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Corporate Decarbonization: Understanding CO_2 Emission Drivers Across High- and Low-Polluting Firms in OECD Countries

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ABSTRACT

Decarbonization of the economy is a central challenge in the fight against climate change. Although most governments show clear commitment to limiting global warming, the drivers of corporate decarbonization remain underexplored. Using a dataset of 1052 firms from OECD, this article analyses how intangible assets and environmental innovation affect corporate environmental performance. By applying bootstrapped quantile regressions, we show how firm- and country-level factors are associated with high- and low-polluting firms. Our results suggest that intangible assets and environmental innovation improve environmental performance across quantiles, with a stronger effect for high-polluting firms. Furthermore, environmental innovation can reduce short-term emission growth. Finally, intangible assets depend on the sectorial CO_2 intensity and have limited significance in sectors with low carbon intensity. At the policy level, our results call for emission-related regulation because it improves corporate decarbonization. Furthermore, it is necessary to have a regulatory strategy that incorporates incentives for intangible asset development and innovation, differentiating between high- and low-polluting firms.

1 | Introduction

In recent decades, climate change has become a central topic in public discussion. Initiatives such as the Kyoto Protocol and the Paris Agreement demonstrate states' commitment, but critics call for the adoption of more sustainable business models in the corporate world to stop climate change (Wright and Nyberg 2024).

To address it, market-based policy instruments such as the European Union Emission Trading Scheme aim to penalize polluting firms and promote decarbonization. Companies facing environmental regulation often innovate or adapt their business operations, which can generate a competitive advantage (Porter and Van Der Linde 1995). However, environmental legislation varies across regions: The European Union aims for net-zero emissions by 2050 (European Commission 2024), whereas the United States recently withdrew from the Paris Agreement. Beyond regulation, firms also respond to stakeholder pressures by adopting corporate social responsibility (CSR) and sustainability strategies (Maon et al. 2009). From the perspective of the natural resource-based view (NRBV), sustainability-oriented innovations can further increase competitiveness (Hart and Dowell 2011; Dangelico et al. 2017).

Although significant research has explored the drivers of emissions at the country and sectoral levels (Grossman and Krueger 1991; Fernández et al. 2018; Shahbaz et al. 2020), fewer studies have analysed the role of the private sector in climate change and drivers of decarbonization (Qureshi et al. 2022;

This study examines the drivers of corporate decarbonization by analysing CO_2 intensity and CO_2 emissions growth rates across high- and low-polluting firms from OECD countries. It focuses on the role of intangible assets, environmental innovation and regulatory pressure in shaping firms' environmental performance.

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López-Manuel et al. 2023). Existing literature often focuses on individual factors such as green R&D (Lee and Min 2015) or specific countries (Karim et al. 2021; Wang et al. 2021; Albitar et al. 2023), providing limited insights into firm heterogeneity. Moreover, distinctions between high- and low-polluting firms are typically addressed only in robustness checks rather than as a central research focus. Given that a small number of firms account for nearly two-thirds of historical emissions (Heede 2014), differentiating between these groups is essential for effective policy design.

In response to these gaps, this paper investigates how intangible assets influence corporate environmental performance (CEP). Intangible assets, such as trademarks, patents, brand value and accumulated R&D achievements, reflect a firm's innovative capacity (Tzouvanas et al. 2020; Flori et al. 2024) and serve as a measurable proxy for innovation capabilities (Bagna et al. 2021). Following previous research (Nadeem et al. 2020; Albitar et al. 2023), we also account for environmental innovation as a measure of sustainability-driven technological advancements. To capture contextual factors, we include country-level regulatory stringency (Ben-David et al. 2021; Qureshi et al. 2022), extending López-Manuel et al.'s (2023) work to identify firm- and country-specific emission drivers.

Our analysis uses an unbalanced panel of 1052 publicly listed companies from OECD countries (6876 firm-year observations) from 2011 to 2019, combining Refinitiv Eikon data with World Bank and OECD data. Applying bootstrapped quantile regressions, we show how intangible assets, environmental innovation and regulation are associated with CO_2 intensity across high- and low-polluting firms. In a second step, we analyse drivers of CO_2 growth rates to understand underlying mechanisms for an efficient decarbonization.

Our results show that firm- and country-level factors affect high- and low-emitting companies differently. Intangible assets, environmental innovation and regulation are linked to lower CO_2 intensity, with stronger effects for high-polluting firms. We further show that the negative association of intangible assets is conditional on the sectorial CO_2 intensity and has limited significance in sectors with low carbon intensity. Environmental innovation is associated with better environmental performance mostly for fast-growing, polluting firms and for low-carbon–intensive sectors, whereas its effect is limited in high-carbon sectors, possibly due to structurally embedded emissions that are difficult to reduce.

