UNIVERSITÀ
DEGLI STUDI
FIRENZE

DISEI
DIPARTIMENTO DI SCIENZE
PER L'ECONOMIA E L'IMPRESA

Working Papers - Economics

Emission Permits and Firms' Environmental Responsibility

Stefano Clo', Gianluca Iannucci, Alessandro Tampieri

Working Paper N. 06/2024

DISEI, Università degli Studi di Firenze
Via delle Pandette 9, 50127 Firenze (Italia) www.disei.unifi.it

Emission Permits and Firms' Environmental Responsibility[⋆]

Stefano Clò[a], Gianluca Iannucci[a], Alessandro Tampieri[a,b,*]

[a]Department of Economics and Management, University of Florence, Italy

[b]CREA, University of Luxembourg, Luxembourg

May 8, 2024

Abstract

This paper examines the interplay between firms' choices regarding Environmental Corporate Social Responsibility (ECSR) activities and the implementation of an emission trading system (ETS) within an oligopoly industry. We determine the equilibrium and stability conditions of an endogenous industry configuration where profit-seeking (PS) and ECSR firms coexist in the presence of an ETS policy. We derive some testable findings: first, the ECSR strategy is favoured by the increase in consumers' environmental concern, irrespective of any policy implementation. Second, the number of ECSR firms increases with the implementation of the ETS policy, provided that the number of allowances is sufficiently high. Finally, the number of ECSR firms decreases with the stringency of the ETS policy. We test the theoretical findings with a longitudinal dataset spanning the years 2002-2021, by evaluating how the number of ECSR firms in several industries and countries is affected by the introduction of the "EU ETS scheme" in 2005. Our empirical results are consistent with what is expected from the theory.

JEL Codes: C73, H23, L13, L21, M14.

Keywords: Emission trading scheme, Mixed oligopoly markets, Emission reduction investment.

[⋆]We are grateful to Simone Borghesi, Andreas Lange and to the seminar audience at the FSR Climate Annual Conference 2023. The usual disclaimer applies.

[*]Corresponding author. Via delle Pandette 9, I-50127 Florence, Italy. *E-mail addresses*: `stefano.clo@unifi.it` (S. Clò), `gianluca.iannucci@unifi.it` (G. Iannucci), `alessandro.tampieri@unifi.it` (A. Tampieri).

1 Introduction

An emission trading system (ETS), is a market-based approach used to control pollution by providing economic incentives for reducing emissions of pollutants. Under an ETS, the regulatory authority sets an overall cap on the total amount of a specific pollutant that can be emitted by participating firms. This cap is usually set to decrease over time, aiming to reduce overall emissions. Under the cap, allowances are acquired by firms through various possible mechanisms (purchase, auction, free and more). These allowances represent the right to emit a certain amount of the pollutant. Firms can then trade allowances with each other: if a firm reduces its emissions below its allocated allowance, it can sell its surplus allowances to other firms that exceed their allowances. This creates a financial incentive to reduce emissions efficiently.

The functioning and the effects of the ETSs have been the subject of recent interest in the economic literature. Different strands have focused either on the analysis of the optimal number of emission rights based on market conditions, (Gersbach and Winkler, 2011, Grüll and Taschini, 2011, Fell et al., 2012; Kollemberg and Taschini, 2016, Perino and Willner, 2016, Lintunen and Kuusela, 2018 and Kollenberg and Taschini, 2019 among others), on the evaluation of aggregate cost saving due to the implementation of new technology in an ETS (Malueg, 1989, Milliman and Prince, 1989, Jung et al., 1996, Unold and Requate, 2001, Requate, 2005, among others) or on the effects of firms' choice on investments in ecoinnovation as a response to the implementation of an ETS (Moreno-Bromberg and Taschini, 2011, Borghesi et al., 2018 and Antoci et al., 2019, among others).

A relevant point that seems largely unexplored is how the introduction of ETSs affect the corporate strategy concerning the implementation of environmental corporate social responsibility (ECSR) practices. The goal of improving the environmental performance of firms is shared between ETS policy and ECSR activities. It is thus natural to expect some kind of interaction. Particularly, a policy maker might want to be aware of the degree of ECSR practices in a certain industry, to design an appropriate stringency of the ETS. On the other hand, the adoption of ECSR activities may be affected by the presence and the level of ETS's restrictions.

Growing evidence confirms this intuition:[1] the interplay between ETS and ECSR may bring

---

[1] See Martin et al. (2016) for a review of the empirical literature on the effects of the ETS on the diffusion of clean technologies.

about cost savings in industries (Lee, 2011). Gasbarro et al. (2013) show that, in the Italian pulp and paper industry, there are relevant sinergies between environmental management practices and compliance to the EU ETS scheme. Kong et al. (2014) find that the introduction of a carbon emission right trading policy in China boosts the evironmental protection initiatives among firms and ultimately rises their market value. Similarly, Feng et al. (2024) find that the implementation of emission reduction policies in China has significantly promoted the reduction of carbon emissions. In general, internal emission reduction practices are mainly applied by companies with high levels of emissions that are subject to external trading schemes (Hörisch, 2013).

Other papers show more ambiguous results. Doda et al. (2015) find that the adoption of abatement practices does not have a significant impact on the level of carbon emissions, even in markets regulated by the European Union ETS. Borghesi et al. (2018) examines innovation data from one thousand Italian companies and shows that a comprehensive indicator of environmental innovation is positively associated with participation in the EU ETS. At the same time, this indicator is negatively correlated with the stringency of the EU ETS.

The ambiguous evidence suggests that the relationship between ETS and ECSR is complex, and calls for a theoretical explanation. One relevant question is whether markets regulated under ETS favour initiatives of environmental concern or, on the contrary, induce firms to decrease their activities of environmental protection and prefer a corporate strategy that pursues pure profits. Another question is how the stringency of the ETS affects the corporate choice of ECSR practices. The present paper aims to address these questions.

We analyse the effects of an emission trading scheme in a mixed N-firms oligopoly model, where firms may adopt either a profit-seeking (PS) or an environmentally responsible (ECSR) statute. When an ETS is in place, carbon intensive firms can produce proportionally to the amount of owned emissions allowances. As a consequence, firms have also an incentive at abating their emissions to reduce their costs stemming from environmental regulation. Hence, firms compete in quantities and in reduction emissions through investment in emissions abatement programs. In addition, ECSR firms internalise their pollution in their objective function, but must pay a fixed cost to implement the cleaner technology. Finally, consumers are “green” in the sense that they are willing to pay more for the product produced by an ECSR firm, because they are aware of their environmental concern.

In equilibrium, the industry configuration depends on the implementation costs associated with the "green" technology: intuitively, a very high or low implementation cost induces the formation of a homogeneous industry consisting of either PS or ECSR firms. For mild values intsead, a mixed industry emerges where PS and ECSR firms coexist.

Our analysis yields some testable findings. First, the number of ECSR firms increases even without the introduction of the ETS if the level of consumers' environmental concern rises. Intuitively, an increase in consumers' sensitivity to environmental issues prompts a higher demand for goods with a lower impact on the environment.

Second, the introduction of an ETS increases the number of ECSR firms, as long as the cap is not too restrictive. Indeed the ECSR firm, by statute, abates more than a PS firm, so that it will need to demand fewer allowances to implement its desirable production. If allowances are too few though, the allowance price will be relatively high, thus making the cost of conversion into the green technology too high to choose an ECSR strategy. Finally, and consistent with the previous point, if the ETS policy becomes too stringent, the price of permits increases and the number of ECSR firms decreases. These findings are consistent with some of the evidence (Borghesi et al., 2018) and provide an explanation for the ambiguity that has emerged empirically in the interaction between ECSR activities and an ETS. In particular, the interaction is affected by different levels of policy stringency.

We empirically test our findings using a firm-level longitudinal dataset covering the years 2002-2021, from which we can extract the number of firms that filed an ECSR report. From these data, we may estimate the quota of ECSR firms by sector and country pair. Using a quasi-experimental "difference-in-differences" design, we empirically assess whether the asymmetric introduction of a cap-and-trade scheme - namely the EU ETS - has affected the number of ECSR firms in ETS-regulated sectors relative to a control group of comparable unregulated sectors. In accordance with the Kyoto protocol, the European Union Emission Trading Scheme (EU ETS) was established in the 2005, and it is currently the largest multi-national, greenhouse gas emissions trading scheme in the world.[2]

---

[2] On top of the EU ETS, several ETSs are nowadays in place over the world. The United States implemented an emission trading scheme for sulfur dioxide (SO2), under the framework of the Acid Rain Program of the 1990 Clean Air Act in the United States. In the 2009, the Regional Greenhouse Gas Initiative (RGGI) was the first

With these data, we may verify whether the number of ECSR firms changed after the introduction of the EU ETS. Also, our specification allows us to check whether the stringency of the ETS, once implemented, affects the share of the ECSR. Finally, by focusing on the trends in the share of ECSR firms in the sectors, we test if the share of ECSR firms is susceptible to other factors than the ETS.

The results shows that the introduction of the ETS brought about an increase in ECSR firms. Since the ETS cap was not set at a critically stringent level (Clò, 2009, Branger and Quirion, 2015 and Lecuyer and Quirion, 2019, among others), the empirical findings are consistent with the predictions of the theoretical model. In addition, we find that the share of ECSR in the considered industries increases with the number of allowances. Moreover, the share of ECSR increases independently of the introduction of the ETS. A possible interpretation, consistent with our theoretical findings, is that their increase is prompted by an increase in the demand for sustainable goods and environmental concern.

The remainder of the paper is organised as follows. Section 2 links our paper to the existing theoretical and empirical literature. Section 3 introduces the ingredients of the model. Section 4 develops the equilibrium conditions, while Section 5 analyses the policy implications. Section 6 tests empirically some of the theoretical results, while Section 7 concludes. All the proofs are developed in Appendix A.

2 Literature

Theoretical literature. Together with the theoretical literature on ETS, the present paper is also related to the body of work exploring oligopoly theory in the context of environmentally and socially concerned (ECSR) firms.

ECSR firms commit themselves to internalise their environmental impact into their objective function, or to invest in activities to improve the quality of the environment. A possible way to model these firms' behaviour is to assume that they maximise an objective function that takes into account not only their profits but also a share of consumer surplus and the level of their

---

mandatory market-based program in the United States to reduce greenhouse gas emissions, within many states of the East Coast. In 1997, most developed nations agreed to legally binding for their emissions under the Kyoto Protocol agreement.

environmental emissions: works who took this approach are Lambertini and Tampieri (2015), Lambertini et al. (2016), Fukuda and Ouchida (2020), Xu and Lee (2022), Xu et al. (2022) and Iannucci and Tampieri (2023), among others.

Another way to introduce an ECSR behaviour is to include an environmental incentive into a managerial compensation contract. By considering an environmental delegation, the manager not only includes profits into its objective function, but also a firm's environmental impact. Poyago-Theotoky and Yong (2019) focus on the interplay between the adoption of environmental delegation and the presence of a tax on emissions. Finally, Graff Zivin and Small (2005), Baron (2007) and Hirose et al. (2017) assume that an ECSR firm commits to donate a monetary amount for environmental improvements.

All the aforementioned contributions abstract away from the presence of environmental concern by consumers. In the literature of ECSR firms, the presence of green consumers has been considered, for instance, by Manasakis et al. (2013), Manasakis et al. (2014), Liu et al. (2015), Xu and Lee (2023) and Fang and Zhao (2023), who assessed the consumers willingness to pay for green products.

