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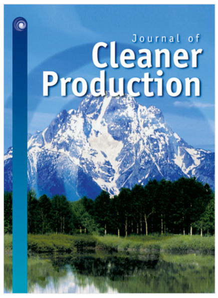

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PII: S0959-6526(23)03194-3
DOI: https://doi.org/10.1016/j.jclepro.2023.139036
Reference: JCLP 139036

To appear in: *Journal of Cleaner Production*

Received date : 6 February 2023
Revised date : 19 September 2023
Accepted date : 25 September 2023

Please cite this article as: L. Lambertini and A. Tampieri, On the private and social incentives to adopt environmentally and socially responsible practices in a monopoly industry. *Journal of Cleaner Production* (2023), doi: https://doi.org/10.1016/j.jclepro.2023.139036.

On the Private and Social Incentives to Adopt Environmentally and Socially Responsible Practices in a Monopoly Industry

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September 19, 2023

Abstract

This paper studies the incentives to adopt Environmental Corporate Social Responsibility (ECSR) in a multiproduct monopoly. In our framework, products are horizontally differentiated, production is polluting and a time-consistent government levies a tax on emissions. The ECSR monopolist may invest in R&D activities to reduce polluting emissions, while emission- reducing innovation may spillover from one product to the other. We show that the monopolist has no incentive to engage in ECSR, unless a regulatory measure is introduced. By contrast, a time consistent tax induces the adoption of a ECSR statute. Under admissible parameter conditions, profits are concave and single-peaked in the ECSR intensity. Finally, ECSR monotonically increases social welfare, by raising consumer surplus and curbing environmental damage.

Keywords: environmental CSR; multiproduct monopolist; time-consistent emission tax; emission abatement; horizontal differentiation; R&D spillovers

1 Introduction

In recent years, an increasing number of firms have introduced environmental and social policies into their business strategy. This tendency is driven not only by regulations but also by an increasing understanding that social and environmental issues have an impact on financial performance and corporate value. Recent evidence from the KPMG Survey of Sustainability (KPMG, 2020) shows that 96% of the world's largest firms implemented programs of "environmental and corporate social responsibility" (later sometimes addressed as CSR or ECSR),[1] with 90% in the Americas region, 77% in Europe, 84% in the Asia Pacific region and 59 % in Africa (KPMG 2020). Much of the attention focusses on how the application of these activities relates with the negative environmental externalities associated to many production processes, together with national and international environmental regulation.[2]

A stream of economic literature on CSR has recently studied the environmental components of CSR activities and its interaction with regulatory measures to control polluting emissions. Lambertini and Tampieri (2015)

[1] CSR stands for "Corporate Social Responsibility". Throughout the paper, we will use this term to refer to studies that set aside environmental concern in the firm's objective function, by focusssing only on social concern. By contrast, a firm that adopts an ECSR ("Environmental and Corporate Social Responsibility") statute takes into account both social and environmental concern.

[2] An important example of environmental activity implemented as a business strategy is green marketing (for a thourough review, see Dangelico and Vocalelli, 2017). Marketing plays a crucial role in creating a green market by effectively communicating with consumers, increasing their awareness of environmental sustainability, and informing them about the benefits of environmentally sustainable products and services. As a result, marketing is highly relevant in promoting both cleaner production and sustainable consumption. Yet, as it appears from Dangelico and Vocalelli (2017), this is form of marketing is not specific of (E)CSR firms, and will not be included in our analysis.

first considered one ECSR firm in a Cournot oligopoly setting, and the introduction of a welfare-maximising tax, without addressing the role of emission-reduction R&D. In a duopoly industry, Xu *et al.* (2022) analyse the interplay between the choice of ECSR level and the introduction of an optimal tax with quantity and price competition. They examine both the scenario in which the government precommits to the tax rate before firms set their ECSR level, and the alternative case in which firms choose before the government. Xu and Lee (2022) investigate the possibility of cooperation among competitors in ECSR activities where the level of ECSR is chosen to maximise joint profits.[3]

While in oligopoly the incentive to establish ECSR activities naturally emerges by the strategic interaction among competitors, the very same incentive might not emerge in a monopolistic industry. To the best of our knowledge, the only papers dealing with ECSR in monopolistic industries are those of Fukuda and Ouchida (2020) and Wang (2021), where, however, the extent of the ECSR commitment is treated as a parameter , and, doing so, these authors find out through comparative statics that increasing the monopolist's ECSR stance may indeed bring about an increase in GHG emissions and the related environmental damage. Yet, may one take for granted that the owners of a monopoly firm separate control from ownership along this dimension? From Friedman (1970) onwards, many have objected to the plausibility of a scenario like this. In this respect, the relevant question is about the necessary and sufficient conditions for a monopolist to endogenously choose to have an incentive to adopt an ECSR stance at a full-fledged

[3]In a dynamic setting, Iannucci and Tampieri (2022) examine how the long run evolutionary market configuration and social welfare are influenced by the level of an emission tax and the adoption of ECSR practices.

equilibrium. Once the nature of the private incentives has been ascertained, the follow up question is to assess whether the adoption of ECSR practices is socially desirable.

The scope of this paper is to address these questions. We develop a model where a multiproduct monopolist engages in ECSR activities while a government time consistently sets an optimal tax on emissions (following Petrakis and Xepapadeas, 2001; 2003). The monopolist may invest in R&D in the production process of each product to curb the level of emissions. The R&D investment aimed at abating emissions brings about technological spillovers, in the sense that the abatement improvement along one production line also facilitates abatement in the other.

First, we evaluate the incentives to adopt an ECSR statute, to show that these incentives are nil if not accompanied by any regulatory measure. This result clarifies the necessity of an interaction between environmental policy and ECSR activities, but it is intuitive: in absence of any strategic interaction, the monopolist cannot increase its profits through the creation of a CSR division.[4] Things change when profits are restrained by environmental taxation. In this case, ECSR activities stimulate R&D investment to emission reduction, which in turn lowers the tax burden. The extra cost due to environmental concern is mitigated by the social concern that spurs production above the profit-maximising level and by the emission reduction technology.

Our results reflect this intuition: social welfare (that, in addition to profits, consumer surplus and the revenue generated by emission taxation, takes

[4]Essentially, this is a special case of the generalised lack of any incentive to separate control from ownership if managerialisation involves the inclusion of magnitudes related to output (like sales or market shares) in the monopolistic firm's objective function (for an overview of the related debate, see, e.g., Lambertini, 2017).

into account the environmental damage due to production emissions) increases with the level of ECSR, prompted by the increase in consumer surplus and the decrease in environmental damage. In addition, the private incentives to adopt ECSR are spurred by the tax on emissions. Indeed, solving the model we find the presence of a positive level of ECSR that maximises profits in several scenarios. The profit maximising level is robust to changes in the degree of spillovers, product substitutability, cost of R&D and environmental damage.

To ease the illustration of our contribution in relation to Fukuda and Ouchida (2020) and Wang (2021), it is appropriate to briefly reconstruct the main features and conclusions of these two papers.

Fukuda and Ouchida (2020) study the effects of a time-consistent tax on GHG emissions on a monopoly industry where the firm adopts an ECSR statute and accounts for the emission tax when choosing its R&D effort for emission abatement and the output level. This means that Fukuda and Ouchida (2020) investigate a three-stage game between the monopolist and the policymaker, in which

- at the first stage, the firm chooses the intensity of the abatement effort, carried out in a single lab or division, to maximise the ECSR objective function;
- at the second stage, the public authority sets the emission tax so as to maximise social welfare, which includes profits, consumer surplus, the environmental damage and the income generated by the tax; then,
- at the third stage, the monopolist maximise the ECSR function with

respect to quantity.

This amounts to saying that Fukuda and Ouchida (2020) assume the incentive to engage in ECSR as given. However (see their Proposition 1, p. 5) they study the effect of variations of the ECSR commitment level, and their findings indeed point at the possible existence of a peak of profits, although this is not explicitly mentioned. In fact, the focus of their analysis is to show that the ECSR incentive, while systematically improving welfare, may boost the volume of emissions and therefore also the resulting damage. This typically happens if the cost function associated to abatement activities and the environmental damage are both sufficiently steep (Fukuda and Ouchida, 2020, Proposition 2, p. 6). This conclusion, of course, is a potentially relevant warning for the policymaker, but, in turn, it calls for a more detailed investigation of the owners' incentive to fine tune the ECSR weight in such a way to maximise profits, since doing so they might not cause an increase of polluting emissions.

Wang (2021) considers a different three-stage game wherein

- the first stage hosts the policymaker's choice of the welfare-maximising emission tax;
- the second characterises the monopolist's optimal R&D strategy for emission abatement; and
- the third stage is for optimal quantity setting, as in Fukuda and Ouchida (2020).

