the day that the list of polluters is released. Lanoie et al. (1998) obtain a different result. Indeed, their analysis suggests that appearing on the British Columbia polluters' list has no impact on a firm's equity value. On the other hand, Klassen and McLaughlin (1996) find that market valuation increases on average by \$80.5 million following the announcement of an environmental award. Similarly, Lundgren (2003) argues that "........by lowering the environmental risk via investments in abatement capital, the company lowers its systematic risk (market risk), and as a consequence its total risk. This tends to, *ceteris paribus*, increase the current stock price." Foulon et al. (2002) state that such programs do indeed create additional and strong incentives for pollution control, and improve the environmental performance of polluters.

On the contrary, there are virtually no papers addressing PDPs from a theoretical point of view[2]. The objective of this paper is to fill this gap by providing a simple theoretical framework to study the impact of a PDP on the optimal policies of the firm as compared to traditional instruments. Our aim is to sort out the mechanisms by which a PDP determines the optimal response of the firms and its economic and environmental consequences. We do so by connecting environmental policy modelling to the literature on firms' goodwill accumulation. The point of view taken here is that the information on the environmental behavior of the firm affects its image (goodwill), and ultimately, its profit. In our model, this impact is endogenous, i.e., a firm polluting less than its prescribed target would win consumer sympathy and raise its goodwill, whereas it is the other way around when the firm exceeds its emissions quota. The evolution of this goodwill is assumed to also depend, as in standard models in this area, on advertising expenditures. In this framework, the latter can be seen as any *green* activity or any communication effort conducted by the firm to enhance its environmental image. The concept of goodwill (or brand equity) is inherently dynamic and so is our model. We view the firm's goodwill as a stock (i.e., capital or state variable) fuelled by two flows; one environmental (by means of the PDP) and the other, the communication effort emanating from the firm (advertising). By using a dynamic approach we capture, first, the fact that it takes time for consumers to get aware of the environmental behaviour firms and, second, that firms make their decisions about their economic and environmental performance considering not only the immediate effects on profit, but also the impact on future conditions.

Although our main focus is on the effect of a PDP, by considering also a traditional regulation in

[2] A couple of exceptions are Kenney et al. (1994), that identifies a market failure in the provision of information about polluting consumer products, and Cohen and Santhakumar (2007), that presents a bargaining model between a polluter and a victim. In both cases the approach is static and very different in nature to one followed in this paper.

the form of a tax/subsidy program, we are able to look at the effects of each type of regulation with and without the other. Our main contributions lay in the simultaneous consideration of both types of regulation within a single dynamic framework, the endogenous determination of the impact of an emission standard on a firm's policies, and more importantly, the consideration of a link between the goodwill of the firm, its environmental record and its profit. Within this framework, we analyse how a PDP affects the firm's optimal policies regarding emissions, pricing and advertising as compared to a market-based environmental regulation and the *laissez-faire* situation (i.e., in the absence of regulation). We also study under which conditions a PDP may be profit improving. Finally, we connect this issue to the possibility that a PDP can result in overcompliance (i.e., a situation in which firm decided to pollute even less than stated by the standard).

The model is set up in Section 2 and the firm's optimal policy is derived in Section 3. We show that the optimal pricing and advertising policies turn out to be increasing in the goodwill, which implies that advertising acts as a complementary device to pricing. Moreover, and perhaps more surprisingly, emissions are also increasing in goodwill, since a firm that enjoys a high goodwill can afford to pollute more without suffering too much in terms of lost demand. We conclude that goodwill turns out to be a key driving force for the firms policy and its reaction to environmental regulation. We also identify the long run solution and the factors that determine its stability. We conclude that market-based instruments do not matter for stability, but a PDP may help to render the steady state stable.

In Section 4, we compare the impact of the two types of regulation on the environmental performance of the firm. It is immediate to conclude that any environmental policy will increase price, reduce output, and therefore pollution, to some extent, and combining two different policy instruments will always result in a stronger effect than implementing only one of them. Nevertheless, the results are not so clear-cut when a market-based instrument is compared to a PDP. Indeed, we come up with the conclusions that the effects of disclosure strategies are more pronounced than those of traditional instruments for well-established brands (i.e., those with a high goodwill). In our setting, it also turns out that those policies which are more effective to control pollution are also more detrimental for consumers surplus and, therefore, there is a conflict between environmental improvement and economic welfare. Concerning advertising, we conclude, first, that implementing a traditional environmental policy (either a PDP exists or not) always leads to less advertising; second, if the emission standard is *tight enough*, firms will advertise more under a market-based than under a disclosure regulation and, third, a PDP renders the advertising policy of the firm less sensitive to the value of goodwill. As for the long run solution, the steady state value achieved under a dual regulatory regime is lower than under a traditional (market-based) one, which in turn is lower than under a *laissez-faire* policy but, if a PDP exists, including a market-based regulation decreases goodwill if and only if the PDP is *soft enough*. On the other hand, if the standard is mild enough firms will tend to accumulate higher levels of goodwill under a PDP than under a traditional regulation. An interesting issue to note is that a standard or target level for emissions plays a totally different role under a market-based regulation and under a PDP approach. In the former case, the standard implies just a fixed effect on profits and, therefore, does not affect the firm behaviour. Conversely, in the latter case, the standard crucially affects the dynamics of goodwill and the optimal response of the firm.

In Section 5 we investigate the possibility that environmental regulation increases firms' profit and the existence of overcompliance. As a matter of fact, we show that there is a strong connection between these two issues: indeed, making environmental policy (either information or market-based) marginally more intense is profit improving if and only if, it is optimal for the firm to overcomply with the emission standard for a long enough period. We also conclude that the profit effect of a PDP and the firm's goodwill is an inverted U-shaped function or, in other words, that a PDP cannot be profit-improving for very low values or for very high values of goodwill.

In order to get some additional insights we provide a numerical illustration in Section 6. In our example, the short run ranking of prices induced by different policies gets reversed in the long run due to the dynamic impact of goodwill accumulation. This serves to illustrate how the dynamic nature of firms decisions regarding goodwill accumulation can be a fundamental issue for the design of environmental policy. We also conclude that tightening either environmental instrument always leads to a lower steady-state goodwill and the effects of a PDP are typically more intense than those of a traditional policy. Finally, in Section 7, some concluding remarks are made.

2 The Model

We assume that a firm operates under monopoly or monopolistic competition. By doing so, we abstract from strategic interaction and focus just on the direct effects of environmental policy on the behaviour of the firm. The firm produces a good at a constant unit cost c. Each instant of time $t \in [0, \infty)$, the firm faces demand $q(t)$. We assume that demand depends negatively on price, $p(t)$, and positively on the goodwill (or brand equity) of the firm, denoted as $G(t)$, according to the standard linear demand specification:

$$q(G, p) = a + G(t) - p(t), \tag{1}$$

which assumes that the product's market potential, i.e., the demand when the price tends towards zero, is given by a constant $a > 0$, which corresponds to an "average" or "normal" market potential, plus the goodwill $G(t)$. In principle, the sign of the latter is not restricted and it depends on the firm's environmental record and on its advertising policy. For simplicity, we will focus on situations with positive goodwill.

Denote by $e(t)$ the (flow of) pollutant emissions that are an inevitable by-product of production. We suppose a simple proportional relationship between emissions and production, i.e., $e(t) = \alpha q(t)$, with $0 < \alpha < 1$. We introduce also a reference level for emissions, $\bar{e}$, which can be interpreted as a standard, i.e., an objective level considered as acceptable by the regulator or a commitment resulting from some signed agreement[3]. To fix ideas, we will refer to this level as a standard.