The present paper nests in these last contributions by assuming environmentally concerned consumers, and linking their willingess to pay on the committment of an ECSR firm to abate its polluting emissions. More importantly, the focus of this analysis is on the interplay between the adoption of measures of emission reduction abatement and the presence of a market of ETS.

Empirical literature. The empirical part of the paper is related to two strands of the economics literature.

First, it is linked to the literature that assesses the impact of the introduction of the EU ETS system on emissions, economic performance and technological change. Teixidó et al. (2019) surveys the papers that study the effects of the EU ETS on technological change, finding that, in general, the first two phases of the EU ETS (2005–2007 and 2008–2012) have been effective at stimulating the developments of emission reduction technologies. Joltreau and Sommerfeld (2019) finds that, while the ETS has the potential to enhance competitiveness and foster innovation (Dechezlêpretre et al., 2019, Marin et al., 2018, Klemetsen et al., 2020, Dechezleprêtre et al., 2023 and Feng et al., 2024, among others), it also introduces additional transaction costs for businesses and imposes a carbon price (Chapple et al., 2013). Consequently, this can impact firms' performance and competitiveness, influencing their investment decisions. In contrast, Dechezlêpretre and Sato (2017) suggests that the negative economic effects are typically short-term or relatively minor. It's worth noting that these studies primarily examine the EU context, and the dynamics in a global framework may differ. In a recent paper, Chen et al. (2024) find that the introduction of an ETS reduces the cross-border merger and acquisition in the countries in which the policy is in place, to avoid complying with regulations. Our paper contributes to this literature by estending the analysis of the adoption of the EU ETS together with ECSR practices.

Like many contributions in this literature (e.g., DeShazo et al., 2017, Marin et al., 2018, Du and Takeuchi, 2019, Clò et al., 2022, Clay et al., 2023, Lin et al., 2023, Chen et al., 2024, Feng et al., 2024 and others), we adopt the difference-in-difference design combined with propensity score matching as the methodological approach. In particular, Marin et al. (2018) employ this methodology to analyse how the implementation of the EU ETS affects the performance of regulated firms compared to unregulated firms, while Feng et al. (2024) use it to test the causal effect of the carbon trading policy adopted in China on carbon emissions.

Second, the paper is linked to the literature studying the impact of the adoption of CSR practices on a firm's economic and financial performance. Several empirical studies have assessed these effects, with mixed results: see, among others, Orlitzky et al. (2003), Marom (2006), Van Beurden and Gossling (2008), Margolis et al. (2009), Crifo and Forget (2012), Newman et al. (2018), Kong et al. (2020), and Saha et al. (2020). We contribute to this literature by including the EU ETS scheme into the analysis of ECSR.

As mentioned in Section 1, a few papers analysed the interaction between an ETS and the adoption by firms of environmental friendly practices (Gasbarro et al., 2013, Hörisch, 2013, Kong et al., 2014, Doda et al., 2015 and Martin et al., 2016). Like our paper, these works somehow put together the environmental policy and the corporate concern of its environmental impact.

3 The model

Consider an economy composed of $N > 2$ firms. Firms can be of two types: profit seeking (PS) and environmental and socially responsible (ECSR). The number of ECSR firms is $m \in$

$\{0, 1, 2, \ldots, N\}$, while the number of PS firms is $N - m$. The good produced by firms of the same type $g \in \{P, E\}$ is assumed to be homogeneous, while it is (vertically) differentiated according to a firm's type. Following Häckner (2000), the utility of a representative consumer who purchases a bundle of products from both groups is given by:

$$\begin{aligned} U = {} & a\left(\sum_{j}^{N-m} q_j + \sum_{i}^{m} q_i\right) + \theta\beta \sum_{i}^{m} q_i \\ & - \frac{1}{2}\left(\sum_{j}^{N-m} q_j^2 + \sum_{i}^{m} q_i^2 + \sum_{j \neq -j} q_j q_{-j} + \sum_{i \neq -i} q_i q_{-i} + 2\sum_{j}^{N-m}\sum_{i}^{m} q_j q_i\right) + c_0. \end{aligned} \tag{1}$$

Vertical differentiation occurs as we assume the different reservation prices: for each good produced by firm of type P, this is a, while it is $a + \theta\beta$ for each firm of type E, where $\theta \in (0, 1)$ represents the representative consumer's sensitivity to environmental issues, while $\beta \in (0, 1)$ is the degree of abatement chosen by ECSR firms (Xu and Lee, 2023): consumers are more willingly to pay a higher price for goods produced from an ECSR firm which, as we will see shortly, is concerned about its own polluting emission, than a PS firm. The implicit assumption is that consumers are environmentally concerned, which reflects the recent tendency to sensitivity towards environmental issues and climate change (see Hidrue et al., 2011, Krishnamurthy and Kriström, 2015, and Kesselring, 2023, among others).

While we allow for vertical differentiation, we abstract away from horizontal differentiation, by assuming that goods produced by firms of different types are perfect substitutes. This assumption allows us to simplify the analytical exposition by setting aside an element that is tangential to the present analysis. This assumption also makes sense, for instance, in energy markets, in which the consumer may be sensitive to the way in which energy is produced, but the final energy obtained is perfectly substitutable whether if it comes from solar panels or from carbon.

Utility (1) is linear in the consumption of the composite good c_0, which is chosen as the numéraire, whose price is normalised to 1. Utility maximisation subject to budget constraint,

$$c_0 + p_j \sum_{j}^{N-m} q_j + p_i \sum_{i}^{m} q_i \leqslant I,$$

where I denotes income, yields the following system of linear inverse demand functions:

$$\begin{aligned} p_P &= a - \sum_{i=1}^{m} q_i - \sum_{j=1}^{N-m} q_j, \\ p_E &= a + \theta\beta - \sum_{i=1}^{m} q_i - \sum_{j=1}^{N-m} q_j. \end{aligned} \tag{2}$$

On the supply side, production is polluting. We assume that the level of emissions amounts to the quantity of the good produced q. Moreover, firms must purchase emission permits (ETS) that correspond to the emissions coming from their production at unit price α. The total number of emission permits in the industry is established by the environmental regulator at $\mathcal{A}$ ("allowances"). To reduce the cost of ETS, firms may invest into *end-of-pipe* technology $z \geqslant 0$ to reduce emissions. Hence, emissions are production quantities minus abatement investments: $e = q - z$. The profit function of a PS firm is

$$\pi_P = (p - c)\, q_P - \frac{z_P^2}{2} - (q_P - z_P)\alpha, \tag{3}$$

where $c \in (0, a)$ is the marginal production cost.

While a PS firm's objective function is to maximise (3), an ECSR firm takes into account its impact in terms of emissions. For its environmental concern, it bears an investment cost $k > 0$ to implement the "green" production technology. Hence, its objective function is:

$$O_E = (p - c)\, q_E - k - \frac{z_E^2}{2} - (\alpha + \beta)(q_E - z_E), \tag{4}$$

where $\beta \in (0, 1)$ is the share of own emissions internalised by the ECSR during its production process.

The timing of the game is as follows. In the first stage, firms choose their type, either PS or ECSR. In the second stage, the market of ETS clears and the price of permits α is set. In the third stage, firms choose simultaneously quantities q and abatement investment z. The equilibrium concept is subgame perfect Nash equilibrium. To ease the exposition, we define as $\mu = a - c$ a measure of market size common to both firm types (Shy, 1995).

4 Analysis of equilibrium

We solve the game by backward induction. In the third (market) stage, a generic firm E and P problem is, respectively,

$$\begin{aligned}\max_{q_P,z_P}\pi_P &= \left(\mu - q_P - \sum_{j=0}^{N-m-1} q_j - \sum_{i=1}^{m} q_i\right) q_P - \frac{1}{2}z_P^2 - (q_P - z_P)\alpha,\\ \max_{q_E,z_E} O_E &= \left(\mu + \theta\beta - q_E - \sum_{i=0}^{m-1} q_i - \sum_{j=1}^{N-m} q_j\right) q_E - k - \frac{1}{2}z_E^2 - (q_E - z_E)(\alpha+\beta),\end{aligned} \tag{5}$$

subject to $q_g \geqslant 0$, $z_g \geqslant 0$, $q_g - z_g \geqslant 0$, for every $g \in \{P, E\}$. In (5), firms take the allowance price α as given. The analysis focuses on the interior solutions.[3] In the second stage, the allowance price α is market clearing for a given supply of emission allowances $\mathcal{A}$, i.e.,

$$\alpha > 0 : (q_E - z_E)m + (q_P - z_P)(N - m) = \mathcal{A}.$$

The following proposition illustrates the features of the second-stage equilibrium.

Proposition 1 *Equilibrium quantities, emission-reduction investments and allowance price are:*

$$\begin{aligned}\alpha^* &= \frac{N\mu - (N+2-\theta)m\beta - (N+1)\mathcal{A}}{(N+2)N},\\ q_E^* &= \frac{\mu - (N-m+1)(1-\theta)\beta - \alpha^*}{N+1},\\ z_E^* &= \alpha^* + \beta,\\ q_P^* &= \frac{\mu + (1-\theta)m\beta - \alpha^*}{N+1},\\ z_P^* &= \alpha^*.\end{aligned} \tag{6}$$

The existence of interior solutions of the equilibrium for each industry configuration is ensured by conditions on the market size, which are summarised in the next corollary. To ease the exposition, we define the following thresholds:

$$\hat{\mu} \equiv \frac{(N+2-\theta)N\beta + (N+1)\mathcal{A}}{N} \quad \text{and} \quad \overline{\beta} \equiv \frac{\mathcal{A}}{N\,(2-\theta)}.$$

---

[3] See in the Appendix A: Proofs the Proof of Proposition 1 for further details.

Corollary 1 *Equilibrium allowance price, quantities and emissions are positive for* $\mu > \widehat{\mu}$ *and* $\beta < \overline{\beta}$ *for every* $m \in \{0, 1, 2..., N\}$.

We are now in a position to determine some sistematic differences in the behaviour of firms according to their type. A quick glance to Proposition 1 reveals that an ECSR firm invests more than a PS firm, $z_E^* > z_P^*$, given that β is positive. In addition, from the equilibrium values (6), one may check that

$$q_P^* - q_E^* = \frac{(N - m + 2)(1 - \theta)\beta}{N + 1} > 0.$$

In addition, $e_P^* - e_E^*$ amounts to

$$\frac{(N - m + 2)(1 - \theta)\beta}{N + 1} + \beta > 0.$$

These findings are summarised in the next proposition.

Proposition 2 *In equilibrium, an ECSR firm produces less and invest more in emission reduction than a PS firm.*

Proposition 2 may be explained by having in mind the more aggressive production strategy engaged by a PS firm, which does not account for its environmental impact. The immediate consequence of Proposition 2 is that the equilibrium emissions of a ECSR firms are always lower than that of a PS firm.

Substituting the optimality conditions summarised in Proposition 1, optimal profits may be rewritten as:

$$\begin{aligned} \pi_E^* &= \left(q_E^*\right)^2 + \beta q_E^* + \frac{(\alpha^*)^2}{2} - \frac{\beta^2}{2} - k, \\ \pi_P^* &= \left(q_P^*\right)^2 + \frac{(\alpha^*)^2}{2} \end{aligned}$$

Notice that k must be low enough to ensure that the equilibrium profit of an ECSR firm is positive. The condition is

$$k \leqslant \widehat{k} \equiv \left(q_E^*\right)^2 + \beta q_E^* + \frac{(\alpha^*)^2}{2} - \frac{\beta^2}{2}. \tag{7}$$

To conclude the equilibrium analysis, we are left with the task of determining the firms' choice of type in the first stage, thus endogenising the industry structure. In what follows, we will leave aside the analysis of "homogeneous industries" composed of only one type of firm and focus on the equilibrium industry configurations in which the types of firms are mixed. This choice is due to the fact that industries in which PS and ECSR firms coexist characterise those that operate in the ETS market.

