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The environmental-financial performance nexus of EU ETS firms: A quantile regression approach

Andrea Flori[a,*], Simone Borghesi[b,c,d], Giovanni Marin[e,c]

[a] Politecnico di Milano, Department of Management, Economics and Industrial Engineering, Milan, Italy
[b] Università di Siena, Italy
[c] SEEDS, Italy
[d] European University Institute, Italy
[e] Università di Urbino Carlo Bo, Italy

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ABSTRACT

Cap-and-trade schemes are particularly attractive climate mitigation policies as they promote investment in low-carbon technologies while allowing firms to minimise their compliance costs. This can generate a positive relationship between firms' environmental and financial performance. However, firms with limited financial resources can find cap-and-trade schemes difficult to manage, leading to their under-participation in the allowances market. This paper examines how participation in the EU ETS (measured by network centrality measures) may affect the relationship between environmental and financial performance. A panel quantile regression analysis is performed to account for possible heterogeneous behaviours at different quantiles of the financial performance distribution. The results suggest that lower emission intensity is associated with higher financial performance, and that the higher the firm's network centrality in selling allowances, the stronger this association is. Moreover, the positive relationship between environmental and financial performance is stronger and clearer at the bottom of the financial performance distribution, thus confirming the importance of accounting for heterogeneous behaviours at different quantiles of the distribution.

1. Introduction

Climate change poses a challenge to the sustainability of human society and global economic systems. The United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement pointed the way towards limiting global warming and mitigating the effects of climate change. Environmental issues are becoming more relevant drivers in the decision-making processes of a wide range of stakeholders (De Villiers and Van Staden, 2010; Griffin and Sun, 2013; Qiu et al., 2016; Dhanorkar et al., 2018; Li and Wu, 2020), as businesses start aligning themselves with the proposed emissions reductions. This has led to an increasing debate on how to properly evaluate externalities and design appropriate policies to prevent severe risks for the economy and society at large (Nordhaus, 1994; McKibbin and Wilcoxen, 2002; Nordhaus, 2007; Stern, 2008; Carney, 2015).

To comply with commitments to reduce greenhouse gas emissions, several national and regional emissions trading systems have been adopted worldwide. The European Union Emissions Trading System (EU ETS) was launched in 2005 as the world's largest carbon trading market, with the aim of promoting greenhouse gas reductions in a cost-effective and economically efficient manner (European Commission, 2003). The existence of a carbon price induces participants in the EU ETS to cut carbon emissions and thus improve their environmental performance (Hoffman, 2005; Kolk and Pinkse, 2005; Laing et al., 2014; Cadez et al., 2019). Moreover, firms investing in low-carbon projects may benefit financially from the containment of long-term operational costs and from selling allowances to polluting firms (Reinhardt and Stavins, 2010; Busch and Hoffmann, 2011; Horbach et al., 2012; Cecere et al., 2018).

Firms' investment decisions interact with both their environmental and financial performance (van Vuuren et al., 2011; Lee, 2012; Dafermos et al., 2018; Dahlmann et al., 2019). This has led to investigations of the relationship between environmental performance (EP) and financial performance (FP) (see, e.g., Ambec and Lanoie, 2008; Horváthová, 2010; Wagner, 2010 and Endrikat et al., 2014). The literature has thus scrutinised the EP-FP relationship, with the aim of answering the question "does it pay to be green?" (see, e.g., Jaffe et al., 1995; Barnett and Salomon, 2012; Dixon-Fowler et al., 2013; Busch and Lewandowski, 2018, among others). This question is key for firms participating in the EU ETS, which have to decide whether to buy allowances to comply

* Corresponding author.
E-mail addresses: andrea.flori@polimi.it (A. Flori), simone.borghesi@unisi.it (S. Borghesi), giovanni.marin@uniurb.it (G. Marin).

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with environmental regulations, or to adopt cleaner, possibly more expensive, technologies to limit their carbon emissions. For this reason, an increasing number of studies have tried to relate EP to the economic results and competitiveness of firms participating in the EU ETS (see, e.g., Anger and Oberndorfer, 2008; Laing et al., 2014; Ellerman et al., 2016; Martin et al., 2016; Dechezleprêtre et al., 2018). However, the manner in which these two performance measures interact with each other is the subject of debate and needs to be explored in further depth.

To investigate more complex EP-FP relationships recent studies have tested a quantile approach enabling the detection of different effects between the tails and the body of the distribution. For instance, Segura et al. (2018) analyse a set of Spanish firms participating in the EU ETS in the period from 2005 to 2015. They employ a quantile analysis based on copulas to study the impact of production levels on the ratio of verified emissions over assigned allowances, and the effect of the latter on economic results. In contrast, Tzouvanas et al. (2019), adopt a quantile analysis to investigate the link between EP and FP for the European manufacturing sector, and study heterogeneous relationships across the conditional distribution of FP. Our study extends these works by exploiting a panel econometric setup including firms from all sectors covered by the EU ETS regulation over the period between 2013 and 2016. This framework allows us to examine two key research questions: (i) how does EP relate to conditional values of FP, thus possibly explaining the non-linear EP-FP relationship discovered in some empirical studies? (ii) how does the level of participation in the EU ETS allowance trade contribute to explaining the EP-FP relationship? For the first question, our results show that there is a positive relationship between EP and FP. However, its magnitude is substantially higher for those firms placed at the lower end of the FP distribution that still have ample room for improvement. Meanwhile, for firms that are already performing well in terms of FP, the relationship with the EP is negligible, thus pointing to the presence of heterogeneous, non-linear effects in the EP-FP relationship of EU ETS firms.

We then analyse if such heterogeneity is related to different levels of participation in allowance trading in the EU ETS, which represents our second research question. For instance, participation differs across sectors, with power and energy firms typically being short in allowances and active purchasers of permits, as their aggregate emissions exceed the allowances at their disposal (Chèze et al., 2020). Conversely, firms in sectors more exposed to carbon leakage (i.e., the relocation of activities outside EU) tend to benefit from a more favourable allocation of allowances (Martin et al., 2014a and Schmidt and Heitzig, 2014), making them potential suppliers of permits to the rest of the system. In general, Abrell et al. (2022) find that firms whose verified emissions exceed their free allocations in a given year are more likely to participate in the EU ETS market and that, conditional on participation, they trade higher volumes of allowances than firms with an opposite balance of allowances.

However, empirical studies have not yet explored in depth whether and how firms' trade activity in the EU ETS can help us to evaluate their EP-FP relationship. Firms can trade European Union Allowances (EUAs) with several counterparts, which can be located in other countries and belong to different sectors, acting as either suppliers or purchasers of allowances. In addition, firms can be very active during the whole compliance period or, conversely, they can operate only in specific periods such as immediately before the surrendering of allowances to compensate for verified emissions. The set of these transactions thus defines a trade network of flows connecting firms within the EU ETS. Some firms are central in the network, since they trade with many counterparts and transfer a large number of allowances, while others are more peripheral and perform only a few transactions at specific times. EP and participation in the transfer of allowances are likely to be interconnected. For example, better EP may reduce the need to rely on additional allowances from the marketplace, thus impacting on the firm's centrality in terms of incoming transactions. However, a firm with better EP might be more active in selling its surplus allowances to counterparts that are short of allowances, thus affecting the firm's centrality in terms of outgoing transactions. More generally, each firm's EP either generates a deficit or a surplus of allowances, which in turn is likely to affect how firms trade allowances. We thus propose to refine our main analysis by controlling for the level of participation of firms in the trading of allowances, and we investigate how a firm's centrality level in such a network, when combined with EP, can contribute to explaining its FP. Specifically, we follow existing literature exploring how the topological features of a given system are informative of its resilience and efficiency. Such a framework relies on tools from network theory and complex system methodologies that have been successfully applied to describe the dynamics of several economic systems, from financial networks to trade interdependencies and social networks (see, e.g., Newman, 2003; Jackson, 2010 and Borgatti and Halgin (2011), among others).

The way firms operate in the trade of allowances reveals a relevant interplay with their EP, thus providing insights into how they effectively manage their allowances in order to comply with regulatory constraints and maximise their net benefits from participating in the EU ETS. We argue that firms' permit trading behaviour, as measured by metrics extracted from the trade network topology, can help better capture their true environmental results and contribute to explaining non-linearities in the EP-FP relationship. For instance, higher centrality in terms of outgoing transactions can be interpreted as a more active role in selling permits that hints at high EP. We thus interpret the combined effect of network centrality and verified emissions over total assets as a refinement of the EP of a firm, which can provide a more informative signal of the actual EP. By accounting for the interaction effects between EP and network centrality, we show that firms' FP is enhanced (diminished) when they have a central role in the network as key and active players in selling (buying) allowances.

