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Corporate Social Responsibility: a theory of the firm revisited with environmental issues

Domenico Buccella • Luciano Fanti • Luca Gori

Abstract The Corporate Social Responsibility (CSR) theory of the firm states that, in strategic markets, social actions lead to a prisoner's dilemma. This paper develops a model with pollution externalities and environmental taxation to incentivise firms' abatement activities through green R&D investments. When the firms' objective function embed environmental issues (Environmental CSR, $ECSR$), a large spectrum of Nash equilibria emerges, from the Pareto inefficient to the Pareto efficient ($ECSR, ECSR$), depending on social concern and product differentiation degree. The time (in)consistency policy affects the endogenous market structure of the $ECSR$ decision game more than in the standard CSR without abatement and taxation.

Keywords Abatement, Corporate Social Responsibility, Duopoly, Emissions tax

JEL Classification H23, L13, M14, Q58

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1. Introduction

In the last decades, engagement in Corporate Social Responsibility (CSR) has emerged as a dominant global business practice. This is generally the result of two main forces. On one hand, the expectations of the public audience and the overall society for business are rising. As McKinsey (2019) reports, customers' interest in being informed about companies' engagement in environmental and social issues has grown; customers also strongly believe that companies have a responsibility on those subjects. On the other hand, a global survey of 350 business leaders conducted by Deloitte (2019) (in collaboration with Forbes) reveals that business leaders are deeply convinced of the companies' role of stewards of society, and they are planning to engage more on societal-impact issues in the next future. Amongst the areas of intervention in which businesses focus their societal impact, climate change ranks high in the business leaders' strategy agendas (4th place) (Deloitte, 2019). A rationale for this is the growing worries in worldwide public opinion due to the climate scientists' call for immediate action to reduce greenhouse gas emissions which can have a deep impact on future global and local politics as well as economics (see "The climate issue" and "COP-out", The Economist, 2019, 2021).

In the recent past, companies have embraced to a greater extent measures concerned with environmental protection such as carbon emission reduction. KPMG (2022) documents that the G250 Fortune Index's global rate of carbon reporting is 80 per cent: in 2015 the percentage was 58 per cent, in 2017 the percentage was 67 per cent, in 2020 the figure was 76 per cent. Among the 15 surveyed industries in 2022, rates range from 60 per cent (healthcare) to 89 per cent (telecommunication, media and technology). At the same time, the KPMG N100 survey (the list of the top 100 companies in 58 selected countries) reveals that in, a large subset, the percentage of companies that discloses carbon reduction targets increased from 50 per cent in 2017 to 65 per cent in 2020, and 71 per cent in 2022 (KPMG, 2015, 2017, 2020, 2022). Moreover, most of the biggest global companies have set targets to commit to procuring 100 per cent of their electricity from renewable sources (KPMG, 2019).

Furthermore, in 2017 a minority of the companies (only 37 per cent of a subset of the N100 and 31 per cent of a subset of the G250) disclosed carbon targets linked them to external targets such as the Paris Agreement goal to limit global warming (the most popular target), nowadays a majority does (55 per cent in 2020 for both N100 and G250 and 73 per cent for N100 and 82 per cent for G250 in 2022). This reveals the increasing responsiveness of businesses toward the climate crisis as well as the global, regional and national targets that have been established to prevent climate calamities. It also suggests that a substantial part of the businesses that disclose carbon targets, now acknowledge the necessity to give their contribution in making efforts to cut emissions. Nonetheless, it is worth remarking that those figures represent just 41 per cent of the entire 5,800 companies included in the global N100 group, and 63 per cent of the entire global G250 group (KPMG, 2020, 2022). This suggests that there is still space for policy interventions to calibrate firms' environmental targets with those programmed by public authorities.

A large body of literature analyses environmental issues in economic models, varying from growth and development to strategic competitive markets. This article focuses precisely on the latter aspect, embedding in it the CSR theory of the firm.

Scholars have studied CSR from different perspectives in the economic literature. Garriga and Melè (2004) argue that there are several approaches to defining the concept of CSR, related to one of the following social aspects: economics, politics, social integration, and ethics. A general definition of CSR is a "company's verifiable commitment to operating in an economically, socially, and environmentally sustainable manner that is transparent and increasingly satisfying to its stakeholders" (Katsoulakos et al., 2004). Looking closer at the economic issues, which are the most relevant for our

analysis, this work concentrates on the so-called adoption of "strategic CSR" (Baron, 2001, p. 17), i.e., "a profit-maximizing strategy that some may view as socially responsible".[1]

The rationale for studying strategic CSR is that this can be a valuable theoretical result in the presence of a government designing and implementing a regulation when firms take CSR actions. Crifo and Forget (2015), Kitzmueller and Shimshack (2012), and Schmitz and Schrader (2015), among others, are outstanding surveys on CSR, explaining the concept of strategic CSR as well. Nonetheless, in oligopolistic markets in which governments set environmental regulations, the impact of firms' strategic choice to engage in CSR on welfare and environmental externalities is barely discussed.

Starting from a simple context in which firms produce homogenous goods at a single production plant (see, for example, Simpson 1995; Katsoulacos and Xepapadeas 1996; Carlsson 2000), at present a vast body of literature on environmental policy exists which has broadened the analysis to various market conformations.

The first line of this literature studies strategic environmental policy in an international context. Scholars investigate the countries' strategic behaviour in setting environmental taxes unilaterally or cooperatively. The ground-breaking contribution is Ulph (1996) who, considering imperfectly competitive markets, studies a strategic environmental policy in an international trade context. In a recent paper, Hambel et al. (2018) suggest an innovative theoretical framework in which the problem of optimal carbon abatement is analysed in a dynamic non-cooperative game with multiple open economies. Moreover, numerous contributions investigate the impact of coordination of environmental taxation on market competition, and its effect on social welfare (e.g., Conrad 1993, 1996a,b; Kennedy, 1994; Bárcena-Ruiz and Campo, 2012; Bárcena-Ruiz and Garzón, 2014).

A second line of the literature studies the strategic interaction between environmental policy and the endogenous location of polluting firms (see e.g., Rauscher 1995; Markusen et al. 1993; Markusen 1997; Bárcena-Ruiz and Garzón, 2003).

A third line of the literature develops the basic oligopoly framework introducing on the one hand managerial delegation (see e.g., Bárcena-Ruiz, 2002; Pal, 2012; Park and Lee, 2023), and on the other hand, labour unions (Bárcena-Ruiz, 2011; Bárcena-Ruiz and Garzón, 2009). More specifically, Park and Lee (2023) analyse a managerial delegation model with green R&D including two explicit incentive-based executive compensation contracts. They propose a managerial retribution scheme which combines environmental and sales delegations and show that (i) the incentives are higher than those under a single incentive retribution scheme, (ii) firms' output and their abatement efforts are higher, (iii) overall emissions are lower, and (iv) a firm's profits are higher than that under a sales delegation. Consequently, to set up an emission tax policy, together with firms' compensation packages related to environmental delegation, can curb market failures and improving welfare.

A fourth line of the literature studies the link between environmental policies and market structures. The ground-breaking works in this field are Lee (1975) and Smith (1976), who show that market structures have an important effect on the efficiency of environmental taxation; however, several scholars have revisited this subject (see Oates and Strassmann, 1984; Conrad and Wang, 1993; Lee, 1999; Althammer and Bucholz, 1999; Cato, 2010). Lambertini et al. (2017) study the relationship between competition and innovation in an industry in which production is polluting, and firms invest in R&D activities to reduce emissions with both exogenous and endogenous emissions taxes.

Finally, a fifth line of the literature includes a set of works that incorporates firms engaging in CSR activities in either a monopolistic (Fukuda and Ouchida, 2020; Wang, 2021; Li and Wang, 2022) or oligopolistic framework with an emission regulation model (Lambertini and Tampieri, 2015; Garcia et al., 2018; Xu and Lee, 2018; Bárcena-Ruiz and Sagasta, 2022; Bárcena-Ruiz et al., 2023).[2]

[1] On this approach to firms' CSR, see also the contributions of Fanti and Buccella (2017a, 2017b) and Planer-Friedrich and Sahm (2020, 2021).

[2] Hirose et al. (2017), Lee and Park (2019), and Hirose and Matsumura (2022) in Cournot polluting oligopolies, and Wang (2022) in a bilateral monopoly study the behaviour of firms engaging voluntarily in emission reduction via environmentally CSR actions in the absence of environmental taxation.

In a monopoly model in which the government sets a time-consistent emissions tax, Fukuda and Ouchida (2020) study the effect of CSR adoption on social welfare and the environment. CSR activities, which consist of environmental concerns and consumer friendliness, always increase social welfare. The authors also show that if the environmental damage is significant and abating pollution is not highly efficient, then a profit-maximizing monopolist is incentivized to undertake CSR actions to increase net profits. However, in contrast to the lieu common, CSR can lead to higher emissions.

Wang (2021) also studies a monopoly in which the firm engages in CSR, product differentiation and environmental R&D. The author shows that advances in environmental R&D technology improve social welfare but profits decrease. On the other hand, more CSR leads to higher R&D and welfare: profits improve but the environmental damage increases. Finally, product differentiation increases profit, environmental R&D, and welfare but increases environmental damage and harms consumers. Li and Wang (2022) develop a dynamic monopoly model in which the government sets an emission tax to analyze the effects of environmental CSR on investments in green products and process innovation. The authors show that environmental CSR increases the steady-state investments of green products and process innovation only when the monopolist attaches a large weight to pollution, while in the long term, CSR does not affect the complementarity (substitutability) relationship between green products and process innovation. The government, to achieve a socially optimal investment in green product innovation, should press the monopolist to take care more of the environment than of consumers.

About oligopoly frameworks, Lambertini and Tampieri (2015) study a polluting Cournot oligopoly in which a CSR firm, which internalizes its share of pollution and takes care of the consumer surplus, operates in the market. The authors show that, regardless of the presence of a socially optimal environmental tax, the CSR firm earns higher profits than its profit-seeking competitors when the market is adequately large, leading to higher social welfare.

The timing of environmental policies in a Cournot duopoly with a consumer-friendly firm and an abatement technology is the subject of the work of Garcia et al. (2018). The authors compare two market-based regulatory instruments, tradable permits and emissions tax regulations, and show that, when the government can credibly commit its policy, the equilibrium outcomes under both policies are identical in terms of permits price and tax rate. However, under the non-committed policy, this equivalence no longer holds. Firms have opposite incentives to induce time-consistent policy to be adjusted ex-post: under the permits policy, the profit-maximizing firm cuts less emission to induce higher emission quotas; under the tax policy, the CSR firm cuts more emissions to reduce the tax rate. The environmental tax leads to higher welfare and lowers environmental damage unless the social concern is adequately high.

In Cournot markets with endogenous entry, Xu and Lee (2018) study the impact of CSR on environmental taxation and welfare. They show that the optimal tax under free entry is higher than under blockaded entry, and it is higher than marginal environmental damage. From the perspective of socially optimal CSR, higher taxation is socially excessive. However, pollution abatement decreases the size of the optimal tax and improves both environmental damage and overall welfare.
In an international Cournot duopoly, Bárcena-Ruiz and Sagasta (2022) study the incentives to engaging in environmental CSR and show, without environmental taxes, that firms do not adopt environmental actions. However, when governments levy environmental taxes, firms engage in $ECSR$ the damage is local, which turns out to be beneficial for consumers, producers, and environmentalists. Under global damage (transboundary pollution), firms adopt environmental CSR only if highly concerned about the environment: transboundary pollution disincentives firms' environmental actions. In the case of governments cooperatively determining environmental taxes, firms engage in $ECSR$ under both local and global damage: their cooperation on environmental policies provides firms with greater incentives to be environmentally oriented.