In practice, we study an industry in which no firm has an incentive in changing its own type. To do so, we need to verify the stability of the industry partition following the coalition theory by D'Aspremont et al. (1983), Donsimoni (1985) and Donsimoni et al. (1986). A stable partition $\{m, N-m\}$ of ECSR and PS firms requires two conditions. First, no PS firm is willing to turn into ECSR. We refer to this condition as *external stability*, which requires $\pi_P^*(m) \geqslant \pi_E^*(m+1)$, namely

$$k \geqslant \underline{k} \equiv [q_E^*(m+1)]^2 + \beta q_E^*(m+1) + \frac{[\alpha^*(m+1)]^2}{2} - \frac{\beta^2}{2} - [q_P^*(m)]^2 - \frac{[\alpha^*(m)]^2}{2}. \tag{8}$$

Since, for $\underline{k} \leqslant 0$ no mixed industry configuration exists, we assume $\underline{k} > 0$.

The second condition requires that no ECSR wants to become PS. We refer to this condition as *internal stability*, which instead requires $\pi_E^*(m) \geqslant \pi_P^*(m-1)$, that is,

$$k \leqslant \overline{k} \equiv [q_E^*(m)]^2 + \beta q_E^*(m) + \frac{[\alpha^*(m)]^2}{2} - \frac{\beta^2}{2} - [q_P^*(m-1)]^2 - \frac{[\alpha^*(m-1)]^2}{2}. \tag{9}$$

Again, to ensure that a mixed industry configuration exists, throughout the analysis we assume $\overline{k} > 0$. Comparing $\overline{k}$ with $\widehat{k}$, one obtains:

$$\widehat{k} - \overline{k} = [q_P^*(m+1)]^2 + \frac{[\alpha^*(m+1)]^2}{2} > 0,$$

from which we get the following preliminary result.

Lemma 1 *$\overline{k}$ is lower than $\widehat{k}$.*

By Lemma 1, we may disregard $\widehat{k}$ as a threshold. The following condition ensures the stability of the industry configuration.

Proposition 3 *An industry composed of* $N - m$ *PS firms and* m *ECSR firms, with* $m \in \{1, 2, \ldots, N-1\}$*, exists if* $k \in [\underline{k}, \overline{k}]$.

By Proposition 3, the condition $k \in [\underline{k}, \overline{k}]$ allows the existence of a mixed oligopoly. Clearly, Proposition 3 also implies that, for $k \in (0, \underline{k})$ all firms are ECSR, while for $k \in (\overline{k}, \widehat{k})$ all firms are PS. This is intuitive: a too high fixed cost of implementation of the green technology prevents any firm to adopt a ECSR statute.

The next corollary guarantees the existence of a mixed industry. For convenience, we define:

$$\widehat{\theta} \equiv \frac{(N+2)\left(3N^2 + N - 6 - N\sqrt{(N+1)(N+13)}\right)}{2(2N^3 + 4N^2 - 3)}.$$

Corollary 2 *A mixed equilibrium exists if the consumers' sensitivity to environmental issue is low enough,* $\theta < \widehat{\theta}$.

When $\theta > \widehat{\theta}$, the possible configurations are a homogeneous industry composed of either all ECSR for $k \in (0, \overline{k})$ or all PS for $k \in (\overline{k}, \widehat{k})$. As stressed above, given that the empirical evidence supports the existence of mixed markets, we abstract away from these cases.

5 Policy analysis

After having outlined the equilibrium industry configuration, we are now in a position to evaluate how this configuration is affected by the introduction the ETS policy, and by allowing for a change in the stringency of the ETS policy. The analysis is carried out by determining how the equilibrium thresholds $\underline{k}, \overline{k}$ are affected by changes in the relevant parameter values.

To begin with, we analyse whether the industry configuration is affected by the demand for green goods. To determine the clearcut effect, we abstract away from the presence of the policy. The result is outlined in the following proposition.

Proposition 4 *Suppose no environmental policy is in place. Then, an increase in the consumers' sensitivity to environmental issue favours the ECSR strategy.*

The result in Proposition 4 is intuitive: the higher the consumers' environmental concern and their demand for sustainable goods, the higher the incentive for firms to adopt ECSR practices.

The next point is central to the paper. We investigate how the introduction of the ETS affects the number of ECSR in the industry. To do so, we compare the equilibrium thresholds with and without the policy in place, and their relationship with the number of allowances, $\mathcal{A}$. The next proposition summarises.

Proposition 5 *There exists a cap level* $\widehat{\mathcal{A}}$ *such that, for* $\mathcal{A} > \widehat{\mathcal{A}}$, *the introduction of an ETS increases the number of ECSR firms.*

Proposition 5 shows that the implementation of an ETS results in a greater proliferation of ECSR firms, provided that the allocation of allowances is abundant. Indeed, a small allotment of allowances leads to a surge in their price. Consequently, the elevated cost associated with transitioning to green technology k may render the adoption of an ECSR strategy economically unfeasible. However, when the number of allowances is sufficiently high, ECSR firms gain a competitive advantage since they require fewer allowances than PS firms. This is because, by mandate, ECSR firms engage in more extensive emission reduction measures compared to PS firms.

Next, we evaluate the relationship between the number of ECSR in the industry and the stringency of the policy.

Proposition 6 *The policy stringency reduces the incentives to engage in ECSR activities.*

Consistent with Proposition 5, as the policy becomes more stringent, fewer firms adopt an ECSR behaviour. The intuition remains the same: the ETS system provides a competitive advantage to ECSR firms because they are mandated to abate more emissions, but only if the allowance price is not too high; otherwise, the competitive advantage is outweighed by the cost of implementing the green technology, k.

The results outlined in Proposition 5 and Proposition 6 are consistent with some empirical findings (see Borghesi et al., 2018 in Section 1). The next section is devoted to a further empirical evaluation of our findings.

6 An empirical test

In this section we test the validity of our theoretical findings using the introduction of the EU ETS in 2005.

Table 1
Public companies geographic and sector distribution

	Number	Frequency (%)
Macroarea		
North America and other OECD countries	7,239	47.1
West Europe	4,866	31.7
East and Central Europe	3,272	21.3
Macrosector		
Agriculture, Forestry And Fishing	186	1.2
Construction	511	3.3
Electricity, Gas, Steam and Air Conditioning supply	317	2.1
High-tech knowledge intensive services	2,351	15.3
High-tech Manufacturing	2,066	13.4
Knowledge intensive financial services	26	0.2
Knowledge intensive market services	842	5.5
Less knowledge intensive market services	2,596	16.9
Low-tech Manufacturing	1,553	10.1
Medium-high tech Manufacturing	1,741	11.3
Medium-low tech Manufacturing	838	5.5
Mining and Quarrying	464	3
Other knowledge intensive services	1,640	10.7
Other less knowledge intensive services	57	0.4
Water Supply; Sewerage, Waste Managemeent	189	1.2
Total	15,377	100

Source: own elaboration on Thompson Reuters; Note: the firms aggregation into macro-sector of economic activity is consistent with the OECD Technology Intensity Definition (OECD, 2011).

6.1 The identification strategy

We gather data from the "Eikon Refinitiv" database (Thomson Reuters), which is one of the world's leading providers of financial market data. Eikon Refinitiv provides annual reports containing financial, accounting, and corporate information on a vast number of listed firms worldwide. We adopt annual data from publicly listed companies operating in Europe, North America, and other OECD countries. Specifically, for the period 2002-2021, we collect data on each company's country of incorporation, macro sector of activity (classified at the 2-digit level according to NACE rev. 2), and, for our analysis, information on the company's ECSR sustainability reporting status.

The Eikon Refinitiv database indicates whether a company publishes a standalone ECSR/ H&S/ Sustainability report or includes a section on ECSR/ H&S/ Sustainability in its annual report. To compile this information, the database manager reviews any separate non-financial reports where the company discloses its environmental and social impact. An integrated annual report containing sustainability data is considered valid, as are web-based non-financial reports. Furthermore, a company is deemed to comply with ECSR standards only if the ECSR section in the annual report contains substantial data.[4] Conversely, if there is no report for the current year, the data measurement is recorded as "False".

After cleaning the dataset and excluding firms that do not report any information (neither true nor false) regarding their ECSR reporting status, we obtain a longitudinally balanced dataset spanning twenty years, comprising 15,377 public companies headquartered in 46 countries and operating across 83 economic sectors at the 2-digit level. The geographic and sector distribution of the firms is presented in Table 1. Then, we aggregate company-level yearly information at the country-sector level (2-digit NACE rev. 2), resulting in a final balanced longitudinal dataset of 32,120 observations.[5] Each year between 2002 and 2021, we record the number of firms operating within each country-sector pair and the number of firms that filed an ECSR report during the same year. This allows us to calculate the proportion of ECSR-reporting firms in each sector-country pair, which is our primary variable of interest. During this timeframe, in

---

[4] In exceptional cases, if a company provides quantitative data in fewer than five pages, it may still be considered compliant.

[5] Within each country, sectors with no reported information in Eikon Refinitiv are excluded from the database.

2005, the EU ETS was launched, enabling us to examine the theoretical implications of the policy's introduction. In Table 2 we compare the share of ECSR-reporting firms between those country-sector pairs included within the EU ETS and the non-included ones.

Table 2
ECSR firms across ETS sectors and non-ETS sectors. Descriptive statistics

	Yearly share of ECSR firms		
	Obs	Mean	St. Dev
No ETS	19,380	0.039	0.157
ETS	12,740	0.113	0.250

Source: own elaboration on Eikon Reuters.

To empirically test the validity of our theoretical propositions, we initially investigate how the number of ECSR firms changes following the introduction of the EU ETS in 2005. To address this question, we employ a "Difference-in-Differences" (DiD) design and employ the "Two-Way Fixed Effects" (TWFE) OLS panel estimator:

$$y_{it} = \phi_0 + \phi_1 ETS_i + \phi_2 POST_t + \phi_3 DID_{it} + \gamma_i + \varepsilon_{it}. \tag{10}$$

The dependent variable, denoted as y_{it}, represents the share of ECSR firms in the country-sector i in year t. ETS_i serves as our treatment dummy variable, taking the value of 1 if a given sector in a specific country is included in the EU ETS and 0 otherwise. This variable is equal to 1 for 39.7% of our sample, with the remaining 60.34% not included in the ETS. $POST_t$ is a dummy variable that equals 1 in the years following the inclusion of the ETS and 0 otherwise.

The coefficient ϕ_2 captures the average change in the share of ECSR firms among the control group of firms not regulated by the ETS. DID_{it} is the interaction term between the ETS_i and $POST_t$ variables: its coefficient ϕ_3 captures the variation in the average outcome before and after treatment in the treatment group, compared to the pre-post variation in the control group.

In line with the central proposition of the theoretical model, we expect that the coefficient ϕ_1 will exhibit positivity and significance. This outcome would suggest that the implementation of an ETS leads to a more pronounced increase in the proportion of ECSR firms within regulated sectors compared to unregulated ones.

Individual fixed effects, γ_i are included to control for time-invariant differences across the considered sectors and countries. This allows to address potential omitted variables' bias, to control for potential confounding factors and for potential unobserved heterogeneity. Indeed, the adoption of a fixed effects model rules out that differences among treated and control units could be potentially driven by unobserved heterogeneity that remains fixed within the time period of our analysis.