In order to compare market-based and disclosure strategies for pollution control, we introduce both of such policy instruments, in the simplest possible way. Concerning the market-based instrument, suppose that the regulator taxes (subsidizes), at a given rate $\tau \geq 0$, each unit of emissions above (below) the target or the standard assigned to the firm. Then, the quantity $\tau\left(e(t) - \bar{e}\right)$ represents a revenue for the firm if it pollutes below the standard (i.e., $e(t) < \bar{e}$), or a cost, otherwise. For simplicity, we assume equal tax and subsidy rates, although this need not to be the case in reality[4]. Note that this simple setting can also be interpreted as a tradeable pollution permits system (which is another important market-based instrument). Indeed, $\bar{e}$ can be defined as the number of emissions permits allocated to the firm by the regulator, and τ as the price of a permit in the competitive market. Thus, the quantity $\tau\left(e(t) - \bar{e}\right)$ would represent the revenue the firm can obtain from selling unused permits in this market (if $e(t) < \bar{e}$), or the cost of buying permits if it is the other way around. Finally, if τ is interpreted as a fine instead of a tax, this instrument resembles a command-and-control strategy in the form of a traditional standard on emissions.

The second environmental policy instrument is a PDP. We model this instrument by resorting to the dynamic approach introduced by Nerlove and Arrow (1962) for advertising. Starting from this seminal paper, there is an extensive literature dealing with advertising and goodwill. See the surveys by Feichtinger *et al.* (1994) for optimal control models and Jørgensen and Zaccour (2004) for the competitive setting. Here we assume that the amount of pollution is revealed to the public, who cares about the level of compliance $\bar{e} - e(t)$. As a consequence, the firm's goodwill increases (or decreases, if $\bar{e} < e(t)$) by the amount $\varphi\left(\bar{e} - e(t)\right)$, where $\varphi \geq 0$ is a parameter measuring the sensitivity of goodwill with respect to

[3] We do not address the question of how the standard is determined. A traditional way of doing so is to assume that the regulator chooses the standard that corresponds to the socially optimal output. Below we provide some insights about what are the consequences of changing this value.

[4] Considering the case with different tax and subsidy rates is computationally more complex because it introduces a nonconvexity and provides little additional insight. Moreover, this simple setting allows also an interpretation in terms of tradeable pollution permits.

the environmental record of the firm. This parameter can also be interpreted as a policy parameter measuring the intensity of the disclosure program. Specifically, if no PDP is implemented, we have $\varphi = 0$, meaning that the environmental information is not revealed or, alternatively, it does not have any impact on consumers' preferences. The value of φ represents the extent to which information is transmitted to the consumers and reflected by their purchase decisions.

Following the Nerlove and Arrow approach, we assume that the firm can increase its goodwill by doing some advertising effort, denoted as $A(t)$. In this framework, $A(t)$ can be interpreted, not only as advertising itself, but more broadly as any "green activity", i.e., any action that serves to improve the firm's environmental image. The interpretation of the advertising message can be different depending on the sign of the term $(\bar{e} - e(t))$. If it is positive, then the message would put forward the idea that the firm is environmentally responsible and is *a good citizen*. Conversely, if $\bar{e} < e(t)$, the firm would probably be perceived by society as a polluter. Therefore, the advertising message would attempt to provide an explanation about why it is so difficult to meet the target. We assume that one unit of advertising or green activities results in a marginal increase of goodwill equal to $\theta A(t)$, where θ is a positive parameter measuring advertising efficiency.

The evolution of the goodwill of the firm is governed by the following differential equation:

$$\dot{G}(t) = \theta A(t) + \varphi\left(\bar{e} - e(t)\right) - \delta G(t),\ G(0) = G_o > 0, \tag{2}$$

where δ is the decay rate and represents the speed at which goodwill depreciates if no advertising is made. The initial value of goodwill, G_o, is assumed to be given and positive. The above specification extends the standard Nerlove and Arrow (1962) dynamics by adding the term $\varphi\left(\bar{e} - e(t)\right)$, which is intended to capture the impact of the regulator's public disclosure program on the firm's goodwill. Thus, we consider that the evolution of the firm's goodwill depends not only on the firm's advertising effort, but also on its emissions behavior. If the firm exceeds (meets) the target set by the regulator, then it loses (attracts) consumers who are sensitive to environmental issues. When the firm meets its target, then its goodwill increases and so does, *ceteris paribus*, its market potential. If the firm does not reach its target ($\bar{e} < e(t)$), then its goodwill suffers. If the latter effect is higher (in absolute value) than the positive impact of advertising, then the goodwill decreases and so does the firm's market potential.

For simplicity, the advertising cost $C(A)$ is assumed to be quadratic, i.e., $C(A) = \frac{A^2}{2}$[5]. Assuming a profit maximizing behavior, and denoting by r the discount rate, the objective functional of the firm then

[5] Such an assumption is made frequently in dynamic models of advertising (see, e.g., Jørgensen and Zaccour (2004)).

reads as follows,

$$\max_{p,A} \pi = \int_0^\infty \exp\left(-rt\right) \left\{ \left(p(t) - c - \tau\alpha\right) \left(a + G(t) - p(t)\right) - \frac{1}{2} A^2(t) + \tau\bar{e} \right\} dt. \tag{3}$$

By (2)-(3) we have defined an infinite-horizon optimal control problem with one state variable ($G(t)$) and two controls ($p(t) \geq 0, A(t) \geq 0$). In the sequel, we will eliminate the time argument when no confusion may arise.

3 The Optimal Policy of the Firm

Using dynamic programming, we find the closed-loop solution of the firm's problem. We denote by $y\left(G; \varphi, \tau\right)$ the optimal value of decision variable y ($y = p$, A, e) for given values of the goodwill and the environmental policy parameters φ and τ. Similarly $V\left(G; \varphi, \tau\right)$ denotes the value function. For simplicity, we focus on interior solutions. For notation convenience, we define the following auxiliary coefficients:

$$m \equiv a - c - \alpha\tau \tag{4}$$

$$v \equiv r + 2\delta + \alpha\varphi \tag{5}$$

$$x \equiv 2\theta^2 + \alpha^2\varphi^2 \tag{6}$$

and, for technical reasons, we make the following **assumptions**:

1.- $m > 0$, which ensures that the firm produces a positive quantity when its goodwill is zero.

2.- $v^2 > x$, to ensure the existence of a real solution.

Under these assumptions, the following proposition characterizes the optimal policy of the firm for an interior solution.

Proposition 1 *In an interior solution, the optimal pricing and advertising policies of the firm and the value function are given by*

$$p\left(G; \varphi, \tau\right) = \frac{a + c + \tau\alpha + G\left(\varphi\alpha k_1 + 1\right) + \varphi\alpha k_2}{2}, \tag{7}$$

$$A\left(G; \varphi, \tau\right) = \theta\left(k_1 G + k_2\right), \tag{8}$$

$$V\left(G; \varphi, \tau\right) = \frac{1}{2} k_1 G^2 + k_2 G + k_3, \tag{9}$$

where

$$
\begin{aligned}
k_1 &\equiv \frac{v-\sqrt{v^2-x}}{x} > 0, && (10)\\
k_2 &\equiv \frac{m\left(1-\alpha\varphi k_1\right)+2\varphi k_1\bar{e}}{r+\sqrt{v^2-x}} > 0, && (11)\\
k_3 &\equiv \frac{1}{4r}\left(k_2^2 x+2\varphi k_2\left(2\bar{e}-\alpha m\right)+4\bar{e}\tau+m^2\right) && (12)
\end{aligned}
$$

Proof. See Appendix. ■

Since k_1, $k_2 > 0$, it is immediate to conclude that the solution is interior (i.e., $p > 0$, $A > 0$) if $G > 0$. Below we identify conditions under which this is always the case.

Proposition 1 shows that, as a consequence of the linear-quadratic structure of the problem, the optimal pricing and advertising policies turn out to be both linear in the goodwill. Recalling that the advertising cost is $C(A) = \frac{A^2}{2}$, (8) states that the level of advertising is chosen so that the marginal cost is equal to the marginal revenue, i.e., the marginal impact on goodwill times the marginal impact of goodwill on the value function. Further, the pricing and advertising policies are increasing in G. Indeed, for an interior solution, $\frac{\partial p}{\partial G}$ and $\frac{\partial A}{\partial G}$ are clearly positive. These results appear to be consistent with observed reality, since well-established brands, in terms of quality, consumer perception, etc., typically command a higher price, and are usually heavily advertised, precisely to reinforce the brand positioning. In that sense, advertising acts as a complementary device to pricing. Indeed, it renders consumers less sensitive to price, or to put it differently, it increases their willingness-to-pay. The pricing result is consistent with the one in Kriström and Lundgren (2003) who argue that "If consumers prefer to buy products from a greener firm, then the cost of being environmentally friendly may be justified by higher revenues."