Bárcena-Ruiz et al. (2023) analyze how firms in a duopoly organize and perform R&D to reduce their pollution levels in the presence of emission taxes when engage in environmental CSR, represented by the inclusion of the environmental damage they generate in their objective function.

Whether firms set up an environmental research joint venture (with or without R&D coordination and knowledge disclosure) crucially depends on the degree of their environmental concern. Social welfare is the highest and environmental damage the lowest when firms form a research joint venture and coordinate R&D investments; however, the firms' organization of green R&D does not always lead to the most socially preferable outcome.

Xing and Lee (2023a) consider a polluting managerial Cournot duopoly within a managerial and analyze conflicting environmental concerns in which the owners pursue strategic environmental CSR while managers undertake diverged environmental R&D investment. The authors find that managerial coordination has a critical effect on industry emissions, profits, and welfare. With an optimal emissions tax, managerial coordination failure might not happen; however, this reduces welfare if the environmental damage is relatively high. A pro-environmental government should incentivise cooperative green R&D, especially when owners cooperatively engage in environmental CSR.

The main goal of this article is to contribute further to the last branch of the literature discussed so far. In doing so, the work develops a multi-stage non-cooperative *Environmental CSR or ECSR decision game* with complete information, in which abating firms choose endogenously the market structure, i.e., they face the binary choice to be $ECSR$ or profit maximisers (PM) at stage one (*the $ECSR$ decision-making stage*). Then, the timing of the game changes depending on the regulator's (in)ability to commit to an emissions tax (no commitment or full commitment). The regulator's ability to commit to an environmental policy greatly affects the sub-game perfect Nash equilibria (and then the endogenous market structure) emerging in the $ECSR$ decision game.

The articles most closely related to ours are Lambertini and Tampieri (2015), Fanti and Buccella (2017a) and Xing and Lee (2023b). The present contribution is also in line with some of the environmental issues recently analysed and discussed by Lee and Park (2021) and Xu et al. (2022) about no commitment and full commitment of the regulator through environmental taxation in models without and with $ECSR$, respectively.

Unlike Lambertini and Tampieri (2015), who show – in an environment without negative pollution externalities and abatement – that CSR firms always obtain higher profits than PM firms, the present article pinpoints the existence of a wide range of sub-game perfect Nash equilibria leading to different scenarios in which firms have an incentive to play or not to play the $ECSR$ strategy depending on the ability of the regulator to credibly commit to an emissions tax rate.

Under no commitment, the $ECSR$ strategy allows to reach the highest possible outcomes for firms and society, but it is anti-green. This is because the aggregate environmental damage at the equilibrium is larger than that observed under the PM strategy. Under full commitment, instead, the $ECSR$ behaviour allows to reach the highest possible social welfare, and it is pro-green by reducing the aggregate environmental damage in comparison with the PM strategy when products are poorly substitutes!

The remainder of the article is organised as follows. Section 2 introduces the basic Cournot model with heterogenous products à la Singh and Vives (1984) with abating firms and then discusses the key ingredients by also clarifying the role of the environmental regulator in setting a time (in)consistent policy and then its (in)ability to commit to an emissions tax. Section 3 (resp. 4) considers the case of no commitment (resp. full commitment) and presents the related sub-game perfect Nash equilibria of the $ECSR$ decision game and the related welfare analysis. Section 5 discusses the differences amongst the endogenous Nash equilibrium outcomes emerging in the $ECSR$ decision game with that observed in the standard CSR decision game without environmental issues (Fanti and Buccella, 2017a) and concentrates also on the analysis of social welfare. Section 6 concludes.

2. $ECSR$ and abatement: the model

Consider a Cournot duopolistic industry in which firm i and firm j produce goods q_i, and q_j, respectively. The current technology allows firm i ($i = \{1,2\}$; $i \neq j$) to produce q_i units of output causing e_i units of emissions (pollution), i.e., $e_i = q_i - k_i$, where $0 \leq k_i < q_i$ is the abatement effort (i.e., the pollutant abated per q_i units of output) resulting from a cleaning technology available to each firm through green R&D effort, implying that emissions cannot be entirely eliminated (Ulph, 1996; Buccella et al., 2021). Firm i produces with a technology displaying constant (marginal) returns to labour. Therefore, the production function is linear and given by $q_i = L_i$, where L_i is the labour force that firm i is employing. Both firms face the same (constant) average and marginal cost $0 \leq w < 1$ (representing the wage per unit of labour) for each unit of output. This implies that firm i's cost function is $C_i = wL_i = wq_i$. The cost function for abating purposes is $CA_i(k_i) = \frac{z}{2}k_i^2$ (end-of-pipe), where z is a positive (exogenous) technological parameter measuring the efficiency the abating R&D technology (the lower z, the higher the efficiency of the abatement technology). This kind of cleaning technology allows the firm to sustain costs with decreasing returns to investment such as, for example, a cleaning technology not directly related to production like "the number of the filters in a refinery's pipe for CO_2 reduction or 'scrubbers' to remove of SO_2 from a fuel gas coal fired electric plant" (Asproudis and Gil-Moltó, 2015, p. 169), and advanced technologies to capture carbon, use, and storage (CCUS) to reduce emissions to draw down CO_2 levels in the atmosphere (McKinsey, 2020).

The index $ED = \frac{g}{2}(e_i + e_j)^2$ measures the aggregate environmental damage that industrial production generates, where g is a positive (exogenous) parameter measuring the public awareness towards a clean environment (the higher g, the higher the weight of the environmental damage as measured by the public authority and then the larger importance of having a clean environment). This index is commonly used in the literature and implies that the environmental damage is (i) a convex function of total pollution and (ii) exogenous on the side of consumers (see, e.g., van der Ploeg and de Zeeuw, 1992; Ulph, 1996). To keep the model as simple as possible and avoid unnecessary analytical complications, we assume henceforth that $z = g = 2$ without loss of generality.

The environmental regulator (government) aims at maximising social welfare by setting an emissions tax at the rate $t \in [0,1)$ per-unit of polluting output to incentivise firms to undertake emission-reduction actions through the green R&D technology. Therefore, firm i's tax base is e_i, and the associated tax revenue is te_i. This implies that pollution abatement allows for tax savings on the firm side. The government can be able or unable to commit to the use of the environmental tax instrument (to tax firms' emissions) in a credible way. When the government can pre-commit on the effect of environmental tax instrument, firms may change the current level of abatement if they are able to know that the policy will be strict. Through a commitment to a future tax policy, the government can therefore affect the firm's decision about the current abatement effort. In this case, the environmental tax rate is chosen once firms have invested in abatement, so that the policy is time consistent (e.g., Petrakis and Xepapadeas, 1999, 2003). When the government cannot pre-commit on the effect of environmental tax instrument, there is no way to affect the firm's decision about the current abatement effort. In this case, the environmental tax rate is chosen before firms invest in abatement, so that the policy is not time consistent (e.g., Poyago-Theotoky and Teerasuwannajak, 2002, who study both cases of full commitment and no commitment).[3]

Following Singh and Vives (1984), the linear (inverse) demand of firm i for horizontally differentiated products is $p_i = 1 - q_i - dq_j$, where p_i denotes the price of the product of variety i and $-1 < d \leq 1$ is the degree of product differentiation (see also Amir et al., 2017, and Choné and Linnemer, 2020). Positive (resp. negative) values of d refer to product substitutability (resp. complementarity). If $d = 0$, products are totally differentiated; i.e., each firm acts as a monopolist in each market. The case $d = 1$ (resp. $d = -1$) refers to perfect substitutability or homogeneous

[3] See also Lee and Park (2021) and Xu et al. (2022).

products (resp. perfect complementarity). The lower d, the higher product differentiation (as perceived by consumers) and the higher the market power of each firm.

Combining the elements discussed so far, profits of the abating firm i are $\Pi_i = (1 - q_i - dq_j)q_i - te_i - k_i^2$. In this context, every abating firm chooses strategically to be either Environmental Corporate Socially Responsible ($ECSR$) or Profit Maximising (PM).

Following recently established literature (e.g., Goering 2007, 2008; Lambertini and Tampieri, 2010, 2012; Kopel and Brand, 2012; Kopel et al., 2014; Lambertini et al., 2016; Fanti and Buccella, 2017a, 2017b, 2018; Planer-Friedrich and Sahm, 2020),[4] we assume that the firm's social concern includes the consumer surplus (CS), which is defined as $CS = \frac{1}{2}(q_i^2 + q_j^2 + 2dq_iq_j)$. Being responsive toward CS is a key feature of a CSR firm: in the standard theory of the firm, each CSR player maximises profits plus the consumer surplus its stakeholders accrue. In addition, as this work brings together CSR and environmental issues, we also follow Lambertini and Tampieri (2015) by assuming that firms integrate social and environmental damages in their objectives. This allows us to define an objective function for the CSR firm including a weighted measure of consumer surplus net to the environmental damage ($ECSR$). Therefore, the $ECSR$ firm's objective function may be specified as a simple parameterised combination of profits, consumers' surplus and environmental damage (Fukuda and Ouchida, 2020). Following a burgeoning literature (e.g., Kopel and Brand, 2012; Lambertini et al. 2016; Lambertini and Tampieri, 2012, 2015; Planer-Friedrich and Sahm, 2020), we assume that firms in the duopoly industry weight equally the net social concerns in their objectives. Thus, the $ECSR$ firm i's objective function is:

$$V_i = \Pi_i + b(CS - ED), \tag{1}$$

where $b \in [0,1]$ denotes the exogenous[5] weight that the $ECSR$ firm attaches to net the social concern. This follows Kreps (1990) according to which a corporate goal can directly enter the firm's objective function in addition to profit by changing the behaviour of the firm that can then be seen as an entity non necessarily profit-driven though profits should remain positive. The larger b, the higher the importance of social issues in the firm's objective. Goering (2007, 2008) assumes that this objective function can be applied also to the non-profit organisations (NPOs) that compete in commercial markets, such as sectors like university bookstores (Schiff and Weisbrod, 1991), water utility, rail track maintenance company, private air-traffic control organisation (Bennett et al., 2003), and even in the high-tech markets (Benz, 2005). Thus, commercial NPOs selling their output and services, which provide them revenues, may be considered in the same manner as CSR firms. From the expression in (1), when $b > 0$ firms are $ECSR$-oriented and when $b = 0$ firms are PM-oriented.

To sum up, abating firms are engaged in a multi-stage non-cooperative $ECSR$ *decision game* in which they choose to be either $ECSR$ or PM (the information across stages is perfect). Both firms abate pollution through an end-of-pipe cleaning R&D technology in an environment in which the government levies a social-welfare-maximising emissions tax to incentivise firms to undertake emission-reduction actions. The work studies both cases of full commitment and no commitment of the regulator. The timing of the game, therefore, changes depending on the stage at which the regulator sets the welfare-maximising environmental tax rate. This, indeed, affects the configuration of the sub-game perfect Nash equilibria of the game, the endogenous market structure and eventually the corresponding welfare outcomes emerging in equilibrium. The game is solved through backward induction.

[4] On the empirical side, see Siegel and Vitaliano (2007) and Fernández-Kranz and Santaló (2010), who provide some empirical findings about CSR.

[5] Some contributions in the CSR literature also assume that the level of social engagement is endogenously chosen, either by only one firm (Kopel and Brand, 2012) or all firms in the market (Fanti and Buccella, 2017a, Supplement; Hino and Zennyo, 2017; Nakamura, 2018; Planer-Friedrich and Sahm, 2020, 2021) as a profit-maximising variable. Unfortunately, adding environmental elements to the strategic CSR behaviour of the firm (i.e., taxation and abatement) does not allow to get closed-from expressions for either the value of the social concern under no commitment or the abatement effort under full commitment. Therefore, we cannot extend the $ECSR$ decision game in this direction.