Short-term CO_2 emission growth, however, is largely driven by economic activity such as size and capital expenditures rather than intangibles. Environmental innovation reduces emission growth across most firms, whereas regulation lowers growth only in the lower quantiles. The negative association between regulation and CO_2 intensity suggests that these policies are effective in promoting long-term decarbonization but have a limited impact on rapidly expanding emitters.

This research contributes to the existing literature in several ways. First, we highlight the role of intangible assets in CO_2 intensity, a dimension often overlooked in prior research (Fethi and Rahuma 2019; Wang et al. 2021; Alakkas et al. 2023). Second, by integrating firm- and country-level factors, we provide a comprehensive perspective on the drivers of CEP. Third, we apply quantile regressions to capture heterogeneous responses across emission levels, emphasizing the importance of distinguishing between high- and low-polluting firms. Although this is common in other fields, this is still missing when analysing firms' environmental performance. Finally, as a more general contribution, this paper adopts an evolutionary approach within environmental economics (see Mulder and Van Den Bergh 2001). Evolutionary economics emphasizes heterogeneous characteristics and paths of firms in the economy. As Monasterolo et al. (2019) point out, the evolutionary approach in ecological economics has been scarcely applied. Therefore, we contribute to this theoretical framework by considering the heterogeneous pollution profile of companies and their dynamics.

The remainder of this paper is structured as follows. Section 2 reviews the literature and hypothesis development. Section 3 describes the data and variables. Section 4 presents the empirical methodology; Section 5 discusses the results, and Section 6 concludes with policy implications and future research directions.

2 | Literature Review

In response to international initiatives, many firms have developed sustainability strategies (Cadez et al. 2019; IPCC 2023). Recent research shows that corporate emissions are predominantly influenced by firm-level factors, followed by industry- and country-level effects (López-Manuel et al. 2023). However, the production of CO_2 is unequally distributed among firms. The existence of high- and low-polluting firms may be associated with different capabilities and strategies to react to firm- and country-level factors. For instance, López-Manuel et al. (2023) showed that CO_2 emissions for high polluters are mostly explained by firm-level factors, whereas for low polluters, they are mostly explained by country-level factors, and Ben-David et al. (2021) showed that high-polluting firms react with increased outsourcing of emissions in response to strengthening environmental regulation. This section explores the key theoretical frameworks that can explain corporate CO_2 emissions at both the firm and country levels and the possible heterogeneous relationships in response to our independent variables.

2.1 | The Role of Intangible Assets and Environmental Innovation on CEP

The relationship between innovation and CEP is supported by different theoretical frameworks. The resource-based view (RBV) focuses on the general utilization of resources within firms. This theory suggests that firms gain a sustained competitive advantage by leveraging intangible capital resources that are valuable, rare, inimitable and non-substitutable (Barney et al. 2001). Generating these competitive advantages is closely linked to a firm's capacity to innovate, which in turn depends on its intangible capital and R&D achievements (Kramer et al. 2011; Lee and Min 2015). Intangible assets mirror a firm's innovation and R&D achievements (Bagna et al. 2021), which

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can improve the environmental performance of companies (Lee and Min 2015; Lee et al. 2015; Fethi and Rahuma 2020; Wang et al. 2021). The main reason is that they lead to more efficient production processes or product designs, which then result in less energy consumption, less pollution or less resource use, thereby improving overall environmental performance (Lee and Min 2015; Alam et al. 2019).

Moreover, intangible assets encapsulate a firm's brand value, monetizing its reputation. In the past, it remained unclear if CSR initiatives had a positive impact on CEP (Kramer and Porter 2006). However, more recent research by Kudłak (2019) or Haque and Ntim (2022) demonstrated that such initiatives can significantly reduce firms' CO_2 emissions, particularly in firms with strong governance structures. Consequently, CSR initiatives may have an impact on the reputation of a firm, and, as a result, the value of its intangible assets will increase.

From the point of view of stakeholder theory, all agents that have a direct or indirect claim on the firm influence the firm's activities, behaviours and strategies (Evan and Freeman 1988). A company must not only generate profits for shareholders and managers but must satisfy all stakeholders—including consumers, governments, the media, NGOs and others—to gain a competitive advantage and legitimacy (Freeman et al. 2021). At the micro level, enhanced environmental performance can be seen as a response to stakeholder pressure and a means of legitimizing corporate behaviour (Azar et al. 2021; van Emous et al. 2021). Based on the previous concepts and empirical works, we can expect that intangible assets are associated with better environmental performance.