Using (7), we get the following optimal value for emissions:

$$
\begin{aligned}
e\left(G;\varphi,\tau\right) &= \alpha q\left(G;\varphi,\tau\right)=\alpha\left(a+G-p\left(G;\varphi,\tau\right)\right), && (13)\\
&= \alpha\left(\frac{m+G\left(1-\varphi\alpha k_1\right)-\varphi\alpha k_2}{2}\right).
\end{aligned}
$$

It is shown in the proof of Proposition 1 that $1-\varphi\alpha k_1 > 0$, and therefore, that emissions are increasing in goodwill which, at first sight, may seem counterintuitive. The interpretation is that a firm that enjoys a high goodwill can afford to pollute more without suffering too much in terms of lost demand. Nevertheless, there is also the reverse causal effect with opposite sign: more emissions result in less goodwill, which prevents goodwill and emissions from increasing indefinitely. Actually, here we have an interesting circular relationship between goodwill, price and demand (and hence emissions). Increasing the price, *ceteris paribus*, reduces demand, which results in lower emissions. This leads to higher goodwill, which shifts output upward, thanks to the demand by consumers having a preference for green products, and this in turn leads to higher emissions, which softens the initial effect.

By substitution in Proposition 1, it is immediate to obtain, as particular cases, the results when any of the environmental policy instrument is no used. In the sequel, $y^T \equiv y\,(G; 0, \tau)$ will denote the optimal value of variable y when only a traditional (market-based) policy, and not a PDP is implemented ($\varphi = 0$). Similarly, $y^{PDP} \equiv y\,(G; \varphi, 0)$ refers to the situation in which only a PDP and not a market-based policy is implemented ($\tau = 0$). Finally, $y^{LF} \equiv y\,(G; 0, 0)$ corresponds to the *laissez-faire* situation ($\varphi = \tau = 0$). For the case where both instruments are used at the same time, we will use the superscript ^{GC}, which stands for "general case". In section 4 the different policy regimes are compared.

Since all the variables can be written as a function of goodwill, by substitution in (2) the system collapses to a unidimensional differential equation in G. Therefore, the dynamic behaviour of the whole model can be studied by focusing on this equation. We start by computing the steady state and checking its stability.

Proposition 2 *The steady state goodwill is given by*

$$G_{ss}\,(\varphi, \tau) = \frac{xk_2 - \varphi\,(\alpha m - 2\bar{e})}{-r + \sqrt{v^2 - x}} \tag{14}$$

and is globally asymptotically stable if and only if

$$2\delta(r + \delta + \alpha\varphi) + r\alpha\varphi > \theta^2 \tag{15}$$

Proof. See Appendix. ■

Global asymptotic stability means that the solution trajectory will converge to its steady-state value for any initial condition. The condition derived in the above proposition identifies the factors that determine the possibility to get a stable solution: the higher is the discount rate (r), the decay rate (δ), and the factor of emissions per unit of production (α), and the lower is the efficiency of advertising (θ), then the easier is the realization of the global asymptotical stability. Concerning the environmental policy variables, note that the stability condition does not depend on the market-based instrument (as represented by τ) but it does depend on the intensity of the disclosure strategy (as measured by φ). The reason for this result is that the market-based instrument does not have a direct impact on goodwill accumulation, which is the key dynamic mechanism of the model. On the other hand, the PDP is designed precisely to determine the dynamics of goodwill. A side-effect of this measure is that it contributes to stability. Therefore, the most unfavourable case for stability is that without a PDP ($\varphi = 0$). In this case, the stability condition collapses to:

$$2\delta(\delta + r) > \theta^2.$$

In the sequel, we will assume that this condition holds, in order to ensure stability in all the cases. Then, the optimal goodwill trajectory is given by

$$G^* = (G_o - G_{ss})\, e^{\lambda t} + G_{ss},$$

where

$$\lambda = \frac{1}{2}\left(xk_1 - 2\delta - \alpha\varphi\right) = \frac{1}{2}\left(r - \sqrt{v^2 - x}\right) < 0.$$

Therefore, if the stability condition holds, the goodwill converges asymptotically to its steady state value. By substitution in (7), (8) and (13), it is also possible to obtain the steady state and the optimal trajectories for p, A and e. Since all three variables are increasing in G, if $G_o > G_{ss}$ convergence of G, p, A and e to the steady state is from above and it is from below if $G_o < G_{ss}$.

Note that, under the global asymptotic stability condition, the denominator of G_{ss} is strictly positive. Thus, the steady state has the same sign as its numerator, i.e.,

$$G_{ss} \geq 0 \Leftrightarrow xk_2 \geq \varphi\left(\alpha m - 2\bar{e}\right). \tag{16}$$

Condition (16), together with $G_0 > 0$, ensures that, in a stable solution, G is always positive and this fact, together with (7), (8), (10), (11) ensure that the solution is always interior.

It is immediate to check that (16) trivially holds if $\varphi = 0$. Therefore, in the absence of a PDP, the globally asymptotic steady-state goodwill is always positive. The reason for this result is the following: if there is not a PDP, the firm's advertising effort is pure addition to goodwill, and hence, to market potential. In the general case, part of this advertising is done to (possibly) offset the negative environmental record. This is especially the case when the standard is "too" restrictive, and therefore, very costly to meet.

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4 Comparing policy regimes

The general framework we have constructed so far allows us to consider market-based and/or disclosure approaches for environmental policies. An interesting feature of this approach is the possibility to compare the consequences of different policy options. Specifically, there are four relevant policy regimes to be considered: the most general scenario with both policy instruments, only the traditional policy (i.e., $\varphi = 0$), only the PDP (i.e., $\tau = 0$), and no policy instrument at all ($\varphi = \tau = 0$), or *laissez-faire* situation.

One first interesting issue to be noted here is the role of the standard $\bar{e}$. Consider first the traditional situation ($\varphi = 0$). In this case, the state equation (2) does not depend on $\bar{e}$ and, therefore, the only effect of the standard on the solution is through the term $\tau\bar{e}$, which appears as a constant in the objective functional (3). As a consequence, the policy of the firm (i.e., the optimal value of variables p, A, e) does not depend on $\bar{e}$ at all. The only role of the standard is, then, to increase or decrease the value function through coefficient k_3.

The situation is totally different when a PDP is implemented ($\varphi > 0$). In this case, the value of the standard enters directly the dynamic goodwill mechanism and it turns out to be a key variable to determine the behaviour of the firm. Actually, it enters the optimal value of p, A and e through coefficient k_2. Specifically, an increment in $\bar{e}$ increases the value of k_2, which, in turn, increases p and A. Interestingly, the increment of p reduces q and, hence, e (note in (13) that e depends negatively on k_2 and, hence, on $\bar{e}$). Therefore, increasing the value of the standard results in a short-term reduction of emissions. Nevertheless, this is a very short-term effect, because the increment of $\bar{e}$ fuels the goodwill accumulation (and this effect is reinforced by the induced increment of advertising and the short-term reduction of emissions). The higher value of goodwill induces an indirect increment of emissions in the long run. In our numerical simulations we always obtain that the second effect quickly overpowers the first one.

We now compare the effects of different regimes on the price policies of the firm, as well as the environmental effects, measured by the level of emissions (which, under our specification, is equivalent to studying the behaviour of q).