- No commitment (time-inconsistent tax). At stage one (*the $ECSR$-decision-making stage*), each firm faces the binary choice to be $ECSR$ or PM through profits comparison. At stage two (*the regulator stage*), the government chooses the optimal emissions tax as a social welfare maximising tool *before* each firm determines the amount of abatement investments. At stage three (*the abatement stage*), firms choose abatement to maximise profits. At stage four (*the market stage*), firms choose output to maximise profits. Nevertheless, the end-of-pipe technology allows each firm to have a profit function in which the control variables q_i and k_i enter additively (they are additively separable) and then the second-order conditions are satisfied. This implies, when the regulator cannot commit, that choosing sequentially the abatement in the third stage and the output in the fourth stage or choosing simultaneously abatement and output in a unique (third) stage give the same outcomes.

- Full commitment (time-consistent tax). At stage one (*the $ECSR$-decision-making stage*), each firm faces the binary choice to be $ECSR$ or PM through profits comparison. At stage two (*the abatement stage*), each firm chooses the amount of abatement investments to maximise profits. At stage three (*the regulator stage*), the government chooses the optimal emissions tax as a social welfare maximising tool *after* each firm have decided on the amount of abatement investments. At stage four (*the market stage*), firms choose output to maximise profits.

The assumption $z = g = 2$ allows us to perform a two-parameter analysis in the space (b, d) and have a complete characterisation of the endogenous market structure emerging in the $ECSR$ decision game under no commitment (Section 3) and full commitment (Section 4).

3. The $ECSR$ decision game: no commitment (NC)

This section concentrates on the case in which the government is unable to commit to an environmental tax and then chooses the welfare-maximising value of the green tax before each firm determines the amount of abatement investments.

3.1. Both firms are PM

Let us first analyse the symmetric sub-game in which both abating firms are profit maximising ($b = 0$) and thus they disregard socially related components. From Eq. (1), this implies that the objective function of firm i boils down to $V_i = \Pi_i$. Then,

$$\Pi_i = (1 - q_i - dq_j)q_i - t(q_i - k_i) - k_i^2. \quad (2)$$

At the third stage, each firm simultaneously chooses output (q_i) and abatement (k_i) to maximise the expression in (2). Then, from the first order conditions one gets:

$$\overline{q}_i = \frac{1-t-dq_j}{2} \text{ and } \overline{k}_i = \frac{t}{2}. \quad (3)$$

An increase in the environmental tax rate increases the abatement effort and shifts inwards the output reaction functions and then contributes, ceteris paribus, to reduce production and emissions. We note that under PM/PM the abatement effort is not a strategic choice as each firm chooses the abatement irrespective of the choice of the rival. This is the result of the end-of-pipe abatement technology.

The solution of the system of output reaction functions (3) in the third stage of the game implies that, in equilibrium, production of firm i as a function of the environmental tax rate and abatement are given by:

$$q_i = \frac{1-t}{2+d} \text{ and } \overline{k}_i = k_i = \frac{t}{2}. \quad (4)$$

By using the expressions of q_i and k_i in (4) one gets the producer surplus ($PS = \Pi_i + \Pi_j$), the consumers surplus (CS), the tax revenue ($TR = t(e_i + e_j)$), and the environmental damage (ED) as a function of the emissions tax rate, that is:

$$PS^{PM/PM} = \frac{4-8t(1-t)+dt^2(4+d)}{2(2+d)^2}, \quad (5)$$

$$CS^{PM/PM} = \frac{(1+d)(1-t)^2}{(2+d)^2}, \quad (6)$$

$$TR^{PM/PM} = \frac{t[2-t(4+d)]}{2+d}, \quad (7)$$

and

$$ED^{PM/PM} = \frac{[2-t(4+d)]^2}{(2+d)^2}, \quad (8)$$

where the upper script PM/PM stands for profit maximisation of both firms. The expressions in (5), (6) and (8) are always positive, whereas the expression in (7) is positive if and only if $t < \frac{2}{4+d} := t_{TH}^{PM/PM} < 1$, which represents the tax threshold below which the total revenue in the sub-game PM/PM remains positive. This means that the total revenue is positive if and only if the tax rate is low enough to avoid incentivising pollution abatement too much. In fact, this tax threshold guarantees that $e_i = q_i - k_i > 0$ for any $i = \{1,2\}$, $i \neq j$ in this sub-game. The social welfare function is given by the index $W = PS + CS + TR - ED$, so that in the sub-game PM/PM one gets:

$$W^{PM/PM} = \frac{-3d^2t^2-22dt^2+8dt-38t^2+2d+28t-2}{2(2+d)^2}, \quad (9)$$

Under no commitment (NC), the government chooses the emissions tax to maximise (9) in the second stage of the game. Then,

$$\frac{\partial W^{PM/PM}}{\partial t} = 0 \Leftrightarrow t_{OPT}^{PM/PM}(NC) = \frac{2(7+2d)}{3d^2+22d+38} > 0. \quad (10)$$

A simple inspection of the expression in (10) allows us to conclude that the condition $t_{OPT}^{PM/PM}(NC) < t_{TH}^{PM/PM}$ always holds, so that the tax revenue is always positive in equilibrium. Making use of the optimal (second-best) tax rate in (10), the Nash equilibrium output and abatement of firm i are the following:

$$q_i^{*PM/PM}(NC) = \frac{3(4+d)}{3d^2+22d+38}, \quad (11)$$

and

$$k_i^{*PM/PM}(NC) = \frac{7+2d}{3d^2+22d+38}. \quad (12)$$

From (11) and (12), the condition $e_i^{*PM/PM} > 0$ is always fulfilled in equilibrium. This implies that when both abating firms are PM there always exist resources to sustain abatement through environmental taxation. Finally, substituting back the optimal tax in (10) along with the expressions in (11) and (12) into Eq. (2), the Nash equilibrium profits of firm i in the sub-game PM/PM are:

$$\Pi_i^{*PM/PM}(NC) = \frac{13d^2+100d+193}{(3d^2+22d+38)^2}. \quad (13)$$

The equilibrium values of tax revenues, environmental damage and social welfare corresponding to the Nash outcome in the sub-game PM/PM are respectively given by the following expressions:

$$TR^{*PM/PM}(NC) = \frac{4(5+d)(7+2d)}{(3d^2+22d+38)^2}, \quad (14)$$

$$ED^{*PM/PM}(NC) = \frac{4(5+d)^2}{(3d^2+22d+38)^2}, \quad (15)$$

and

$$W^{*PM/PM}(NC) = \frac{3(5+d)}{3d^2+22d+38}. \quad (16)$$

3.2. Both firms are ECSR

Consider now the symmetric sub-game in which both firms are $ECSR$ ($b > 0$), so that they are both aware of the net social concern. In the third stage of the game, the generic firm i aims at maximising the utility function defined in (1) by simultaneously choosing q_i and k_i. Then, from the first order conditions one gets:

$$\overline{q}_i = \frac{1-t-dq_j(1-b)-2b(e_j-k_i)}{2+b} \text{ and } \overline{k}_i = \frac{t+2b(e_j+q_i)}{2(1+b)}. \quad (17)$$

First, in an environment in which firms are $ECSR$ the abatement becomes a strategic choice and the reaction function of firm i contributes to generate a positive Nash equilibrium abatement effort irrespective of whether the regulator levies emissions taxes, and the larger the weight of social concerns, the larger (ceteris paribus) the amount of abatement. Second, $ECSR$ firms react differently than PM firms as aggregate emissions enter the expression of $\overline{k}_i$ in (17). If $b = 0$, the amount of pollutant abated by each firm is independent of the amount of pollutant abated by the rival. Third, the systems of output and abatement reaction functions of firm i (as well as those of the symmetric counterpart of the rival, firm j) generate some counterbalancing effects when b varies: 1) there exists a direct effect which tends to shift inwards the output and abatement reaction functions when the degree of social concern increases; 2) an increase in the degree of social concern also contributes to shift outwards the abatement reaction function of firm i; however, the increase in abatement contributes to increasing production of firm i to avoid losing its market share. This effect also passes through the increase in production of the rival, which allows an increase in its emissions that negatively impact the output of firm i, which observes an inwards shift in its output reaction function through this channel. The final effects, however, of an increase in b are expected as it eventually generates an outwards shift in both the output and abatement reaction function and then in the amount of the Nash equilibrium values of output and abatement in the sub-game $ECSR/ECSR$. This, in turn, implies being aware of the net social concern incentivises output and abatement, but increases the environmental damage and reduces the tax revenues in comparison to the PM case discussed so far.

The solution of the system of output and abatement reaction functions in (17) implies that the third-stage equilibrium values of q_i and k_i as a function of the tax rate are the following:

$$q_i = \frac{1-t+2b}{2+d+b(7+d)-2b^2(1+d)} \text{ and } k_i = \frac{2t+b(4-t)+dt(1-b)}{2[2+d+b(7+d)-2b^2(1+d)]}. \quad (18)$$

By using the expressions of q_i and k_i in (18) one gets:

$$CS^{ECSR/ECSR} = \frac{(1+d)(1-t+2b)^2}{[2+d+b(7+d)-2b^2(1+d)]^2}, \quad (19)$$

$$TR^{ECSR/ECSR} = \frac{t\{2-t[3+(1+d)(1-b)]\}}{2+d+b(7+d)-2b^2(1+d)}, \quad (20)$$

and

$$ED^{ECSR/ECSR} = \frac{\{2-t[3+(1+d)(1-b)]\}^2}{[2+d+b(7+d)-2b^2(1+d)]^2}, \quad (21)$$

where the upper script $ECSR/ECSR$ means that both firms are environmentally corporate socially responsible. The expressions in (19) and (21) are always positive, whereas the expression in (20) is positive if and only if $t < \frac{2}{3+(1+d)(1-b)} := t_{TH}^{ECSR/ECSR} < 1$, which represents the tax threshold above which the total revenue in the sub-game $ECSR/ECSR$ is positive, resembling the condition obtained in the previous sub-game about the inventive towards pollution abatement, thus guaranteeing that $e_i = q_i - k_i > 0$ for any $i = \{1,2\}$, $i \neq j$. We do not report the expressions of the producer surplus ($PS^{ECSR/ECSR}$) and the social welfare function ($W^{ECSR/ECSR}$), as they are cumbersome and not very informative. Now, given the no commitment hypothesis, the government chooses the emissions tax rate in the second stage of the game to maximise $W^{ECSR/ECSR}$, that is:

$$\frac{\partial W^{ECSR/ECSR}}{\partial t} = 0 \Leftrightarrow t_{OPT}^{ECSR/ECSR}(NC) = \frac{14+4d+8b^2(1+d)-2b(11+3d)}{38+22d+3d^2+3b^2(1+d)-2b(10+13d+3d^2)}. \quad (22)$$

The tax rate in (22) is always positive if products are substitutes ($d > 0$). It can be negative if products are complements ($d < 0$). This will be clear later in the article by looking at Figure 1. From Eq. (22) one gets that the condition $t_{OPT}^{ECSR/ECSR}(NC) < t_{TH}^{ECSR/ECSR}$ always holds, so that the tax revenue is always positive in equilibrium. Making use of the optimal (second-best) tax rate in (22), the Nash equilibrium output and abatement of firm i are the following:

$$q_i^{*ECSR/ECSR}(NC) = \frac{12+3d-3b(1+d)}{38+22d+3d^2+3b^2(1+d)-2b(10+13d+3d^2)}, \quad (23)$$

and

$$k_i^{*ECSR/ECSR}(NC) = \frac{7+2d-b(1+d)}{38+22d+3d^2+3b^2(1+d)-2b(10+13d+3d^2)}. \quad (24)$$