Given the various range of sectors and countries within our sample, we conduct a heterogeneous analysis by estimating equation (10) on two distinct sub-samples. Initially, we confine our analysis to countries subject to the EU ETS, contrasting sectors within and outside the scheme. This restriction enhances homogeneity across countries in terms of macroeconomic factors, as well as cultural and institutional dynamics. However, energy-intensive sectors within the EU ETS may exhibit structural disparities compared to non-regulated sectors, warranting further investigation. To address this, we supplement our analysis by exclusively focusing on energy-intensive sectors within the EU ETS. In this scenario, we compare these sectors across countries both included and excluded from the ETS.

Subsequently, we adopt an "Event Study Design" and enhance the baseline model by examining its dynamic specification:

$$\begin{aligned} y_{it} = \phi_0 &+ \sum_{j=1}^{J} \phi_j LAG_j + \sum_{k=1}^{K} B_k LEAD_k + \sum_{j=1}^{J} \nu_j \left(LAG \times ETS_i \right) \\ &+ \sum_{k=1}^{K} \nu_k \left(LEAD \times ETS_i \right) + \gamma_i + \gamma_t + \varepsilon_{it}. \end{aligned} \tag{11}$$

Lags and leads are binary variables that capture the years before and after the initial implementation of the ETS. Specifically, LAG_j represents the years from 2002 to 2004, while $LEAD_k$ covers the years from 2005 to 2021. Including lags and leads enables us to examine the dynamic trend of the treatment, assessing whether the change in the proportion of ECSR firms included in the ETS is increasing or decreasing over time, whether it exhibits stability or volatility, and whether it is of a permanent or temporary nature. Furthermore, this dynamic specification enables us to consider potential pre-existing trends in the outcome variable. Specifically, this approach allows us to compare the proportion of ECSR for the treated and control groups in the years leading up to the launch of the ETS, thereby testing the parallel trend assumption necessary for DiD to yield unbiased estimates.

In this dynamic specification, we add year fixed-effects γ_t which account for capture time-specifc common shocks including macroeconomic exogenous shocks occurred throughout the considered period (2002-2021). Yearly dummy variables capture the trend in the share of CSR companies belonging to the control group of firms not regulated by the ETS.

Finally, we proceed to empirically test Proposition 6 by examining whether the proportion of ECSR firms varies in response to the stringency of environmental policies. To accomplish this, we consider the number of allowances (ETS cap) allocated to each sector within each country as the primary proxy for the stringency of the ETS. This information is sourced from sector-specific data available in the European Environmental Agency's EU Emissions Trading System (ETS) data viewer. We then extend the previous DiD design in the following way:

$$y_{it} = \phi_0 + \phi_1 DID_{it} + \phi_2 DID_{it} \times ETS\_CAP_{it} + \gamma_i + \gamma_t + \varepsilon_{it}. \tag{12}$$

In equation (12), the interaction term DID_{it} further interacts with the variable ETS_CAP_{it}, which measures the number of allowances allocated to sector i in year t.

Then, we proceed to exclude non-ETS sectors from our analysis, aiming to examine variations in the proportion of ECSR firms across ETS sectors based on the stringency of environmental regulations. According to the findings of our theoretical analysis, we anticipate a decline in the proportion of ECSR firms as the stringency of the ETS intensifies. Therefore, we anticipate a positive coefficient for our variable of interest when the stringency is represented by the ETS cap (as an increase in allocated allowances implies a reduction in compliance costs). Conversely, we expect a negative coefficient when policy stringency is assessed through the proportion of allowances allocated via auctioning.

6.2 Empirical results

Column (1) of Table 3 reports the outcomes of the TWFE DiD model estimated across the full sample. The positive and statistically significant coefficient of the $POST_t$ variable indicates that during the post-treatment phase, after adjusting for time and sector fixed effects, the share of ECSR firms in the control group increases by an average of 4.3%.

This result suggests that the proportion of ECSR firms has increased over time, partly independently of the introduction of the ETS, due to other influencing factors that are relevant to both the treated and control groups. These factors may include, in line with the findings of Proposition 4, a heightened societal demand for environmental quality, which tends to favour firms producing goods and services in accordance with sustainable criteria. Alternative explanations not covered in our theoretical approach are: the adoption of international commitments on climate and sustainability objectives endorsed by the UNFCCC COP, or the growing significance of sustainable finance, which increasingly takes into account environmental, social, and governance standards in investment decisions.

Table 3
Impact of ETS on the share of ECSR firms – TWFEDD

Variables	Full Sample		ETS countries		ETS sectors	
	(1)		(2)		(3)	
Post	0.043	***	0.071	***	0.025	***
	(0.004)		(0.007)		(0.006)	
DID	0.074	***	0.065	***	0.085	***
	(0.009)		(0.011)		(0.010)	
Constant	0.007	**	0.010	**	0.008	
	(0.003)		(0.005)		(0.005)	
Observations	32,120		20,520		15,400	
R-squared	0.045		0.058		0.055	

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

The positive and highly significant coefficient of the $ETS_i \times POST_t$ interaction term indicates that, on average, the proportion of ECSR firms further increases by 7.4% for the ETS sectors compared to the non-ETS ones during the post-treatment period. This finding is consistent with the result of Proposition 5, which suggests that the implementation of an environmental regulation such as a cap-and-trade scheme leads to an increase in the proportion of ECSR firms, provided that an ample number of allowances are available. This scenario precisely unfolded with the introduction of the EU ETS in 2005, as emission allowances were indeed distributed at no cost to specific sectors and entities. This allocation strategy aimed to facilitate the transition for industries that might encounter competitiveness challenges due to the heightened costs associated with emissions reductions (European Commission, 2003 and European Environment Agency, 2005).

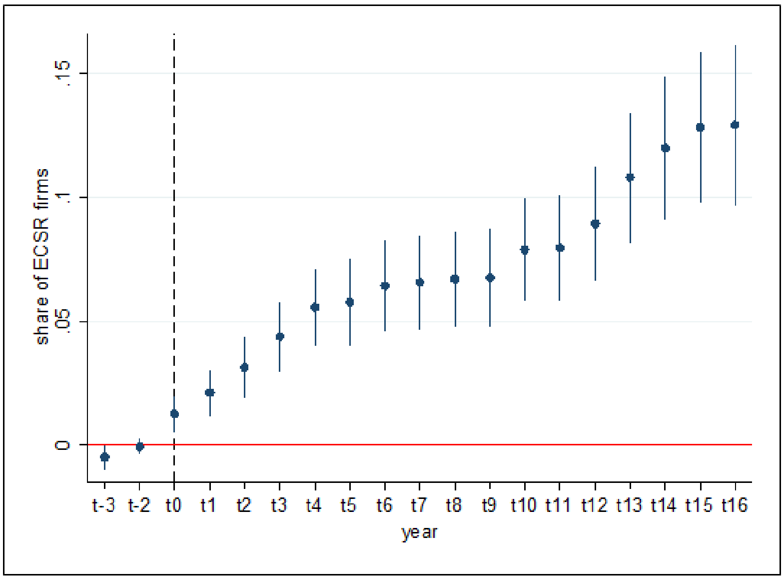
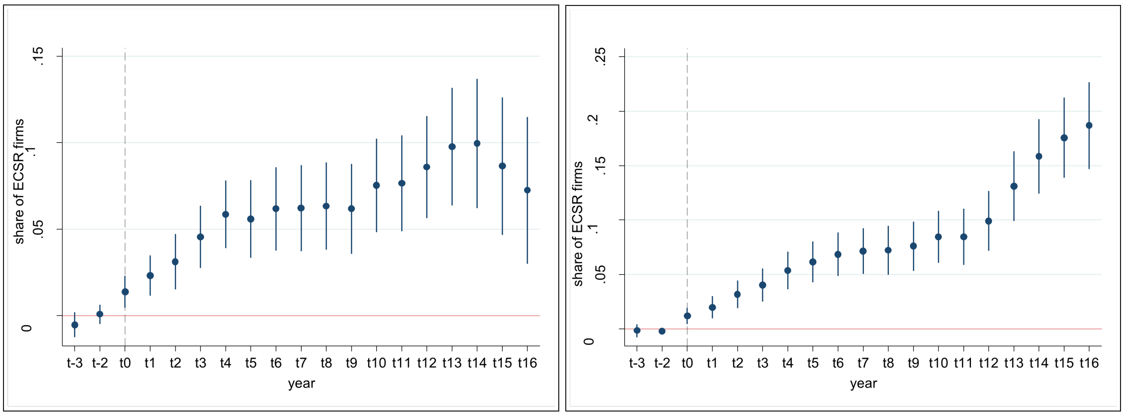


Figure 1. Impact of ETS on the share of CSR companies – Dynamic Analysis: full sample.

The results presented in Columns (2) and (3) of Table 3 reinforce the robustness of this main finding across different subsamples. Specifically, they demonstrate consistency when comparing various sectors – those included and excluded from the ETS – within the same countries that have adopted the ETS (Column 2). Similarly, the main result persists when comparing identical sectors that are either included or excluded from the ETS but belong to countries within the same geographical region (Column 3). The estimated average treatment effect slightly decreases from 7.4% to 6.5% when focusing on sectors included within the EU area under the ETS (Column

2). Conversely, the estimated effect of the ETS introduction on the proportion of ECSR firms is most pronounced, resulting in an 8.5% increase, when comparing identical sectors among countries that have been both included and excluded from the ETS (Column 3). In conclusion, the empirical analysis substantiates the predictions of the theoretical model, demonstrating that this outcome remains consistent regardless of the countries or sectors under consideration.

Next, we develop a dynamic analysis to investigate how the impact of the introduction of the ETS regulation evolves over time. Fig. 1 refers to the analysis developed on the full sample, while Fig. 2 reports the results of the analysis conducted on the subsamples of ETS countries and ETS sectors. Our findings remain robust regardless of the selected sample and indicate that, relative to the control group, the post-treatment change in the proportion of ECSR firms included in the ETS steadily and permanently increases over time. Furthermore, this dynamic specification enables us to consider potential pre-existing trends in the outcome variable. The results of our analysis reveal that during the pre-treatment period, there is no statistically significant difference in the proportion of ECSR firms between the treated and control groups. Consequently, we can assert that the parallel trend assumption is satisfied.



(a) ETS countries subsample.

(b) ETS sector subsample.

Figure 2. Impact of ETS on the share of CSR companies – Dynamic Analysis: countries and sectors subsamples.

Finally, Table 4 assesses the empirical validity of Proposition 6 by examining whether the proportion of ECSR firms varies depending on the stringency of the ETS environmental regulation. Initially, we present the findings from the TWFEDD analysis, where we augment the baseline regression by incorporating the ETS sectoral cap variable as one of the regressors, serving as a proxy for the ETS environmental stringency. While our earlier results are entirely confirmed, the positive and significant coefficient of the ETS sector cap variable indicates that, in comparison to the control group, the proportion of ECSR firms increases with the level of the ETS cap during the post-treatment period. This suggests that the proportion of ECSR firms diminishes marginally as the environmental regulation's stringency intensifies. This outcome aligns with the findings of Proposition 6, thereby affirming the validity of our theoretical results.