Proposition 3 *Consider a market-based environmental policy associated with a value of τ and a PDP associated with a given value of φ. Then, for any given value of goodwill G, the following results hold:*
i) Implementing both policy instruments at the same time increments the price and reduce emissions more

than implementing any single instrument, i.e.,

$$p^{GC} > p^{T} \qquad e^{GC} < e^{T}$$
$$p^{GC} > p^{PDP} \qquad e^{GC} < e^{PDP}$$

ii) In turn, implementing any single instrument increases the price and reduces emissions with respect to the laissez-faire situation, i.e.,

$$p^{T} > p^{LF} \qquad e^{T} < e^{LF}$$
$$p^{PDP} > p^{LF} \qquad e^{PDP} < e^{LF}$$

Moreover, there is a threshold value of goodwill, $\tilde{G} \equiv \frac{1}{k_1}\left(\frac{\tau}{\varphi} - k_2^{PDP}\right)$, *where* k_2^{PDP} *is the value of* k_2 *with* $\tau = 0$, *such that*

$$p^{T} \leq p^{PDP},\ e^{T} \geq e^{PDP} \Leftrightarrow G \geq \tilde{G}$$

Proof. See Appendix. ■

Given the negative linear relationship between price and quantity, and the positive linear relationship between quantity and emissions, the behaviour of these variables is necessarily linked. As for the environment, the two first parts of the proposition are not very surprising: any environmental policy will reduce output, and therefore pollution, to some extent, and combining two different policy instruments will always result in a stronger effect than implementing only one of them. The third part is less obvious and it states that pollution is more sensitive to disclosure strategies than to traditional instruments if goodwill is high enough. The policy implication of this result is that firms with well-established brands (i.e., with a high goodwill) would probably prefer a traditional regulation (which they can actually afford thanks to their high price, or equivalently to a high consumer willingness-to-pay), because a disclosure mechanism may hurt their prestige. The threshold that determines which policy option is more effective for cutting down emissions depends directly on τ and φ in an obvious way but it also depends on all model parameters (through k_1 and k_2^{PDP}). An alternative way to write this condition is $\varphi\left(k_1 G + k_2^{PDP}\right) > \tau$, which states that a PDP will be more effective if the marginal impact of information disclosure is higher than the marginal tax/subsidy rate.

Just the opposite results hold for price: a dual regulation leads to a higher price to consumer than does any individual regulation, which in turn induces a higher price than does the *laissez-faire* scenario. A simple explanation is that, to some extent, the firm is shifting to the consumer the cost increase that results from regulation. The comparison between the market-based instrument and the PDP also hinges on the value of goodwill. Since consumer surplus increases when the solution moves downward the demand curve (i.e, when quantity increases and price decreases), Proposition 3 provides very straightforward results for consumer surplus (CS):

$$CS^{GC} < CS^{T} < CS^{LF},$$
$$CS^{GC} < CS^{PDP} < CS^{LF},$$
$$CS^{T} > CS^{PDP} \Leftrightarrow G \geq \tilde{G}.$$

where $\tilde{G}$ was defined above.

The consumer surplus would be obviously higher under *laissez-faire* policy than under any regulation, and both regulations, if applied simultaneously, would harm surplus more than a single one. On the other hand, when goodwill is *high* the firm will be more sensitive (i.e., the quantity will decrease and the price will increase more) to a disclosure strategy than to a market-based instrument. Therefore, for high values of G, consumer surplus will suffer a larger reduction under a PDP than under a market-based instrument. At first sight, this result may seem somehow paradoxical: disclosing environmental information about well established firms may have a detrimental effect on consumers' welfare. Note however, that CS only provides a measure for consumer welfare from a purely economic point of view. In the presence of pollution (and, hence, externalities), a fully-fledged welfare analysis would require a valuation of the welfare effect of pollution.

The comparative results of the advertising strategies are not so clear-cut. Table 1 presents sufficient conditions for the relevant cases:

Table 1: Comparison of Advertising Strategies

	A^{T}	A^{PDP}	A^{LF}
A^{GC}	$<$ if $\bar{e} < \frac{\alpha(a-c-\alpha\tau)}{2}$	$<$	$<$ if $\bar{e} < \frac{\alpha(a-c-\alpha\tau)}{2}$
A^{T}	$=$	$>$ if $\bar{e} < \frac{\alpha(a-c)}{2} - \frac{\alpha\tau}{2\varphi k_1}$	$<$
A^{PDP}		$=$	$<$ if $\bar{e} < \frac{\alpha(a-c)}{2}$

A first result is that, for a given φ (either positive or zero), implementing a traditional environmental policy always leads to less advertising, i.e.,

$$A^{GC} < A^{PDP},$$
$$A^{T} < A^{LF}.$$

This can be explained as follows: introducing a traditional regulation induces a reduction in emissions, and in turn, a reduction in the deviation with respect to the standard. Consequently, less advertising is needed to achieve the same goodwill. On the other hand, if the standard $\bar{e}$ is low enough, *ceteris paribus*, the firm advertises at a lower level when there is a PDP ($\varphi > 0$) than in the absence of a PDP ($\varphi = 0$). To understand this result, note that, from (8) and (11), it is immediate to conclude that A is increasing in $\bar{e}$ if $\varphi > 0$, while it does not depend on $\bar{e}$ when $\varphi = 0$. The reason for this result is that the only channel through which the standard may influence advertising is by its impact on goodwill. The higher the standard, the easier it is to build up goodwill and, therefore, the more productive (in terms of future profits) it is to do advertising. By a similar argument, we conclude that, if the standard is *tight enough*, firms will advertise more under a market-based than under a disclosure regulation. To shed a light on the interpretation of the thresholds, note that

$$\begin{aligned} \frac{\alpha\left(a-c-\alpha\tau\right)}{2} &= \left. e^{T}\right\rfloor_{G=0} \equiv e\left(0;0,\tau\right), \\ \frac{\alpha\left(a-c\right)}{2} &= \left. e^{LF}\right\rfloor_{G=0} \equiv e\left(0;0,0\right). \end{aligned}$$

Since the building up of goodwill is the key mechanism of this paper, it is also interesting to analyse how a change in the value of goodwill affects the policy of the firm. Specifically, we ask how different policy regimes affect the slope of the advertising policy with respect to goodwill. Proposition 4 shows the remarkable result that, while the order of the advertising strategies depends on the model parameters, their slopes with respect to goodwill do not.

Proposition 4 *The slopes of the advertising strategies in the different scenarios compare as follows:*

$$\frac{\partial A^{GC}}{\partial G} = \frac{\partial A^{PDP}}{\partial G} < \frac{\partial A^{T}}{\partial G} = \frac{\partial A^{LF}}{\partial G}.$$

Proof. See Appendix. ■

This Proposition states that the advertising policy of the firm is less sensitive to the value of goodwill when a PDP is in place and this sensitivity does not depend on the presence of a market-based instrument. The rationale behind these results is the following: the tax/subsidy has an instantaneous impact of profit but do not have any direct effect on the dynamic evolution of the solution. Therefore, including this kind of policy is not relevant to determine how the firm reacts to changes in its brand equity. On the other hand, a PDP goes right to the goodwill accumulation mechanism. Actually, there are two factors that affect the firm's advertising decision: the current situation of its brand equity and the impact of emissions by means of the disclosure strategy. The firm must react to these driving forces taking into account that advertising is costly and, moreover, the marginal cost is increasing. When the second driving force does not exist, the firm can concentrate on reacting to changes in goodwill. Conversely, if a PDP is implemented, the firm must react to both factors at the same time and, advertising costs being convex, the marginal reaction to each of them will be necessarily softer.

We now investigate how the steady state depends on the environmental policy regime. Proposition 5 illustrates how the long run value of goodwill behaves in each case.