From (23) and (24), the condition $e_i^{*ECSR/ECSR} > 0$ is always fulfilled in equilibrium. This implies that when both abating firms are $ECSR$ there always exist resources to sustain abatement through environmental taxation. Finally, substituting back the optimal tax in (22) along with the expressions in (23) and (24) into Eq. (2), the Nash equilibrium profits of firm i in the sub-game $ECSR/ECSR$ are:

$$\Pi_i^{*ECSR/ECSR}(NC) = \frac{193+100d+13d^2-b(100+282d+99d^2+9d^3)+b^2(2+86d+102d^2+18d^3)+b^3(7+5d-11d^2-9d^3)}{[38+22d+3d^2+3b^2(1+d)-2b(10+13d+3d^2)]^2}. \quad (25)$$

The equilibrium values of tax revenues, environmental damage and social welfare corresponding to the Nash outcome in the sub-game $ECSR/ECSR$ are respectively given by the following expressions:

$$TR^{*ECSR/ECSR}(NC) = \frac{4[5+d-2b(1+d)][7+2d+4b^2(1+d)-b(11+3d)]}{[38+22d+3d^2+3b^2(1+d)-2b(10+13d+3d^2)]^2}, \quad (26)$$

$$ED^{*ECSR/ECSR}(NC) = \frac{4[5+d-2b(1+d)]^2}{[38+22d+3d^2+3b^2(1+d)-2b(10+13d+3d^2)]^2}, \quad (27)$$

and

$$W^{*ECSR/ECSR}(NC) = \frac{3[5+d-2b(1+d)]}{38+22d+3d^2+3b^2(1+d)-2b(10+13d+3d^2)}. \quad (28)$$

3.3. The asymmetric sub-game in which one firm is ECSR and the rival is PM

To analyse the firms' endogenous incentive to become $ECSR$, one must evaluate the outcomes of the asymmetric behaviour in which one firm, say firm i, is $ECSR$ and the rival (firm j) is PM. The maximisation of V_i with respect to q_i and k_i, and the maximisation of Π_j with respect to q_j and k_j in the third stage of the game lead to first order conditions as in (17) for the $ECSR$ firm i and as in (3) for the PM firm j. Therefore, equilibrium output and abatement as a function of the tax rate in the two cases are given by the following expressions:

$$q_i = \frac{(2-d)(1-t)+b^2d(1-t)+4bt}{2+(2-d^2)(1-b^2)+2b(3-d)} \text{ and } k_i = \frac{t(4-d^2)+b[8-10t-2d(2-t)+2td^2]+b^2[t(4-d^2)-2+2d(1-t)]}{4+2(2-d^2)(1-b^2)+4b(3-d)}, \quad (29)$$

and

$$q_j = \frac{(2-d)(1-t)+b(1-t)(3-b)+bd(1+t)}{2+(2-d^2)(1-b^2)+2b(3-d)} \text{ and } k_j = \frac{t}{2}. \quad (30)$$

From (29), the condition that guarantees $e_i = q_i - k_i > 0$ is $t < \frac{2(2-d)(1-2b)+2b^2}{(4-d^2)(1+b^2)+2(2-d)-2b(9-d-d^2)} := t_{i,TH}^{ECSR/PM} < 1$. From (30), the condition that guarantees $e_j = q_j - k_j > 0$ is $t < \frac{2(1-d)+2(1-b^2)+2b(3-d)}{(4-d^2)(1-b^2)+2(2-d)-12b} := t_{j,TH}^{ECSR/PM} < 1$. By using the expressions in (29) and (30) one gets:

$$TR^{ECSR/PM} = \frac{t\{(2-d)(2-4t-dt)+b[3t-1-d^2t+d(1-t)]\}}{2+(2-d^2)(1-b^2)+2b(3-d)}, \quad (31)$$

and

$$ED^{ECSR/PM} = \frac{\{(2-d)(2-4t-dt)+b[3t-1-d^2t+d(1-t)]\}^2}{[2+(2-d^2)(1-b^2)+2b(3-d)]^2}, \quad (32)$$

where the upper script $ECSR/PM$ means that firm i is corporate socially responsible and firm j is profit maximising. We do not report the expressions of the consumer surplus ($CS^{ECSR/PM}$), the producer surplus ($PS^{ECSR/PM}$) and the social welfare function ($W^{ECSR/PM}$), as they are cumbersome and not very informative. From Eq. (31) one can obtain the tax rate below which the tax revenue is positive in the asymmetric sub-game, that is if and only if $t < \frac{4-b-d(2-b)}{8-3b-d(2-b)-d^2(1-b)} := t_{TH}^{ECSR/PM} < 1$. It is possible to show numerically that the tax rate prevailing at the exogenous equilibrium in this sub-game (or the tax rate prevailing at the SPNE) is consistent with the positivity of quantities and the tax revenue in this sub-game. Differently, the environmental damage given in (32) is always positive.

As usual, given the no commitment hypothesis, in the second stage of the game, the government chooses the emissions tax to maximise the expression $W^{ECSR/PM}$, that is:

$$\frac{\partial W^{ECSR/PM}}{\partial t} = 0 \Leftrightarrow$$

$$t_{OPT}^{ECSR/PM}(NC) = \frac{56-40d-2d^2+4d^3+b(-72+66b-d^2-7d^3)+b^2(73-66d-d^2+8d^3)+b^3(-28+22d+9d^2-5d^3)+b^4(3-4d+d^2)}{152-64d-38d^2+10d^3+3d^4+b(-116+58d+52d^2-14d^3-6d^4)+b^2(115-68d-31d^2+8d^3+4d^4)+b^3(-58+30d+26d^2-6d^3-2d^4)+b^4(11-8d-5d^2+2d^3+d^4)} < 1. \quad (33)$$

The expression of the tax rate in (33) is positive irrespective of the value of d and is consistent with the conditions that guarantee the positivity of the main variables of the model.

3.4. The endogenous market structure under no commitment

In the first decision-making stage each firm choose whether being $ECSR$ and then determine endogenously the market structure. This choice is done by comparing profits under $ECSR$ and PM strategically. Using the equilibrium profit expressions obtained in each sub-game, $\Pi_i^{*PM/PM}(NC)$, $\Pi_i^{*ECSR/ECSR}(NC)$, $\Pi_i^{*ECSR/PM}(NC)$ and $\Pi_j^{*ECSR/PM}(NC)$, it is possible to build on the payoff matrix regarding the $ECSR$ decision game under no commitment (Table 1).

Table 1. The $ECSR$ decision game under NC (payoff matrix).

Firm j $\rightarrow$ Firm i $\downarrow$	$ECSR$	PM
$ECSR$	$\Pi_i^{*ECSR/ECSR}(NC)$, $\Pi_i^{*ECSR/ECSR}(NC)$	$\Pi_i^{*ECSR/PM}(NC)$, $\Pi_j^{*ECSR/PM}(NC)$
PM	$\Pi_i^{*PM/ECSR}(NC)$, $\Pi_j^{*PM/ECSR}(NC)$	$\Pi_i^{*PM/PM}(NC)$, $\Pi_i^{*PM/PM}(NC)$

To satisfy the technical constraints and have well-defined SPNE for every strategic profile, the analysis is restricted to the feasibility constraints, which are given by $\Pi_i^{*ECSR/ECSR}(NC) > 0$ when d is positive and $t_{OPT}^{ECSR/ECSR}(NC) > 0$ when d is negative. Then, to derive all possible SPNE of the $ECSR$ decision game under no commitment, one must study the sign of the profit differentials for $i = \{1,2\}, i \neq j$, which are given by the following expressions:

$$\Delta\Pi_A^{NC}(b,d) \coloneqq \Pi_i^{*ECSR/PM}(NC) - \Pi_i^{*PM/PM}(NC), \quad (34)$$

$$\Delta\Pi_B^{NC}(b,d) \coloneqq \Pi_i^{*PM/ECSR}(NC) - \Pi_i^{*ECSR/ECSR}(NC), \quad (35)$$

and

$$\Delta\Pi_C^{NC}(b,d) \coloneqq \Pi_i^{*PM/PM}(NC) - \Pi_i^{*ECSR/ECSR}(NC). \quad (36)$$

The first threshold defines the incentive of firm i to deviate from $ECSR$ to PM when its sign is negative (and vice versa when its sign is positive) when the rival, firm j, is playing PM. The second threshold defines the incentive of firm i to deviate from PM to $ECSR$ when its sign is negative (and vice versa when its sign is positive) when the rival, firm j, is playing $ECSR$. The third threshold determines the Pareto efficiency/inefficiency of a symmetric SPNE.

From (34), the sign of $\Delta\Pi_A^{NC}(b,d)$ is positive (resp. negative) if $b < b_{\Delta_A}^{NC}(d)$ (resp. $b > b_{\Delta_A}^{NC}(d)$), where $b_{\Delta_A}^{NC}(d)$ is the threshold value of the quasi-fixed cost of compatibility (as a function of the extent of the network externality) such that $\Delta\Pi_A^{NC}(b,d) = 0$.

From (35), the sign of $\Delta\Pi_B^{NC}(b,d)$ is negative (resp. positive) if $b < b_{\Delta_B}^{NC}(d)$ (resp. $b > b_{\Delta_B}^{NC}(d)$), where $b_{\Delta_B}^{NC}(d)$ is the threshold value of the quasi-fixed cost of compatibility (as a function of the extent of the network externality) such that $\Delta\Pi_B^{NC}(b,d) = 0$.

From (36), the sign of $\Delta\Pi_C^{NC}(b,d)$ is negative (resp. positive) if $b < b_{\Delta_C}^{NC}(d)$ (resp. $b > b_{\Delta_C}^{NC}(d)$), where $b_{\Delta_C}^{NC}(d)$ is the threshold value of the quasi-fixed cost of compatibility (as a function of the extent of the network externality), such that $\Delta\Pi_C^{NC}(b,d) = 0$.

The relative shapes of the three thresholds contribute to determine the outcomes of the $ECSR$ decision game under NC and depend on the extent of the social concern and the degree of product substitutability. To this purpose, Proposition 1 shows the spectrum of SPNE in this multi-stage game under no commitment. In this regard, Figure 1 symmetrically shows the geometry behind Proposition 1 reporting the main Nash equilibrium outcomes in an intuitive, but rigorous, way.

Proposition 1. The endogenous market structure of the $ECSR$ decision game under no commitment (NC) is the following.

[1] If $d = 1$ then (1.1) $(ECSR, ECSR)$ is the unique Pareto inefficient SPNE and the $ECSR$ decision game under NC is a prisoner's dilemma for any $0 \leq b < 0.295$; (1.2) $(PM, ECSR)$ and $(ECSR, PM)$ are two asymmetric SPNE and the $ECSR$ decision game under NC is an anti-coordination game for any $0.295 < b < 0.337$; (1.3) (PM, PM) is the unique Pareto efficient SPNE and the $ECSR$ decision game under NC is an anti-prisoner's dilemma for any $b > 0.337$.

[2] If $1 > d \geq 0.961$ then (2.1) $(ECSR, ECSR)$ is the unique Pareto inefficient SPNE and the $ECSR$ decision game under NC is a prisoner's dilemma for any $0 \leq b < b_{\Delta_B}^{NC}(d)$; (2.2) $(PM, ECSR)$ and $(ECSR, PM)$ are two asymmetric SPNE and the $ECSR$ decision game under NC is an anti-coordination game for any $b_{\Delta_B}^{NC}(d) < b < b_{\Delta_A}^{NC}(d)$; (2.3) (PM, PM) is the unique Pareto efficient SPNE and the $ECSR$ decision game under NC is an anti-prisoner's dilemma for any $b > b_{\Delta_A}^{NC}(d)$.