The main differences between this model and Fukuda and Ouchida's (2020) are (i) the choice of the emission tax at the first stage, which makes this environmental policy time-inconsistent (as we know from Petrakis and Xepapadeas, 2001, 2003; see also Ouchida and Goto, 2016; and Yong *et al.*, 2018); and (ii) the fact that the firm is assumed to sell two differentiated varieties and to use two labs to perform R&D, with technological spillovers between labs. The main conclusions are that increasing the intensity of the ECSR commitment (again treated as an exogenous parameter) boosts R&D and social welfare, the latter effect being driven by consumer surplus and profits, which more than offset the increase in GHG emissions and the associated environmental damage. Given the time structure of Wangs's (2021) game, these conclusions are not reliable as the policymaker has a strict incentive to modify the emission tax ex post, once the firm has invested in R&D to abate its emissions.

What we propose is a model based upon the layout proposed by Wang (2021), accompanied by two alternative assumptions concerning the timing of the policy choice and the nature of the ECSR commitment. Namely, our game is structured into four stages:

- stockholders optimally choose the weight of the ECSR component to maximise firm's profits at the first stage;
- at the second, the monopolist chooses the two labs' abatement efforts to maximise the ECSR objective;
- the policymaker intervenes at the third stage to introduce the welfare-maximising emission tax; and
- at the fourth, the firm the firm chooses the output levels of the two differentiated goods.

This setup encompasses the modelling details in Wang (2021) while at the same time making the environmental policy time-consistent and the ECSR weight an endogenous strategic variable. Our results regarding the relationship between the level of ECSR activities and profits are consistent with the comparative statics exercise carried out by Fukuda and Ouchida (2020). However, although not characterising a fully analytical solution, we show the existence of a single profit-maximising level of ECSR activities, in correspondence of which the undesirable increase in emissions emerging from the analysis carried out by Fukuda and Ouchida (2020) and Wang (2021) is not observed. In itself, this is a novel result, especially if one interprets the adoption of an ECSR objective as the outcome of a strategic delegation to a manager, being incentivised through an ECSR function. From Vickers (1985) onwards, the acquired wisdom about of strategic delegation holds it that a monopolist would not separate control from ownership as this move is inherently connected with the acquisition of market leadership, which makes sense in oligopoly but of course not in monopoly. Instead, our approach and Fukuda and Ouchida's (2020) envisages a scenario in which a form of ECSR managerialisation may be triggered by environmental policy even if the firm stands alone on the market place, with desirable consequences from both the private and the social standpoint.

By contrast, our results differ from Fukuda and Ouchida's (2020) as far as the relationship between the level of ECSR activities and polluting emissions is concerned: indeed in a single product monopoly, ECSR activities may increase polluting emissions if the efficiency of abatement reduction is sufficiently low, since the higher cost of abatement reduces the incentive to invest in such activities. By contrast, in our multiproduct setting the level of ECSR activities always brings about a decrease in the level of environmental damage. This result is explained by the presence of spillovers among the two products, which reduce the level of abatement without raising costs. This, by the way, points out that investment smoothing through the adoption of more than a single lab allows the firm to reduce the marginal cost of green R&D, all else equal, in particular, for any given level of overall abatement effort.

Similar considerations can be extended to Wang (2021), where it is also shown, through comparative statics, that increasing the degree of ECSR has ambiguous effects as it involves more intense R&D investments and higher social welfare but also an expansion of emissions due to the increase in output driven by the presence of consumer surplus in the firm's objective function. Wang's analysis, however, relies on a stage sequence envisaging the government setting the emission tax at the first stage, which makes the resulting outcome time inconsistent as the public authority would have an incentive to design taxation anew as soon as the firm has taken its R&D decisions.

1.1 Literature

The paper is related, in different degrees, to two strands of the economic literature, namely, the literature on CSR and the literature on environmental policy.

The concept of CSR has a long tradition in economics and management, and indeed the early phase of the debate hosted a lively discussion about the nature and aim of CSR, as well as it plausibility as an instrument delegated to managers by stockholders. Actually, Friedman (1970) states that the firms' unique responsibility is to maximise firm's profits. By contrast, Freeman (1994) argues that a firm is responsible towards all its stakeholders, and that the success of a business lies on the ability to handle its relationships with these groups: debtholders, shareholders, employees, customers, and also societies and communities (van Beurden and Gossling, 2008). In addition, Freeman (1994) argues that there exists a positive correlation between corporate social responsibility and financial performance. The empirical evidence provides mixed results (see Orlitzky *et al.*, 2003, Marom, 2006; van Beurden and Gossling, 2008; Margolis *et al.*, 2009; Crifo and Forget, 2012; Kong *et al.*, 2019; and Saha *et al.*, 2019 *inter alia*).

In the past two decades, the economic literature on CSR has taken different directions, according to several definitions of the concept of CSR that have been developed.[5]

One strand defines of the literature defines CSR activities as the private provision of (corporate) public goods or the private curtailment of public bads (Bagnoli and Watts 2003, Kotchen 2006; and Besley and Ghatak 2010, *inter alia*). In general, they show that CSR social activities may turn into a by-product of market competition. By contrast, Kirchhoff (2000) describes CSR in the context of eco-labeling and voluntary overcompliance.

The present analysis is based on the definition of "strategic CSR" (Baron, 2001), according to which firms engage in CSR activities since these have a positive effect on firms' profits. This could be due, for instance, to the impact that CSR behavior has on firms' reputation (Kim, 2019), which in turn may

[5]Kitzmueller and Shimshack (2012), Lambertini (2013, chapter 5) and Crifo and Forget (2015) survey much of the recent literature on CSR.

affect sensitive consumers and investors (Arora and Gangopadhyay, 1995; Garcia-Gallego and Georgantzís, 2009; Baron, 2009; Liu *et al.*, 2015; and Mantovani *et al.*, 2017, *inter alia*), increasing firms' profits and stock prices (Starks, 2009; Fernández-Kranz and Santaló, 2010; and Khojastehpour and Johns, 2014, *inter alia*).

Another strand of the literature sets aside consumers' sensitivity (without necessarily excluding it) to investigate uniquely the role played by CSR activities on the production decisions of competitors. As anticipated above, this approach is somehow related to the economic literature on strategic delegation in oligopoly (Vickers, 1985; and Fershtman and Judd, 1987, *inter alia*): in these models, a managerial firm may have an incentive to consider consumer surplus in their objective function to push rivals to reduce their production level. The literature of strategic CSR has developed largely in the past decade, and it is not possible to list here all the relevant works: early contributions are Goering (2008a, 2008b, 2010), Kopel and Brand (2012), while most recent are Gioffré *et al.* (2021), Dong and Bárcena Ruiz (2021a, 2021b), Bàrcena-Ruiz and Sagasta (2021) and Dong *et al.* (2023), *inter alia*.

This brings us to the core elements of the approach in which the adoption of ECSR has instead a strictly strategic nature. According to this standpoint, which is the one we take in the present paper, an ECSR firm not only includes a share of consumer surplus in its business strategy, but also the environmental impact of its own polluting emissions (Lambertini and Tampieri, 2015; Lambertini *et al.*, 2016; Nie *et al.* 2018; Fukuda and Ouchida, 2020; Wang, 2021; Iannucci and Tampieri, 2022, *inter alia*), only consumer surplus (Garcia *et al.*, 2018; Leal *et al.*, 2018) or only emissions (Hirose *et al.*, 2017; Buccella *et al.*, 2022). While the concern for consumer surplus boosts the level of production, considering emissions reduces it. Yet, the combination of the two factors may allow the ECSR firm to get higher profits than its competitors, provided the market is large enough.

This stream of literature is based on models containing several variations in terms of industry structure, the presence or absence of green R&D, the exogenous or endogenous nature of the emission tax, and, in the latter case, its time consistency or inconsistency, depending on the position of the policy stage along the time structure of the game. To clarify these elements, the aforementioned papers' main features are summarised in Table 1. Note that both Leal *et al.* (2018) and Garcia *et al.* (2018) examine both consistent and inconsistent taxation (labelling as uncommitted or committed, respectively) and assess their relative pressure and performance. Yet, though useful and interesting in itself, this must be taken with some caution as it leaves aside two aspects of critical importance. The first is obviously the time inconsistency of a policy receding investments, and the second is the lock-up effect of R&D commitments: once these have taken place and R&D divisions are fully functional, they can be adjusted to an inconsistent policy very slowly and also costly, while a modification of the tax might be rather quick.