Proposition 5 *The steady-state values satisfy*

$$\begin{aligned} G_{ss}^{GC} &< G_{ss}^{T} < G_{ss}^{LF}, \\ G_{ss}^{GC} &< G_{ss}^{PDP} \Leftrightarrow \varphi < \frac{\theta^2}{\alpha\left(r+\delta\right)}. \end{aligned}$$

Moreover, there exists one threshold value of the standard, $\tilde{e}$, such that

$$G_{ss}^{PDP} > G_{ss}^{T} \Leftrightarrow \bar{e} > \tilde{e}.$$

Proof. See Appendix. ■

It turns out that the steady-state value of goodwill achieved under a dual regulatory regime is lower than under a traditional (market-based) one, which in turn is lower than under a *laissez-faire* policy. This seems a natural result since the environmental policy makes it harder to build up goodwill. Nevertheless, the result is not so clear-cut when a tax/subsidy is implemented once a PDP already exists (i.e., when we move from the *PDP* regime to the *GC* regime). Actually, including a market-based regulation decreases goodwill if and only if the PDP is *soft enough* (i.e., φ is low enough). The reason is that, including a tax/subsidy program will result in additional emission reductions and, if goodwill is sensitive enough to the environmental results of the firm (i.e., if φ is high enough) this can result in a long-run improvement of the image of the firm. On the other hand, firms will tend to accumulate higher levels of goodwill under a PDP than under a traditional regulation if and only if the standard is mild enough ($\bar{e} > \tilde{e}$). In order to interpret this conclusion note that, from (14), we conclude that the steady-state value of goodwill does not depend on $\bar{e}$ if a PDP is not implemented whereas it is increasing in $\bar{e}$ if $\varphi > 0$. The reason is, once again, that under a PDP building up goodwill is easier if and only if the standard is mild enough.

5 Environmental policy firm's profits and overcompliance

In this section, we study the effects of environmental regulation on the profit of the firm. Specifically, we ask under which conditions is it possible that environmental policy has a positive, rather than negative effect on profits. We will show that there is a strong connection between the possibility that increasing the intensity of either of the environmental polices has a positive effect on discounted profits and the existence of overcompliance. We define overcompliance as $e < \bar{e}$, i.e., a situation in which the firm decides to cut down its emissions below the standard. Symmetrically, we can define undercompliance as a situation in which the standard is violated: $e > \bar{e}$. Therefore, the value of the standard turns out to be a key to determine the marginal effect of policy instruments on firm's profit. Overcompliance is a phenomenon that has been recently addressed in the literature. For example, Arora and Gangopadhyay (1995) show how, with consumers' preferences for environmental quality and publicly available information, minimum environmental standards are overmet. More recently, Arguedas (2005) explores the possibility that firms and regulators achieve cooperative agreements in environmental regulation, and show that all the policies in the bargaining set induce the firm to exceed the standard. Lundgren (2003) and Kriström and Lundgren (2003) suggest that goodwill accumulation can explain overcompliance. This is also the main mechanism in our paper.

Define the Hamiltonian of the firm's problem as

$$H = \exp(-rt)\left[(p(t) - c - \tau\alpha)(a + G(t) - p(t)) - \frac{1}{2}A^2(t) + \tau\bar{e}\right] + \mu\left[\theta A(t) + \varphi(\bar{e} - e(t)) - \delta G(t)\right]$$

where μ is the costate variable and it is easy to check that, in an interior solution, $\mu > 0$.[6]

Following Caputo (1990), we know that the derivative of the discounted profits with respect to a parameter can be computed by integrating the derivative of the Hamiltonian with respect to that parameter and evaluating the result in the optimal solution. Therefore, we can compute the derivative of the discounted profit with respect to the standard as

$$\frac{\partial \pi}{\partial \bar{e}} = \int_0^\infty \{\exp(-rt)\tau + \mu(t)\varphi\}\, dt = \frac{\tau}{r} + \varphi\int_0^\infty \mu(t)\, dt \geq 0.$$

[6] Actually, comparing the Pontryagin Maximum Principle conditions with the first order conditions associated to the H-J-B equations reveals that μ corresponds to the derivative of the value function, V'.

Softening the standard (i.e., increasing $\bar{e}$) obviously has a nonnegative effect on profits. In the *laissez-faire* situation, since $\tau = \varphi = 0$, this effect is zero because there is no link between emissions and profit. If a market-based instrument is implemented, softening the standard reduces the amount of taxes paid or increases the amount of subsidy received at each moment of time. The discounted value of this effect on total profits, $\frac{\tau}{r}$, is higher the lower is the discount rate (i.e., the more concerned the firm is about the future). On the other hand, if a PDP is in place, softening the standard benefits the firm because it is easier to build up goodwill. Therefore the instantaneous economic value of this change can be calculated as the marginal effect of the standard on profit accumulation (φ) times the shadow price of goodwill, as measured by $\mu(t)$.

In turn, the derivative of discounted profit with respect to the tax/subsidy and the intensity of the disclosure program is given by

$$\begin{aligned} \frac{\partial \pi}{\partial \tau} &= \int_0^\infty \{\exp(-rt)(\bar{e} - e(t))\}\, dt \\ \frac{\partial \pi}{\partial \varphi} &= \int_0^\infty \{\mu(t)(\bar{e} - e(t))\}\, dt \end{aligned}$$

where $e(t)$ is the optimal value of emissions. If the tax/subsidy rate marginally increases, the instantaneous effect of this change is equal to $\bar{e} - e(t)$. If the firm is overcomplying (undercomplying), i.e., $e < \bar{e}$ ($e > \bar{e}$), then its profit will increase (decrease) with τ. Similarly, the effect of a marginal increase in φ is $\mu(\bar{e} - e(t))$, where μ measures the discounted unit value of $(\bar{e} - e(t))$. The final discounted effect on profits of these changes result from the time aggregation of instantaneous effects.

It turns out that, for both of the derivatives displayed above, their values can only be positive if the firm overcomplies (i.e., if $\bar{e} > e(t)$) for, at least, some time. If $\bar{e} > e(t)$ ($\bar{e} < e(t)$) throughout all the planning period, then the overall effect is trivially positive (negative). It is also possible that the firm overcomplies for one period and undercomplies for other period. In this case, the final effect will be positive if and only if the aggregation of the positive period is higher than the negative one. Since we have showed that, in an interior solution, e converges smoothly to its steady state value, this condition can be translated into a condition about the length of the overcompliance period. Therefore, we have proven the following proposition:

Proposition 6 *The discounted profit of the firm depends positively on τ and φ if and only if it is optimal for the firm to overcomply with the emission standard for a long enough period.*

So, in order to determine the marginal effect of policy variables on profits, it is crucial to analyze to what extent the firm decides to overcomply.

In our framework, a first trivial channel by which the firm may be interested in overcomplying is by means of the subsidy. Indeed, if polluting below the standard is subsidized by τ, it is not surprising that it might be profit improving for firms to do so. The second channel is more interesting for our purpose: if a PDP is in place, even if there is no immediate reward for cutting down emissions, firms might accept an instantaneous cost in exchange of improving their environmental image and enjoy higher demand in the future (as suggested by Lundgren (2003) and Kriström and Lundgren (2003)).

Using (13) we can compute $\bar{e} - e(t)$ and check if the firm is over- or undercomplying under any given policy scenario. The result is particularly simple in the traditional case, since the optimal level of emissions do not depend on the value of the standard:

$$\bar{e} - e^T = \bar{e} - \frac{\alpha}{2}(m + G)$$

and we conclude that, in a stable solution, the level of overcompliance is time-increasing (or the level of undercompliance is time-decreasing) if and only if $G_0 > G_{ss}$, i.e., if convergence to the steady state is from above, and the other way around. The steady-state goodwill is also independent of the standard:

$$G_{ss}^T = \frac{xk_2^T}{-r + \sqrt{v^2 - x}} = \frac{2\theta^2 m}{\left(-r + \sqrt{(r+2\delta)^2 - 2\theta^2}\right)\sqrt{(r+2\delta)^2 - 2\theta^2}}$$

The same procedure can be applied to determine the level of overcompliance when a PDP exists, but the results are more complicated since the optimal value of emissions depend on $\bar{e}$.