[3] If $0.961 > d \geq 0.899$ then (3.1) $(ECSR, ECSR)$ is the unique Pareto inefficient SPNE and the $ECSR$ decision game under NC is a prisoner's dilemma for any $0 \leq b < b_{\Delta_A}^{NC}(d)$; (3.2) (PM, PM) and $(ECSR, ECSR)$ are two symmetric SPNE (PM payoff dominates $ECSR$) and the $ECSR$ decision game under NC is a coordination game for any $b_{\Delta_A}^{NC}(d) < b < b_{\Delta_B}^{NC}(d)$; (3.3) (PM, PM) is the unique Pareto efficient SPNE and the $ECSR$ decision game under NC is an anti-prisoner's dilemma for any $b > b_{\Delta_B}^{NC}(d)$.

[4] If $0.899 > d \geq 0.763$ then (4.1) $(ECSR, ECSR)$ is the unique Pareto efficient SPNE and the $ECSR$ decision game under NC is an anti-prisoner's dilemma for any $0 \leq b < b_{\Delta_C}^{NC}(d)$; (4.2) $(ECSR, ECSR)$ is the unique Pareto inefficient SPNE and the $ECSR$ decision game under NC is a prisoner's dilemma for any $b_{\Delta_C}^{NC}(d) < b < b_{\Delta_A}^{NC}(d)$; (4.3) (PM, PM) and $(ECSR, ECSR)$ are two symmetric SPNE (PM payoff dominates $ECSR$) and the $ECSR$ decision game under NC is a coordination game for any $b_{\Delta_A}^{NC}(d) < b < b_{\Delta_B}^{NC}(d)$; (4.4) (PM, PM) is the unique Pareto efficient SPNE and the $ECSR$ decision game under NC is an anti-prisoner's dilemma for any $b > b_{\Delta_B}^{NC}(d)$.

[5] If $0.763 > d \geq 0.715$ then (5.1) $(ECSR, ECSR)$ is the unique Pareto efficient SPNE and the $ECSR$ decision game under NC is an anti-prisoner's dilemma for any $0 \leq b < b_{\Delta_A}^{NC}(d)$; (5.2) (PM, PM) and $(ECSR, ECSR)$ are two symmetric SPNE ($ECSR$ payoff dominates PM) and the $ECSR$ decision game under NC is a coordination game for any $b_{\Delta_A}^{NC}(d) < b < b_{\Delta_C}^{NC}(d)$; (5.3) (PM, PM) and $(ECSR, ECSR)$ are two symmetric SPNE (PM payoff dominates $ECSR$) and the $ECSR$ decision game under NC is a coordination game for any $b_{\Delta_C}^{NC}(d) < b < b_{\Delta_B}^{NC}(d)$; (5.4) (PM, PM) is the unique Pareto efficient SPNE and the $ECSR$ decision game under NC is an anti-prisoner's dilemma for any $b > b_{\Delta_B}^{NC}(d)$.

[6] If $0.715 > d \geq 0.192$ then (6.1) $(ECSR, ECSR)$ is the unique Pareto efficient SPNE and the $ECSR$ decision game under NC is an anti-prisoner's dilemma for any $0 \leq b < b_{\Delta_A}^{NC}(d)$; (6.2) (PM, PM) and $(ECSR, ECSR)$ are two symmetric SPNE ($ECSR$ payoff dominates PM) and the $ECSR$ decision game under NC is a coordination game for any $b_{\Delta_A}^{NC}(d) < b < b_{\Delta_B}^{NC}(d)$; (6.3) (PM, PM) is the unique Pareto inefficient SPNE and the $ECSR$ decision game under NC is a prisoner's dilemma for any $b_{\Delta_B}^{NC}(d) < b < b_{\Delta_C}^{NC}(d)$; (6.4) (PM, PM) is the unique Pareto efficient SPNE and the $ECSR$ decision game under NC is an anti-prisoner's dilemma for any $b > b_{\Delta_C}^{NC}(d)$.

[7] If $0.192 > d \geq 0.151$ then (7.1) $(ECSR, ECSR)$ is the unique Pareto efficient SPNE and the $ECSR$ decision game under NC is an anti-prisoner's dilemma for any $0 \leq b < b_{\Delta_A}^{NC}(d)$; (7.2) (PM, PM) and $(ECSR, ECSR)$ are two symmetric SPNE ($ECSR$ payoff dominates PM) and the $ECSR$ decision game under NC is a coordination game for any $b_{\Delta_A}^{NC}(d) < b < b_{\Delta_B}^{NC}(d)$; (7.3) (PM, PM) is the unique Pareto inefficient SPNE and the $ECSR$ decision game under NC is a prisoner's dilemma for any $b > b_{\Delta_B}^{NC}(d)$.

[8] If $0.151 > d > -1$ then (8.1) $(ECSR, ECSR)$ is the unique Pareto efficient SPNE and the $ECSR$ decision game under NC is an anti-prisoner's dilemma for any $0 \leq b < b_{\Delta_A}^{NC}(d)$; (8.2) (PM, PM) and $(ECSR, ECSR)$ are two symmetric SPNE ($ECSR$ payoff dominates PM) and the $ECSR$ decision game under NC is a coordination game for any $b > b_{\Delta_A}^{NC}(d)$.

Proof. Let $d = 1$ hold. If $0 \leq b < 0.295$ then $\Delta\Pi_A^{NC}(b,d) > 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$; if $0.295 < b < 0.337$ then $\Delta\Pi_A^{NC}(b,d) > 0$, $\Delta\Pi_B^{NC}(b,d) > 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$; if $b > 0.337$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) > 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$, so that Point [1] holds. Let $1 > d \geq 0.961$ hold. If $0 \leq b < b_{\Delta_B}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) > 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$; if $b_{\Delta_B}^{NC}(d) < b < b_{\Delta_A}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) > 0$, $\Delta\Pi_B^{NC}(b,d) > 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$; if $b > b_{\Delta_A}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) > 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$, so that Point [2] holds. Let $0.961 > d \geq 0.899$ hold. If $0 \leq b < b_{\Delta_A}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) > 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$; if $b_{\Delta_A}^{NC}(d) < b < b_{\Delta_B}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$; if $b > b_{\Delta_B}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) > 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$, so that Point [3] holds. Let $0.899 > d \geq 0.763$ hold. If $0 \leq b < b_{\Delta_C}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) > 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) < 0$; if $b_{\Delta_C}^{NC}(d) < b < b_{\Delta_A}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) > 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$; if $b_{\Delta_A}^{NC}(d) < b < b_{\Delta_B}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$; if $b > b_{\Delta_B}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) > 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$, so that Point [4] holds. Let $0.763 > d \geq 0.715$ hold. If $0 \leq b < b_{\Delta_A}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) > 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) < 0$; if $b_{\Delta_A}^{NC}(d) < b < b_{\Delta_C}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) < 0$; if $b_{\Delta_C}^{NC}(d) < b < b_{\Delta_B}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$; if $b > b_{\Delta_B}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) > 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$, so that Point [5] holds. Let $0.715 > d \geq 0.192$ hold. If $0 \leq b < b_{\Delta_A}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) > 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) < 0$; if $b_{\Delta_A}^{NC}(d) < b < b_{\Delta_B}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) < 0$; if $b_{\Delta_B}^{NC}(d) < b < b_{\Delta_C}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) > 0$ and $\Delta\Pi_C^{NC}(b,d) < 0$; if $b > b_{\Delta_C}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) > 0$ and $\Delta\Pi_C^{NC}(b,d) > 0$, so that Point [6] holds. Let $0.192 > d \geq 0.151$ hold. If $0 \leq b < b_{\Delta_A}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) > 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) < 0$; if $b_{\Delta_A}^{NC}(d) < b < b_{\Delta_B}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) < 0$; if $b > b_{\Delta_B}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) > 0$ and $\Delta\Pi_C^{NC}(b,d) < 0$, so that Point [7] holds. Let $0.151 > d > -1$ hold. If $0 \leq b < b_{\Delta_A}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) > 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) < 0$; if $b > b_{\Delta_A}^{NC}(d)$ then $\Delta\Pi_A^{NC}(b,d) < 0$, $\Delta\Pi_B^{NC}(b,d) < 0$ and $\Delta\Pi_C^{NC}(b,d) < 0$, so that Point [8] holds. **Q.E.D.**

Proposition 1 shows that both b and d play a relevant role in determining, under no commitment, the endogenous market configuration of the $ECSR$ decision game. In the degree of social concerns of the firm's stakeholders is sufficiently low, there exists one and only one dominant strategy for every player, $ECSR$, so that the SPNE of the $ECSR$ decision game is $(ECSR, ECSR)$ irrespective of the degree of horizontal product differentiation. The only emerging difference concerns the Pareto

efficiency/inefficiency of the SPNE. If products are scarcely differentiated, the degree of competition between the two firms is sufficiently high so that the Nash equilibrium outcome resembles the one emerging the managerial delegation literature à la FJSV (Fershtman and Judd, 1987; Sklivas, 1987; Vickers, 1985), i.e., the Environmental Corporate Social Responsibility results to be a Pareto inefficient strategic device implying that self-interest and mutual benefit of $ECSR$ conflict. This implies that firms would be better off jointly playing PM, but no one has a unilateral interest the deviate from $ECSR$, thereby avoiding being the only firm that plays PM in turn getting the worst possible result in equilibrium. If products are highly differentiated, the degree of competition between the two firms becomes lower and this leads to an increase in output, abatement and the tax rate, which eventually result in higher profits and environmental damage. The SPNE becomes Pareto efficient so that self-interest and mutual benefit of $ECSR$ do not conflict.

We pinpoint that in this article we are considering abating firms that must choose to become $ECSR$ or remain PM-oriented. Specifically, in this section we are considering the NC scenario according to which there is no pre-commitment ability about the emission tax rate. On one hand, we recall that in this case the government/regulator can ex-post modify (increase) the environmental taxation and then reduce firms' profits of the abating firms through this channel. On the other hand, however, the abating firms can increase abatement to skip the increase in the environmental tax rate and then profits increase through this channel. Therefore, in the absence of a pre-commitment ability of the regulator, every abating firms has a strategic incentive to become environmentally socially responsible to induce the regulator to levy a lower tax rate and get the best possible outcome strategically.

Interestingly, as also Figure 1 reveals, the strategic incentive to become environmentally socially responsible reduces if the degree of social concern becomes higher, giving way to other possible endogenous equilibrium configurations depending on the degree of horizontal product differentiation. An increase in b tends to erode profits emerging from playing the $ECSR$ strategy. As usual, the outcome depends on the degree of horizontal product differentiation. The trend is as follows: the for a given value of d, the higher b, the lower the incentive for each firm to play $ECSR$. The result of the $ECSR$ decision game can be an anti-prisoner's dilemma in which self interest and mutual benefit of playing PM do not conflict if d is sufficiently low, passing also from an anti-coordination game in which only one of the two firms plays $ECSR$ (and multiple asymmetric equilibria exist) to a coordination game in which there are multiple symmetric equilibria. A reduction in d tends to favour the emergence of the $ECSR$ strategy. This is because in the coordination game scenario the $ECSR$ strategy Pareto dominates the PM strategy.