	IS	R&D	tax	delegation
Lambertini and Tampieri 2015	CO	no	con	ECSR
Lambertini *et al.* 2016	CO	yes	no	ECSR
Hirose *et al.* 2017	BO	no	no	E
Nie *et al.* 2018	CO	no	no	ECSR
Leal *et al.*, 2018	CO	yes	con/inc	CS
Garcia *et al.*, 2018	CO	yes	con/inc	CS
Fukuda and Ouchida 2020	M	yes	con	ECSR
Wang 2021	M	yes	inc	ECSR
Iannucci and Tampieri 2022	CO	yes	exo	ECSR
Buccella *et al.* 2022	CO	yes	inc	E
Xu and Lee 2022	CO	yes	inc	ECSR

IS = industry structure, CB/O = Bertrand/Cournot oligopoly,

con = consistent, inc = inconsistent, exo =exogenous,

ECSR includes E = emissions and CS = consumer surplus

Table 1

Only a relatively small subset of the literature focusses on the interplay of firms' strategic ECSR with environmental regulation and its effects on social welfare. To mention some relevant contributions, Garcia *et al.* (2018), Leal *et al.* (2018) and Xu and Lee (2018) investigate the interplay between CSR practices and the introduction of a tax on emissions, even if the environmental component which would lead to ECSR is absent. By contrast, Xu and Lee (2022) introduce an optimal emission tax in a duopoly by comparing cooperative versus noncooperative ECSR activities between firms, where the firm's objective also includes environmental concern. Lee and Park (2019) analyse the implementation of ECSR activities in the presence of an eco-firm that sells abatement goods to polluting firms. All of these works focus on oligopolistic markets, so that the strategic interaction between ECSR activities and environmental policy is intertwined with strategic interaction between competitors.

The present paper is also related to the literature on environmental policy, with a focus on the timing of environmental policy (Petrakis and Xepapadeas, 2003). Much of the literature on environmental regulation assumes that governments are effective at precommitting to policy plans, in particular when the policies being adopted are taxes on emissions or emission standards (see Chiou and Hu, 2001; Lambertini *et al.* 2017; and Sagasta and Usategui, 2018, *inter alia*). At the same time, the credibility of the policymaker has been questioned by studies wherein the policymaker is unable to precommit itself (see Poyago-Theotoky, 2007; Brunner *et al.*, 2012; Ouchida and Goto, 2014, 2016; Moner-Colonques and Rubio, 2016; Fukuda and Ouchida, 2020, *inter alia*).

The present analysis nests in the aforementioned strands of literature. In particular, we study the ECSR strategic incentives in a multiproduct monopoly, first, in absence of environmental regulation, then by introducing a time-consistent, welfare maximising tax on emissions. This approach clarifies the role played by environmental policy in triggering the adoption of ECSR activities when no strategic interaction occurs among competitors, and shows the role played by spillovers in determining the ECSR effect on social welfare.

The remainder of the paper is organised as follows. Section 2 introduces the layout of the model. Section 2.1 illustrates the results of the paper: subsection 2.1.1 investigates the incentives to adopt ECSR practices in absence of emission taxation, while subsection 2.1.2 introduces the tax and evaluates public and private incentives to engage in ECSR practices. Section 3 concludes.

2 Model and methodology

Consider a multiproduct monopolist that supplies two products, 1 and 2, in an economy where the utility function of the representative consumer is linear-quadratic in the consumption levels (see Levitan and Shubik, 1980; Singh and Vives, 1984; and Choné and Linnemer, 2020, *inter alia*):

$$U = a\left(q_1 + q_2\right) - \frac{1}{2}\left(q_1^2 + q_2^2 + 2\theta q_1 q_2\right) + y. \tag{1}$$

In (1), $a > 0$ represents the reservation price, while q_1 and q_2 are the demand of goods 1 and 2, respectively. Utility is linear in the consumption of the composite good y, which is chosen as the *numéraire*. Parameter $\theta \in [-1, 1]$ is an inverse measure of the degree of product differentiation between goods 1 and 2, or, equivalently, a direct measure of their degree of substitutability: if $\theta \in (0, 1]$, products are demand substitutes; if $\theta = 0$, products are independent and so are the two industries where they are traded; finally, if $\theta \in [-1, 0)$, products are demand complements. Utility maximisation subject to budget constraint, $y + p_1 q_1 + p_2 q_2 \leq Y$ (where the price of the *numéraire* is normalised to one and Y denotes income) yields the following system of inverse demand function:

$$p_i = a - q_i - \theta q_j,\ i \in \{1,2\},\ j \in \{1,2\},\ j \neq i. \tag{2}$$

On the supply side, the production of good i entails a linear cost cq_i, with $c \in [0, a)$. Moreover, production pollutes the environment, and the monopolist can invest in *end-of-pipe* R&D activities $z_i \geq 0$ to abate emissions for each good. To account for decreasing returns in research activities, the cost of R&D investment for good i is quadratic in the level of emission abatement and it is given by $C(z_i) = \gamma z_i^2$, where $\gamma > 0$ scales the marginal cost of the environmental R&D effort in abating emissions. Therefore, the total cost related to variety i is

$$c(q_i, z_i) = cq_i + \gamma z_i^2. \tag{3}$$

Additionally, there exist knowledge spillovers in environmental R&D across the monopolist's product range. The magnitude of such bidirectional spillovers is measured by parameter $\beta \in [0, 1]$, which scales the size of a positive technological externality associated with R&D efforts carried out in separate divisions or labs, which may belong to either different firms or a single one, whereby observing your neighbours, no matter whether inside or outside the same firm turns out to be beneficial. Indeed, the appearance of this theme can be traced back to informal discussions with a typical Mashallian flavour on the circulation of technological knowledge within industrial districts. A reconstruction of the early view, which usually adopted the term external economies, is in Becattini (2002). The presence of technological spillovers in oligopoly models has been accounted for since the seminal papers by d'Aspremont and Jacquemin (1988), Kamien *et al.* (1992) and Suzumura (1992), subsequently followed by many others, and also empirically measured across sectors (see Jaffe, 1986; Geroski, 1995; Griliches, 1995; and Cassiman and Veugelers, 2002, *inter alia*). In a monopolistic industry, the parcelisation of R&D efforts is justified as it allows the firm to decrease marginal R&D cost, in the first place, and then also to exploit the spillover mechanism to circulate information between the two labs. As we shall see in the remainder, this aspect will play a relevant role, as far as the private and collective desirability of ECSR is concerned.

In presence of spillovers, the production of good i involves the following amount of net emissions

$$e_i(q_i, z_i, z_j) = \varepsilon q_i - z_i - \beta z_j, \tag{4}$$

where $\varepsilon > 0$ is a parameter measuring the relationship between output and polluting emissions. Here we shall consider GHG emissions, that is, carbon dioxide (CO_2), or alternatively any other CO_2-equivalent GHGs. Hence, ε measures the amount of CO_2 per-unit of the final good.

Total emissions may be defined as $E = e_1 + e_2$. The monopolist is subject to emission taxation, which is a linear function of net emissions: $T = tE$. Whenever $t > 0$, i.e., it is indeed a tax, we have to assume $a - c > t$ to ensure firms supply strictly positive outputs at the equilibrium if $z_i = z_j = 0$, namely, if no investment abatement technologies is undertaken. We shall come back to this aspect in the next Section. Profits engendered by variety i are

$$\pi_i = p_i q_i - c(q_i, z_i) - t e_i(q_i, z_i, z_j), \tag{5}$$

while total profits are obviously equal by $\Pi = \pi_1 + \pi_2$.

We assume that the monopolist adopts a statute of environmental and social corporate responsibility (ECSR). Following the relevant literature, this implies that the monopolist objective includes not only its own profit but also the levels of consumer surplus and environmental damage brought about by the production process. We define the ECSR objective function of the monopolist as

$$O = \Pi + v\left(CS - D\right), \tag{6}$$

where $v \in [0, 1]$ represents the monopolist's level of environmental and social concern, as in Fukuda and Ouchida (2020) and Wang (2021). If $v = 0$, the firm behaves as a pure profit-seeker, while if $v = 1$ the firm's objective function coincide with social welfare except for the absence of the income produced by emission taxation. Consumer surplus CS is the representative consumer's indirect utility function from the consumption of goods 1 and 2

$$CS = a\left(q_1 + q_2\right) - \frac{1}{2}\left(q_1^2 + q_2^2 + 2\theta q_1 q_2\right) - p_1 q_1 - p_2 q_2, \tag{7}$$

while D denotes environmental damage, assumed to be quadratic in the overall level of emissions, $D = gE^2$, and $g > 0$ captures the level of marginal damage. Accordingly, the social welfare function may be written as:

$$SW = \Pi + CS - D + T \tag{8}$$

that is, the sum of monopoly profits, consumer surplus and the tax revenue, minus the environmental damage. Note that the revenue yielded by emission taxation is transferred to consumers as additional surplus, for instance in the form of public expenditure in health services or education.