The rest of the paper is organised as follows. Section 2 reviews the literature background motivating our study, with a particular focus on the EP-FP relationship and the functioning of the EU ETS. Section 3 presents the data used in the study and describes the panel quantile approach employed in the investigation framework. Our empirical findings are shown and discussed in Section 4. Section 5 contains some concluding remarks.

2. Literature review

The interplay between EP and FP has been widely debated both in the theoretical and empirical literature. Two main competing perspectives have emerged among scholars: the *win–win* (i.e. Porter hypothesis) and the *win–lose* (i.e. trade-off EP-FP) (see, e.g., Porter and Van der Linde, 1995; Pinkse and Kolk, 2010; Hart and Dowell, 2011; Boiral et al., 2012 and Dixon-Fowler et al., 2013). According to the instrumental stakeholder theory, firms with higher EP tend to perform better financially, since trust and cooperation help to strengthen competitive advantages and attract investors. By contrast, neoclassical theory points to the fact that firms involved in investments for carbon reduction face additional costs and competitive disadvantages, which increase their marginal cost of production.

The empirical literature on the EP-FP relationship reports mixed results (Ambec and Lanoie, 2008; Horváthová, 2010; Albertini, 2013; Endrikat et al., 2014). Some authors have found a positive relationship between the two types of performance (see, e.g., Klassen and McLaughlin, 1996; Judge and Douglas, 1998; King and Lenox, 2002 and López-Gamero et al. (2009)), while others have found evidence of a negative link (see, e.g., Sarkis and Cordeiro, 2001; Filbeck and Gorman, 2004 and Wagner, 2005), or even a neutral relationship (see, e.g., McWilliams and Siegel, 2001; Gilley et al., 2000 and Elsayed and Paton, 2005). As a consequence, more complex frameworks to reconcile these opposite relationships have been proposed in the literature. For instance, Trumpp and Guenther (2017) estimate a U-shaped relationship between EP and FP in the manufacturing and service sectors.

Similarly, Lewandowski (2017) finds that the non-linear relationship between annual carbon emissions and FP is positive for firms with superior EP but negative for those with inferior EP. Our study aims to specifically investigate the emergence of non-linearities in the EP-FP relationship by analysing the conditional distribution of FP in a panel quantile framework. Hence, we aim to verify if different pre-existing financial conditions shape the strength and sign of the EP-FP relationship. Our results indicate that a simple linear functional form for the whole sample is likely to misrepresent the EP-FP relationship, with effects that are stronger and positive at the low end of the FP distribution and appear to decrease almost monotonically when moving up the distribution.

We test the EP-FP relationship in a panel of firms participating in the EU ETS. The EU ETS covers about 40% of European greenhouse gas emissions and was the world's first international emissions trading system, a prototype for several ETS regimes deployed in other regions (Ellerman et al., 2010).[1] It relies on the principle of "cap-and-trade". Installations participating in the EU ETS can emit a total amount of greenhouse gas that is "capped" and decreases over time, in order to reduce the aggregate emissions produced by the system. The effectiveness of such a mechanism is related to the fact that energy-intensive installations are mandated to participate in the EU ETS, although only installations above a certain size (in terms of production capacity) are included. Every year, liable entities under the EU ETS regulations are required to surrender an amount of EUAs that covers their emissions during the year.[2] One EUA equates to one tonne of carbon dioxide. Installations that manage to reduce their emissions can either retain the excess of allowances to comply with their future needs, or sell them to other participants that have a shortage of allowances. By allowing permit trading across installations, the EU ETS creates a carbon price mechanism that stimulates firms to reduce their emissions. As a consequence, robust EUA market price signals provide a key economic rationale for the promotion of investments in clean and low-carbon intensive technologies.[3]

Many studies have examined the consequences of the EU ETS for participating firms, investigating its impact on three different but related aspects (Ellerman et al., 2016; Martin et al., 2016): (i) innovation (Hoffmann, 2007; Rogge et al., 2011; Schmidt et al., 2012; Borghesi et al., 2015; Calel and Dechezlepretre, 2016; Cainelli et al., 2020) (ii) emission abatement (Ellerman and Buchner, 2008; Anderson and Di Maria, 2011; Bel and Joseph, 2015; Jaraite-Kažukauske and Di Maria, 2016), and (iii) economic performance and competitiveness (Fabra and Reguant, 2014; Martin et al., 2014a; Branger et al., 2016; Joltreau and Sommerfeld, 2019; Marin et al., 2018; Borghesi et al., 2020). Moreover, some studies have focused on EUA market price dynamics (see, e.g., Alberola et al., 2008; Chevallier, 2011; Koch et al., 2014; Medina et al., 2014; Hintermann et al., 2016 and Fan et al., 2017), while others have analysed the policy design of the EU ETS (see, e.g., Sijm, 2005; Hepburn et al., 2006; Convery, 2009; De Perthuis and Trotignon, 2014; Kollenberg and Taschini, 2016; Koch et al., 2016; Perino and Willner, 2016; Naegele and Zaklan, 2019 and Borghesi et al., 2023).

Despite this large number of studies on several different aspects of the EU ETS, hardly any attention has been paid to the structure governing the EU ETS trade network of permits. Jaraitė et al. (2013a,b) describe the ownership structure of firms participating in the EU ETS during Phase I by mapping individual EU ETS accounts to their global ultimate owners. Liu et al. (2017) use EUA transaction data from the first two phases to study how emission levels affect the trading performance of emitting firms. Betz and Schmidt (2016) find that most installations regulated by the EU ETS in Phase I were either not participating or hardly participating in the trade system, while only a small portion of accounts, often belonging to non-regulated companies, were very active. The fact that regulated firms showed limited participation in the EU ETS – mainly due to initial lack of knowledge about its functioning – was also reported in early studies based on surveys (see, e.g., Pinkse and Kolk, 2007; Engels et al., 2008 and Trotignon and Delbosc, 2008). A similar result emerges from a network-based analysis which shows that non-regulated entities heavily influence the configuration of the system (Borghesi and Flori, 2018). Furthermore, the low level of trading performed by small firms has been related to transaction costs (Jaraitė et al., 2010; Jaraitė-Kažukauskė and Kažukauskas, 2015; Cludius and Betz, 2018; Karpf et al., 2018; Naegele, 2018; Zaklan, 2023), with significant information and search costs also leading to a home market bias (Hintermann and Ludwig, 2022). In addition, it has been observed that firms belonging to energy intensive sectors react differently to EU ETS regulations (Ellerman et al., 2010; Demailly and Quirion, 2008; Chan et al., 2013), while firms in sectors regarded as more exposed to carbon leakage tend to benefit from a more favourable allocation of allowances compared to other sectors (Martin et al., 2014a, Schmidt and Heitzig, 2014). Firms with higher deficits of allowances generally make more purchases, due to compliance reasons (Sandoff and Schaad, 2009; Martin et al., 2014b), while firms with larger surpluses experience higher trading profits (Liu et al., 2017; Guo et al., 2020). In particular, Nordic countries, energy and carbon leakage sectors, and larger and more productive firms or firms managing many installations show stronger participation in the trade network of allowances (Martino and Trotignon, 2013; Abrell et al., 2022).

Our paper intends to contribute to this literature by using network theory instruments to study how firms' participation in the EU ETS affects their EP-FP relationship. In particular, we propose to use the centrality in the permit trading network to refine the true environmental results of the participating firms. Specifically, higher centrality in terms of outgoing transactions, meaning a more active role in selling permits to counterparts, can be related to improved EP generating a potential surplus of allowances to be placed on the market. Conversely, higher incoming centrality indicates a more active role in purchasing permits, which suggests a worse EP.

[1] It was originally divided into three different phases: (i) Phase I: 2005 to 2007, which was intended as a pilot learning phase; (ii) Phase II: 2008 to 2012 corresponding to the first commitment period of the Kyoto Protocol; (iii) Phase III: 2013 to 2020, in which a single EU-wide cap on emissions replaced the previous system based on national caps, and the allocation method shifted progressively from free allocation to auctioning. In the period under study in this paper (2013 to 2016), member states generated nearly $15.8 billion from the auctioning of EUAs. More than 80% of these revenues have been utilised for climate and energy purposes in line with Article 10(3) of the ETS Directive (Le Den et al., 2017).

[2] EUAs are either auctioned or granted for free by the regulator on the primary market (Ellerman et al., 2016). While initially most EUAs were freely allocated to EU ETS participants, the share of auctioned allowances has increased to 57% of total EUAs during the period 2013–20. The transition from free allocation to auctioning has proceeded at different speeds in different sectors. For instance, the power sector has completed the transition to full auctioning since 2013, while the share of free allowances received by the manufacturing industry decreased progressively from 80% in 2013 to 30% in 2020. Nowadays, free allowances are restricted to particularly energy-intensive or trade-exposed sectors that are regarded as being at risk of carbon leakage and, therefore, exempted from the auctioning of allowances.