However, high-polluting firms may benefit more from intangible assets, as these assets often reflect prior innovations or corporate strategies enhancing environmental performance. Haque and Ntim (2022) found that sustainability strategies have a stronger emission-reducing effect for high-polluting firms compared to low-polluting firms. Additionally, they demonstrated that a higher proportion of tangible assets relative to total assets has a stronger positive effect on CO_2 emissions for high-polluting companies (Haque and Ntim 2022). In contrast, we anticipate that intangible assets, due to their association with previous innovation and corporate strategies, will also have a stronger effect—albeit negative—on emissions for high-polluting companies compared to low-polluting ones.

Hypothesis 1. *Intangible assets have stronger positive linkages with the environmental performance of high-polluting companies compared to low-polluting companies.*

The NRBV extends the RBV theory by adding three strategic capabilities focused on environmental challenges: pollution prevention, product stewardship and sustainable development with a long-term vision (Hart 1995). Developing these sustainability capabilities facilitates the development of eco-innovations, which enable firms to generate a sustained competitive advantage (Hart and Dowell 2011; Arranz et al. 2020). In comparison to intangible assets, environmental innovation has a more direct impact on environmental performance because these investments are devoted to developing innovations to diminish pollution or implement more sustainable products.

Most of the studies analysing the role of investment in environmental innovation on CO_2 emissions adopt a country-level approach (Fethi and Rahuma 2019; Hashmi and Alam 2019; Cheng et al. 2021). Mainly, these studies demonstrate that environmental innovation reduces CO_2 emissions at the country level. At the firm level, there is a scarce number of studies that analyse this relationship. For instance, Qureshi et al. (2022) showed that country-level eco-innovation improves CEP, and Fethi and Rahuma (2020) observe a similar relationship for eco-innovation at the firm level, in line with Lee and Min (2015) showing that green R&D activities reduce carbon emissions in Japanese manufacturing companies. Albitar et al. (2023) further demonstrate that environmental innovation enhances environmental performance among firms listed on the London Stock Exchange. Hence, we can assume that environmental innovation is positively associated with CEP.

Generally, environmental innovation can lower costs by reducing energy use in production processes, reducing packaging costs or through newly designed products whose production is cheaper (Porter and Van Der Linde 1995). High-polluting firms may have a stronger incentive to adopt eco-innovations, as their potential return on investment is likely higher compared to low-polluting firms. Supporting this argument, Frondel et al. (2008) demonstrated that more polluting facilities engage more extensively in abatement activities than less polluting ones. Similarly, Albitar et al. (2023) find that companies with high ESG scores exhibit a stronger negative relationship between environmental innovation and CO_2 emissions than companies with low ESG scores. Furthermore, Wang et al. (2021) suggest that innovation has a stronger negative correlation with environmental performance for manufacturing firms than for non-manufacturing firms, potentially due to greater efficiency gains among higher polluters. Based on this evidence, we expect that the relationship between environmental innovation and environmental performance is stronger for companies with poorer environmental performance.

Hypothesis 2. *Environmental innovation has stronger positive linkages with the environmental performance of high-polluting companies compared to low-polluting companies.*

2.2 | Regulatory Factors Affecting Firms' Environmental Performance

Apart from firm-level factors, a country's legal framework and societal pressures can drive improvements in CEP (van Emous et al. 2021). Although often viewed as a threat to profitability, Porter (1991) proposed that environmental regulation can trigger innovation and increase a company's competitiveness. Therefore, environmental policies developed by governments are crucial to force firms to identify inefficiencies and differentiate themselves from competitors, thereby achieving a sustained competitive advantage.

Concerning the empirical evidence, several studies have shown that regulation enhances environmental innovation of companies (Porter and Van Der Linde 1995; Frondel et al. 2008; Carrión-Flores and Innes 2010; Yunus et al. 2020), although it does not have the same effect for all companies. For instance,

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highly innovative firms may not respond as strongly to regulatory pressure, and some firms already engage in sustainability practices that exceed regulatory requirements (Kesidou and Demirel 2012). Some companies may also respond to stricter regulations by relocating polluting activities to countries with more lenient environmental laws—a concept known as the pollution-haven theory. In this line, Ben-David et al. (2021) found that although multinational corporations outsource emissions to countries with weaker regulations, they still achieve a net reduction in total emissions as a response to environmental policies in the home country. Hence, we expect that environmental regulation is associated with better environmental performance.

However, some firms may be less affected by regulation if their industries are not significant environmental contributors. Frondel et al. (2008) found that more polluting facilities are more likely to engage in abatement activities and environmental innovation than less polluting ones, whereas Horbach (2008) demonstrated a similar trend for high- versus low-environmentally intensive industries. Hence, high-polluting firms may face stronger regulatory pressures ('regulation push') to improve environmental performance, whereas less polluting firms may be less affected. In support of this, Cadez et al. (2019) and Yunus et al. (2020) found that stronger regulatory pressure led to more robust environmental strategies aimed at reducing carbon emissions. Therefore, we expect high-polluting companies to exhibit a stronger response to environmental regulation.