We will investigate two different scenarios. In the first, the firm's activity is not subject to emission taxation, and the sequence of moves takes place in two stages: in the first, stockholders choose v to maximise firm's profits; in the second, R&D efforts and output levels are chosen to maximise the ECSR objective O. In the second scenario, there are four stages. The first stage hosts the choice of v by owners, as in the previous case. In the second stage, the monopolist sets the R&D investment in emission abatement. The emission tax is set by the policymaker to maximise social welfare at the third stage, immediately before the fourth stage, at which the firm designs its output plan. This sequence captures the fact that the monopolist, anticipating the adoption of the emission tax, must separate the decision about R&D from the other concerning outputs, and locates the investment choice upstream of the policymaker's move. The opposite sequence would imply that the government would have a strict incentive to modify the tax once the firm's decision about green R&D had been taken, thereby making the policy itself, as well as the whole game, time inconsistent. In both cases, the solution concept is subgame perfection by backward induction, with the sequence of stages ensuring time consistency.

2.1 Results

Here we proceed with the exposition of the findings of our analysis. First, we illustrate the solution of the unregulated case, and then we extend it to account for the presence of a welfare-maxising tax on emissions.

2.1.1 The unregulated equilibrium

Here, we want to evaluate whether the monopolist has an economic incentive to implement an ECSR statute in case no tax on emissions is present in the two industries. The firm, standing alone in the market place, may simultaneously determine q_1 and q_2 as well as z_1 and z_2 to maximize the objective function O given by the ECSR statute.[6]

Hereinafter, in order to simplify notation, we define $a - c \equiv m > 0$ as the measure of market size. The system of first order conditions is condensed in the following:

$$\frac{\partial O}{\partial q_i} = m + v\left[2\varepsilon g\left((1+\beta)(z_i+z_j) - \varepsilon\left(q_i+q_j\right)\right) + q_i + \theta q_j\right] - 2\left(q_i - \theta q_2\right) = 0,$$

$$\frac{\partial O}{\partial z_i} = 2gv\left(1+\beta\right)\left[\varepsilon\left(q_i+q_j\right) - (1+\beta)(z_i+z_j)\right] - \gamma z_i = 0, \tag{9}$$

for $i, j = 1, 2,\ j \neq i$. The corresponding equilibrium quantities and R&D efforts are:

$$q_i^* = \frac{m\left[4gv(1+\beta)^2+\gamma\right]}{2\gamma + \theta\left(2-v\right)\left[4gv(1+\beta)^2+\gamma\right] + v\left[4g\left(2-v\right)\left(1+\beta\right)^2 + \gamma\left(4g-\varepsilon^2\right)\right]}, \tag{10}$$

$$z_i^* = \frac{4\varepsilon gmv(1+\beta)}{2\gamma + \theta\left(2-v\right)\left[4gv(1+\beta)^2+\gamma\right] + v\left[4g\left(2-v\right)\left(1+\beta\right)^2 + \gamma\left(4g-\varepsilon^2\right)\right]}, \tag{11}$$

and it is evident that $m > 0$ is a sufficient condition for the numerators of the above expressions to be positive. Then, $g \geq \varepsilon^2/4$ is a sufficient condition

[6] For the sake of clarity, we may add that it can be quickly demonstrated that expanding this setup to host an additional stage in order to sequentially separate the choices of R&D efforts and outputs yields exactly the same vector of equilibrium magnitudes.

to ensure the positivity of the denominator of q_i^* and z_i^* and therefore also of the whole expressions in (10-11).[7]

Now we may turn our attention to the first stage, where stockholders set the ECSR engagement level v to maximise their firm's profits. The roots of $\partial \Pi \left(q_i^*, z_i^*\right) / \partial v = 0$ are those of the following equation:

$$-\left(64v^4\Lambda_1 + 48v^3\Lambda_2 + 12v^2\Lambda_3 + v\Lambda_4\right) = 0, \tag{12}$$

with

$$\Lambda_1 \equiv g^3(1+\beta)^6(1+\theta)^2\,;\; \Lambda_2 \equiv g^2(1+\beta)^4(1+\theta)^2\gamma, \tag{13}$$

$$\Lambda_3 \equiv g(1+\beta)^2\gamma^2(1+\theta)\left(1-4\varepsilon^2 g+\theta\right), \tag{14}$$

$$\Lambda_4 \equiv \gamma^3(1+\theta)\left(1-8\varepsilon^2 g+\theta\right)+16\varepsilon^2 g^2\gamma^2\left[\varepsilon^2\gamma+2\left(1+\theta\right)+2\beta\left(2+\beta\right)\right](1+\theta). \tag{15}$$

Now note that these four polynomials above are strictly positive for any $g \geq 1/4$, and (12) admits the solution $v = 0$, which satisfies the second order condition:

$$\left.\frac{\partial^2 \Pi\left(q_i^*, z_i^*\right)}{\partial v^2}\right|_{v=0} = -\frac{m\Lambda_4}{4\gamma(1+\theta)^2} < 0. \tag{16}$$

Consequently, the above discussion entails the following

Proposition 1 *Suppose that the multiproduct monopolist does not bear any tax on emissions. Then the monopolist has no incentive to adopt an ECSR statute.*

[7] Indeed, as it can be easily ascertained by looking at the expression appearing at the denominator of (10-11), the sufficient condition on g for the equilibrium magnitudes to be positive holds for any $v \in [0, 2]$. This means that, in line of principle, the ECSR statute could contemplate a scenario in which the weight of the ECSR component is larger than that attached to profits.

Proposition 1 suggests that the introduction of an environmental policy is necessary for the monopolist to implement ECSR practices. The results substantially differ from any oligopoly setting we are accustomed with, in which ECSR practices strategically affect the competitor's production choices and thus may lead ultimately to raise profits. In a monopoly industry, the profit-maximisation process of the unique firm is not influenced by the production decision of any competitor, so that any strategic choice that differs from profit maximisation necessarily has a negative impact on profits. In particular, without regulation, the presence of ECSR in the objective function would be equivalent to an irrational form of self-taxation by the firm.

In fact, this problem is analogous to that pertaining to an area of the theory of industrial organization investigating the strategic incentive to separate control from ownership by hiring a manager interested in expanding production or revenues (as in Vickers, 1985; and Fershtman and Judd, 1987, respectively) or other magnitudes connected with output (see Lambertini, 2017). Here, the ECSR manager would be hired on the basis of a wage increasing in the size of the ECSR objective (6), and, as it happens in IO models, even this form of delegation is not incentive-compatible from the owners' standpoint. The fact itself that a monopolistic firm won't set up an ECSR division also entails

Corollary 2 *The lack of an ECSR stance in absence or environmental regulation annihilates green innovation efforts in monopoly.*

Corollary 2 demonstrates that, contrary to Fukuda and Ouchida (2020), assuming the existence of incentives for engaging in ECSR activities is not innocuous in a monopoly context, as endogenising it with a view to maximise firm's profits indeed induces stockholders to keep the pure profit-seeking nature of their firm unaltered. And obviously, the straightforward consequence is that the incentive to invest in green technologies disappears. This Corollary can be interpreted in two ways. Since an unregulated market has to be at least duopolistic for ECSR to emerge at equilibrium, (i) when the first firm enters, we may not expect it to adopt an ECSR statute; but also (ii) should a firm remain alone because of the competitive advantage created by ECSR driving profit-seeking rivals out, at the resulting long-run equilibrium we should expect it to abandon the ECSR stance which has delivered monopoly power.

The results in Corollary 2 imply the necessity to introduce environmental policy to spur the adoption of ECSR activities. This is indirectly corroborated by empirical evidence. Indeed, the diffusion of innovation in emission reduction, which is in turn prompted by ECSR practices, is strictly related to the presence of environmental policy (see, for example, Horbach and Rammer 2018).

2.1.2 The introduction of the emission tax

The results of the previous setting are not confirmed when an emission tax is levied. In this case, the adoption of an ECSR statute may provide an incentive to invest in green R&D activities stronger than those of a profit-seeking firm, to curb the tax burden. In turn, there may exist a level of ECSR commitment that maximises profits.

We assume the government is able to levy a time consistent tax on emissions. This implies that the tax is set only after the firm takes its investment decisions in R&D (see Petrakis and Xepapadeas, 2001, 2003). The implications in terms of timing are the following. In the first stage, the owners set v to maximise their firm's profits. In the second, the firm chooses the level of R&D investment to maximise the ECSR objective function. In the third stage, the government introduces the time consistent tax rate with the aim to maximise social welfare. Finally, the fourth stage hosts the firm's decision about the level of output that maximises the ECSR's objective function.