In order to get some additional information about the effect of a PDP on profits, we compare the situation before and after the introduction of a PDP. Define $D(G)$ as the difference in the value function (or, alternatively, the discounted profits) before and after implementing a PDP, as a function of goodwill, i.e.:

$$D(G) \equiv V^{GC} - V^T \equiv V(G; \varphi, \tau) - V(G; 0, \tau)$$

Proposition 7 *The following results hold:*
(i) $D(G)$ is an inverted U-shaped function with $\lim_{G\to\pm\infty} D(G) = -\infty$.
(ii) If $\left(k_2 - k_2^T\right)^2 \leq 2\left(k_1 - k_1^T\right)\left(k_3 - k_3^T\right)$, where k_1^T, k_2^T and k_3^T are the values of k_1, k_2 and k_3 when $\varphi = 0$, introducing a PDP has a non-positive impact on the value function. Otherwise, there exists two thresholds for goodwill, G_1, G_2 such that $D(G)$ is positive if and only if $G_1 < G < G_2$.

Proof. See Appendix. ■

Proposition 7 states that the relationship between the profit impact of a PDP and the firm's goodwill, as given by $D(G)$, is an inverted U-shaped function. Therefore, the PDP could be beneficial for firms with "intermediate" values of goodwill, but it can never be profit-improving for very low values or for very high values of goodwill. The interpretation of this fact is that firms with a very poor image would never be interested in a disclosure program and the same applies for very well-established firms, who might consider that a PDP would threaten their position.

6 Simulation

To get an additional insight into the nature of the solution and the comparison between different policies, we provide a numerical illustration. The model has nine parameters, namely $a, c, r, \alpha, \delta, \theta, \bar{e}, \tau, \varphi$ and one initial condition for $G(0) = G_0$. Figure 1 shows the solution for the following parameter values:

$$\begin{aligned} a &= 100, c = 5, r = 0.10, \alpha = 0.05, \delta = 0.05, \theta = 0.10, \\ \bar{e} &= 6, \tau = 12, \varphi = 0.05, G_0 = 185. \end{aligned}$$

Given these parameter values, the steady state values for goodwill are:

$$G_{ss}^{LF} = 190,\ G_{ss}^{T} = 188.8,\ G_{ss}^{PDP} = 182.8,\ G_{ss}^{GC} = 181.7$$

and, therefore, we have $G_{ss}^{GC} < G_{ss}^{PDP} < G_0 < G_{ss}^{T} < G_{ss}^{LF}$. As a consequence, the convergence to the steady state is from above (G is decreasing) for a disclosure strategy and for the general case, and it is from below (G is increasing) for a market-based policy and for the *laissez-faire* situation. Consistently with these long-run values for goodwill, optimal advertising expenditures are ranked in the same way (as predicted by Proposition 3).

Concerning pollution, with these parameter values, a PDP turns out to be much more effective than a traditional policy in the sense that emissions are always lower and decreasing whereas they are higher and increasing under a market-based regulation. As expected, if both instruments are combined, emissions are even lower.

The most remarkable results are those related to price behaviour. Initially, the price is higher when both instruments are implemented and, in turn, it is higher under a PDP than under a traditional policy which, in turn, is higher than in the *laissez-faire* situation. These are the predicted results by the theory (Proposition 3) because goodwill is initially the same in all the regimes. Nevertheless, since price is increasing in goodwill and, in turn, G^T and G^{LF} is increasing while G^{PDP} and G^{GC} is decreasing, it turns out that, in the long run, price is higher under a traditional regulation than under a PDP. Moreover, contrary to what one may expect a priori, price is higher in the *laissez-faire* situation than under any policy instrument and higher under a single policy than under a dual one. The reason for this counterintuitive result lays in the goodwill building up mechanism, which in the long rung dominates the cost shifting mechanism that tends to increase price under any environmental instrument. These results illustrate that considering goodwill accumulation can be crucial to understand the long run effects of environmental policy.

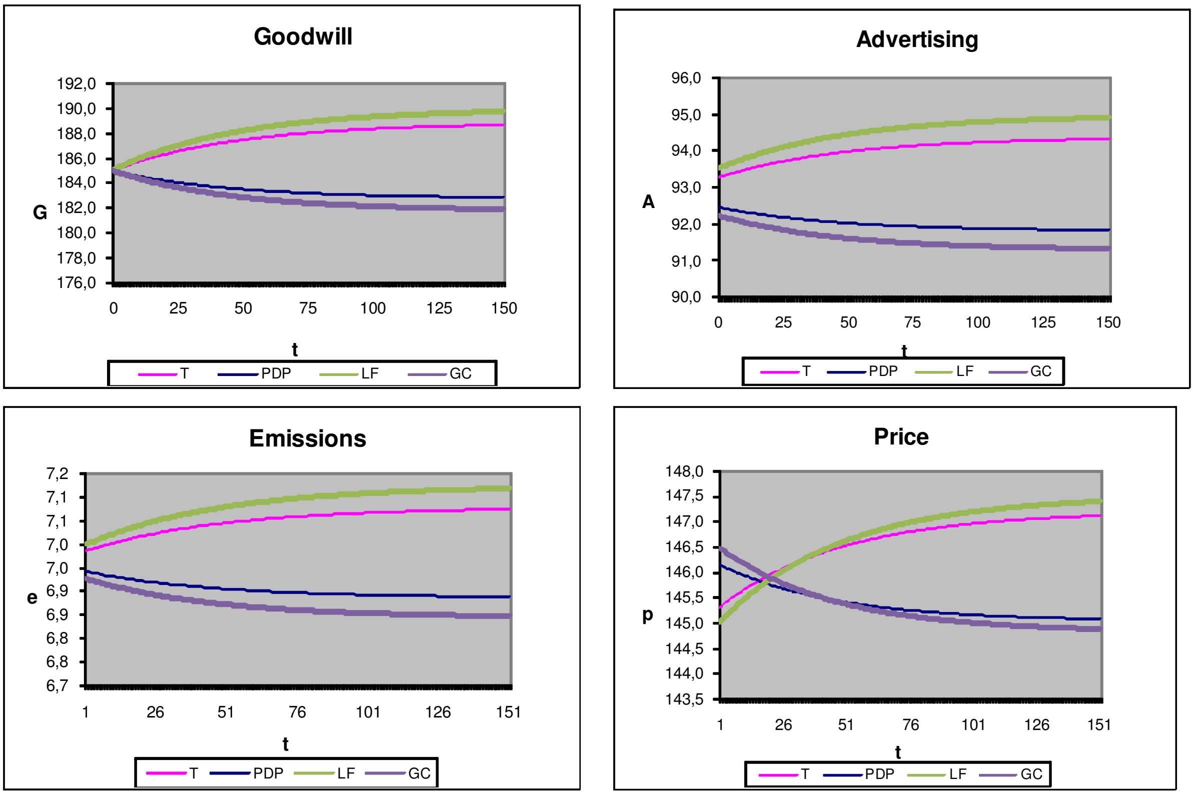

Figure 1: comparing the solution with a PDP and a market-based policy

Figure 2 shows how the discounted value of profits (or, alternatively, the value function evaluated in $t = 0$) depends on the standard, $\bar{e}$. Obviously, the standard does not have any effect in the *laissez-faire* situation and the effect is positive for all the rest of scenarios (the values for the general case are not shown because they are virtually identical to those under a PDP). For very tough (=low) values of the standard, any policy (either a PDP or market-based) is profit detrimental. As the standard gets milder, discounted profit gets higher. For a soft enough standard, discounted profit under an environmental policy, either a PDP or a market-based instrument, becomes higher than under *laissez-faire*. Given these parameter values, profit is more sensitive to the standard under a PDP than under a traditional regulation. As a matter of fact, if the standard is very tough, V^{PDP} is considerable lower than under a tax-subsidy and it is the other way around when the standard is very mild.

Figure 2. Effects of $\bar{e}$ on discounted profit.

Figure 3 illustrates the effect of including a PDP in the solution, i.e., the value of $D(G) \equiv V^{GC} - V^{T}$ depending on the initial condition of goodwill. As predicted by Proposition 7, $D(G)$ has an inverted U shape. In other words, the effect of a PDP is negative for very low and for very high values of goodwill and it can only be positive for intermediate values. In our example, "very low" involves negative values. Since we are focusing on positive values of goodwill, we can summarize our results saying that a PDP has positive effects for low and positive values of goodwill and negative effects for high values of goodwill. The reason is that, for well established firms, goodwill is an important asset, and they are more prone to suffer from a policy that may erode it. Figure 3 also shows that, consistently with our previous discussion, the range of values for which the effect of a PDP is positive is wider when the standard is higher. In other words, the milder the standard, the easier it is that the firm benefits from a PDP.