The economic intuition of the results following an increase in the degree of social concern can be detailed more in-depth below. An increase in b causes a reduction in the environmental tax rate, which in turn allows for an increase in output and abatement. However, the increase in q is followed by an increase in the environmental damage, which contributes to lower profits for $ECSR$ firms due to the lower market price (when both firms are playing $ECSR$). Each firm, however, has the incentive to be the only one to play $ECSR$ to get the advantages of having intermediate taxation between $ECSR$ and PM, to increase output less and then have the highest possible profit in turn avoiding the peril of being the only firm to play PM, which would result in the lowest possible outcome. Firms are eventually entrapped in a dilemma because they would jointly prefer to be PM and have a higher profit. The mechanism that is triggered by an increase in b in the case of non-commitment is like the one emerging in a standard CSR decision game (Fanti and Buccella, 2017a), a summary of which is reported in Figure 3 for the reader's convenience.

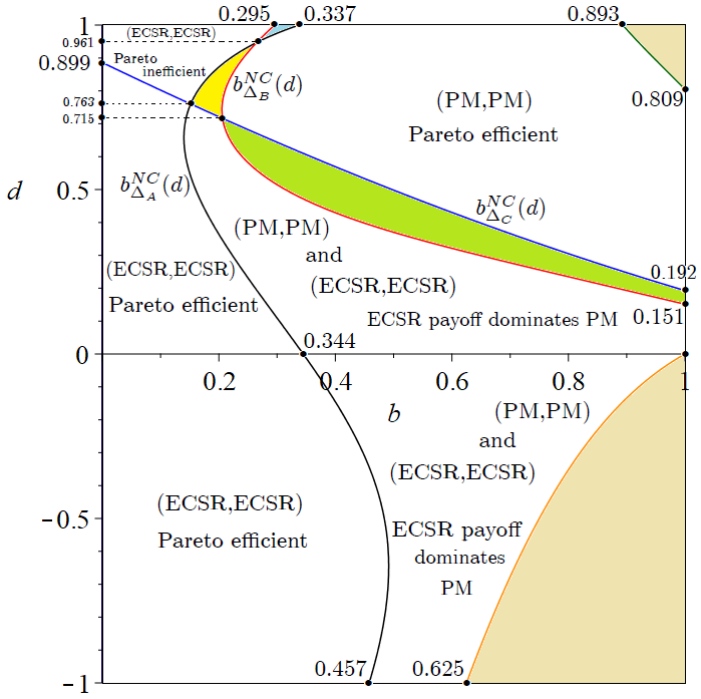


Figure 1. The $ECSR$ decision game under no commitment (NC): SPNE in the (b, d) space. The sand-coloured regions represent the unfeasible parameter areas: north-east $\Pi_i^{*ECSR/ECSR}(NC) < 0$; south-east $t_{OPT}^{ECSR/ECSR}(NC) < 0$. Light-blue region: $(PM, ECSR)$ and $(ECSR, PM)$ are two asymmetric SPNE and the $ECSR$ decision game under NC is an anti-coordination game. Yellow region: (PM, PM) and $(ECSR, ECSR)$ are two symmetric SPNE (PM payoff dominates $ECSR$) and the $ECSR$ decision game under NC is a coordination game. Green region: (PM, PM) is the unique Pareto inefficient SPNE and $ECSR$ decision game under NC is a prisoner's dilemma.

4. The $ECSR$ decision game: full commitment (FC)

The main difference between the case in which the government/regulator has no pre-commitment ability about the emission tax rate (no commitment) and the case in which he/she has pre-commitment ability (time-consistent tax) concerns the different timing schedule, within the logical timing of the events, at which the government/regulator levies the environmental tax rate. This, indeed, causes different reactions on the firm side. Under no commitment, the regulator levies the tax rate before firms have chosen the abating investment. Unlike this, under full commitment, the tax rate is levied after firms have chosen the abating investment. In the former case, the regulator can an ex-post modify taxation. This implies that selfish firms have the incentive to change their choices to induce the authority the reduce the tax rate. In the latter case, the regulator does not modify the environmental taxation so that firms have no opportunity to induce the government/regulator to behave differently. This problem regards the standard credibility issue of a regulator aiming to tax emissions in an oligopolistic industry (Petrakis and Xepapadeas (1999, 2003).

More specifically, by using the backward induction logic as discussed and applied in the previous sections, the regulator chooses the environmental tax rate as a second-best fiscal instrument immediately after firms has chosen output in the market stage. Therefore, the main difference between the optimal tax rate under NC and the optimal tax rate under FC is the dependence of the tax rate in the last case on the abatement investments of firm i and firm j, i.e., k_i and k_j. We pinpoint that we do not report all the calculations here related to the behaviour of the firms and the regulator in each sub-game. This is because they are cumbersome and not so much informative and partially resemble what was done previously. However, these calculations are available on request.

The results about the endogenous the market structure prevailing in the $ECSR$ decision game under FC are summarised in Proposition 2, whose geometrical representation is also given in Figure 2. The SPNE depend on the firm behaviour in the first decision-making stage. This choice is done by comparing profits under $ECSR$ and PM strategically under FC. Using the equilibrium profit expressions obtained in each sub-game, $\Pi_i^{*PM/PM}(FC)$, $\Pi_i^{*ECSR/ECSR}(FC)$, $\Pi_i^{*ECSR/PM}(FC)$ and $\Pi_j^{*ECSR/PM}(FC)$, it is possible to build on the payoff matrix regarding the $ECSR$ decision game under full commitment (Table 2).

Table 2. The $ECSR$ decision game under FC (payoff matrix).

Firm j $\rightarrow$ Firm i $\downarrow$	$ECSR$	PM
$ECSR$	$\Pi_i^{*ECSR/ECSR}(FC), \Pi_i^{*ECSR/ECSR}(FC)$	$\Pi_i^{*ECSR/PM}(FC), \Pi_j^{*ECSR/PM}(FC)$
PM	$\Pi_i^{*PM/ECSR}(FC), \Pi_j^{*PM/ECSR}(FC)$	$\Pi_i^{*PM/PM}(FC), \Pi_i^{*PM/PM}(FC)$

The technical constraints that must be satisfied to have well-defined SPNE under FC $\Pi_i^{*ECSR/ECSR}(FC) > 0$ when d is positive and $t_{OPT}^{ECSR/ECSR}(FC) > 0$ when d is negative. Then, to derive all possible SPNE of the $ECSR$ decision game under full commitment, one must evaluate the sign of the profit differentials for $i = \{1,2\}, i \neq j$ resembling what was done in the previous section under NC (see Eqs. (34)-(36)). The profit differentials under FC are given by the following expressions:

$$\Delta\Pi_A^{FC}(b,d) \coloneqq \Pi_i^{*ECSR/PM}(FC) - \Pi_i^{*PM/PM}(FC), \tag{37}$$

$$\Delta\Pi_B^{FC}(b,d) \coloneqq \Pi_i^{*PM/ECSR}(FC) - \Pi_i^{*ECSR/ECSR}(FC), \tag{38}$$

and

$$\Delta\Pi_C^{FC}(b,d) \coloneqq \Pi_i^{*PM/PM}(FC) - \Pi_i^{*ECSR/ECSR}(FC). \tag{39}$$

Then, the following proposition holds.

Proposition 2. The endogenous market structure of the $ECSR$ decision game under full commitment (FC) is the following.

[1] If $d = 1$ then (PM, PM) is the unique Pareto efficient SPNE and the $ECSR$ decision game under FC is an anti-prisoner's dilemma for any $0 \leq b < 0.898$.

[2] If $1 > d \geq 0.376$ then (2.1) (PM, PM) is the unique Pareto inefficient SPNE and the $ECSR$ decision game under FC is a prisoner's dilemma for any $0 \leq b < b_{\Delta_C}^{FC}(d)$; (2.2) (PM, PM) is the unique Pareto efficient SPNE and the $ECSR$ decision game under FC is an anti-prisoner's dilemma for any $b > b_{\Delta_C}^{FC}(d)$.

[3] If $0.376 > d \geq 0.182$ then (3.1) $(ECSR, ECSR)$ is the unique Pareto efficient SPNE and the $ECSR$ decision game under FC is an anti-prisoner's dilemma for any $0 \leq b < b_{\Delta_A}^{FC}(d)$; (3.2) (PM, PM) and $(ECSR, ECSR)$ are two symmetric SPNE ($ECSR$ payoff dominates PM) and the $ECSR$ decision game under FC is a coordination game for any $b_{\Delta_A}^{FC}(d) < b < b_{\Delta_B}^{FC}(d)$; (3.3) (PM, PM) is the unique Pareto inefficient SPNE and the $ECSR$ decision game under FC is a prisoner's dilemma for any $b_{\Delta_B}^{FC}(d) < b < b_{\Delta_C}^{FC}(d)$; (3.4) (PM, PM) is the unique Pareto efficient SPNE and the $ECSR$ decision game under FC is an anti-prisoner's dilemma for any $b > b_{\Delta_C}^{FC}(d)$.

[4] If $0.182 > d \geq -0.1$ then (4.1) $(ECSR, ECSR)$ is the unique Pareto efficient SPNE and the $ECSR$ decision game under FC is an anti-prisoner's dilemma for any $0 \leq b < b_{\Delta_A}^{FC}(d)$; (4.2) (PM, PM) and $(ECSR, ECSR)$ are two symmetric SPNE ($ECSR$ payoff dominates PM) and the $ECSR$ decision game under FC is a coordination game for any $b_{\Delta_A}^{FC}(d) < b < b_{\Delta_B}^{FC}(d)$; (4.3) (PM, PM) is the unique Pareto inefficient SPNE and the $ECSR$ decision game under FC is a prisoner's dilemma for any $b > b_{\Delta_B}^{FC}(d)$.

[5] If $-0.1 > d \geq -0.447$ then (5.1) $(ECSR, ECSR)$ is the unique Pareto efficient SPNE and the $ECSR$ decision game under FC is an anti-prisoner's dilemma for any $0 \leq b < b_{\Delta_A}^{FC}(d)$; (5.2) (PM, PM) and $(ECSR, ECSR)$ are two symmetric SPNE ($ECSR$ payoff dominates PM) and the $ECSR$ decision game under FC is a coordination game for any $b > b_{\Delta_A}^{FC}(d)$.

[6] If $-0.447 > d > -1$ then $(ECSR, ECSR)$ is the unique Pareto efficient SPNE and the $ECSR$ decision game under FC is an anti-prisoner's dilemma for any $0 \leq b < 0.437$.