Table 4
Impact of ETS on the share of ECSR firms: Focus on ETS stringency – TWFEDD

Variables	Full Sample		ETS countries		ETS sectors	
	(1)		(2)		(3)	
DID	0.093	***	0.116	***	0.112	***
	(0.010)		(0.014)		(0.013)	
DID× ETS_CAP	0.006	***	0.016	***	0.008	***
	(0.002)		(0.003)		(0.002)	
Constant	-0.168	***	-0.408	***	-0.199	***
	(0.057)		(0.072)		(0.064)	
Observations	32,120		20,520		15,400	
R-squared	0.163		0.228		0.177	

Robust standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.1

We further explore this issue by excluding non-ETS sectors from the sample and employing an OLS Fixed Effects model to examine whether the proportion of ECSR firms varies across ETS sectors depending on the stringency of the environmental regulation. This stringency is proxied by both the level of the ETS cap and the share of auctioned allowances. Our findings are consistent with previous results. In Column (1) of Table 5, the positive coefficient of the ETS cap variable indicates that the share of ECSR firms decreases as the ETS cap is reduced, reflecting the increased stringency of the environmental regulation. Furthermore, in Column (2) of Table 5, the negative coefficient of the ETS Auctioning share suggests that the proportion of ECSR firms declines as the share of allowances allocated via auctioning increases. According to the Coase theorem, the allocation criteria do not impact the efficiency of cap and trade or the related equilibrium price. However, they are likely to affect the financial compliance costs, implying that auctioning allowances increases the financial burden of the environmental regulation. Lastly, Column (3) of Table 5 shows that the significance of the Auctioning share decreases when we include the ETS cap among the regressors, which serves as the true measure of cap and trade stringency.

Table 5
Impact of ETS on the share of ECSR firms: Focus on ETS stringency – OLS FE

Variables	Full Sample		ETS countries		ETS sectors	
	(1)		(2)		(3)	
ETS cap	0.029	***			0.029	***
	(0.005)				(0.006)	
ETS auction share			-0.149	***	-0.015	
			(0.036)		(0.039)	
Constant	-0.664	***	0.011		-0.657	***
	(0.130)		(0.009)		(0.138)	
Observations	8,183		8,183		8,183	
R-squared	0.226		0.213		0.226	

Robust standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.1 .

6.3 Robustness checks

In this section we check whether our main results are robust to alternative specifications of the dependent variable, the chosen estimator, and the chosen sample. First, we investigate whether our findings hold when we use the number of ECSR firms as the dependent variable instead of their proportion. To do so, we first estimate (10) using a TWFEDD estimator. Additionally, given that we are working with a counting dependent variable comprising only positive integer values and exhibiting a positively skewed distribution with a long right tail, we also employ the Poisson model with standard errors robust to heteroskedasticity.

The Poisson regression model is resilient to various misspecifications, including over-dispersion (which can be addressed by using robust standard errors), an excessive number of zeros, and temporal as well as cross-sectional dependence. The results presented in Table 6 align entirely with our earlier findings, confirming that the positive influence of environmental regulation introduced in the form of cap and trade on ECSR adoption persists even when focusing on the count of ECSR firms rather than their proportion. Moreover, this outcome remains consistent across different estimators (either OLS FE or Poisson) and sample considerations.

Table 6
Impact of ETS on the number of ECSR firms – TWFEDD and Poisson

Variables	Full Sample		ETS countries		ETS sectors		Full Sample		ETS countries		ETS sectors	
	TWFEDD Regression Model						Poisson Regression Model					
	(1)		(2)		(3)		(4)		(5)		(6)	
Post	0.185	***	0.263	***	0.210	***	2.880	***	2.908	***	3.034	***
	(0.019)		(0.028)		(0.055)		(0.171)		(0.221)		(0.383)	
DID	0.449	***	0.477	***	0.344	***	0.471	***	2.112	***	0.942	***
	(0.054)		(0.065)		(0.072)		(0.052)		(0.061)		(0.078)	
Constant	0.033	*	0.049	*	0.044		-26.120		-5.131	***	-6.041	***
	(0.020)		(0.029)		(0.032)		(245.252)		(0.285)		(0.504)	
Observations	32,120		20,520		15,400		32,120		20,520		15,400	

Robust standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.1 .

6.4 Propensity score matching

A potential limitation of our analysis concerns the interpretability of our results in terms of causality. It is well known that "randomised controlled trials" (RCTs) are the golden rule for assessing causality and avoiding potential endogeneity problems arising from non-random allocation of treatment. In our case, however, this approach was not a viable option: firms were not randomly assigned to the ETS scheme. Therefore, although the results of the dynamic analysis show that the treated and control groups do not differ in the number of ECSR firms in the pre-treatment period, we cannot completely rule out the possibility that the treated and control groups have some statistically significant differences along several dimensions.

Nevertheless, robust methods have been developed to address potential endogeneity issues and to assess causality when randomisation cannot be implemented due to some exogenous constraints. Among these, "propensity score matching" (PSM) combined with a DiD is a widely used empirical strategy.[6] As recognised by Djoumessi Tiague (2023), "DiD matching solves the problem of selection on time-invariant unobservables because differencing outcomes after and before treatment removes the unobserved fixed time and individual effects that may be correlated with both the treatment and outcome variables" (page 354).

Table 7
Impact of ETS on the share of ECSR firms and role of the ETS cap stringency – PSM-DID: static analysis

Variables	Baseline		Cap stringency	
	(1)		(2)	
DID	0.063	***	0.091	***
	(0.010)		(0.012)	
ETS sector cap			0.009	***
			(0.002)	
Constant	0.007		-0.238	***
	(0.005)		(0.059)	
Observations	19,680		19,680	
R-squared	0.189		0.193	

Robust standard errors in parentheses. ***p<0.01, **p<0.05, *p<0.1

Hence, we used a PSM to select a control group that, prior to treatment, was not statistically different from the treated group on a number of observable dimensions. For brevity, the details and results of the PSM procedure are reported in the Appendix B. The matching procedure resulted in restricting our analysis from the initial sample of 1,606 units to a subsample of 984 units. The PSM balance test shows that, before treatment, the matched treated and untreated units do not show a statistically significant difference on all the variables considered, allowing us to reject the null hypothesis (see the results in Appendix B). As shown in both Table 7 and Fig. 3, the previous results of both the static and dynamic analysis are fully confirmed when we

---

[6] See Section 2.

restrict our analysis to a sub-sample selected by a matching procedure that ensures a balance between treated and control units along a number of dimensions.

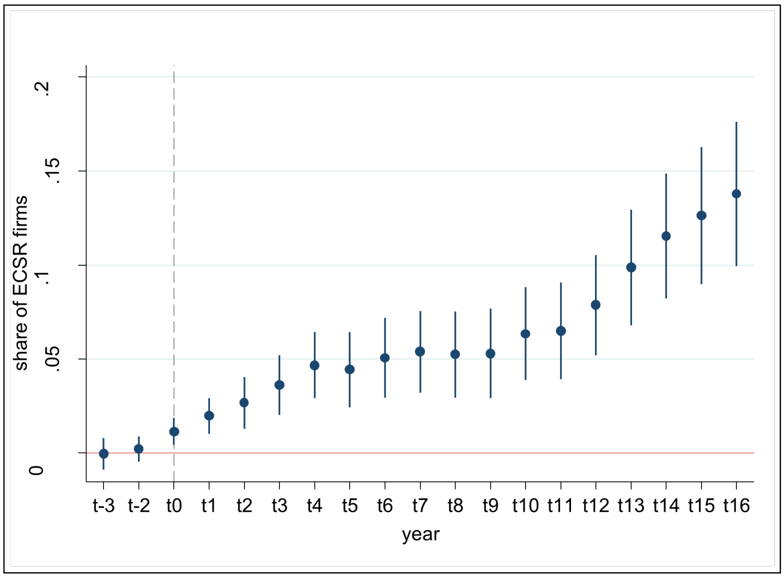


Figure 3. Impact of ETS on the share of CSR companies. PSM-DID: Dynamic Analysis.

7 Concluding remarks

We have investigated the relationship between the adoption of Environmental Corporate Social Responsibility (ECSR) strategies and the implementation of an emission trading system (ETS) within an oligopolistic industry. After assessing the market equilibrium and the endogenous industry configuration, we examined how the introduction and characteristics of the policy influence firms' decisions. Our findings indicate that, given a sufficiently high number of emission allowances, the adoption of ECSR strategies increases with the implementation of the ETS policy. However, this adoption decreases with the stringency of the ETS policy. Furthermore, we have found that the adoption of ECSR strategies occurs even in the absence of any policy when stimulated by an increased demand for sustainable goods.

Subsequently, we empirically tested the validity of our theoretical results by evaluating changes in the number of ECSR firms across various industries and countries following the introduction of the EU ETS scheme. Our empirical findings support the theoretical results.

Our framework does not take into account the possibility that firms relocate to avoid the ETS regulation, which is a relevant challenge to effective environmental governance (Ellerman et al., 2000). This phenomenon, known as “carbon leakage”, occurs when companies move their operations to regions with less stringent emissions standards to avoid compliance costs associated with emissions trading schemes. Such actions undermine the objectives of emission reduction policies and can exacerbate global environmental degradation. Our framework could be extended by allowing firms to relocate. This would require considering a relocation cost that counterbalances the cost for allowances. Active policies to counteract carbon leakage (such as implementing carbon border adjustments or harmonising regulations across jurisdictions, or providing allowances for free in some sectors) may be included. The inclusion of carbon leakage adds further elements to the interplay between the ETS policy and the choice of adopting ECSR strategies and is left for future research.

Appendix A: Proofs

Proof of Proposition 1

The Lagrangian functions associated with the maximization problems are:

$$\mathcal{L}_E = O_E + \lambda_1 q_E + \lambda_2 z_E + \lambda_3 (q_E - z_E),$$

$$\mathcal{L}_P = \pi_P + \lambda_4 q_P + \lambda_5 z_P + \lambda_6 (q_P - z_P).$$

where $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6 \geqslant 0$ are the Khun-Tucker multipliers. The first order conditions w.r.t. q_g and z_g are ($\mu = a - c$):

$$\begin{aligned}
\frac{\partial \mathcal{L}_E}{\partial q_E} &= \mu + \theta\beta - 2q_E - \sum_{i=0}^{m-1} q_i - \sum_{j=1}^{N-m} q_j - \alpha - \beta + \lambda_1 + \lambda_3 = 0,\\
\frac{\partial \mathcal{L}_E}{\partial z_E} &= \alpha + \beta - z_E + \lambda_2 - \lambda_3 = 0,\\
\frac{\partial \mathcal{L}_P}{\partial q_P} &= \mu - 2q_P - \sum_{j=0}^{N-m-1} q_j - \sum_{i=1}^{m} q_i - \alpha + \lambda_4 + \lambda_6 = 0,\\
\frac{\partial \mathcal{L}_P}{\partial z_P} &= \alpha - z_P + \lambda_5 - \lambda_6 = 0.
\end{aligned} \tag{13}$$

Invoking symmetry between firms of the same type, from (13) we obtain the optimality conditions for ECSR firms:

$$\begin{cases}
\mu + \theta\beta - (m+1)q_E - (N-m)q_P - \alpha - \beta + \lambda_1 + \lambda_3 = 0,\\
\alpha + \beta - z_E + \lambda_2 - \lambda_3 = 0,\\
\lambda_1 q_E = 0,\ \lambda_1 \geqslant 0,\\
\lambda_2 z_E = 0,\ \lambda_2 \geqslant 0,\\
\lambda_3 (q_E - z_E),\ \lambda_3 \geqslant 0,\\
q_E \geqslant 0,\ z_E \geqslant 0,\ q_E - z_E \geqslant 0,
\end{cases} \tag{14}$$

and for PS firms:

$$\begin{cases} \mu - mq_E - (N-m+1)q_P - \alpha + \lambda_4 + \lambda_6 = 0, \\ \alpha - z_P + \lambda_5 - \lambda_6 = 0, \\ \lambda_4 q_P = 0, \ \lambda_4 \geqslant 0, \\ \lambda_5 z_P = 0, \ \lambda_5 \geqslant 0, \\ \lambda_6 (q_P - z_P), \ \lambda_6 \geqslant 0, \\ q_P \geqslant 0, \ z_P \geqslant 0, \ q_P - z_P \geqslant 0, \end{cases} \tag{15}$$