[3] Due to the absence of reliable information on emissions, in Phase I the cap was based on emissions estimates, causing an excess of supply of allowances with respect to verified emissions. Since these allowances could not be banked for use in the following phase, the price of allowances declined to zero in 2007 (at the end of Phase I). At the beginning of Phase II, the financial crisis led to a drastic fall in emissions. This caused another large surplus of allowances, which meant that the market price of EUAs remained very low throughout Phase II. In response to this, a new Directive was passed (European Commission, 2018) aimed at reforming the EU ETS in several directions: by revising the legislative framework for Phase IV (2021–2030), by enforcing the so-called market stability reserve (an automatic adjustment mechanism to address any surplus of EUAs), and by defining safeguard measures for the international competitiveness of industrial sectors at risk of carbon leakage.

There are only a few papers that employ network properties to study the EU ETS structure. For instance, Borghesi and Flori (2018) adopt a network perspective to assess the centrality of national registries within the EU ETS over the period from 2005 to 2012, and detect which types of account are most responsible for shaping the structure of the EU ETS. In Borghesi and Flori (2019) a Brexit scenario is investigated through the application of complex systems tools that reallocate links of the transaction network according to the relevance of the United Kingdom trading partners. Instead, Karpf et al. (2018) exploit the transactions network to evaluate how the topological configuration affects price formation and detect structural causes leading to the emergence of information asymmetries on the carbon market. In Zhang et al. (2019) a directed limited penetrable visibility graph and a coarse graining method are applied to study the dynamic evolution characteristics of carbon prices. In our paper, we rely on a firm-level network representation, in which nodes are firms participating in the EU ETS that are connected by the EUAs they are transferring. To highlight the role of firms as sellers or buyers of EUAs, we characterise firms' topological properties by means of centrality measures which are computed on the transaction network. To avoid endogeneity between the network indicators and FP, we opt to consider the number of links and not the amount (or value) of the transferred allowances that instead may interact with FP through the market results of the permit trade.

This representation allows us to bridge the two streams of literature (on the EU ETS and the EP-FP relationship, respectively), adopting an innovative, network-based perspective. In the following sections we will investigate how measures of network centrality and active participation in the EU ETS market may shape the nexus between the EP and FP of firms.

3. Data and methodology

3.1. Data

The study employs a large database of EU firms participating in the EU ETS in the period between 2013 and 2016, thus covering the first four years of Phase III. We collect EU ETS transaction data from the *European Transaction Log* (EUTL) database.[4] Following existing literature, in order to represent the EU ETS system we focus on transactions – both within and across national registries – that consist of pure trade flows (EUTL codes: 3-0, 3-21, 10-0). Hence, we disregard those transactions, such as the issuance and surrendering of allowances, performed for regulatory and compliance purposes through governmental accounts. Beside the latter, the main types of accounts in the EUTL correspond to liable entities, which must comply with the EU ETS regulations, and trading accounts, often specifically created by brokerage firms and financial intermediaries to trade allowances. Under the EU ETS regulatory framework, by the end of April each year liable entities are required to surrender an amount of allowances equal to their emissions produced during the previous compliance year. In accordance with Annex XIV (4) of Regulation 389/2013, transaction data are made available with a lag of three years after the recording of the information.

In the EUTL, information regarding compliance aspects, such as the amount of verified emissions, allocation and surrendering of allowances, is provided at the installation level. Each installation has an account that manages its allowances (namely, the *Operator Holding Account*), but several accounts may be held by the same account holder representing a firm that owns and manages multiple accounts. In order to match EUTL information with balance sheet data for each firm, we rely on the account holder level and collect the compliance data needed to compute the firm's environmental performance by aggregating information from single installations at firm and country level. The list of account holders from the EUTL is then matched with the Orbis Bureau van Dijk (BvD) database to get balance sheet information at the firm level. To match EUTL accounts with BvD firms we mainly use the company registration number and we supplement it with the name and address of the account.[5]

3.2. Model

Our analysis is based on a quantile regression model estimated using the penalised fixed-effects estimation procedure proposed by Koenker (2004). This approach starts from the classical linear model:

$$y_{i,t} = x_{i,t}^T \beta + \alpha_i + u_{i,t}, \tag{1}$$

where subscript i identifies the N firms, and t is the index for time. The extension to the quantile regression framework states that the conditional quantile functions of the response $y_{i,t}$ of firm i at time t can be modelled as follows:

$$Qy_{i,t}(\tau|x_{i,t}) = x_{i,t}^T \beta(\tau) + \alpha_i, \tag{2}$$

where τ refers to the selected quantile. Model (2) indicates that the effects of covariates $x_{i,t}$ depend upon the selected quantile τ, whereas the effects of α_i do not. Hence, α_i implies a pure location shift effect on the conditional quantiles of y and is intended to capture time-invariant unobserved characteristics of the firms such as managerial quality, technological level, and geographical features which are likely to be correlated with both EP and FP.

Koenker (2004) proposes to simultaneously estimate model (2) for several quantiles using the following minimisation problem:

$$min_{\alpha,\beta} \sum_{k=1}^{Q} \sum_{i=1}^{N} \sum_{t=1}^{T} w_k \rho_{\tau_k}(y_{i,t} - \alpha_i - x_{i,t}^T \beta(\tau_k)) \tag{3}$$

in which $\rho_\tau(u) = u(\tau - I(u < 0))$ stands for the piecewise linear quantile loss function of Koenker and Bassett (1978) and the weights w_k control for the influence of the Q quantiles on the estimation of α_i. Model (3) can be solved with interior point methods which proceed iteratively by solving a sequence of diagonally weighted least squares steps based on a Cholesky factorisation.

Furthermore, the quantile loss function includes a l_1 penalty, $P(\alpha) = \sum_{i=1}^{N} |\alpha_i|$, instead of a typical Gaussian penalty. This determines that the linear programming problem preserves the sparsity of the design matrix, while providing computational advantages. As pointed out by Koenker (2004), the penalised version of model (2) becomes:

$$min_{\alpha,\beta} \sum_{k=1}^{Q} \sum_{i=1}^{N} \sum_{t=1}^{T} w_k \rho_{\tau_k}(y_{i,t} - \alpha_i - x_{i,t}^T \beta(\tau_k)) + \lambda \sum_{i=1}^{N} |\alpha_i| \tag{4}$$

in which the fixed effects vanish when $\lambda \to \infty$, while the fixed effects estimator restores to that of models (2)–(3) when $\lambda \to 0$.

The resulting fixed effects estimator is obtained through a minimisation problem based on the weighted sum of Q ordinary quantile regression objective functions in which the slope coefficients of the covariates depend on the selected values of τ, whereas coefficients corresponding to the fixed effects do not, thus reducing the dimensionality added by the estimation of many fixed effects. Following the procedure proposed by Koenker (2004), the corresponding vector of the fixed effects coefficients is computed by imposing an l_1 penalty term that shrinks these coefficients towards zero. We use identical weights for each τ, while λ is set to the value of 1 (see, e.g., Damette and Delacote, 2012; Zhu et al., 2016; Cheng et al., 2019 and Akram et al., 2020).

[4] Source: https://ec.europa.eu/clima/ets/.

[5] For other examples and initiatives on matching EUTL data with firm-level information, the interested reader may refer to "Firm level data in the EU ETS (JRC-EU ETS-FIRMS)" (https://data.jrc.ec.europa.eu/dataset/bdd1b71f-1bc8-4e65-8123-bbdd8981f116) and "EUETS.INFO" (https://www.euets.info/).

3.3. Variables selection

Our analysis intends to relate the EP of the firm to its profitability (see, e.g., Horváthová, 2010; Busch and Hoffmann, 2011 and Lewandowski, 2017). To this end, we measure the firm's FP in terms of returns on equity (ROE).[6]

EP is measured as the ratio of reported emissions by the firm during a compliance period to its size, typically measured by total assets or sales (Aragón-Correa, 1998; Wagner, 2005; Aggarwal and Dow, 2012; Misani and Pogutz, 2015; Trumpp et al., 2015; Fernández-Cuesta et al., 2019). In this study, we rely on the logarithmic ratio of the verified emissions reported by each firm over its total assets (*log(CO2/TA)*).