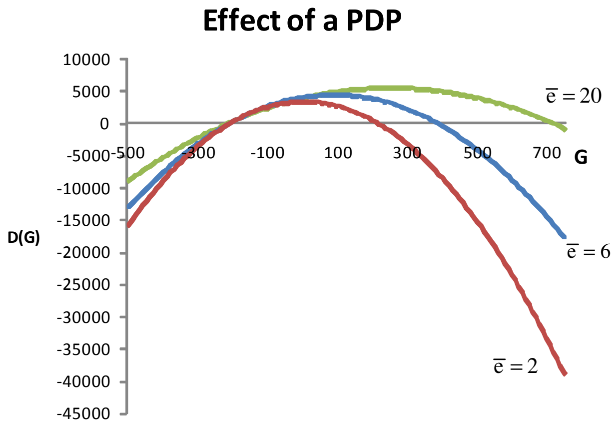

Figure 3. Effect of a PDP on profit depending on G

In order to complete this simulation exercise, we have also explored the effects of different policies combinations on the steady state by trying different values of τ and φ. Recalling that the tax rate τ appears in the objective and the PDP parameter φ appears in the goodwill dynamics, we performed a numerical simulations taking into account the "comparable" parameters, i.e., the production cost c (for τ) and the marginal impact of advertising θ (for φ). Specifically, we tested the following combinations:

$$\begin{aligned}\tau &= 0, \tau < c, \tau = c, \tau > c,\\ \varphi &= 0, \varphi < \theta, \varphi = \theta, \varphi > \theta,\end{aligned}$$

which leads in total to 16 scenarios. This exercise allowed us to conclude, first, that increasing the value of either φ or τ, or both, leads to a lower steady-state goodwill and, second, that the impact of φ, on both the steady-state goodwill and profit, is much more pronounced then the impact of τ. This can be attributed to the fact that φ hurts the market potential, whereas τ is "only" an additional cost. For instance, multiplying by 10 the value of τ when φ is equal to 0.05 leads to a decrease in total profit, evaluated at the steady state, and in G_{ss} of less than 1%. However, multiplying by 2 the value of φ when τ is equal to 1 lowers the steady state value and profit by approximately 10%.

7 Conclusions

This paper has presented a setting where a regulator supplements the traditional tax/subsidy environmental regulation by a public disclosure program. The latter affects positively or negatively the brand image and the market potential of the firm. This framework allows us to compare the effects of a disclosure strategy with those of a *traditional* (market-based) regulation. Both instruments are essentially different in the sense that the tax/subsidy has an immediate effect on the firms' profit whereas the PDP acts through a dynamic channel by determining the evolution of future demand.

We show how building up goodwill is a key mechanism to explain the economic and environmental behaviour of the firm and its reaction to a disclosure strategy. The initial level of goodwill turns out to be a crucial determinant for the optimal pricing and advertising strategies and also for the possibility that a PDP is profit improving. A notable result is that emissions are increasing in goodwill, which seems to indicate that, paradoxically, a firm with a green reputation can afford to pollute more to some extent. The value of goodwill is also crucial to determine what policy instrument is more effective.

We also conclude that, apart from reducing emissions, as a first side-effect, a PDP may help to render the steady state stable. As a second interesting effect, and for intermediate values of goodwill (neither too high nor too low) introducing a PDP may be profit improving.

The role of a standard or target level for emissions turns out to be totally different under both policy regimes. In the case of a tax/subsidy approach, this target level only acts as constant who increases or decreases profit by a fixed amount, but it does not affect the policy of the firm. On the contrary, if a PDP is implemented, the target value for emissions enters in an important way in the goodwill accumulation mechanism and determines how the firm reacts to the regulation and what is the time path for the economic and environmental variables. Moreover, this value is also crucial to determine the possibility that a PDP is profit improving. A policy implication of this fact is that regulators should be particularly careful in fixing the emission standard when a PDP is applied.

A natural extension to our work is to consider an oligopolistic industry where firms compete for consumers having a preference for greener products and to take abatement capital into account. A first step on including competition is Martín-Herrán et al.

8 Appendix

8.1 Proof of Proposition 1

To derive the optimal solution, we denote by $V(G)$ the value function of the firm and write down its Hamilton-Jacobi-Bellmann (HJB) equation:

$$\begin{aligned} rV(G) &= \max_{p,A} \Big\{ (p - c - \tau\alpha)(a + G - p) - \frac{1}{2}A^2 + \tau\bar{e} + \\ &\quad V'(G)(\theta A - \varphi(\alpha(a + G - p) - \bar{e}) - \delta G) \Big\} \end{aligned} \tag{17}$$

Assuming an interior solution and performing the maximization on the right-hand side, we obtain the following strategies

$$p(G) = \frac{a + G + c + \tau\alpha + \varphi\alpha V'}{2}, \tag{18}$$

$$A(G) = \theta V'. \tag{19}$$

Inserting $p(G)$ and $A(G)$ from above into (17) leads to

$$\begin{aligned} rV(G) &= \left(\frac{m + G + \varphi\alpha V'}{2}\right)\left(\frac{m + G - \varphi\alpha V'}{2}\right) \\ &\quad + \frac{1}{2}(\theta V')^2 + \tau\bar{e} + V'\left(-\varphi\left(\alpha\left(\frac{m + G - \varphi\alpha V'}{2}\right) - \bar{e}\right) - \delta G\right) \end{aligned} \tag{20}$$

Postulating a quadratic value function

$$V(G) = \frac{1}{2}k_1 G^2 + k_2 G + k_3,$$

and substituting in (20) leads to

$$\begin{aligned} r\left(\frac{1}{2}k_1 G^2 + k_2 G + k_3\right) &= G^2\left(k_1^2\left(\frac{\theta^2}{2} + \frac{\alpha^2\varphi^2}{4}\right) - k_1\left(\delta + \frac{\alpha\varphi}{2}\right) + \frac{1}{4}\right) \\ &+ G\left(k_1 k_2\left(\theta^2 + \frac{\alpha^2\varphi^2}{2}\right) - k_2\left(\delta + \frac{\alpha\varphi}{2}\right) - \varphi k_1\left(\frac{\alpha m}{2} - \bar{e}\right) + \frac{m}{2}\right) \\ &+ k_2^2\left(\frac{\theta^2}{2} + \frac{\alpha^2\varphi^2}{4}\right) - \varphi k_2\left(\frac{\alpha m}{2} - \bar{e}\right) + \bar{e}\tau + \frac{m^2}{4} \end{aligned}$$

By identification, we get the following system to be solved in the three unknowns k_1, k_2, k_3:

$$\begin{aligned}
\frac{1}{2} r k_1 &= \frac{1}{4}\left[k_1^2\left(2\theta^2+\alpha^2\varphi^2\right)-k_1\left(4\delta+2\alpha\varphi\right)+1\right], \\
r k_2 &= \frac{1}{2}\left[k_1 k_2\left(2\theta^2+\alpha^2\varphi^2\right)-k_2\left(2\delta+\alpha\varphi\right)-\varphi k_1\left(\alpha m-2\bar{e}\right)+m\right], \\
r k_3 &= \frac{1}{2}\left[k_2^2\left(\theta^2+\frac{\alpha^2\varphi^2}{2}\right)-\varphi k_2\left(\alpha m-2\bar{e}\right)+2\bar{e}\tau+\frac{m^2}{2}\right]
\end{aligned}$$

Solving the first equation gives

$$k_1=\frac{(r+2\delta+\alpha\varphi)\pm\sqrt{(r+2\delta+\alpha\varphi)^2-\left(2\theta^2+\alpha^2\varphi^2\right)}}{\left(2\theta^2+\alpha^2\varphi^2\right)}=\frac{\nu\pm\sqrt{\nu^2-x}}{x}.$$

which, under the assumption $\nu^2 > x$, has too real positive solutions. We choose, for stability, to retain the smallest one, i.e., the root with the negative sign. By straightforward successive substitutions one obtains easily the expressions of k_2 and k_3 given in the Proposition.