Proof. Let $d = 1$ hold. If $0 \leq b < 0.898$ then $\Delta\Pi_A^{FC}(b,d) < 0$, $\Delta\Pi_B^{FC}(b,d) > 0$ and $\Delta\Pi_C^{FC}(b,d) > 0$, so that Point [1] holds. Let $1 > d \geq 0.376$ hold. If $0 \leq b < b_{\Delta_C}^{FC}(d)$ then $\Delta\Pi_A^{FC}(b,d) < 0$, $\Delta\Pi_B^{FC}(b,d) > 0$ and $\Delta\Pi_C^{FC}(b,d) < 0$; if $b > b_{\Delta_C}^{FC}(d)$ then $\Delta\Pi_A^{FC}(b,d) < 0$, $\Delta\Pi_B^{FC}(b,d) > 0$ and $\Delta\Pi_C^{FC}(b,d) > 0$, so that Point [2] holds. Let $0.376 > d \geq 0.182$ hold. If $0 \leq b < b_{\Delta_A}^{FC}(d)$ then $\Delta\Pi_A^{FC}(b,d) > 0$, $\Delta\Pi_B^{FC}(b,d) < 0$ and $\Delta\Pi_C^{FC}(b,d) < 0$; if $b_{\Delta_A}^{FC}(d) < b < b_{\Delta_B}^{FC}(d)$ then $\Delta\Pi_A^{FC}(b,d) < 0$, $\Delta\Pi_B^{FC}(b,d) < 0$ and $\Delta\Pi_C^{FC}(b,d) < 0$; if $b_{\Delta_B}^{FC}(d) < b < b_{\Delta_C}^{FC}(d)$ then $\Delta\Pi_A^{FC}(b,d) < 0$, $\Delta\Pi_B^{FC}(b,d) > 0$ and $\Delta\Pi_C^{FC}(b,d) < 0$; if $b > b_{\Delta_C}^{FC}(d)$ then $\Delta\Pi_A^{FC}(b,d) < 0$, $\Delta\Pi_B^{FC}(b,d) > 0$ and $\Delta\Pi_C^{FC}(b,d) > 0$, so that Point [3] holds. Let $0.182 > d \geq -0.1$ hold. If $0 \leq b < b_{\Delta_A}^{FC}(d)$ then $\Delta\Pi_A^{FC}(b,d) > 0$, $\Delta\Pi_B^{FC}(b,d) < 0$ and $\Delta\Pi_C^{FC}(b,d) < 0$; if $b_{\Delta_A}^{FC}(d) < b < b_{\Delta_B}^{FC}(d)$ then $\Delta\Pi_A^{FC}(b,d) < 0$, $\Delta\Pi_B^{FC}(b,d) < 0$ and $\Delta\Pi_C^{FC}(b,d) < 0$; if $b > b_{\Delta_B}^{FC}(d)$ then $\Delta\Pi_A^{FC}(b,d) < 0$, $\Delta\Pi_B^{FC}(b,d) > 0$ and $\Delta\Pi_C^{FC}(b,d) < 0$, so that Point [4] holds. Let $-0.1 > d \geq -0.447$ hold. If $0 \leq b < b_{\Delta_A}^{FC}(d)$ then $\Delta\Pi_A^{FC}(b,d) > 0$, $\Delta\Pi_B^{FC}(b,d) < 0$ and $\Delta\Pi_C^{FC}(b,d) < 0$; if $b > b_{\Delta_A}^{FC}(d)$ then $\Delta\Pi_A^{FC}(b,d) < 0$, $\Delta\Pi_B^{FC}(b,d) < 0$ and $\Delta\Pi_C^{FC}(b,d) < 0$, so that Point [5] holds. Let $-0.447 > d > -1$ hold. If $0 \leq b < 0.437$ then $\Delta\Pi_A^{FC}(b,d) > 0$, $\Delta\Pi_B^{FC}(b,d) < 0$ and $\Delta\Pi_C^{FC}(b,d) < 0$, so that Point [6] holds. **Q.E.D.**

As Proposition 2 and Figure 2 show the SPNE of the $ECSR$ decision game under full commitment are sharply different than those prevailing under no commitment. The reason is the different timing at which the regulator chooses the tax rate which relates to credibility issues.

Under full commitment, the environmental tax rate reduces more than under no commitment when the degree of social concern of the firms increases. This implies an increase in production, but a reduction in abatement compared to the case studied in the previous section. However, production increases more than in the NC case by playing the $ECSR$ strategy and this reduces the profits of $ECSR$ firms below the level of profits that can be obtained by playing the PM strategy even when they are the only ones playing $ECSR$. Therefore, there is no longer any unilateral advantage in playing $ECSR$ to avoid being the only firm to obtain the lowest possible outcome. Each firm therefore has a dominant strategy (PM) allowing it to obtain the best possible result. Society would be better off if firms played $ECSR$ (see Section 5) because consumer surplus would be greater, but firms' selfish behaviour prevents this outcome. Ultimately, the government's ability to credibly commit to taxing emissions (FC) induces firms not to be environmentally socially responsible in order not to reduce profits. This occurs regardless of the size of b when the degree of product differentiation is sufficiently low and then competition between firms is relatively high. The regulator's full commitment therefore generates an anti-green outcome compared to what happens in the NC case if the degree of product

differentiation is low (products are highly substitutes) and it s pro-green when products become poorly substitutes.

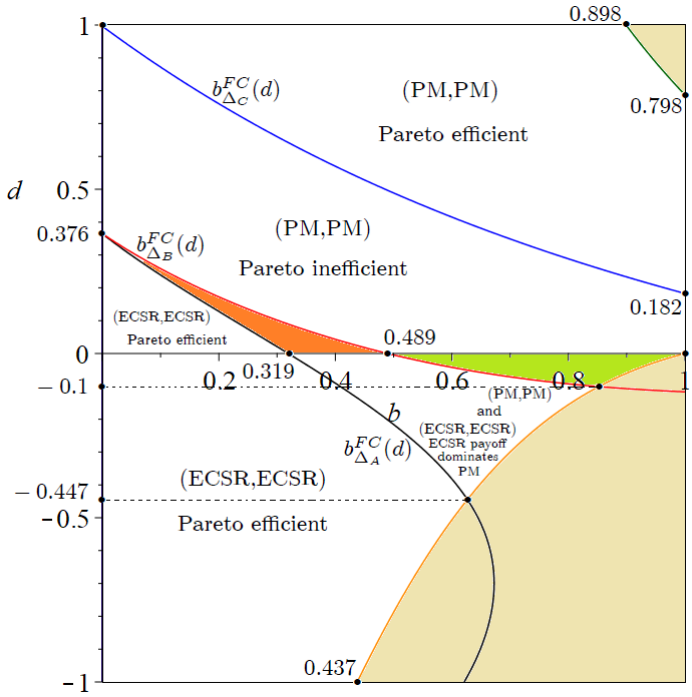


Figure 2. The $ECSR$ decision game under full commitment (FC): SPNE in the (b, d) space. The sand-coloured regions represent the unfeasible parameter areas: north-east $\Pi_i^{*ECSR/ECSR}(FC) < 0$; south-east $t_{OPT}^{ECSR/ECSR}(FC) < 0$. Orange region: (PM, PM) and $(ECSR, ECSR)$ are two symmetric SPNE ($ECSR$ payoff dominates PM) and the $ECSR$ decision game under FC is a coordination game. Green region: (PM, PM) is the unique Pareto inefficient SPNE and the $ECSR$ decision game under FC is a prisoner's dilemma.

5. Discussion of the main results

The main difference between NC and FC in the $ECSR$ decision game stems from the timing of levying the environmental tax rate by the regulator. Credibly setting the tax environmental rate allows firms to avoid choosing the $ECSR$ strategy and then playing PM. This behaviour, however, is anti-green as social welfare would be higher under $ECSR$ and the aggregate environmental damage is higher under PM, which is the SPNE of the game when products are highly substitutes. The SPNE outcomes emerging when firms are environmentally socially responsible are sharply different than those prevailing in the standard CSR decision game (Fanti and Buccella, 2017a), which are reported and summarised in Figure 3 for comparison purposes. More specifically, in the NC case the $ECSR$ decision game can become an anti-prisoner's dilemma in which self-interest and mutual benefit of being environmentally socially responsible do not conflict, a result that cannot emerge in CSR decision game if products are substitutes. This represents the main difference[6] between the two modelling structures, and it is driven by the behaviour of the regulator that can be induced by the firms to change (reduce) the size of the tax rate (by abating more than in the FC case) as it is not able to commit itself to a given environmental tax. The Pareto efficient outcome (anti-prisoner's dilemma) in which both firms play the $ECSR$ strategy under FC can be observed only when product are highly

[6] Indeed, the $ECSR$ decision game can also produce the anti-prisoner's dilemma as a possible stable outcome. This holds only when products are sufficiently homogeneous and the degree of social concern of the firms is at an intermediate level, in turn, relatively similar causing counterbalancing effects when b slightly changes.

differentiated, so that abatement and CSR allow a strategic increase in profits. In this case, in fact, firms are not able to induce the regulator to reduce the tax rate through an increased abatement effort.

The analysis of the SPNE emerging in the $ECSR$ can usefully be accompanied by the social welfare outcomes corresponding to the emerging Nash equilibrium of the game. To avoid lengthening the paper too much, we restrict the study to the different behaviour of social welfare, environmental tax and environmental damage when the degree of social concern of the firms (b) varies for two different values of the degree of product differentiation $d = 1$ (Figures 4A-4F) and $d = 0.1$ (Figures 5A-5F). In the former case, products are homogeneous. In the latter case, products are substitutes but highly differentiated. The figures refer to the NC case (left panels) and the FC case (right panels). The solid lines in the figures refer to the values of W, t and ED prevailing at the SPNE emerging in the $ECSR$ decision game. The dash-dotted lines prevail when the $ECSR$ decision game is a coordination game and there are multiple symmetric Nash equilibria in pure strategies. The dotted lines are fictitious are drawn only for comparison purposes.

The set of Figure 4A-4F ($d = 1$) reveals that the highest social welfare can be obtained under NC when the degree of social concern of the firms is sufficiently low to incentivise the emergence of $ECSR$ as a dominant strategy ($b = 0.295$). However, this outcome is Pareto inefficient for firms that would be better off by playing PM (self-interest and mutual benefit of being $ECSR$ conflict). The environmental tax is the lowest and this incentivises the abatement effort of the firms. However, the reduced taxation favours production and this, in turn, contributes to increase the environmental dagame, which results to the highest under the $ECSR$ strategy. Therefore, no win-win solutions can emerge in this scenario.

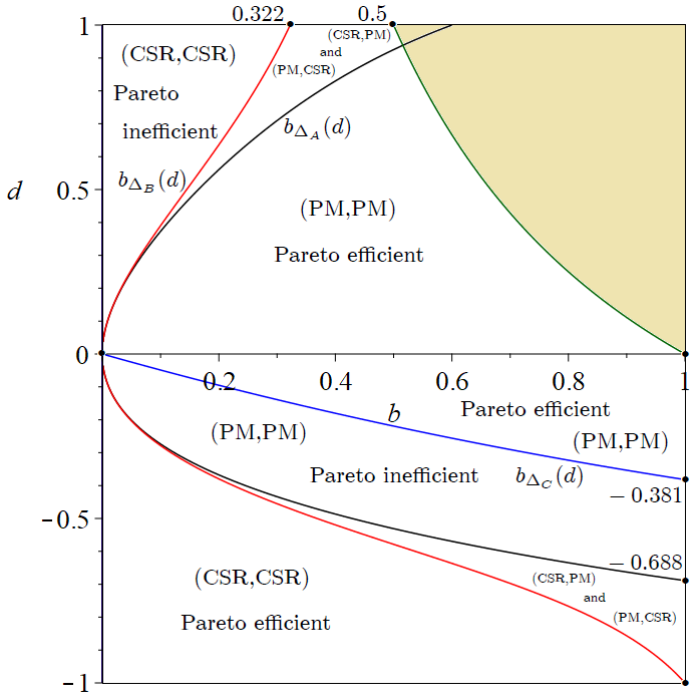
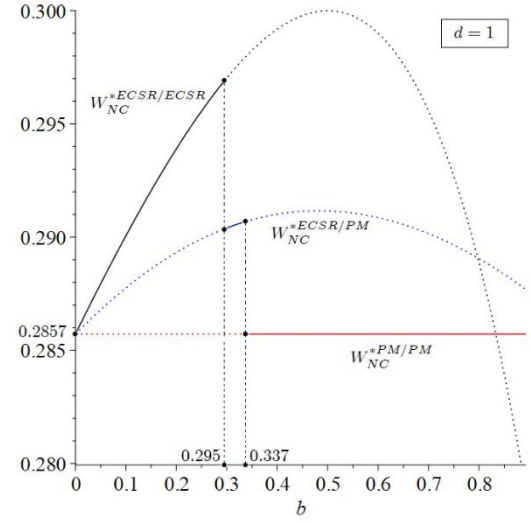
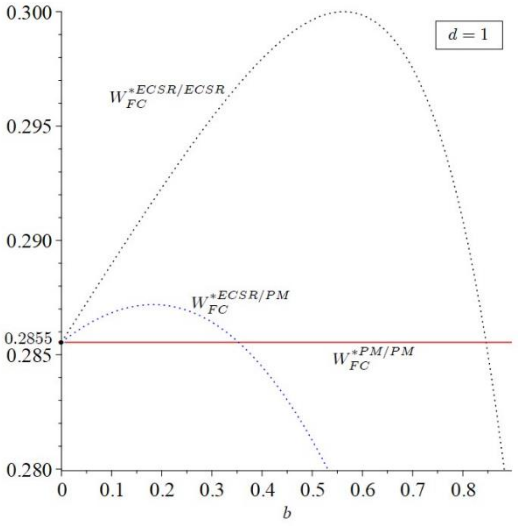