Proceeding by backward induction, we set out to examine the fourth stage. The equilibrium quantities chosen by the monopolist in the market stage of the game correspond to

$$q_i^* = \frac{m + 2\varepsilon g v(1+\beta)(z_i + z_j) - \varepsilon t}{v(4\varepsilon^2 g - \theta - 1) + 2(1+\theta)},\ i = 1, 2. \tag{17}$$

Plugging (17) into the social welfare function (8), we obtain the objective function of the time-consistent government, $SW\left(q_1^*, q_2^*\right)$, so that its problem is

$$\max_t SW\left(q_1^*, q_2^*\right) = \Pi\left(q_1^*, q_2^*\right) + CS\left(q_1^*, q_2^*\right) - D\left(q_1^*, q_2^*\right) + T\left(q_1^*, q_2^*\right). \tag{18}$$

The first order condition is

$$\frac{\partial SW\left(q_1^*, q_2^*\right)}{\partial t} = \tag{19}$$

$$\frac{2\left[t(1+\theta+4g) - 4g(1+\beta)(1+\theta)(1-v)(z_1+z_2) - m(1-v)(1+\theta-4g)\right]}{\left[v(4g-\theta-1)+2(1+\theta)\right]^2} = 0,$$

while the second partial derivative is always negative, as

$$\frac{\partial^2 SW\left(q_1^*, q_2^*\right)}{\partial t^2} = -\frac{2\varepsilon^2(1+\theta+4\varepsilon^2 g)}{\left[v(4\varepsilon^2 g - 1 + \theta) - 2(1+\theta)\right]^2} < 0. \tag{20}$$

Solving (19) with respect to t, we get:

$$t^* = \frac{(1-v)\left[4\varepsilon g(1+\beta)(1+\theta)(z_1+z_2) + m\left(4\varepsilon^2 g - 1 - \theta\right)\right]}{\varepsilon\left(4\varepsilon^2 g + 1 + \theta\right)}. \tag{21}$$

Condition $g > \widehat{g} \equiv (1+\theta)\,/\,(4\varepsilon^2)$ suffices to ensure that (21) is positive, thereby restricting the analysis to the case in which the government has an incentive in levying a tax.

In the second stage, the monopolist chooses the level of investment for green R&D for both products so as to maximise $O\left(t^*, q_1^*, q_2^*\right)$. The first order condition for i is:

$$\frac{\partial O\left(t^*, q_1^*, q_2^*\right)}{\partial z_i} = \frac{8g^2\varepsilon^3\left[\left(z_i\left(\Theta v - 2\left(\Theta + \gamma\varepsilon^2\right)\right) + z_j\Theta(v-2)\right)\right] +}{\varepsilon(1+\theta+4\varepsilon^2 g)^2} \tag{22}$$

$$+\frac{\varepsilon\left[2g(1+\theta)\left((z_i+z_j)\,\Theta\,(3v-4) + z_i\gamma\varepsilon^2\right) - z_i\gamma(1+\theta)^2\right]}{\varepsilon(1+\theta+4\varepsilon^2 g)^2}$$

$$-\frac{m(1+\beta)\left[-16g^2\varepsilon^4 + (1+\theta)v\left(4g\varepsilon^2 - (1+\theta)\right) - 8\varepsilon^2 g(1+\theta) + (1+\theta)^2\right]}{\varepsilon(1+\theta+4\varepsilon^2 g)^2} = 0,$$

where $\Theta \equiv (1+\beta)^2(1+\theta)$. The second order conditions are always verified (see the appendix).

Solving (22) with respect to z_i, one gets

$$z_i^* = \frac{m(1+\beta)\left[16\varepsilon^4 g^2 + 4\varepsilon^2 g(1+\theta)(2-v) - (1+\theta)^2(1-v)\right]}{\varepsilon\left[\gamma(1+\theta)^2 + 16\varepsilon^2 g^2\left(\Theta\left(2-v\right)+\gamma\varepsilon^2\right) + 4g(1+\theta)\left(\Theta\left(4-3v\right)-2\gamma\varepsilon^2\right)\right]}, \tag{23}$$

which is positive for $g > \widehat{g}$ (see the appendix for details).

Given the equilibrium conditions, we may evaluate the private incentives to adopt ECSR activities in the first stage, when the environmental tax is in place. To do so, we may verify whether there exists a positive level of the ECSR commitment v that maximises profits. Given the analytical complexity of the expression $\partial\Pi^*/\partial v$ and the elevated number of parameters, it is not possible to obtain an entirely analytical solution of the profit maximization problem at the contractual stage. Yet, it is possible to show that a profit-maximising choice of v requires

$$\frac{\partial^2\Pi^*}{\partial v^2} < 0 \iff \gamma \in \left(0, \widehat{\gamma}\right), \tag{24}$$

where $\Pi^* = \Pi\left(q_2^*, q_1^*, z_2^*, z_2^*, t^*\right)$, and

$$\widehat{\gamma} \equiv \frac{4g(1+\beta)^2(4\varepsilon^2 g + \theta + 1)}{4\varepsilon^2 g - \theta - 1} > 0, \tag{25}$$

for all $g > \widehat{g}$. Consequently, we may formulate the following

Lemma 3 *For any $g > \widehat{g}$, the monopolist chooses to adopt an ECSR statute if and only if $\gamma < \widehat{\gamma}$.*

Intuitively, there are private incentives to engage in ECSR activities only if the abatement technology is sufficiently efficient, which is equivalent to saying that the convex cost of green R&D must not be excessively steep.

A quick numerical example may be appropriate. Set $a = 1.1, c = 0.1$ (so that $m = 1$), $\beta = 1/5$, $\theta = 1/2$, $\varepsilon = 1$ and the two critical parameters at

$$g = 2\widehat{g} = \frac{3}{4}\,;\ \gamma = 4 < \widehat{\gamma} = 12.96. \tag{26}$$

Using these numerical values, one obtains $\partial\Pi^*/\partial v = 0$ at $v \simeq 0.348673$, with $\partial^2\Pi^*/\partial v^2 \simeq -0.0459 < 0$.[8]

Then, one may run a large number simulations, from which it is possible to engender a level of sensitivity to environmental and social concern v that maximises monopolist's profits. Additionally, Figures 1-4 report a representative sample of simulations. We set market size $m = 1$, and explore the change in the products' degree of substitutability, the level of spillovers, the cost of R&D investment and the impact of emissions on environmental damage.

Figure 1 shows that the profit maximising v decreases with the level of spillovers: this result is intuitive, considering that higher spillovers imply a lower level of R&D investment to reach a certain level of abatement. Given the relatively lower amount of R&D investment, in turn profits reach their peak in correspondence of a lower degree of ECSR commitment. Figure 2 shows that the optimal value of v also decreases as the degree of substitutability between the products increases. Indeed, the lower is product differentiation, the more the demand of one product substitutes that of the other, thereby reducing consumer surplus. A lower consumer surplus in turn curbs the incentive towards ECSR activities.

[8] The numerical values of the other relevant equilibrium magnitudes are $q_i^* \simeq 0.2912$, $z_i^* \simeq 0.1140$, $t^* \simeq 0.0172$, $\Pi^* \simeq 0.2125$, $CS^* \simeq 0.1272$, $D^* \simeq 0.0715$, and $SW^* \simeq 0.2735$.

Figure 1 Impact of β on profits, with $g > \widehat{g}$ and $\gamma < \widehat{\gamma}$; $\theta = 1/2$, $\gamma = 5$, $\varepsilon = 1$, $g = 2$, $\beta = 4/5, 3/5, 2/5, 1/5$.

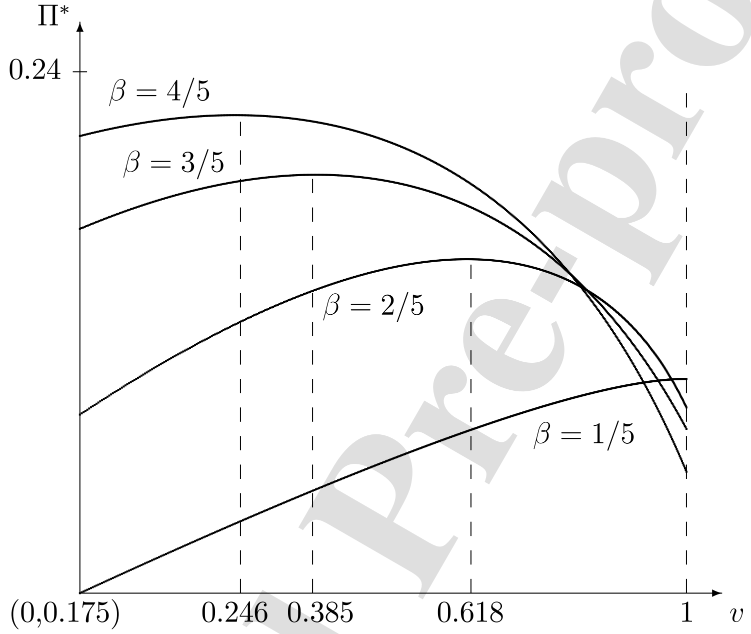
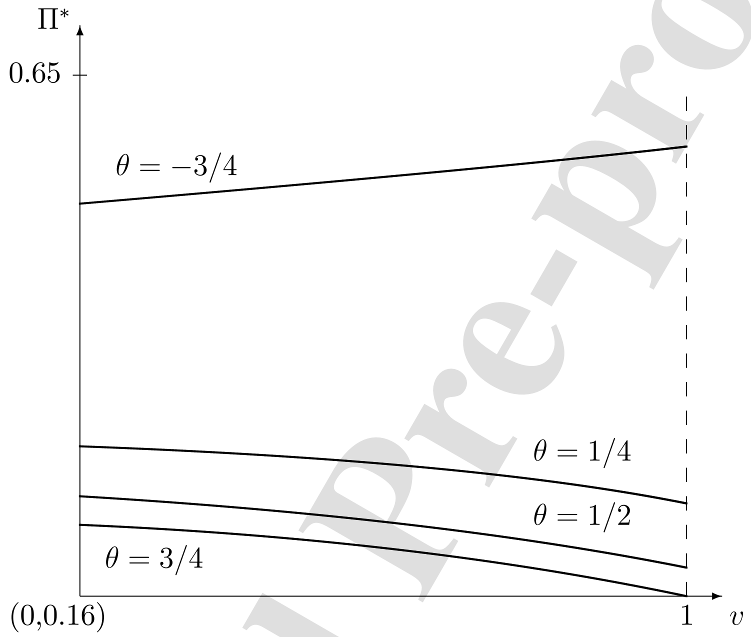


Figure 2 Impact of θ on profits, with $g > \widehat{g}$ and $\gamma < \widehat{\gamma}$;
$\beta = 4/5$, $\gamma = 5$, $\varepsilon = 1$, $g = 2$, $\theta = -3/4, 1/4, 1/2, 3/4$.