In order to show that k_2 is positive, multiply the numerator and the denominator of k_1 by $\nu+\sqrt{v^2-x}$ to get

$$k_1=\frac{\left[v-\sqrt{v^2-x}\right]\left[v+\sqrt{v^2-x}\right]}{x\left[v+\sqrt{v^2-x}\right]}=\frac{1}{v+\sqrt{v^2-x}}.$$

Compute

$$1-\alpha\varphi k_1=1-\frac{\alpha\varphi}{v+\sqrt{v^2-x}}=\frac{r+2\delta+\sqrt{v^2-x}}{v+\sqrt{v^2-x}}>0$$

An, therefore, $k_2 > 0$.

8.2 Proof of Proposition 2

Inserting the optimal values for A and p in the state dynamics yields

$$\dot{G}=\frac{G}{2}\left(2\theta^2 k_1-2\delta-\alpha\varphi\left(1-\alpha\varphi k_1\right)\right)+\theta^2 k_2-\frac{\varphi}{2}\left(\alpha\left(m-\alpha\varphi k_2\right)-2\bar{e}\right).$$

Substituting for k_1, equating to zero and solving leads to the expression for the steady state.

The steady state is globally asymptotically stable if and only if the coefficient of G in $\dot{G}$ above is negative. After substitution for k_1 and straightforward calculations, this is equivalent to

$$r-\sqrt{v^2-x}<0.$$

which, rearranging, gives rise to (15).

8.3 Proof of Proposition 3

Recall that

$$e(G;\varphi,\tau)=\alpha\left(a+G-p(G;\varphi,\tau)\right).$$

After substitution for the price, we get

$$\begin{aligned}
e(G;\varphi,\tau)-e(G;0,\tau) &= -\alpha^2\varphi\left(\frac{k_1G+k_2}{2}\right)<0,\\
e(G;0,\tau)-e(G;0,0) &= \frac{-\tau\alpha^2}{2}<0,\\
e(G;\varphi,\tau)-e(G;\varphi,0) &= -\alpha^2\left(\frac{\tau+\varphi\left(k_2-k_2^{PDP}\right)}{2}\right)<0,\\
e(G;\varphi,0)-e(G;0,0) &= -\alpha^2\varphi\left(\frac{k_1G+k_2^{PDP}}{2}\right)<0,\\
e(G;0,\tau)-e(G;\varphi,0) &= \frac{\alpha^2}{2}\left(-\tau+\varphi\left(k_1G+k_2^{PDP}\right)\right).
\end{aligned}$$

from which the displayed conditions follow.

8.4 Proof of Proposition 4

Recalling that the advertising strategies are given by

$$\begin{aligned}
A(G;\varphi,\tau) &= \theta\left(k_1G+k_2\right), \quad A(G;0,\tau)=\theta\left(k_1^TG+k_2^T\right),\\
A(G;\varphi,0) &= \theta\left(k_1G+k_2^{PDP}\right), \quad A(G;0,0)=\theta\left(k_1^TG+k_2^T\right),
\end{aligned}$$

where k_2^{PDP} is the value of k_2 when $\tau=0$ whereas k_1^T and k_2^T are the values of k_1 and k_2 when $\varphi=0$. It suffices to compare k_1 and k_1^T to get the results.

8.5 Proof of Proposition 5

Straightforward calculations lead to the two first results. Concerning the third result, we get

$$G_{ss}^{PDP} < G_{ss}^{T} \Leftrightarrow$$
$$\frac{2\delta(r+\delta)-\theta^2}{\left(2\delta(r+\delta)-\theta^2+\varphi\alpha(r+2\delta)\right)} < \frac{\theta^2 m}{\left(\theta^2-\varphi\alpha(r+\delta)\right)(a-c)+\varphi\bar{e}\left(2r+2\delta+\alpha\varphi\right)}.$$

which can be rewritten as

$$G_{ss}^{PDP} < G_{ss}^{T} \Leftrightarrow$$
$$-2\delta\varphi\alpha(a-c)(r+\delta)^2+(2\delta r+2\delta^2-\theta^2)\varphi\bar{e}\left(2r+2\delta+\alpha\varphi\right)$$
$$< \theta^2\alpha\left[\varphi\alpha(a-c-2\alpha\tau)+\tau\left(\theta^2-2\delta r-\alpha\varphi r-2\delta^2\right)\right] \Leftrightarrow$$
$$\bar{e} < \frac{\theta^2\alpha\left[\varphi\alpha(a-c-2\alpha\tau)+\tau\left(\theta^2-2\delta r-\alpha\varphi r-2\delta^2\right)\right]+2\delta\varphi\alpha(a-c)(r+\delta)^2}{\varphi(2\delta r+2\delta^2-\theta^2)\left(2r+2\delta+\alpha\varphi\right)} \equiv \tilde{e}$$

8.6 Proof of Proposition 7

The difference between a firm's payoffs with and without a PDP is given by:

$$D(G) \equiv V^{GC}-V^{T} = \frac{1}{2}\left(k_1-k_1^T\right)G^2+\left(k_2-k_2^T\right)G+\left(k_3-k_3^T\right).$$

We establish in the proof of Proposition 1 that k_1 can be written as

$$k_1 \equiv \frac{1}{v+\sqrt{v^2-x}} \equiv \frac{1}{r+2\delta+\alpha\varphi+\sqrt{(r+2\delta)^2-2\theta^2+2\alpha\varphi(r+2\delta)}}.$$

Clearly $k_1$is decreasing in φ, and hence $k_1 < k_1^T$. This shows that $D(G)$ is concave with $\lim_{G\to\pm\infty} D(G) = -\infty$ and it has a maximum at $\bar{G}$, which is determined by

$$D'(\bar{G}) = \left(k_1-k_1^T\right)\bar{G}+\left(k_2-k_2^T\right) = 0 \Leftrightarrow \bar{G} = -\frac{\left(k_2-k_2^T\right)}{\left(k_1-k_1^T\right)}.$$

Therefore, $D(G)$ is an inverted U-shaped function. At $\bar{G}$, we have

$$D(\bar{G}) = -\frac{1}{2}\frac{\left(k_2-k_2^T\right)^2}{\left(k_1-k_1^T\right)}+\left(k_3-k_3^T\right).$$

Let $\triangle \equiv \left(k_2 - k_2^T\right)^2 - 2\left(k_1 - k_1^T\right)\left(k_3 - k_3^T\right)$ .The following cases may arise:

1. $\triangle \leq 0 \Longleftrightarrow D(\bar{G}) \leq 0$. In this case, $D(G) \leq 0, \forall G \geq 0$, and the PDP has a non-positive impact on the value function.

2. $\triangle > 0 \Longleftrightarrow D(\bar{G}) > 0$. In this case, the equation $D(G) = 0$ has the following two roots:

$$
\begin{aligned}
G_1 &= -\frac{\left(k_2 - k_2^T\right)}{k_1 - k_1^T} + \frac{\sqrt{\left(k_2 - k_2^T\right)^2 - 2\left(k_1 - k_1^T\right)\left(k_3 - k_3^T\right)}}{k_1 - k_1^T}, \\
G_2 &= -\frac{\left(k_2 - k_2^T\right)}{k_1 - k_1^T} - \frac{\sqrt{\left(k_2 - k_2^T\right)^2 - 2\left(k_1 - k_1^T\right)\left(k_3 - k_3^T\right)}}{k_1 - k_1^T},
\end{aligned}
$$

   between which $D(G)$ is positive. Therefore, if the initial goodwill G_0 is such that $G_1 \leq G_0 \leq G_2$,then the firm benefits from a PDP; otherwise, such a program is profit deteriorating.

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