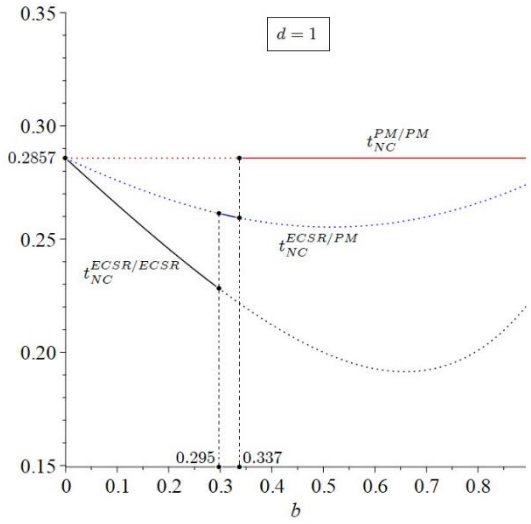
Figure 3. The (standard) CSR decision game: Nash equilibrium outcomes in the (b, d) space (Fanti and Buccella, 2017a). The sand-coloured region represents the unfeasible parameter area: $\Pi_i^{*CSR/CSR} < 0$; the solid green threshold is given by the expression $b_{TH}(d) := \frac{1}{1+d}$. The solutions of the profit differentials $\Delta_A := \Pi_i^{*CSR/PM} - \Pi_i^{*PM/PM}$ and $\Delta_C := \Pi_i^{*PM/PM} - \Pi_i^{*CSR/CSR}$ are given by the expressions $b_{\Delta_A}(d) := \frac{(4-d^2)d^2}{4-d^4+2d(2-d^2)}$ and $b_{\Delta_C}(d) := \frac{-(2+d)d}{1+d}$ respectively. The solution of the profit differential $\Delta_B := \Pi_i^{*PM/CSR} - \Pi_i^{*CSR/CSR}$, given by $b_{\Delta_B}(d)$, cannot be dealt with in a neat analytical form.



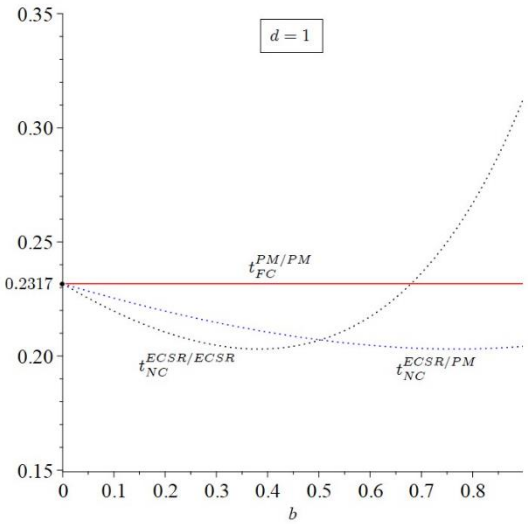
(A)



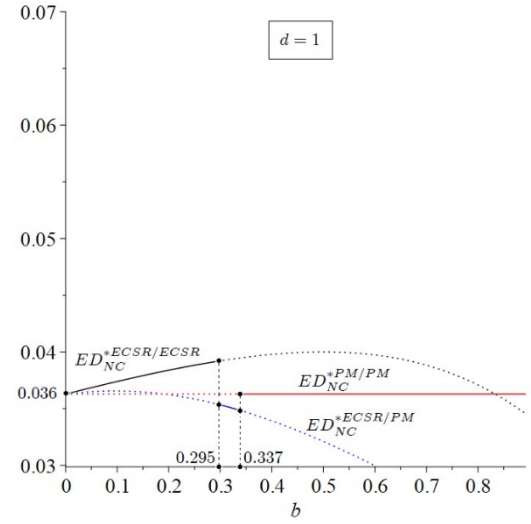
(B)



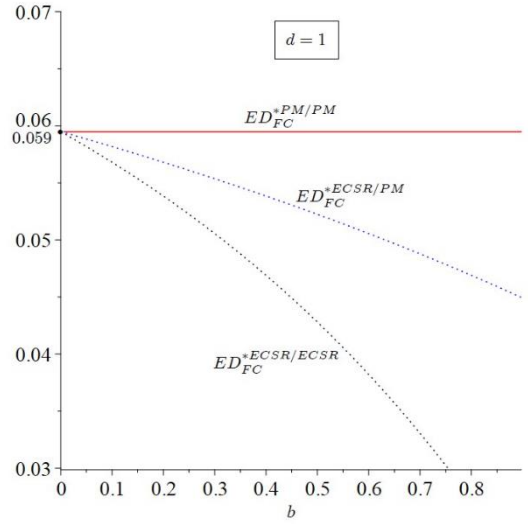
(C)



(D)



(E)



(F)

Figure 4. Social welfare, environmental tax and environmental damage corresponding to the prevailing SPNE when b varies for $d = 1$: NC (left panels); FC (right panels).

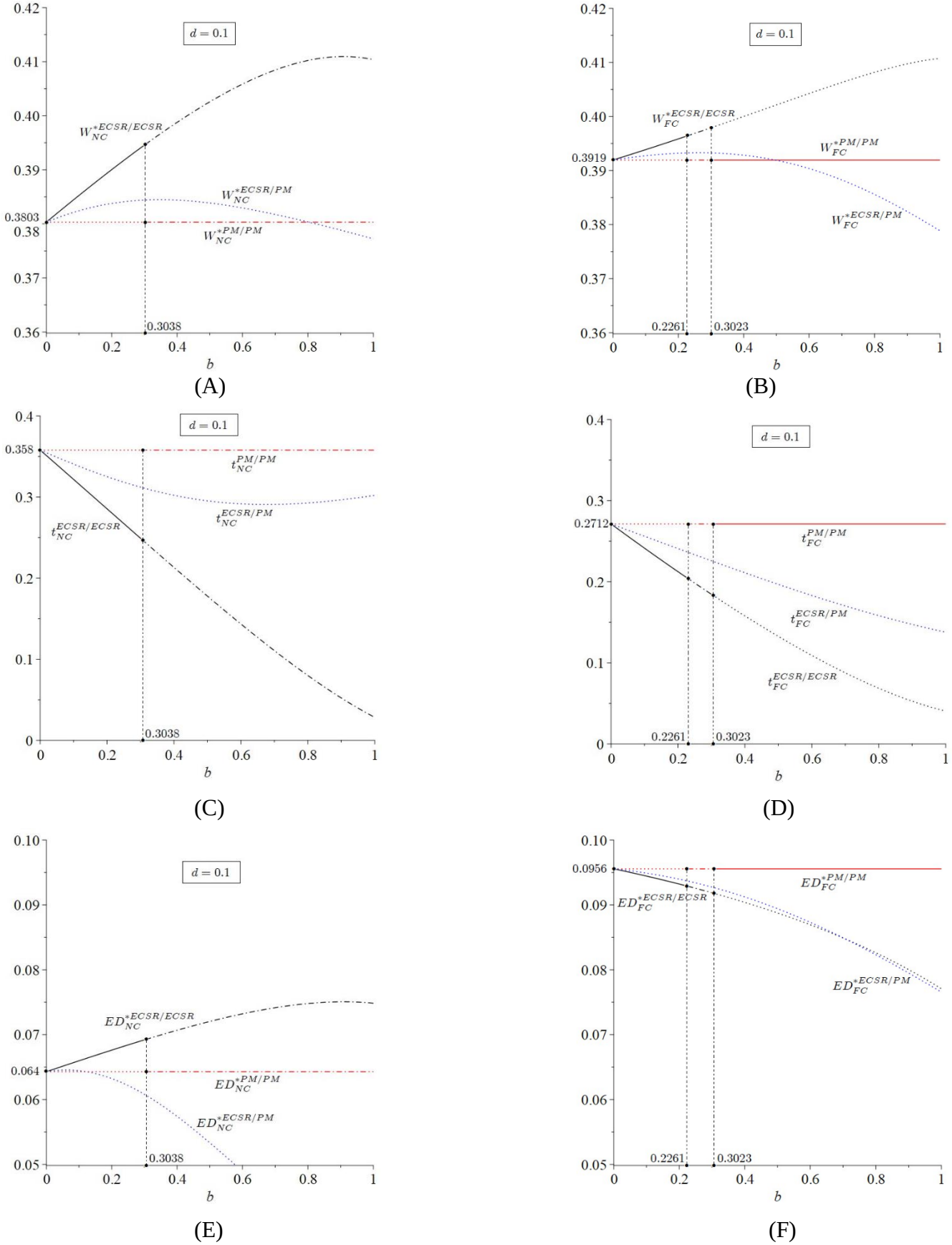


Figure 5. Social welfare, environmental tax and environmental damage corresponding to the prevailing SPNE when b varies for $d = 0.1$: NC (left panels); FC (right panels).

An increase in b gradually favours the emergence of PM as the dominant strategy of the game, but the related social welfare is the lowest and the environmental tax rate is the highest.

The absence of win-win solutions holds also under FC although PM emerges as the dominant strategy of the game and self-interest and mutual benefit of being PM do not conflict, so that firms cannot be better off by playing $ECSR$. However, consumers are worse off, and the tax rate and the environmental damage are the highest. In this sense, the time consistent behaviour of the regulator is anti-green.

Interestingly, when products becomes highly differentiated ($d = 0.1$), the set of Figure 5A-5F reveals that society obtains the highest welfare when $b = 0.2261$ and the regulator can commit to an environmental tax rate. In this case, consumers and firms are better off and both the environmental tax rate and environmental damage are the lowest. Product differentiation, therefore, allows the regulator to behave in a pro-green way by levying the environmental tax rate according to the time consistent rule.

6. Conclusions

This article developed a novel multi-stage non-cooperative game framed in a differentiated Cournot duopoly (Singh and Vives, 1984) allowing to study the firms' strategic adoption of environment-oriented Corporate Social Responsibility ($ECSR$) strategy. The analysis is done by considering abating firms that use an end-of-pipe cleaning technology and the government/regulator levy an ad hoc environmental tax rate to incentivise firms to undertake emission-reduction actions. The article compares the cases in which the government/regulator cannot (no commitment, NC) and can (time-consistent taxation or full commitment, FC) credibly commit itself to an announced environmental taxation on industrial production and develops the $ECSR$ decision game.

The article concentrates on the emergence of SPNE outcomes. It develops the corresponding social welfare analysis pinpointing at the same time the results on the aggregate environmental damage under NC and FC. The wide spectrum of Nash equilibrium scenarios and social welfare outcomes allows us to show that time-consistent taxation can be anti-green or pro-green. Interestingly, when it is pro-green the SPNE is such that self-interest and mutual benefits of being environmentally socially responsible do not conflict and consumers are better off with the lowest possible values of environmental damage and the highest social welfare. This implies that the environmental policy under FC can be compatible with a win-win solution.

Compliance with Ethical Standards

Disclosure of potential conflict of interest The authors declare that they have no conflict of interest.

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