Intuitively, the profit-maximising ECSR commitment v decreases also with the cost of R&D investment in reduction emission (Figure 3), since a steeper R&D cost function reduces the firm's willingness to invest in abatement technologies, as it obviously makes ECSR activities more expensive, all else equal. Finally, the optimal level of v is increasing in the in parameter g which scales the environmental impact of emissions (Figure 4). This effect translates from the optimal unit tax t^* into profits (and their peak): stronger environmental damages engendered by polluting emissions trigger a higher tax, whose impact can be mitigated by a higher ECSR commitment.

Figure 3 Impact of γ on profits, with $g > \widehat{g}$ and $\gamma < \widehat{\gamma}$; $\beta = 4/5$, $\theta = 1/2$, $\varepsilon = 1$, $g = 2$, $\gamma = 5, 8, 12, 15$.

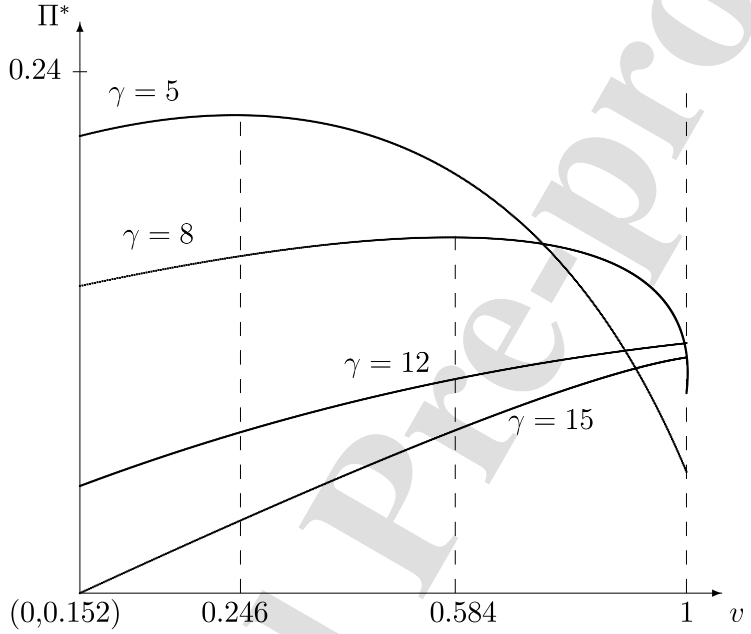
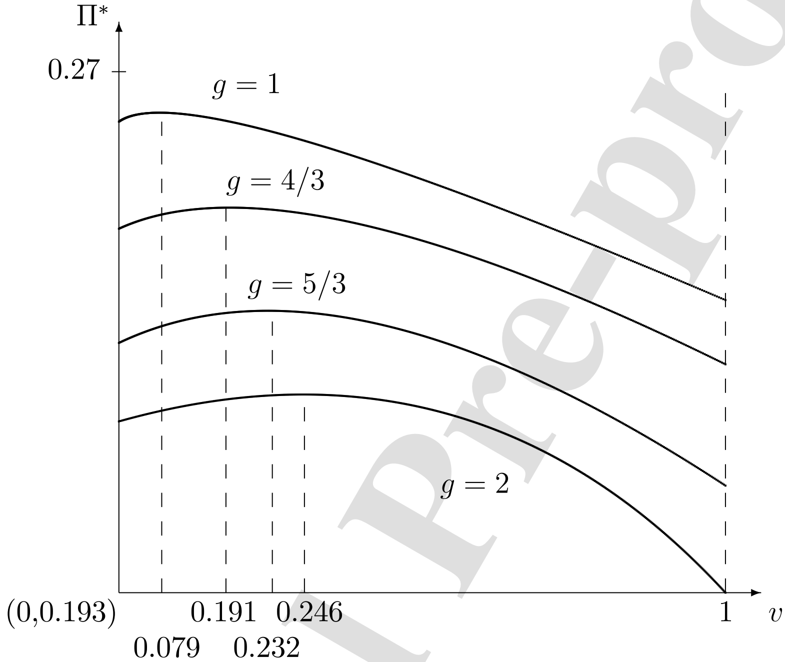


Figure 4 Impact of g on profits, with $g > \widehat{g}$ and $\gamma < \widehat{\gamma}$; $\beta = 4/5$, $\gamma = 5$, $\varepsilon = 1$, $\theta = 1/2$, $g = 1, 4/3, 5/3, 2$.



We are left with the task of determining how the social welfare level at equilibrium is influenced by the intensity of ECSR. To do so, we insert the optimal levels of the relevant variables $\{z_2^*, z_2^*, t^*, q_2^*, q_1^*\}$ into the social welfare function, in such a way that it remains defined in terms of the intensity of the ECSR incentive v and of course the vector of the model parameters. Then, differentiating welfare with respect to v, we obtain:

$$\frac{\partial SW^*(z_2^*, z_2^*, t^*, q_2^*, q_1^*)}{\partial v} = \tag{27}$$

$$\frac{2\Theta(1+\theta)m^2(1-v)\left(4g\varepsilon^2+1+\theta\right)^2\left[\gamma(1+\theta)+16(\beta+1)^2g^2\varepsilon^2+4g\left(\Theta-\gamma\varepsilon^2\right)\right]^2}{\varepsilon^2\left(\gamma(1+\theta)^2+16g^2\varepsilon^2\left(\Theta\left(2-v\right)+\gamma\varepsilon^2\right)+4g(1+\theta)\left(\Theta\left(4-3v\right)-2\gamma\varepsilon^2\right)\right)^3}>0,$$

over the whole admissible parameter range. Moreover, we may verify that the result is driven by both the increase in consumer surplus and the decrease in the environmental damage. Differentiating consumer surplus and environmental damage in equilibrium ($CS^* = CS\left(z_2^*, z_2^*, t^*, q_2^*, q_1^*\right)$ and $D^* = D\left(z_2^*, z_2^*, t^*, q_2^*, q_1^*\right)$) with respect to v yields, respectively,

$$\frac{\partial CS^*\left(z_2^*, z_2^*, t^*, q_2^*, q_1^*\right)}{\partial v} = \tag{28}$$

$$\frac{8g\Theta(1+\theta)m^2\left(4g\varepsilon^2+\theta+1\right)\left[\gamma(1+\theta)+16(1+\beta)^2g^2\varepsilon^2+4g\left(\Theta-\gamma\varepsilon^2\right)\right]}{\left(\gamma(1+\theta)^2+16g^2\varepsilon^2\left(\Theta\left(2-v\right)+\gamma\varepsilon^2\right)+4g(1+\theta)\left(\Theta\left(4-3v\right)-2\gamma\varepsilon^2\right)\right)^3}\times$$

$$\frac{\left[\gamma(\theta+1)+16(1+\beta)^2g^2\varepsilon^2+4g\left(\Theta\left(3-2v\right)+\gamma\varepsilon^2\right)\right]}{\left(\gamma(1+\theta)^2+16g^2\varepsilon^2\left(\Theta\left(2-v\right)+\gamma\varepsilon^2\right)+4g(1+\theta)\left(\Theta\left(4-3v\right)-2\gamma\varepsilon^2\right)\right)^3}>0,$$

for all $\gamma < \widehat{\gamma}$, and

$$\frac{\partial D^*\left(z_2^*, z_2^*, t^*, q_2^*, q_1^*\right)}{\partial v} = -8m^2g\Theta\left(1+\theta\right)\left(4g\varepsilon^2+1+\theta\right)^2\times \tag{29}$$

$$\frac{\left[\gamma(1+\theta)+16(1+\beta)^2g^2\varepsilon^2+4g\left(\Theta-\gamma\varepsilon^2\right)\right]\left[\Theta\left(1-v\right)+\gamma\varepsilon^2\right]}{\varepsilon^2\left(\gamma(1+\theta)^2+16g^2\varepsilon^2\left(\Theta\left(2-v\right)+\gamma\varepsilon^2\right)+4g(1+\theta)\left(\Theta\left(4-3v\right)-2\gamma\varepsilon^2\right)\right)^3}<0,$$

for all $\gamma < \widehat{\gamma}$. On this basis, we can state

Proposition 4 *In a multiproduct monopoly with multiple R&D labs, social welfare increases with the degree of ECSR, driven by both the increase in social surplus and the decrease in environmental damage.*

Proposition 4 shows a few findings differing from those engendered by the analysis of a single-product monopoly with no technological spillovers.