Solving the system (14)-(15), we get:

$$q_E = \begin{cases} \frac{\mu-(N-m+1)(1-\theta)\beta-\alpha}{N+1}, \text{ if } \beta < \frac{\mu-(N+2)\alpha}{(2-\theta)(N+1)+(1-\theta)m}, \\ \frac{2(\mu+\theta\beta)+(N-m)\theta\beta}{2(N+2)}, \text{ if } \beta \geqslant \frac{\mu-(N+2)\alpha}{(2-\theta)(N+1)+(1-\theta)m}; \end{cases}$$

$$z_E = \begin{cases} \alpha+\beta, \text{ if } \beta < \frac{\mu-(N+2)\alpha}{(2-\theta)(N+1)+(1-\theta)m}, \\ \frac{2(\mu+\theta\beta)+(N-m)\theta\beta}{2(N+2)}, \text{ if } \beta \geqslant \frac{\mu-(N+2)\alpha}{(2-\theta)(N+1)+(1-\theta)m}; \end{cases}$$

$$q_P = \begin{cases} \frac{\mu+(1-\theta)\beta m}{N+1}, \text{ if } \beta > \frac{(N+1)\alpha-\mu}{(1-\theta)m}, \\ \frac{2\mu-\theta\beta m}{2(N+2)}, \text{ if } \beta \leqslant \frac{(N+1)\alpha-\mu}{(1-\theta)m}; \end{cases}$$

$$z_P = \begin{cases} \alpha, \text{ if } \beta > \frac{(N+1)\alpha-\mu}{(1-\theta)m}, \\ \frac{2\mu-\theta\beta m}{2(N+2)}, \text{ if } \beta \leqslant \frac{(N+1)\alpha-\mu}{(1-\theta)m}. \end{cases}$$

The condition

$$\beta \in \left(\frac{(N+1)\alpha-\mu}{(1-\theta)m}, \ \frac{\mu-(N+2)\alpha}{(2-\theta)(N+1)+(1-\theta)m} \right) \tag{16}$$

ensures interior solutions. Notice that if $q_g - z_g = 0$ then $\alpha = 0$ and so the demand for emission permits is nil. By focusing on interior solutions, the optimal values at stage 2 are

$$\begin{aligned} q_E(\alpha) &= \frac{\mu - (N-m+1)(1-\theta)\beta - \alpha}{N+1} \\ z_E(\alpha) &= \alpha + \beta \\ q_P(\alpha) &= \frac{\mu + (1-\theta)m\beta - \alpha}{N+1} \\ z_P(\alpha) &= \alpha \end{aligned} \tag{17}$$

In the first stage, α is market clearing for emission allowances $\mathcal{A}$, i.e.,

$$\alpha > 0 : (q_E - z_E)m + (q_P - z_P)(N-m) = \mathcal{A}.$$

Substituting quantities and investments from (17) and solving with respect to α, one obtains

$$\alpha^* = \frac{N\mu - (N+2-\theta)\beta m - (N+1)\mathcal{A}}{(N+2)N},$$

with

$$\mu > \frac{(N+2-\theta)\beta m + (N+1)\mathcal{A}}{N} \tag{18}$$

to guarantee a strictly positive emission allowance price. ☐

Proof of Corollary 1

Since inequality (18) is increasing in m, a sufficient condition of positivity of the price of the ETS for each $m \in \{0, 1, 2, ..., N\}$ amounts to

$$\mu > \frac{(N+2-\theta)N\beta + (N+1)\mathcal{A}}{N}$$

Turning to the equilibrium values of PS firms, we see that

$$q_P^* - z_P^* = \frac{(2-\theta)\beta m + \mathcal{A}}{N}$$

which is always positive, therefore, the condition

$$\beta < \frac{(N+1)\alpha^* - \mu}{(1-\theta)m}$$

is always satisfied. Regarding to ECSR firms, we find that $q_E^* - z_E^* > 0$ for

$$\beta < \frac{\mathcal{A}}{(N-m)\,(2-\theta)}$$

Since it is increasing in m, therefore

$$\beta < \frac{\mathcal{A}}{N\,(2-\theta)}$$

is a sufficient condition such that $q_E^* - z_E^* > 0$ for each $m \in \{0, 1, 2, ..., N\}$. □

Proof of Corollary 2

The range $(\underline{k}, \overline{k})$ exists if

$$\overline{k} - \underline{k} = A\theta^2 + B\theta + C > 0, \tag{19}$$

with

$$A = \frac{(2N^3 + 4N^2 - 3)\beta^2}{(N+2)^2 N^2}, \;\; B = \frac{-(3N^2 + N - 6)\beta^2}{(N+2)N^2}, \;\; \textit{and } C = \frac{(N-3)\beta^2}{N^2}.$$

The discriminant of (19) is

$$\Delta = \frac{(N^2 + 14N + 13)\beta^4}{(N+2)^2 N^2}.$$

Since $A > 0$ and $\Delta > 0$, then $\overline{k} - \underline{k} = 0$ admits always two solutions,

$$\widehat{\theta}_1 \equiv \frac{(N+2)\left(3N^2 + N - 6 + N\sqrt{(N+1)(N+13)}\right)}{2(2N^3 + 4N^2 - 3)},$$
$$\widehat{\theta} \equiv \frac{(N+2)\left(3N^2 + N - 6 - N\sqrt{(N+1)(N+13)}\right)}{2(2N^3 + 4N^2 - 3)}.$$

It may be shown that $\widehat{\theta}_1 > 1$ for all $N > 2$. Conversely, $\widehat{\theta} \geqslant 0$ and $\widehat{\theta} < 1$ for $N > 2$. □

Proof of Proposition 4

Consider the equilibrium elements when the policy is not in place, and denote them with superscript n. Therefore, $\underline{k}^n > 0$ is the minimum value of k such that the external stability holds for a market without ETS, i.e.,

$$\underline{k}^n = [q_E^n(m+1)]^2 + \beta q_E^n(m+1) - \frac{\beta^2}{2} - [q_P^n(m)]^2, \tag{20}$$

with

$$q_E^{*\,n}(m+1) = \frac{\mu - (N-m)(1-\theta)\beta}{N+1},$$

and

$$q_P^{*\,n}(m) = \frac{\mu + (1-\theta)\beta m}{N+1}.$$

First, we differentiate $\underline{k}^n$ with respect to the consumers' sensitivity. We obtain:

$$\frac{\partial \underline{k}^n}{\partial \theta} = 2\frac{\partial q_E^{*\,n}(m+1)}{\partial \theta} q_E^{*\,n}(m+1) + \beta\frac{\partial q_E^{*\,n}(m+1)}{\partial \theta} - 2\frac{\partial q_P^{*\,n}(m)}{\partial \theta} q_P^{*\,n}(m) > 0,$$

because

$$\frac{\partial q_E^{*\,n}(m+1)}{\partial \theta} = \frac{(N-m)\beta}{N+1} > 0, \quad \frac{\partial q_P^{*}(m)}{\partial \theta} = \frac{-\beta m}{N+1} < 0.$$

This implies that an increase in θ increases the interval $(0, \underline{k}^n)$ where the ECSR strategy is dominant. Analogously, we differentiate $\overline{k}^n$ with respect to θ, yielding

$$\frac{\partial \overline{k}^n}{\partial \theta} = 2\frac{\partial q_E^{*\,n}(m)}{\partial \theta} q_E^{*\,n}(m) + \beta\frac{\partial q_E^{*\,n}(m)}{\partial \theta} - 2\frac{\partial q_P^{*\,n}(m-1)}{\partial \theta} q_P^{*\,n}(m-1) > 0,$$

since

$$\frac{\partial q_E^{*\,n}(m)}{\partial \theta} = \frac{(N-m+1)\beta}{N+1} > 0, \quad \frac{\partial q_P^{*}(m-1)}{\partial \theta} = \frac{-(m-1)\beta}{N+1} < 0.$$

This implies that an increase in θ decreases the interval $(\overline{k}^n, \hat{k}^n]$ where the PS strategy is dominant. $\square$

Proof of Proposition 5 and Proposition 6

Differentiating the equilibrium threshold $\underline{k}$ with respect to the number of allwoances $\mathcal{A}$, one gets

$$\frac{\partial \underline{k}}{\partial \mathcal{A}} = 2\frac{\partial q_E^*(m+1)}{\partial \mathcal{A}} q_E^*(m+1) + \beta \frac{\partial q_E^*(m+1)}{\partial \mathcal{A}} - 2\frac{\partial q_P^*(m)}{\partial \mathcal{A}} q_P^*(m) + \frac{\partial \alpha^*(m+1)}{\partial \mathcal{A}} \alpha^*(m+1) - \frac{\partial \alpha^*(m)}{\partial \mathcal{A}} \alpha^*(m). \tag{21}$$

Since

$$\frac{\partial q_E^*(m+1)}{\partial \mathcal{A}} = \frac{\partial q_P^*(m)}{\partial \mathcal{A}} = \frac{1}{(N+2)N},$$

$$\frac{\partial \alpha^*(m+1)}{\partial \mathcal{A}} = \frac{\partial \alpha^*(m)}{\partial \mathcal{A}} = -\frac{N+1}{(N+2)N},$$

$$2q_E^*(m+1) + \beta - 2q_P^*(m) = \frac{[2(N^2+N-1)\theta - N^2 + 4]\beta}{(N+2)N},$$

and

$$\alpha^*(m+1) - \alpha^*(m) = \frac{(N+2-\theta)\beta}{(N+2)N},$$

we may rewrite (21) as

$$\frac{\partial \underline{k}}{\partial \mathcal{A}} = \frac{[2(2N+1)\theta N + 6(N-\theta) + 12]\beta}{2(N+2)^2 N^2} > 0, \tag{22}$$

for all $\theta \in (0,1)$, $\beta \in (0,1)$ and $N > 2$. Since $\frac{\partial \underline{k}}{\partial \mathcal{A}}$ is a positive constant, then the threshold $\underline{k}$ is an increasing linear function in $\mathcal{A}$. By equation (20), $\underline{k}^n$ is a constant function in $\mathcal{A}$: then there is only one intersection point between $\underline{k}^n$ and $\underline{k}$, that we can denote as $\widehat{\mathcal{A}}$. Assuming $\widehat{\mathcal{A}} \in (0, \mathcal{A}^{\max})$, where $\mathcal{A}^{\max}$ is the business as usual emissions level, then $\underline{k} < \underline{k}^n$ for $\mathcal{A} \in (0, \widehat{\mathcal{A}})$, while the opposite occurs for $\mathcal{A} \in (\widehat{\mathcal{A}}, \mathcal{A}^{\max})$. If $\underline{k} < \underline{k}^n$, then the introduction of the ETS reduces the interval $(0, \underline{k})$ where the strategy ECSR is dominant. On the contrary, if $\underline{k} > \underline{k}^n$, then the introduction of the ETS increases the interval $(0, \underline{k})$, favoring the ECSR strategy.