The list of covariates includes balance sheet information at the firm level. Following Tzouvanas et al. (2019), we add the share of intangible assets over total fixed assets (*Intangibles share*) as an indicator of the firm's capacity to generate value in the future, such as through research and development investments. To account for capital deepening, we include the logarithmic ratio of the total fixed assets (tangible and intangible) over the number of employees (*log(K/L)*). In line with recent studies on the EU ETS (see, e.g., Segura et al., 2018; Fernández-Cuesta et al., 2019; Makridou et al., 2019 and Tzouvanas et al., 2019), we control for risk and liquidity dimensions. We measure the risk of the firm in terms of the Altman z-score computed for non-listed firms (*Z-score*), while liquidity conditions are included by using the ratio of current assets minus stocks over current liabilities (*Liquidity*) and the firm's ability to generate cash flows as measured by the annual growth rate of sales (*Sales growth*). Finally, we control for the firm's size using the number of employees in logarithmic form (*log(L)*) (see, e.g., Clarkson et al., 2011; Broadstock et al., 2018 and Tzouvanas et al., 2019). To limit endogeneity issues and reduce simultaneity bias, all balance sheet variables are lagged by one year, in line with previous studies (see, e.g., Wagner, 2010; Busch and Hoffmann, 2011; Clarkson et al., 2011; Misani and Pogutz, 2015; Lewandowski, 2017; Pekovic et al., 2018 and Makridou et al., 2019, to name a few).

To measure how firms operate in the EU ETS, we employ two network centrality indicators representing the number of both incoming (*In-degree*) and outgoing (*Out-degree*) links of a given node (representing a firm). Since the direction of the flows from transferring counterparts to acquiring ones indicates two opposite business needs, we specify the orientation of the links connecting pairs of nodes. This allows us to highlight the role of a node in the network, in terms of being a purchaser or seller of allowances. The use of network-based measures allows us to provide additional insights compared to indicators based on the company's net position on the EUA market or its status as a net seller or buyer. In- and out-degree provide direct evidence about firms' engagement in the EUA market. A large number of trade counterparts (nodes) signals that the firm is trying to take full advantage of the EUA market by buying and selling allowances not only for contingent needs of compliance but also with the aim of optimising their net benefits from the EU ETS. Practically, we represent the network of EU ETS transactions by means of an adjacency matrix A whose element a_{ij} is 1 if there is a link from a source node i to a target node j, and zero otherwise. We denote with $\textit{In-degree}_i = \sum_j^N a_{ji}$ the number of links entering into node i, while we refer to $\textit{Out-degree}_i = \sum_j^N a_{ij}$ as the number of departing links from node i to the rest of the network. Hence, for firm i the *In-degree* is the number of firms it purchases from and the *Out-degree* is the number of firms it sells to. We compute these network indicators for each year separately, including firms with at least one incoming or departing link during the year.

We also include a list of controls for economic, environmental and country conditions. To map the market dynamic of EU ETS allowances, we include their average annual price. EUA prices have experienced very volatile market patterns, especially during the financial crisis of 2007–08 and the switch from Phase I to Phase II of the EU ETS programme (Engels, 2009; Ellerman et al., 2016; Hintermann et al., 2016). One tCO_2 was priced at about €0.02 at the end of Phase I, rising to about €30 at the beginning of Phase II before dropping at the end of 2008 to about €15. It then remained at about €10-15 until 2011 when it sharply decreased to about €4-5 in 2013, reaching a more stable market pattern in the first years of Phase III when it was around €4-8. It is worth mentioning that – unlike Phase I – in Phase II firms were allowed to bank allowances and use them in Phase III, when the cap was planned to decrease at a faster pace, which was thought likely to result in market pressure on prices. Such market dynamics are important to assess the commitment of firms to control emissions, as very low carbon prices deter firms from investing in cleaner technologies to reduce carbon emissions.

We then add indicators for the energy and electricity markets to control for the well-documented impacts of policies and sector conditions on firms' EP (see, e.g., del Río González, 2007; Böhringer and Rosendahl, 2010; Jaraitė and Kažukauskas, 2013 and Doumpos et al., 2017). We consider: (i) the energy and supply components of the electricity price for both households and non-household consumers, and (ii) energy productivity measured as the ratio of gross domestic product over gross energy use for a given calendar year. In addition, we include the energy efficiency policy score from the output-based scoreboard on energy efficiency targets computed by Measures d'Utilisation Rationnelle de l'Energie (values are expressed in a scale ranging from 0 to 100, where 100 is the best score; see, e.g., Makridou et al., 2019). All these indicators are computed on a country-year basis. They represent the domestic energy and electricity market conditions and the effectiveness of the policy framework. These conditions may influence firms' adoption of energy-saving and cleaner technologies aimed to stimulate their EP.

Finally, to capture different macro-economic conditions faced by firms operating in different countries and to control for country level environmental conditions, for each year and country we include the gross domestic product per capita growth rate and the logarithmic amount of greenhouse gas emissions by all NACE activities.

Table 1 reports summary descriptive statistics for each variable in the period from 2012 to 2016.[7] As shown in the table, ROE exhibits an increasing trend at the end of the reference period, while the proxy for EP (namely, *log(CO2/TA)*) appears to be more stable. In addition, centrality indicators show a declining trend and a tendency towards a narrower dispersion over time. Balance sheet features, such as *Liquidity*, *log(K/L)*, and *Intangibles share*, are pretty stable, while others like *Z-score* and *Sales growth* behave more erratically. The size of the firms (*log(L)*) is also very stable over the reference period.

4. Results

4.1. Baseline results

Table 2 shows the baseline estimation of the EP-FP relationship for different quantiles ranging from $\tau = 0.1$ to $\tau = 0.9$, with FP proxied by ROE. Panel A reports results for a simpler specification without any macro-level controls, while the specification for the full set of macro-level controls is shown in Panel B. The measure of EP, log(CO2/TA), presents an almost monotonic pattern across quantiles, with significant and negative coefficients for lower quantiles of FP. For upper quantiles, the data still points to a negative sign but it is not statistically significant. Hence, we find that for firms at the lower end of the ROE distribution, better EP is associated with better FP, in line

[6] It should be noted that ROE also accounts for the cost of purchasing EUAs and for revenue from the sale of EUAs.

[7] The period under study is from 2013 to 2016 but descriptive statistics start from 2012 since balance sheet information is included in the models with a one year lag.

Table 1
Summary descriptive statistics.

	2012				2013				2014				2015				2016			
	Q1	Mean	Q3	SD	Q1	Mean	Q3	SD	Q1	Mean	Q3	SD	Q1	Mean	Q3	SD	Q1	Mean	Q3	SD
ROE	−1.46	2.46	13.65	65.10	−1.62	−0.48	12.70	71.40	−0.64	2.24	13.73	71.90	0.00	3.30	15.02	64.90	0.58	7.00	16.49	61.56
log(CO2/TA)	−2.60	−1.25	0.22	2.49	−2.50	−1.30	0.06	2.39	−2.49	−1.30	0.09	2.45	−2.44	−1.25	0.18	2.39	−2.36	−1.18	0.24	2.40
In-degree	1.00	1.49	2.00	3.48	1.00	1.51	2.00	2.15	1.00	1.37	1.00	1.68	1.00	1.28	1.00	1.42	1.00	1.19	1.00	1.10
Out-degree	1.00	1.45	1.00	3.62	0.00	1.19	1.00	3.04	0.00	1.06	1.00	2.31	0.00	0.94	1.00	1.84	0.00	0.69	1.00	1.47
Z-score	0.85	4.98	2.48	139.72	0.84	2.71	2.50	48.75	0.84	2.69	2.51	35.48	0.88	1.92	2.53	15.33	0.89	2.38	2.52	30.94
Liquidity	0.85	2.37	2.17	5.16	0.85	2.64	2.18	6.78	0.85	2.51	2.22	5.83	0.88	2.54	2.26	5.97	0.89	2.60	2.27	6.17
Sales growth	−0.06	8.42	0.14	507.09	−0.05	8.52	0.11	409.34	−0.21	0.14	−0.06	8.68	−0.17	0.79	−0.03	38.92	−0.11	1.57	0.02	62.99
Intangibles share	0.00	0.07	0.05	0.17	0.00	0.06	0.04	0.24	0.00	0.06	0.04	0.17	0.00	0.06	0.04	0.17	0.00	0.06	0.03	0.17
log(K/L)	4.45	5.40	6.22	1.72	4.52	5.42	6.29	1.73	4.41	5.33	6.18	1.72	4.32	5.24	6.09	1.72	4.30	5.18	6.03	1.70
log(L)	3.69	7.35	6.30	9.44	3.76	7.35	6.35	9.43	3.78	7.32	6.33	9.43	3.83	7.32	6.33	9.47	3.83	7.30	6.33	9.48

The table reports for the years from 2012 to 2016, the first (Q1) and third quartile (Q3) of the distribution, the mean value and the standard deviation (SD) of the variables described in Section 3.3.

Table 2
Baseline results.