In particular, Fukuda and Ouchida (2020) find that polluting emissions (and, in turn, the environmental damage) may either increase or decrease with the degree of ECSR according to whether the efficiency of abatement technology is high or low, respectively (see their Proposition 2, p. 6).

Furthermore, Wang (2021), in a different setting in which the government must be able to precommit itself, finds out that an increase in the degree of ECSR increases the environmental damage (Proposition 2, p.11). Notice that these findings imply that adopting an ECSR statute may indeed be harmful for the environment in single product monopolies in which the emission abatement technology is inefficient.

This is not confirmed here: an increase in the level of ECSR activities - as far as this is compatible with stockholders' incentives - is systematically beneficial for the environment *under a time consistent taxation policy*. The result stated in Proposition 4 is driven by the presence of spillovers in the emission reduction process among the two product varieties, which makes it cheaper to abate emissions in equilibrium and compensates the increase in equilibrium quantity (associated with the increase in consumer surplus as v increases) which would in itself imply a larger volume of emissions.

Summing up, both Fukuda and Ouchida (2020) and Wang (2021) identify the possible emergence of an increase in GHG emission seemingly driven by an increase in the intensity of ECSR in models where such magnitude is parametric and, in Wang (2021), emission taxation is time inconsistent. If one formulates the model with a timing allowing for time consistency, and the extent of ECSR is endogenised as a strategic variable, what would appear as a potential problem indeed fades away. By the way, with the addendum of the presence of two R&D labs, the setup in Fukuda and Ouchida (2020) can be reconstructed by posing $\theta = 1$ in order to treat the case of product homogeneity (although with two labs), to reproduce (25) and the related implications about the inner optimum of the monopolistic firm.

Having said that, a few additional consideration can be added concerning the factual implementation of a consistent tax policy like the one envisaged here. The scenario would be one in which the policymaker credibly announces the introduction of the optimal tax corresponding as much as possible, given the available information, to its optimal level if decided after firms have invested in R&D correctly anticipating that tax. The alternative sequence, in which the regulator announces the tax and then introduces it, thereby inducing firms to react by investing in green R&D, would be inconsistent precisely because there would exist an incentive to design the tax anew after firms have committed themselves (and before they set the relevant market variable, which as a result would also be affected by time inconsistency). And all of this holds irrespective of whether firms are entrepreneurial, managerial or (E)CSR.

As a final complement to this discussion, it is also appropriate to dwell upon the fact that Proposition 4 sets out mentioning explicitly the multiproduct and multiplant structure of the firm, to note a relevant aspect, which has both industrial and policy implications. The presence of more than one R&D division or lab, with knowledge transfers via spillovers, is not necessarily associated with the supply of differentiated products, although one could reasonably identify the need of product-specific investments behind this modelling choice. In fact, the rationale is simply the opportunity to diminish the maximum marginal R&D cost borne by the firm via parcelisation and investment smoothing, for any level of spillovers, including the case in which no spillover takes place at all. Having said that, going back to Lemma 3 and looking at the expression of $\widehat{\gamma}$ in (25), one easily verifies that $\partial\widehat{\gamma}/\partial\beta > 0$ for all $g > \widehat{g}$. Together with the positive effect of spillover on equilibrium profits, as Figure 1 illustrate, this implies the following

Remark 5 *The decision to go multilab smooths R&D costs and triggers a spillover mechanism which boosts profits and expands the parameter range wherein the incentive to become an ECSR firm exists.*

The intuition behind this result is that, from the firm's standpoint, increasing β looks pretty much like decreasing the steepness of the R&D cost function, making it more plausible that the crucial condition $\gamma < \widehat{\gamma}$ be satisfied. Should the firm (irrational, one might say at this point) activate a single lab, a plausible alternative for the government would be to subsidise green R&D, possibly using a portion of the income generated by the emission tax itself, which could instead be used for some other purpose.

3 Concluding remarks

We have analysed the private and public incentives to introduce Environmental Corporate Social Responsibility activities in a multiproduct monopoly. We have considered a framework with horizontally differentiated products and polluting emissions generated by production. The government adopts a time-consistent tax on emissions, while the ECSR monopolist may invest in emission reduction R&D to mitigate the tax burden.

In line with a consolidated result in the theory of managerial firms based on strategic delegation, our results show that there are no private incentives to engage in ECSR unless a tax on emissions is present in the industries. The private incentive emerges with the introduction of the tax, and changes according to the features of the economy. From the standpoint of social efficiency, we have found that the adoption of ECSR increases social welfare through the increase of consumer surplus and the decrease of environmental damage. Hence, in contrast with the conclusions for single product monopolies from the literature, our policy implications favour the adoption of ECSR activities in monopolistic, multiproduct industries.

Of course, this analysis could be extended in several directions. In this paper, we have set aside consumers' sensitivity to environmental issues. Allegedly, environmental concern by consumers may provide a further incentive to the monopolist to engage in ECSR activities in absence of environmental regulation. Another possible and relevant extension of this work may take into account R&D investments for proper cleaner production rather than end-of-pipe reduction emissions. More explicitly, investment could be directed at the attainment of replacement (or backstop) technologies rather than abatement ones. And any replication of the above results in this alternative scenario would obviously imply a thoughtful comparative assessment of the features of the optimal tax as against the one emerged from the model presented in this paper, in order to outline robust policy implications and prescriptions. Last but not least, one might also look at an analogous perspective hinging upon other instruments contained in the policymaker's toolkit, like environmental standards and the costly allocation of emission quotas, i.e., emission trading systems. All of this is left for future research.

Acknowledgements

We would like to thank three anonymous referees for helpful comments. The first author gratefully acknowledges funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101037193, "I-CHANGE". The paper reflects the author's views. The European Commission is not responsible for any use that may be made of the information it contains.

Declaration of interest

The authors have no conflicting interest to declare. Please see the Acknowledgements, concerning the first author's participation in the EU H2020 "I-CHANGE" project.

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Appendix

Second order conditions in the first stage

Here, we verify the second order conditions of the monopolist's problem in the first stage. The Hessian matrix is:

$$\mathcal{H} = \begin{pmatrix} \dfrac{\partial^2 O}{\partial z_1^2} & \dfrac{\partial^2 O}{\partial z_1 \partial z_2} \\ \dfrac{\partial^2 O}{\partial z_2 \partial z_1} & \dfrac{\partial^2 O}{\partial z_2^2} \end{pmatrix}, \tag{30}$$

where

$$\frac{\partial^2 O}{\partial z_1^2} = \frac{\partial^2 O}{\partial z_2^2} = \tag{31}$$

$$-\frac{16\varepsilon^2 g^2 \Theta + \gamma \left(1+\theta+4g\varepsilon^2\right)^2 + 8g\Theta(1+\theta)(1-v) - 2gv\Theta\left(4\varepsilon^2 g - 1 - \theta\right)}{\left(1+\theta+4g\varepsilon^2\right)^2}$$

$$\frac{\partial^2 O}{\partial z_1 \partial z_2} = \frac{\partial^2 O}{\partial z_2 \partial z_1} = \tag{32}$$

$$-\frac{2\left(1+\beta\right)^2 g(1+\theta\left[4g(2-v)+(1+\theta)(4-3v)\right]}{(1+\theta+4g)^2}$$

At a first glance, the expression in (32) appears to be negative, while that in (31) is negative whenever

$$6\varepsilon^2 g^2 \Theta + \gamma\left(1+\theta+4g\varepsilon^2\right)^2 + 8g\Theta(1+\theta)(1-v) > 2gv\Theta\left(4\varepsilon^2 g - 1 - \theta\right). \tag{33}$$

Defining $\alpha \equiv \varepsilon^2$, we rewrite the above inequality as follows,

$$
\begin{aligned}
&16\alpha^2\gamma g^2 + \alpha\left(16\Theta g^2 - 8\Theta g^2 v + 8\gamma g\theta + 8\gamma g\right) \\
&+8g\Theta(\theta+1)(1-v) + 2gv\Theta + 2g\theta v\Theta \\
&+\gamma\theta^2 + 2\gamma\theta + \gamma > 0
\end{aligned} \tag{34}
$$

which is convex in α and therefore positive for values of α external to the interval identified by

$$
\alpha_{\pm} = \frac{-g\Theta(2-v) + \gamma(1+\theta) \pm \sqrt{g\Theta(1+\theta)\left((1+\beta)^2 g(2-v)^2 - 4\gamma(1-v)\right)}}{4\gamma g} \tag{35}
$$

While α_- is clearly negative, it can be ascertained that α_+ is also negative provided

$$
\begin{aligned}
&\left(g^2\Theta(2-v) + \gamma g(1+\theta)\right)^2 > g^3\Theta(1+\theta)\left((1+\beta)^2 g(2-v)^2 - 4\gamma(1-v)\right) \\
&\Leftrightarrow \gamma g^2(1+\theta)^2\left[\gamma + 2(1+\beta)^2 g(4-3v)\right] > 0
\end{aligned} \tag{36}
$$

which is always true.