Analogously, differentiating $\overline{k}$ with respect to $\mathcal{A}$, we get:

$$\begin{aligned}\frac{\partial \overline{k}}{\partial \mathcal{A}} = {} & 2\frac{\partial q_E^*(m)}{\partial \mathcal{A}} q_E^*(m) + \beta \frac{\partial q_E^*(m)}{\partial \mathcal{A}} - 2\frac{\partial q_P^*(m-1)}{\partial \mathcal{A}} q_P^*(m-1) + \frac{\partial \alpha^*(m)}{\partial \mathcal{A}} \alpha^*(m) \\ & - \frac{\partial \alpha^*(m-1)}{\partial \mathcal{A}} \alpha^*(m-1).\end{aligned} \tag{23}$$

Since

$$\frac{\partial q_E^*(m)}{\partial \mathcal{A}} = \frac{\partial q_P^*(m-1)}{\partial \mathcal{A}} = \frac{1}{(N+2)N},$$

$$\frac{\partial \alpha^*(m)}{\partial \mathcal{A}} = \frac{\partial \alpha^*(m-1)}{\partial \mathcal{A}} = \frac{-(N+1)}{(N+2)N},$$

$$2q_E^*(m) + \beta - 2q_P^*(m-1) = \frac{[2(N^2+N-1)\theta - N^2 + 4]\beta}{(N+2)N},$$

and

$$\alpha^*(m) - \alpha^*(m-1) = \frac{(N+2-\theta)\beta}{(N+2)N},$$

we can rewrite equation (23) as

$$\frac{\partial \overline{k}}{\partial \mathcal{A}} = \frac{[2(2N+1)\theta N + 6(N-\theta) + 12]\beta}{2(N+2)^2 N^2}, \tag{24}$$

which is positive for all $\beta \in (0,1)$, $\theta \in (0,1)$, and $N > 2$. Since $\frac{\partial \overline{k}}{\partial \mathcal{A}}$ is a positive constant, then the threshold $\overline{k}$ is an increasing linear function in $\mathcal{A}$. Denoting now $\overline{k}^n > 0$ as the maximum value of k such that the internal stability holds for a market without ETS, i.e.,

$$\overline{k}^n = [q_E^n(m)]^2 + \beta q_E^n(m) - \frac{\beta^2}{2} - [q_P^n(m-1)]^2,$$

with

$$q_E^{*\,n}(m) = \frac{\mu - (N-m+1)(1-\theta)\beta}{N+1},$$

and

$$q_P^{*\,n}(m-1) = \frac{\mu + (1-\theta)(m-1)\beta}{N+1}.$$

Since $\overline{k}^n$ is a constant function in $\mathcal{A}$, then there is only one intersection point between $\overline{k}^n$ and $\overline{k}$, that we can denote as $\hat{\mathcal{A}}$. Assuming $\hat{\mathcal{A}} \in (0, \mathcal{A}^{\max})$, then $\overline{k} < \overline{k}^n$ for $\mathcal{A} \in (0, \hat{\mathcal{A}})$, while the opposite occurs for $\mathcal{A} \in (\hat{\mathcal{A}}, \mathcal{A}^{\max})$. If $\overline{k} < \overline{k}^n$, then the introduction of the ETS increases the interval $(\overline{k}, \hat{k}]$ where the strategy PS is dominant. On the contrary, if $\overline{k} > \overline{k}^n$, then the introduction of the ETS reduces the interval $(\overline{k}, \hat{k}]$, disadvantages the PS strategy.

To conclude, since (22) is always positive, an increase in the number of the emission allowances increases the interval $(0, \underline{k})$ where the strategy ECSR is dominant. Analogously, since (24) is always positive, an increase in the number of the emission allowances decreases the interval $(\overline{k}, \hat{k}]$ where the strategy PS is dominant. □

Appendix B: PSM procedure

Here we specify the PSM procedure that brought to select from the entire control group a sub-sample which, before the treatment, was not statistically different from the treated group along a variety of observable dimensions We first estimated through a Logit model to what extent the probability of being treated was explained by a plurality of covariates: sector and country, number of firms, ESG total score and Environmental Pillar total score per sector-country pair and share of ECSR firms. Following Marin et al. (2018), we included the households' pre-treatment variation in the share of ECSR firms ("ΔECSR"), thus forcing the treated and control units to have parallel trends of the outcome variable before the treatment. [7]

From the results reported in Table 8, we can observe that the p-values of various matching variables are significant, denoting that these matching variables can affect the probability of being treated. In particular, the number firms, the number of ECSR firms and the ESG pillar score are positively related with the probability of being treated, while the Environmental pillar score is negative related with that probability.

---

[7] It is important to recognise that treated and control units can only be matched on their observable and available characteristics, and therefore the validity of the PSM relies on the assumption that matching on observable characteristics allows matching on unobservable characteristics as well. The use of a fixed effects model allows to control for unobservables that do not vary over time.

Table 8
Propensity score estimates

Variables	Est. coeff.		Marginal eff.	
	(1)		(2)	
ECSR firms	1.565	**	0.274	**
	(0.732)		(0.128)	
ΔECSR firms	0.136		0.024	
	(1.506)		(0.264)	
Number of Firms	0.002	*	0.000	*
	(0.001)		(0.000)	
Total Environmental Pillar Score	-0.014	***	-0.002	***
	(0.005)		(0.001)	
ESG Score	0.033	***	0.006	***
	(0.005)		(0.001)	
Constant	1.565	**	0.274	**
	(0.732)		(0.128)	
Observations	4,818		4,818	
Sector and Country Fixed Effects	Yes		Yes	
Title	Logistic reg.		Average marg. eff.	

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Next, treated and untreated units were matched on estimated propensity scores, that is, on the estimated probability of being treated given a set of observable characteristics of the treated and control units. Based on the estimated propensity scores, we matched each treated unit to a maximum of its two nearest non-treated neighbours (in terms of estimated propensity score). Non-treated units that were outside the common support of the estimated propensity score were excluded from the analysis. This matching procedure restricted our analysis from the initial sample of approximately 1,606 units to a subsample of 984 units. An inspection of the density distribution of the propensity scores in both groups, before and after matching, visually confirms the common support between the treatment and comparison groups and the soundness of the PSM procedure (see Fig. 4).

The PSM balance test shows that the differences between the treated and untreated units on

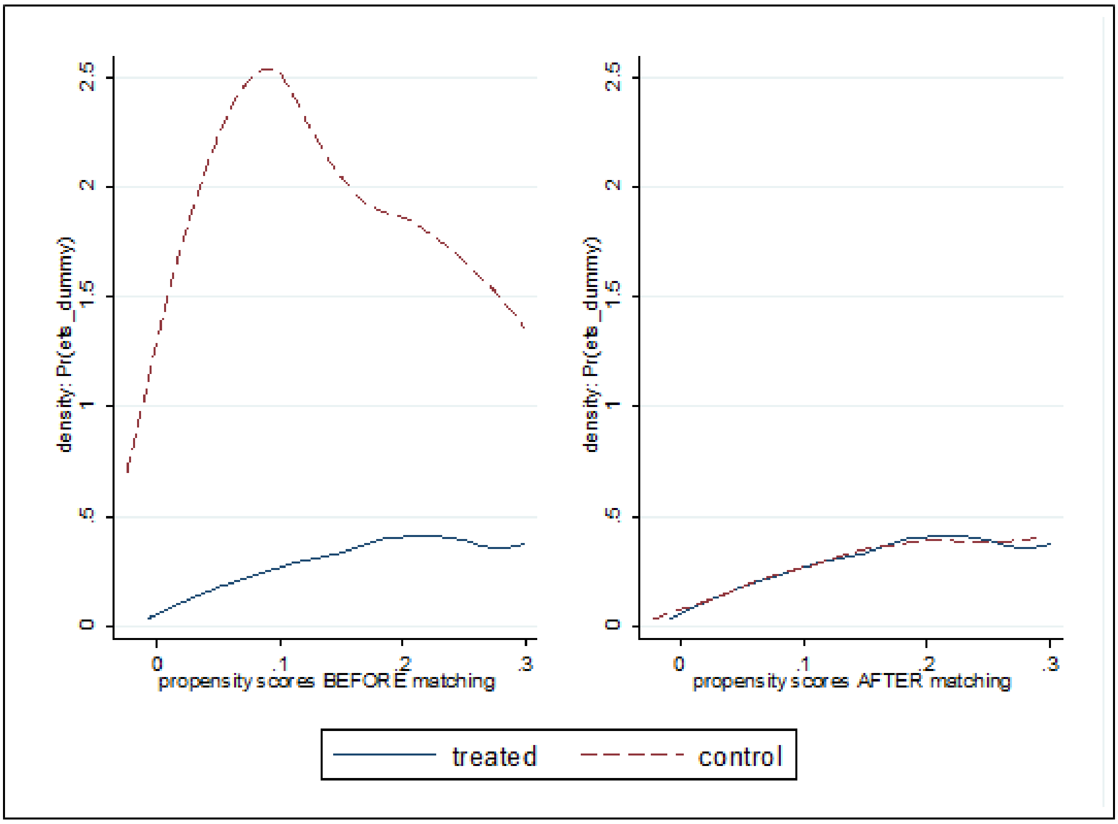


Figure 4. Probability of receiving the treatment before and after the matching.

several dimensions were significant only before the matching procedure. Conversely, the matched treated and untreated units do not show a statistically significant difference on all the variables considered, allowing us to reject the null hypothesis (Table 9).

Table 9
Balance test.

Variable	Unmatched (U)	Mean		t-test	
	Matched (M)	Treated	Control	T	p>t
ECSR firms	U	0.01377	0.00258	6.28	0.000
	M	0.01377	0.01156	0.85	0.398
ΔECSR firms	U	0.00431	0.00173	3.57	0.000
	M	0.00431	0.00497	-0.63	0.532
Number of Firms	U	9.8854	8.4403	1.72	0.085
	M	9.8854	9.3705	0.5	0.617
Environmental Pillar Score	U	7.5567	1.5397	11.85	0.000
	M	7.5567	7.7009	-0.18	0.856
ESG Score	U	10.281	2.5093	12.8	0.000
	M	10.281	11.724	-1.51	0.131
NACE 2- digit sectors	U	25.482	49.39	-37.52	0.000
	M	25.482	26.28	-1.58	0.114
Country	U	27.889	28.822	-2.02	0.044
	M	27.889	27.464	0.82	0.413

References

Antoci, A., Borghesi, S., Iannucci, G., Russu, P., 2019. Emission permits and the dynamics of clean and dirty firms in an evolutionary competition model. Metroeconomica 70, 476–487.

Baron, D., 2007. Corporate social responsibility and social entrepreneurship. Journal of Economics and Management Strategy 16, 683–717.

Borghesi, S., Cainelli, G., Mazzanti, M., 2018. Linking emission trading to environmental innovation: Evidence from the italian manufacturing industry. Research Policy 44, 669–683.

Branger, F., Quirion, P., 2015. Reaping the carbon rent: Abatement and overallocation profits in the European cement industry, insights from an LMDI decomposition analysis. Energy Economics 47, 189–205.

Chapple, L., Clarkson, P., Gold, D., 2013. The cost of carbon: Capital market effects of the proposed emission trading scheme (ETS). Abacus 49, 1–33.

Chen, Y., Zhang, D., Guo, K., Ji, Q., 2024. Emission trading schemes and cross-border mergers and acquisitions. Journal of Environmental Economics and Management 124, 102949.