Panel A - Results without macro-level control variables									
Dep. var.: ROE	$\tau = 0.1$	$\tau = 0.2$	$\tau = 0.3$	$\tau = 0.4$	$\tau = 0.5$	$\tau = 0.6$	$\tau = 0.7$	$\tau = 0.8$	$\tau = 0.9$
log(CO2/TA)	−0.777***	−0.370***	−0.291***	−0.249***	−0.186***	−0.148***	−0.086	−0.040	−0.195
	(0.176)	(0.077)	(0.059)	(0.053)	(0.055)	(0.055)	(0.066)	(0.092)	(0.148)
Z-score	1.561***	1.157***	1.005***	0.979***	0.978***	1.000***	0.932***	0.851***	0.726***
	(0.329)	(0.212)	(0.193)	(0.184)	(0.178)	(0.171)	(0.171)	(0.169)	(0.198)
Liquidity	−0.048	−0.066	−0.089*	−0.103**	−0.111**	−0.120***	−0.121***	−0.105*	−0.084
	(0.086)	(0.056)	(0.046)	(0.045)	(0.045)	(0.045)	(0.046)	(0.056)	(0.067)
Sales growth	−0.016	−0.023	0.022	0.021	0.090	0.087	0.174	0.168	0.155
	(0.048)	(0.063)	(0.071)	(0.078)	(0.132)	(0.133)	(0.130)	(0.126)	(0.117)
Intangibles share	−4.003	0.724	0.726	1.016	1.285*	1.429*	1.369	0.942	0.909
	(3.522)	(0.974)	(0.841)	(0.741)	(0.737)	(0.754)	(0.890)	(1.163)	(2.326)
log(K/L)	0.015	0.188	0.210*	0.115	0.086	0.020	−0.098	−0.298**	−0.641***
	(0.308)	(0.128)	(0.108)	(0.098)	(0.093)	(0.097)	(0.106)	(0.140)	(0.207)
log(L)	0.461*	0.301***	0.346***	0.364***	0.375***	0.363***	0.312***	0.256**	−0.088
	(0.241)	(0.091)	(0.065)	(0.061)	(0.065)	(0.068)	(0.070)	(0.103)	(0.177)
Panel B - Results with macro-level control variables									
log(CO2/TA)	−0.713***	−0.296***	−0.223***	−0.213***	−0.159***	−0.097	−0.064	0.012	0.124
	(0.181)	(0.075)	(0.058)	(0.056)	(0.056)	(0.059)	(0.066)	(0.086)	(0.166)
Z-score	1.491***	1.099***	0.996***	0.977***	0.984***	0.980***	0.906***	0.826***	0.703***
	(0.280)	(0.216)	(0.203)	(0.204)	(0.196)	(0.193)	(0.195)	(0.197)	(0.239)
Liquidity	−0.048	−0.086	−0.116**	−0.120**	−0.123**	−0.140***	−0.113**	−0.101*	−0.088
	(0.081)	(0.057)	(0.052)	(0.051)	(0.050)	(0.050)	(0.052)	(0.057)	(0.069)
Sales growth	−0.019	0.008	0.022	0.021	0.082	0.079	0.174	0.168	0.156
	(0.087)	(0.102)	(0.129)	(0.146)	(0.166)	(0.165)	(0.160)	(0.151)	(0.141)
Intangibles share	−5.374	1.138	1.438*	1.316*	1.707**	2.137***	2.043**	1.427	1.856
	(3.650)	(1.218)	(0.831)	(0.765)	(0.732)	(0.747)	(0.909)	(1.234)	(2.458)
log(K/L)	0.148	0.087	0.121	0.047	0.047	−0.010	−0.161	−0.370***	−0.652***
	(0.272)	(0.126)	(0.094)	(0.089)	(0.087)	(0.092)	(0.106)	(0.141)	(0.222)
log(L)	0.431*	0.220**	0.247***	0.318***	0.317***	0.357***	0.316***	0.284***	0.074
	(0.234)	(0.096)	(0.075)	(0.069)	(0.063)	(0.064)	(0.076)	(0.096)	(0.208)
Macro-level controls:	YES	YES	YES	YES	YES	YES	YES	YES	YES

The table reports the quantile regression model, estimated using the penalised fixed-effects estimation procedure proposed by Koenker (2004) with intercept, for values of τ ranging from $\tau = 0.1$ to $\tau = 0.9$. Standard errors are reported in parenthesis. The number of firm-year observations are 10,596 in Panel A and 10,585 in Panel B. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Results for macro-level controls in Panel B are not shown and remain available upon request.

with the view of Porter and Van der Linde (1995). On the contrary, we observe that for those firms at the top of the distribution, FP is not statistically related to log(CO2/TA). Overall, these results suggest that for a consistent portion of the ROE distribution, there is a statistically significant negative relationship with log(CO2/TA), meaning that solutions improving firms' EP are likely to improve financial results. By applying a quantile analysis on a restricted sample of manufacturing firms, Tzouvanas et al. (2019) observe that the EP-FP relationship is U-shaped. Here, we notice that for a subset of firms performing very well financially, there is no statistically significant relationship with EP. As a result, a simple linear functional form for the whole sample is likely to misrepresent the EP-FP relationship.

We also observe that balance sheet features play an important role in shaping firms' FP. The Z-score presents estimated coefficients that are statistically significant and positive in all quantiles. Lower financial distress is thus associated with better financial results, especially for those firms corresponding to lower values of τ. The marginal effect of the Z-score for those firms at the bottom of the FP distribution is about twice as large as that of the best-performing firms, thus supporting the use of a quantile representation to uncover differences between firms. Regarding liquidity conditions, we note a negative and statistically significant coefficient, except in the extremes of the FP distribution where the sign is still negative but the effect is not statistically significant. Overall, higher mismatches between current levels of assets and liabilities seem to reduce firms' ROE in our sample. Instead, the annual growth rate of sales does not appear to play any significant role, with coefficients of sales growth that are statistically indistinguishable from zero. Similarly, the share of intangible assets has a (weakly) statistically significant and positive effect only in the middle of the ROE distribution, suggesting weak links between short-term profitability measures and longer term effects of innovation activities on performance. However, we find that capital deepening, log(K/L), has negative and significant coefficients at the upper end of the ROE distribution, meaning that for firms performing very well financially, higher capital intensity is likely to negatively affect their FP. This could be related to the fact that for these very profitable firms additional increases in capital intensity lower the (already very high) returns to capital. Finally, the coefficients of firm size, log(L), are almost always significant and positive, with a larger effect at the lower end of the ROE distribution: expanding firms are more profitable in the short run. All these results are robust to the inclusion of macro-level control variables, as evident from Panel B.

4.2. Results accounting for network measures

This section enriches the investigation framework discussed in Section 4.1 by including network indicators to better shape the nexus between EP and FP. In particular, we describe the behaviour of each firm within the EU ETS by means of topological measures of centrality indicating how active a firm is in trading allowances either as an acquiring or selling counterpart. In so doing, we attempt to disentangle the role played by the position of firms within the EU ETS trade network in driving FP, possibly highlighting peculiar effects across τ values of the FP distribution (see Table 3).[8] Specifically, by controlling for firms' network centrality, we aim to provide a more effective assessment of their EP, with the inclusion of centrality levels as a refinement of the true environmental results.

A high In-degree value means that the corresponding firm is an acquirer of EUAs from many different counterparts, while a high Out-degree value indicates a firm selling EUAs to many other EU ETS participants. We use these two simple network indicators to differentiate the active role of a firm as a buyer or seller of EUAs and provide a clearer signal of its EP. We investigate how the active role of a firm relates to its FP by estimating the relationship between FP and both In-degree and Out-degree for different values of τ. Although not statistically significant in general, we observe in Table 3 that network centrality indicators seem to point to opposite results for firms belonging to the bottom and top deciles of the ROE distribution. Specifically, In-degree shows a positive relationship with FP for low performing firms, that declines and becomes negative at higher values of τ. Conversely, Out-degree shows a negative relationship with FP at lower values of τ, while again an opposite relationship is found for those firms in the upper part of the ROE distribution. However, the lack of any direct relationship between network centrality and FP is not surprising, as a strong link between network centrality and FP would imply that profits and losses, arising directly from allowance trading, contribute substantially to the overall level of FP. While this could be relevant for a subset of firms in emission-intensive sectors (e.g., power sector), it is less likely to be the case for sectors in which the overall value of traded allowances (allocated, purchased and sold) is small compared to the economic size of the firm.