The determinant of the Hessian Matrix in (30) is

$$
\begin{aligned}
\det\mathcal{H} = \frac{\gamma}{(1+\theta+4\varepsilon^2 g)^2}\times \\
\gamma(1+\theta)^2 + 16g^2\varepsilon^2\left[\Theta\left(2-v\right) + \gamma\varepsilon^2\right] + 4g(1+\theta)\left[\Theta\left(4-3v\right) + 2\gamma\varepsilon^2\right] > 0
\end{aligned} \tag{37}
$$

Since $\partial^2 O/\partial z_i^2$, $i = 1, 2$, is always negative and the above determinant is always positive, the solution of the optimisation problem solved by the firm at the second stage delivers a maximum across the whole admissible parameter space.

Positivity of the optimal R&D effort

In order for z_i^* to be positive, its numerator and denominator must have the same sign. To begin with, we take a look at the denominator, denoted as

$$den = \varepsilon\left[\gamma(1+\theta)^2 + 16\varepsilon^2 g^2\left(\Theta\left(2-v\right)+\gamma\varepsilon^2\right) + 4g(1+\theta)\left(\Theta\left(4-3v\right)-2\gamma\varepsilon^2\right)\right]. \quad (38)$$

This is a quadratic function of g and, since the coefficient of the quadratic component is positive, it is convex in the environmental damage coefficient. Hence, $den > 0$ for all levels of g outside the interval of the roots of $den = 0$, which are

$$g^{den} = -\frac{(1+\theta)\left[\Theta(4-3v)+2\varepsilon^2\gamma \pm (1+\theta)\sqrt{\Theta\left[8\left(2\Theta+\gamma\varepsilon^2\right)+\Theta v\left(9v-24\right)-8v\gamma\varepsilon^2\right]}\right]}{8\varepsilon^2\left[\gamma\varepsilon^2+\Theta(2-v)\right]}. \quad (39)$$

Simple algebra suffices to show that both roots are negative, and therefore the denominator is positive for all $g > 0$.

Checking the numerator, there emerges that it is also quadratic in g, and may be written as

$$num = m(1+\beta)\left[16\varepsilon^4 g^2 + 4\varepsilon^2 g(1+\theta)(2-v) - (1+\theta)^2(1-v)\right], \quad (40)$$

where again the coefficient of the quadratic component is positive, and the roots of $num = 0$ are

$$g_{\pm}^{num} = -\frac{(1+\theta)}{8\varepsilon^2}\left(2 - v \pm \sqrt{v^2 - 8v + 8}\right). \tag{41}$$

At a first glance, g_{+}^{num} is always negative, while g_{-}^{num} turns out to be positive after simple computation. Comparing g_1^{num} with $\widehat{g}$, we obtain

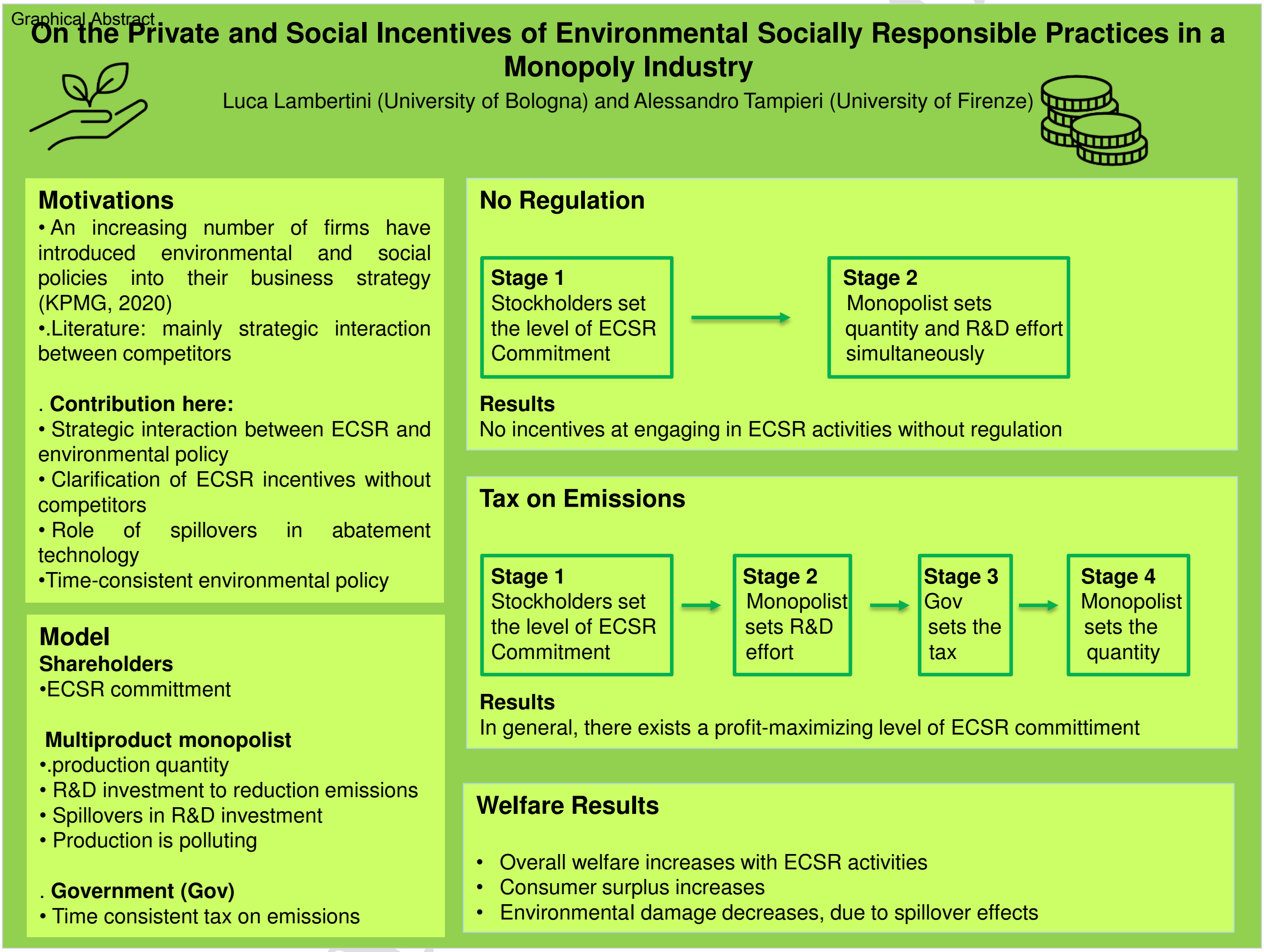
$$\widehat{g} - g_1^{num} = \frac{1}{8\varepsilon^2}(1+\theta)\left(4 - v - \sqrt{(v-8)v + 8}\right) > 0. \tag{42}$$

Therefore, $g > \widehat{g}$ is a sufficient condition for R&D investment to be positive in equilibrium.

Highlights

- We study the interplay between environmental social responsibility (ECSR) and a tax on emissions
- We consider a multiproduct monopolist smoothing its investment in emission abatement over multiple R&D labs.
- Spillovers operate across labs, boosting emission abatement.
- First, we prove that, without regulation, there is no incentive to adopt a ECSR stance.
- With regulation, we identify parametric conditions for the existence of a profit-maximising level of ECSR.
- ECSR monotonically decreases the environmental damage and increases consumer surplus and welfare, thanks to technological spillovers.

Graphical Abstract



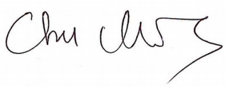
CRediT authorship contribution statement

Luca Lambertini: Conceptualization, Formal analysis, Methodology, Writing – original draft, revision. Alessandro Tampieri: Conceptualization, Formal analysis, Methodology, Writing – original draft, revision.

Declaration of interest

The authors have no conflicting interest to declare. Please see the ackowledgements, concerning the first author's participation in the EU H2020 "I-CHANGE" project.

On behalf of both authors,



Luca Lambertini (corresponding author)

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