Clay, K., Severnini, E., Sun, X., 2023. Does leed certification save energy? Evidence from retrofitted federal buildings. Journal of Environmental Economics and Management 121, 102866.

Clò, S., 2009. The effectiveness of the EU emissions trading scheme. Climate Policy 9, 227–241.

Clò, S., Frigerio, M., Vandone, D., 2022. Financial support to innovation: The role of european development financial institutions. Research Policy 51, 104566.

Crifo, P., Forget, V., 2012. The economics of corporate social responsibility: A survey. Working Papers HAL-00720640.

D'Aspremont, C., Jaquemin, A., Jaskold Gabszewicz, J., Weymark, J., 1983. On the stability of collusive price leadership. Canadian Journal of Economics 16, 17–25.

Dechezleprêtre, A., Nachtigall, D., Venmans, F., 2023. The joint impact of the European Union emissions trading system on carbon emissions and economic performance. Journal of Environmental Economics and Management 118, 102758.

Dechezlêpretre, A., Koźluk, T., Kruse, T., Nachtigall, D., de Serres, A., 2019. Do environmental and economic performance go together? A review of micro-level empirical evidence from the past decade or so. International Review of Environmental and Resource Economics 13, 1–118.

Dechezlêpretre, A., Sato, M., 2017. The impacts of environmental regulations on competitiveness. Review of Environmental Economics and Policy 11, 183–206.

DeShazo, J. R., Sheldon, T. L., Carson, R. T., 2017. Designing policy incentives for cleaner technologies: Lessons from california's plug-in electric vehicle rebate program. Journal of Environmental Economics and Management 84, 18–43.

Djoumessi Tiague, B., 2023. Floods, agricultural production, and household welfare: Evidence from Tanzania. Environmental and Resource Economics 85, 341–384.

Doda, B., Gennaioli, C., Goundson, A., Grover, D., Sullivan, R., 2015. Are corporate carbon management practices reducing corporate carbon emissions? Corporate Social Responsibility and Environmental Management 23, 257–270.

Donsimoni, M., 1985. Stable heterogeneous cartels. International Journal of Industrial Organizations 3, 451–467.

Donsimoni, M., Economides, N., Polemarchakis, H., 1986. Stable cartels. International Economic Review 27, 317–327.

Du, Y., Takeuchi, K., 2019. Can climate mitigation help the poor? Measuring impacts of the CDM in rural China. Journal of Environmental Economics and Management 95, 178–197.

Ellerman, A. D., Joskow, P. L., Schmalensee, R., Montero, J. P., Bailey, E. M., 2000. Markets for Clean Air: The U.S. Acid Rain Program. Cambridge University Press.

European Commission, 2003. Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC. Tech. rep., European Commission.

European Environment Agency, 2005. Annual European Community greenhouse gas inventory 1990–2003 and inventory report 2005. Tech. rep., European Environment Agency.

Fang, L., Zhao, S., 2023. On the green subsidies in a differentiated market. International Journal of Production Economics 257, 108758.

Fell, H., Burtraw, D., Morgestern, R., Palmer, K., 2012. Soft and hard price collars in a cap-and-trade system: A comparative analysis. Journal of Environmental Economics and Management 64, 183–198.

Feng, X., Zhao, Y., Yan, R., 2024. Does carbon emission trading policy have emission reduction effect? An empirical study based on quasi-natural experiment method. Journal of Environmental Management 351, 119791.

Fukuda, K., Ouchida, Y., 2020. Corporate social responsibility (CSR) and the environment: Does CSR increase emissions? Energy Economics 92, 104933.

Gasbarro, F., Rizzi, F., Frey, M., 2013. The mutual influence of Environmental Management Systems and the EU ETS: Findings for the Italian pulp and paper industry. European Management Journal 31, 16–26.

Gersbach, H., Winkler, R., 2011. International emission permit markets with refunding. European Economic Review 55, 759–773.

Graff Zivin, J., Small, A., 2005. A Modigliani-Miller theory of altruistic corporate social responsibility. The B.E. Journal of Economic Analysis and Policy 5, 1–19.

Grüll, G., Taschini, L., 2011. Cap-and-trade properties under different hybrid scheme designs. Journal of Environmental Economics and Management 61, 107–118.

Häckner, J., 2000. A note on price and quantity competition in differentiated oligopolies. Journal of Economic Theory 93, 233–239.

Hidrue, M. K., Parsons, G. R., Kempton, W., Gardner, M. P., 2011. Willingness to pay for electric vehicles and their attributes. Resource and Energy Economics 33, 686–705.

Hirose, K., Matsumura, T., Lee, S., 2017. Environmental corporate social responsibility: A note on the first-mover advantage under price competition. Economics Bulletin 37, 214–221.

Hörisch, J., 2013. Combating climate change through organisational innovation: An empirical analysis of internal emission trading schemes. Corporate Governance 13, 569–582.

Iannucci, G., Tampieri, A., 2023. On the evolutionary interplay between environmental CSR and emission tax. Energy Economics 128, 107165.

Joltreau, E., Sommerfeld, K., 2019. Why does emissions trading under the EU emissions trading system (ETS) not affect firms' competitiveness? Empirical findings from the literature. Climate Policy 19, 453–471.

Jung, C., Krutilla, K., Boyd, R., 1996. Incentives for advanced pollution abatement technology at the industry level: An evaluation of policy alternatives. Journal of Environmental Economics and Management 30, 95–111.

Kesselring, A., 2023. Willingness-to-pay for energy efficiency: Evidence from the European common market. Environmental and Resource Economics 86, 893–945.

Klemetsen, M., Rosendahl, K. E., Jakobsen, A. L., 2020. The impact of the EU ETS on norwegian plants' environmental and economic performance. Climate Change Economics 11, 2050006.

Kollemberg, S., Taschini, L., 2016. Emissions trading systems with cap adjustments. Journal of Environmental Economics and Management 80, 20–36.

Kollenberg, S., Taschini, L., 2019. Dynamic supply adjustment and banking under uncertainty in an emission trading scheme: The market stability reserve. European Economic Review 118, 213–226.

Kong, D., Liu, S., Dai, Y., 2014. Environmental policy, company environment protection, and stock market performance: Evidence from China. Corporate Social Responsibility and Environmental Management 21, 100–112.

Kong, Y., Antwi-Adjei, A., Bawuah, J., 2020. A systematic review of the business case for corporate social responsibility and firm performance. Corporate Social Responsibility and Environmental Management 27, 444–454.

Krishnamurthy, C. K. B., Kriström, B., 2015. Determinants of the price-premium for green energy: Evidence from an OECD cross-section. Environmental and Resource Economics 39, 68–88.

Lambertini, L., Palestini, A., Tampieri, A., 2016. CSR in an asymmetric duopoly with environmental externality. Southern Economic Journal 83, 236–252.

Lambertini, L., Tampieri, A., 2015. Incentives, performance and desirability of socially responsible firms in a Cournot oligopoly. Economic Modelling 50, 40–48.

Lecuyer, O., Quirion, P., 2019. Interaction between CO2 emissions trading and renewable energy subsidies under uncertainty: feed-in tariffs as a safety net against over-allocation. Climate Policy 19, 1002–1018.

Lee, M., 2011. Potential cost savings from internal/external CO2 emissions trading in the Korean electric power industry. Energy Policy 39, 6162–6167.

Lin, X., He, L., Bateman, I. J., 2023. The more the merrier? evidence from firm-level exports and environmental performance in China. Environmental and Resource Economics 84, 125–172.

Lintunen, J., Kuusela, O., 2018. Business cycles and emission trading with banking. European Economic Review 101, 397–417.

Liu, C., Wang, L., Lee, S., 2015. Strategic environmental corporate social responsibility in a differentiated duopoly market. Economic Letters 129, 108–111.

Malueg, D., 1989. Emission credit trading and the incentive to adopt new pollution abatement technology. Journal of Environmental Economics and Management 18, 52–57.

Manasakis, C., Mitrokostas, E., Petrakis, E., 2013. Certification of corporate social responsibility activities in oligopolistic markets. Canadian Journal of Economics 46, 282–309.

Manasakis, C., Mitrokostas, E., Petrakis, E., 2014. Strategic corporate social responsibility activities and corporate governance in imperfectly competitive markets. Managerial and Decision Economics 35, 460–473.

Margolis, J. D., Elfenbein, H. A., Walsh, J. P., 2009. Does it pay to be good... and does it matter? A meta-analysis of the relationship between corporate social and financial performance. Available at SSRN 1866371.

Marin, G., Marino, M., Pellegrin, C., 2018. The impact of the European emission trading scheme on multiple measures of economic performance. Environmental and Resource Economics 71, 551–582.

Marom, Y. Y., 2006. Toward a unified theory of the CSP–CFP link. Journal of Business Ethics 67, 191–200.

Martin, R., Muûls, M., Wagner, U., 2016. The impact of the European union emissions trading scheme on regulated firms: What is the evidence after ten years? Review of Environmental Economics and Policy 10, 129–148.

Milliman, S., Prince, R., 1989. Firm incentives to promote technological change in pollution control. Journal of Environmental Economics and Management 17, 247–265.

Moreno-Bromberg, S., Taschini, L., 2011. Pollution permits, strategic trading and dynamic technology adoption, CESifo Working Paper Series, Munich, Germany.

Newman, C., Rand, J., Tarp, F., Trifkovic, N., 2018. The transmission of socially responsible behaviour through international trade. European Economic Review 101, 250–267.

OECD, 2011. ISIC REV. 3 Technology Intensity Definition. OECD Directorate for Science, Technology and Industry 7 July, 2011 Economic Analysis and Statistics Division.

Orlitzky, M., Schmidt, F., Rynes, S., 2003. Corporate social and financial performance: A meta-analysis. Organization Studies 24, 403–441.

Perino, G., Willner, M., 2016. Procrastinating reform: The impact of the market stability reserve on the EU ETS. Journal of Environmental Economics and Management 80, 37–52.

Poyago-Theotoky, J., Yong, S., 2019. Managerial delegation contracts, "green" R&D and emissions taxation. The B.E. Journal of Theoretical Economics 19, 20170128.

Requate, T., 2005. Dynamic incentives by environmental policy instruments — a survey. Ecological Economics 54, 175–195.

Saha, R., Shashi, Cerchione, R., Singh, R., Dahiya, R., 2020. Effect of ethical leadership and corporate social responsibility on firm performance: A systematic review. Corporate Social Responsibility and Environmental Management 27, 409–429.

Shy, O., 1995. Industrial organization: Theory and applications. MIT Press. Cambridge, MA, US.

Teixidó, J., Verde, S. F., Nicolli, F., 2019. The impact of the EU Emissions Trading System on low-carbon technological change: The empirical evidence. Ecological Economics 164, 106347.

Unold, W., Requate, T., 2001. Pollution control by options trading. Economics Letters 73, 353–358.

Van Beurden, P., Gossling, T., 2008. The worth of values – a literature review on the relation between corporate social and financial performance. Journal of Business Ethics 82, 407–424.

Xu, L., Chen, Y., Lee, S., 2022. Emission tax and strategic environmental corporate social responsibility in a Cournot–Bertrand comparison. Energy Economics 107, 105846.

Xu, L., Lee, S., 2022. Non-cooperative and cooperative environmental corporate social responsibility with emission taxes. Managerial and Decision Economics 43, 2849–2862.

Xu, L., Lee, S., 2023. Cournot–Bertrand comparisons under double managerial delegation contracts with sales and environmental incentives. Managerial and Decision Economics 44, 3409–3421.