Firms within the EU ETS can experience the emergence of a surplus or deficit of EUAs for compliance purposes. This depends on their level of production, and thus of emissions, but also on their investments in carbon abatement technologies and activities. Therefore, within a given compliance period, a firm with improved EP may exhibit an excess of allowances that it may seek to sell in the EU ETS marketplace. Meanwhile, firms with more emission-intensive production processes and less ability to improve their EP may rely more on acquiring EUAs from other operators. Hence, there exists a relationship between a firm's EP and how it actively manages its portfolio of EUAs. When both factors are jointly considered, this may contribute to better identifying the firm's true environmental results. For this reason, in Table 4 we evaluate the impact of the interaction effects between log(CO2/TA) and the network indicators In-degree and Out-degree. To ease the interpretation of interaction terms, we take out from log(CO2/TA) its median value. This allows us to interpret the coefficients for In-degree and Out-degree as the effects for firms with median emission intensity.

The effects of In-degree and Out-degree on ROE for the median firm are shown in Table 4. As expected, they reflect the results from Table 3: the relationship is positive for In-degree and negative for Out-degree, and generally not statistically significant.[9] However, we observe a generally positive interaction term for In-degree (except for the two top quantiles) and a generally negative and significant interaction term for Out-degree, again except the top quantiles. More importantly, by considering the interaction effects between network centrality measures and EP, we can quantify the relationship between EP and FP for different levels of involvement in the allowance trading. While we find, on average (see, e.g., Table 3), a positive relationship between EP (i.e., low emission intensity) and FP, this relationship is significantly attenuated for firms with a high In-degree value and reinforced for firms with a high Out-degree value. We uncover, therefore, that the relationship between EP and FP is affected by how firms participate in the EU ETS as acquirers or sellers of allowances. This is consistent with the idea that a more active role as a seller of allowances may better signal a firm's improved environmental result than having a higher level of centrality in terms of acquiring allowances.[10] In our framework, a lower ratio of verified emissions over total assets, when combined with an active role as a central player in the selling of allowances, is thus a stronger indication of improved EP.[11]

To disclose how the interplay between EU ETS participation and EP influences FP, we propose to report a simple visualisation plot (Fig. 1) for different combinations of In-degree and Out-degree values, such

[8] The inclusion of In-degree and Out-degree in the panel quantile regression largely confirms the findings reported in Table 2. This supports our previous discussion on the presence of heterogeneous effects across the deciles of the response variable, and highlights the importance of including firm level information as well as macro and sectoral dimensions.

[9] We have repeated the estimation, adding the lagged value (1 year) of ROE to address the dynamic nature of profitability measures and the persistence of ROE. Results are qualitatively very similar to those in Table 4. It should be noted, however, that just adding the lagged dependent variable introduces a bias, which could be large for small T (as in our case). We thank an anonymous Reviewer for this suggestion.

[10] In this work, we opt for measures of network centralities that simply count the number of links without considering the associated volumes. Importantly, it must be considered that firms (since Phase II of the EU ETS) can bank their allowances to carry over to future years. Therefore allowances traded in a given year should be considered with respect to the pre-existing stock of allowances accumulated in the previous years. This would certainly provide a better assessment of the general surplus or deficit position. However, as highlighted in Abrell et al. (2022) there may be some inconsistencies in the data that prevent a proper computation of banked allowances. Table 5 in Appendix A provides the estimation of Table 4 employing the weighted degree (namely, *Strength*) that takes into account the amount of permits exchanged. The correlation between In-degree and the number of purchased units is 0.51, while the correlation between Out-degree and the number of sold units is 0.60. Despite the limitations in using traded volumes, the results in Table 5 confirm the main relationship between EP and FP. Alternative measures, such as the net exchanged allowances as measured by verified emissions minus free allowances, could be used for a similar task. We thank an anonymous Reviewer for this observation.

[11] We have also repeated the analysis of Table 4 for firms referring to a particularly relevant sector within the EU ETS represented by firms operating in energy-related activities. In particular, we subset the sample using NACE Rev.2 code D-Electricity, Gas, Steam and Air Conditioning Supply. The corresponding estimates are reported in Table 6 of Appendix B, showing that energy firms' relationship with EP is highly statistically significant and much stronger than that in the whole sample, while the interaction effects of EP with both In-degree and Out-degree are not statistically significant and very close to zero. Energy firms are typically carbon-intensive and short in allowances, which may contribute to explaining the role of EP. These estimates suggest that energy participants in the EU ETS may have a distinctive role in the EU ETS, dissimilar from that of firms in many other sectors. We thank an anonymous Reviewer for this suggestion.

Table 3
Specification with network centrality measures.

Dep. var.: ROE	$\tau = 0.1$	$\tau = 0.2$	$\tau = 0.3$	$\tau = 0.4$	$\tau = 0.5$	$\tau = 0.6$	$\tau = 0.7$	$\tau = 0.8$	$\tau = 0.9$
In-degree	0.643	0.155	0.187	0.090	0.189*	0.191*	0.131	0.022	−0.141
	(0.540)	(0.205)	(0.134)	(0.106)	(0.109)	(0.114)	(0.142)	(0.162)	(0.354)
Out-degree	−0.767	−0.112	−0.126	−0.012	−0.082	−0.065	−0.024	0.163	0.264
	(0.626)	(0.207)	(0.128)	(0.098)	(0.103)	(0.126)	(0.150)	(0.171)	(0.268)
log(CO2/TA)	−0.779***	−0.294***	−0.192***	−0.213***	−0.276***	−0.239***	−0.212***	−0.007	0.013
	(0.177)	(0.091)	(0.067)	(0.061)	(0.064)	(0.071)	(0.077)	(0.095)	(0.190)
Z-score	2.096***	1.574***	1.503***	1.477***	1.562***	1.662***	1.740***	1.708***	1.599***
	(0.314)	(0.243)	(0.232)	(0.229)	(0.226)	(0.236)	(0.247)	(0.269)	(0.298)
Liquidity	0.006	−0.119*	−0.166***	−0.151***	−0.167***	−0.144**	−0.094	−0.064	0.052
	(0.073)	(0.062)	(0.059)	(0.057)	(0.056)	(0.056)	(0.057)	(0.07)	(0.099)
Sales growth	0.027	−0.028	−0.040	0.083	0.068	0.055	0.552	0.516	0.774
	(0.107)	(0.157)	(0.209)	(0.254)	(0.350)	(0.404)	(0.429)	(0.495)	(0.820)
Intangibles share	0.814	1.043	1.727*	2.028***	2.335***	2.205***	2.772***	2.161	3.969
	(3.265)	(1.252)	(0.891)	(0.766)	(0.777)	(0.849)	(1.065)	(1.359)	(2.456)
log(K/L)	0.167	0.078	0.183	0.097	0.051	0.006	−0.213*	−0.380***	−0.885***
	(0.290)	(0.137)	(0.121)	(0.109)	(0.105)	(0.110)	(0.125)	(0.145)	(0.276)
log(L)	0.488*	0.173	0.267***	0.277***	0.232***	0.230***	0.095	0.014	−0.554**
	(0.271)	(0.110)	(0.086)	(0.078)	(0.084)	(0.086)	(0.100)	(0.116)	(0.247)
Macro-level controls:	YES	YES	YES	YES	YES	YES	YES	YES	YES

The table reports the quantile regression model, estimated using the penalised fixed-effects estimation procedure proposed by Koenker (2004) with intercept, for values of τ ranging from $\tau = 0.1$ to $\tau = 0.9$. Standard errors are reported in parenthesis. The number of firm-year observations are 6455. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Results for macro-level controls are not shown and remain available upon request.

Table 4
Interaction between network centrality measures and EP.

Dep. var.: ROE	$\tau = 0.1$	$\tau = 0.2$	$\tau = 0.3$	$\tau = 0.4$	$\tau = 0.5$	$\tau = 0.6$	$\tau = 0.7$	$\tau = 0.8$	$\tau = 0.9$
In-degree	0.843	0.253	0.230	0.174	0.211*	0.269*	0.290*	0.137	0.456
	(0.583)	(0.235)	(0.153)	(0.113)	(0.122)	(0.151)	(0.173)	(0.222)	(0.359)
Out-degree	−1.053	−0.325	−0.241	−0.144	−0.129	−0.145	−0.091	−0.053	−0.240
	(0.673)	(0.213)	(0.151)	(0.111)	(0.100)	(0.124)	(0.140)	(0.179)	(0.310)
log(CO2/TA)	−0.784***	−0.263**	−0.195**	−0.259***	−0.321***	−0.301***	−0.255***	0.025	−0.131
	(0.272)	(0.111)	(0.088)	(0.073)	(0.070)	(0.081)	(0.091)	(0.131)	(0.243)
log(CO2/TA) × In-degree	0.252*	0.151**	0.118**	0.094*	0.116**	0.131**	0.115*	0.093	0.147
	(0.145)	(0.075)	(0.057)	(0.051)	(0.049)	(0.057)	(0.060)	(0.080)	(0.133)
log(CO2/TA) × Out-degree	−0.376**	−0.213***	−0.151**	−0.107*	−0.114**	−0.117**	−0.085	−0.141**	−0.129
	(0.185)	(0.075)	(0.063)	(0.057)	(0.055)	(0.059)	(0.058)	(0.071)	(0.144)
Firm-level controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Macro-level controls	YES	YES	YES	YES	YES	YES	YES	YES	YES

The table reports the quantile regression model, estimated using the penalised fixed-effects estimation procedure proposed by Koenker (2004) with intercept, for values of τ ranging from $\tau = 0.1$ to $\tau = 0.9$. Standard errors are reported in parenthesis. The number of firm-year observations are 6455. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Results for other firm-level controls, Z-score, Liquidity, Sales growth, Intangibles share, log(K/L), log(L), and macro-level controls are not shown and remain available upon request.

that the relationship between EP and FP is positive (i.e., Porter-like effect, green area), null (EP and FP are independent, blue line) and negative (i.e., trade-off between EP and FP, red area) for the different quantiles of FP.[12] Moreover, the white dot in each panel identifies the average firm (in terms of In- and Out-degree) within each quantile. Note how, in general, the 'average' firm falls within the Porter-like area for all quantiles except $\tau = 0.8$, for which the average firm lies in the 'trade-off' area but close to the 'no-relationship' line.[13]

A possible implication of these results is that to take advantage of EP-FP complementarities, we need to consider firms' behaviour on the permits market. For instance, increasing Out-degree (i.e., increasing the number of counterparts to which a firm sells allowances) and decreasing In-degree (i.e., reducing the number of counterparts from which allowances are bought) would signal a possible excess of allowances and thus a better EP that contributes to boosting FP. However, such a combination of strategies appears to be unlikely in our sample, as for all τ we observe a strong positive linear correlation between In-degree and Out-degree (see the yellow dashed line in Fig. 1 which represents the linear fit between In-degree and Out-degree for each τ).[14] Interestingly, for lower quantiles of FP the yellow line lies completely in the green area (for In-degree and Out-degree lower than 4, which represents a typical range for firms in our sample), while for $\tau = 0.8$ (and, to a lesser extent, $\tau = 0.9$) the yellow line lies in the 'EP-FP trade-off' area for low values of In-degree and Out-degree. Hence, on average among firms in the bottom quantiles of FP, the positive relationship between EP and FP is reinforced by participation in the EU ETS as a seller of (excess) allowances. On the other hand, firms which are very active in purchasing allowances are less likely to exploit synergies between EP and FP, probably because they choose to comply with EU ETS regulation by purchasing allowances rather than by reducing emissions.[15] Therefore, combining high Out-degree with low In-degree

[12] This is done by taking the first derivative of FP with respect to EP and setting it equal to zero.

[13] For $\tau = 0.9$ we estimate that the average firm lies close to the 'no-relationship' line, but on the 'Porter-like' side.

[14] The smallest correlation coefficient is about 0.53 for $\tau = 0.1$ and $\tau = 0.3$, while the greatest correlation coefficient is about 0.87 for $\tau = 0.4$ and $\tau = 0.9$. If anything, there is weak evidence of a relative stronger correlation between In-degree and Out-degree for higher quantiles than for lower quantiles.

[15] A firm might purchase allowances even when it performs abatement activities, if these are insufficient to offset the increase in the firm's production.

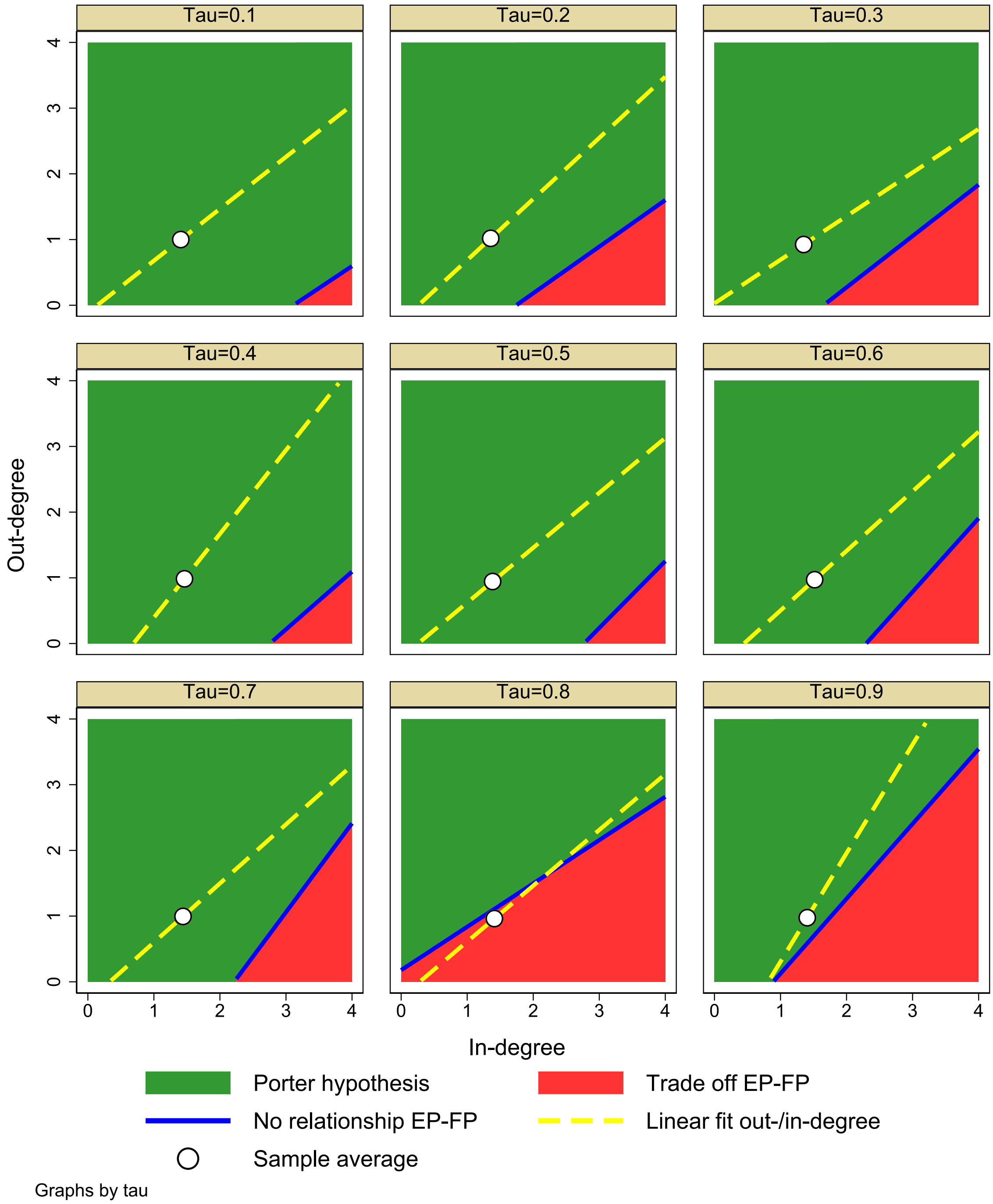

Fig. 1. Estimated relationship between EP and FP by FP quantile and In-/Out-degree. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

turns out to be the best way to take advantage (in terms of increased FP) of improvements in EP. However, such an 'optimal' combination appears to be quite unlikely given the strong positive correlation (in all τ_s) between In-degree and Out-degree values in our sample of firms.

To avoid being "trapped" in the red area of Fig. 1 and ensure that they enjoy the EP-FP synergies characterising the green area, firms should move north-west in the diagram by increasing their Out-degree and reducing their In-degree. This requires a shift in strategy from purchasing emission allowances to abating emissions. This can be pursued by developing and adopting low-carbon technologies (see, e.g., Calel and Dechezlepretre, 2016). This reduces the need to purchase allowances (leading to a lower In-degree value) and could create a surplus of allowances, to be sold on the market (leading to a higher Out-degree value). Firms are unable to choose their centrality level (since it also depends on the partners' centrality) but they may influence it by adopting the above-mentioned strategy. However, this strategy may be particularly hard to implement for firms at the top of the FP distribution, as switching into the green area would require particularly large Out-degree values and, at the same time, very small In-degree values.

However, in our regressions we control for changes in output by accounting for the sales growth rate and total assets. Therefore, a high allowance demand is very likely to reflect little or no abatement activities.

Table 5
Interaction between network centrality measures (Strength) and EP.

Dep. var.: ROE	$\tau = 0.1$	$\tau = 0.2$	$\tau = 0.3$	$\tau = 0.4$	$\tau = 0.5$	$\tau = 0.6$	$\tau = 0.7$	$\tau = 0.8$	$\tau = 0.9$
In-strength	−6.494e−07	−2.209e−07	−2.817e−07	−8.397e−08	−1.133e−07	−1.454e−07	−1.760e−07	−1.795e−07	−1.138e−07
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Out-strength	3.990e−07	7.297e−08	1.975e−07	8.211e−08	1.415e−07	1.749e−07	2.172e−07	2.157e−07	1.459e−07
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
log(CO2/TA)	−0.555**	−0.222**	−0.130*	−0.186***	−0.255***	−0.201***	−0.178**	0.007	0.007
	(0.224)	(0.097)	(0.079)	(0.071)	(0.069)	(0.071)	(0.084)	(0.102)	(0.196)
log(CO2/TA) × In-strength	−5.817e−08	−1.145e−07	−1.190e−07	−9.193e−08	−8.389e−08	−9.280e−08	−1.031e−07	−1.176e−07	3.806e−08
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
log(CO2/TA) × Out-strength	−1.889e−07	−3.878e−08	2.654e−08	6.713e−08	6.542e−08	8.042e−08	1.027e−07	1.034e−07	−5.265e−08
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Firm-level controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Macro-level controls	YES	YES	YES	YES	YES	YES	YES	YES	YES

The table reports the quantile regression model, estimated using the penalised fixed-effects estimation procedure proposed by Koenker (2004) with intercept, for values of τ ranging from $\tau = 0.1$ to $\tau = 0.9$. Standard errors are reported in parenthesis. In-strength and Out-strength refer to the weighted degree in terms of acquired and transferred allowances, respectively. The number of firm-year observations are 6455. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Results for other firm-level controls, Z-score, Liquidity, Sales growth, Intangibles share, log(K/L), log(L), and macro-level controls are not shown and remain available upon request.

5. Conclusions

A vast literature has addressed the issue of whether it pays to be green. To that end, increasing attention has been devoted over the years to the relationship between firms' environmental performance (EP) and financial performance (FP). Moreover, following the well-known Porter hypothesis, many studies have examined whether and how environmental regulation affects firms' competitiveness and profits. Among the numerous environmental regulations, the EU ETS is perhaps one of the most interesting, being the cornerstone of EU climate policy and a prototype for other ETSs around the world.

This paper aims to contribute to the long-standing literature on the EP-FP relationship with a fresh look from an innovative perspective. It focuses on the role of the EU ETS in particular, and utilises network theory instruments that have received little or no attention in the literature so far. The present study differs from previous contributions in several respects. Firstly, it focuses on the EP-FP relationship for EU ETS firms, utilising only recent data (taken from Phase III of the EU ETS, which differed markedly from the first two phases and finished at the end of 2020). Secondly, it investigates how active participation in the EU ETS (captured by centrality measures in the EU ETS network) affects the EP-FP relationship, thus combining three research strands (Porter hypothesis, EU ETS and network theory) that have never previously been brought together. Finally, it uses quantile regression analysis to capture possible non-linearities in the EP-FP relationship and heterogeneous behaviours among EU ETS firms.

Three main results emerge from the empirical analysis. Firstly, we find that lower emissions intensity is associated with higher FP, which suggests a statistically significant positive relationship between EP and FP, in line with the well-known Porter hypothesis.

Secondly, the EP-FP relationship varies depending on the FP level of the firms. EP has a stronger relationship with FP for firms at the bottom of the FP distribution, while it has almost no role (on average) for highly profitable firms. Therefore, the use of a quantile regression allows us to shed light on the existence of heterogeneous effects among EU ETS firms. Those firms that are already performing well in financial terms are unlikely to be affected by changes in their EP. On the contrary, EP can make a remarkable difference for those firms that still have much room for improvement in their financial positions.

Thirdly, the nature of the EP-FP relationship is better specified when features of the EU ETS network are taken into account. More precisely, the EP-FP relationship depends on the centrality of the firm in the EU ETS network and on the direction of its exchanges with other counterparts in the network. The estimated positive impact of better EP (i.e., lower emissions intensity) on the firm's FP increases with its Out-degree level while it decreases with the firm's In-degree level. In other words, the firm's FP tends to improve with its EP, and the higher the centrality of the firm in terms of selling allowances, the stronger this relationship is. This result suggests that the EU ETS can become a driver of additional financial returns for those virtuous firms that, by lowering their emissions, are able to sell their excess of allowances. On the contrary, the financial benefits of investing in lowering emissions are reduced if the firm still needs to purchase many allowances on the EU ETS market. Therefore, increasing the Out-degree and decreasing the In-degree is crucial for the firms that lie in the red area illustrated in this paper. It can enable them to cross the line and move to the green area where they can fully exploit EP-FP complementarities. However, the strong positive correlation between the two measures in the sample suggests that such a strategy of increasing the Out-degree and decreasing the In-degree may be hard to implement in practice, and that economic dimensions other than EP may impact on the trading intensity. Nevertheless, adopting low-carbon technologies can help to achieve this goal as it reduces the need to purchase additional allowances while increasing the likelihood of having excess of allowances to sell on the market.

The findings emerging from this paper may enrich our understanding of the role that heterogeneity can play in carbon markets. EU ETS firms differ in many respects: abatement costs, EP, FP, but also network centrality. This has relevant policy implications. For instance, it suggests that auction revenues would be better invested in improving the EP of firms that are at the lower end of the FP distribution since that is where the relationship between EP and FP is strongest. In other words, EU ETS revenues are more effective in improving FP if channelled towards financially less successful firms. This has been mainly ignored in the policy debate thus far. Most of the previous literature and the related debate has focused on how to use auction revenues to address distributional issues among households. While this is crucial for the social acceptability of the policy, attention should also be devoted to how revenues are distributed among firms with different features (i.e., different EP and FP), in order to increase the efficacy of government spending. This could create a virtuous circle between EP and FP: better EP generates better FP in firms lagging behind, which in turn may increase their capacity to cut emissions.

CRediT authorship contribution statement

Andrea Flori: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Simone Borghesi:** Conceptualization, Formal analysis, Writing – original draft, Writing – review & editing. **Giovanni Marin:** Methodology, Software, Formal analysis, Investigation, Writing – original draft, Writing – review & editing.

Appendix A. Strength indicator of centrality

See Table 5.

Table 6
Energy firms.

Dep. var.: ROE	$\tau = 0.1$	$\tau = 0.2$	$\tau = 0.3$	$\tau = 0.4$	$\tau = 0.5$	$\tau = 0.6$	$\tau = 0.7$	$\tau = 0.8$	$\tau = 0.9$
In-degree	−0.082	−0.092	0.043	−0.013	0.065	0.085	0.117	0.365	0.465
	(0.907)	(0.437)	(0.248)	(0.187)	(0.195)	(0.230)	(0.278)	(0.324)	(0.500)
Out-degree	0.032	0.016	0.191	0.215	0.367**	0.432**	0.475**	0.483**	0.238
	(0.787)	(0.332)	(0.237)	(0.205)	(0.185)	(0.179)	(0.210)	(0.237)	(0.382)
log(CO2/TA)	−1.248***	−0.672***	−0.662***	−0.653***	−0.631***	−0.670***	−0.569***	−0.636***	−0.426
	(0.408)	(0.193)	(0.137)	(0.122)	(0.122)	(0.137)	(0.147)	(0.173)	(0.333)
log(CO2/TA) × In-degree	0.007	0.062	0.042	0.048	0.036	0.026	0.024	0.086	0.092
	(0.207)	(0.128)	(0.083)	(0.067)	(0.064)	(0.073)	(0.075)	(0.087)	(0.140)
log(CO2/TA) × Out-degree	0.031	−0.084	−0.003	−0.009	0.038	0.059	0.051	0.065	0.049
	(0.252)	(0.115)	(0.088)	(0.080)	(0.073)	(0.073)	(0.070)	(0.073)	(0.120)
Firm-level controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Macro-level controls	YES	YES	YES	YES	YES	YES	YES	YES	YES

The table reports the quantile regression model for the energy firms, estimated using the penalised fixed-effects estimation procedure proposed by Koenker (2004) with intercept, for values of τ ranging from $\tau = 0.1$ to $\tau = 0.9$. Energy firms are identified by filtering the sample using NACE Rev.2 code D-Electricity, Gas, Steam and Air Conditioning Supply. Standard errors are reported in parenthesis. The number of firm-year observations are 1652. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Results for other firm-level controls, Z-score, Liquidity, Sales growth, Intangibles share, log(K/L), log(L), and macro-level controls are not shown and remain available upon request.

Appendix B. Energy firms

See Table 6.

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