Hypothesis 3. *Regulation has stronger positive linkages with the environmental performance of high-polluting companies compared to low-polluting companies.*

3 | Data

3.1 | Database and Sample

This research uses firm-level data from the Eikon database and country-level data from the World Bank and the OECD. The Eikon database is widely used in research (van Emous et al. 2021; Haque and Ntim 2022; Qureshi et al. 2022; Albitar et al. 2023). Within the Eikon database, we filter for firms with CO_2 emission data for the last 3 years. Our initial sample included roughly 5000 companies with data on CO_2 emissions, intangible assets, country of headquarters, Global Industry Classification Standard (GICS) sectors and other firm-related variables. Following related studies, we assign country-level variables based on the country of the firm's headquarters (Qureshi et al. 2022; López-Manuel et al. 2023), because previous research shows that firms' responses to societal and regulatory pressures are often shaped by their home country (Ben-David et al. 2021; López-Manuel et al. 2023).

To refine the sample, we proceed with several cleaning filters: (i) observations with CO_2 emissions reported as zero; (ii) firms with negative capital expenditures or intangible assets; and (iii) firms lacking GICS sector classifications. Regulatory data are drawn from the OECD Environmental Policy Stringency (EPS) Index, which is available until 2020. The sample period is restricted to 2011–2019: The starting year 2011 is chosen due to the limited availability of CO_2 observations in earlier years, and the end year 2019 is selected to avoid potential distortions in 2020 associated with the Covid-19 pandemic.

Within this timeframe, we apply several filters to ensure data consistency. First, we exclude firms with fewer than three CO_2 observations. Second, we remove firms headquartered in countries with fewer than 10 firms in the sample, as isolated cases may bias country-level effects. Finally, we restrict the sample to OECD countries. This restriction allows us to focus on firms operating in relatively homogeneous institutional and economic environments of advanced economies. OECD countries account for a substantial share of global emissions, while also providing comparatively favourable conditions for corporate decarbonization due to higher income levels and strong innovation capacity. Across the sample period, OECD countries are all high-income countries and score consistently high scores in the Global Innovation Index (Table A1). This institutional and economic homogeneity reduces distortions that may arise from structural differences between high- and low-income economies. By excluding non-OECD countries, we aim to isolate firm-level decarbonization mechanisms in contexts where technological capabilities, policy environments and financial resources are broadly comparable. This resulted in a final, unbalanced panel dataset including 1052 companies from 18 countries and 6876 firm-year observations.

Table A1 reports the country distribution of firms in the sample. Most firms come from the United States (27%), Japan (20%) and the United Kingdom (14%), whereas the remaining ones are in several European countries such as France, Germany and Switzerland. This composition reflects the structure of the Refinitiv Eikon database, which primarily includes publicly listed companies with consistent CO_2 disclosure and therefore provides a stronger representation of large markets. Focusing exclusively on OECD countries ensures that firms operate under comparable institutional and economic conditions, while still allowing variation across major regulatory regimes by accounting for the different CO_2-affecting regulations of the EPS Index. This heterogeneity provides insights into how different policy and market contexts shape corporate decarbonization behaviour. To further mitigate cross-country differences, we include several country-level controls outlined in the next subsection.

3.2 | Variables

This section describes the variables used in this research (Table 1). We measure CEP in two ways. Consistent with prior research, we first analyse a firm's CO_2 intensity, which captures the firm's 'CO_2 efficiency' (Lee and Min 2015; Haque and Ntim 2022; Qureshi et al. 2022). CO_2 intensity is calculated as total CO_2 emissions[1] divided by total assets, thereby assessing emission levels relative to firm size. This measure enables a consistent comparison of environmental performance across firms of different sizes. A higher CO_2 intensity indicates lower environmental performance, as the firm emits more CO_2 per US dollar of assets. Second, we investigate the year-over-year growth rate of absolute CO_2 emissions. We calculate the growth rate of CO_2 emissions by taking the first difference of the natural logarithm of firm-level emissions between two consecutive years.

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TABLE 1 | Definition of variables.

Variables	Definition	Source
CO_2	Natural logarithm of total CO_2 and CO_2 equivalent emissions in metric tonnes.	Eikon
CO_2int	Kilograms of CO_2 per US dollar asset.	Eikon
CO_2 growth	First difference of the natural logarithm of CO_2.	Eikon
Intangible assets	Share of intangibles over total assets.	Eikon
Environmental innovation	Environmental innovation score from 0 to 100.[a]	Eikon
Regulation	Average of emission trading stringency and CO_2 tax stringency on a scale of 0–6.	OECD
Employees	Natural logarithm of employees.	Eikon
ROA	Return on assets (net income/total assets).	Eikon
Leverage	Debt over total assets in percentage.	Eikon
Capex	Share of capital expenditures over total assets.	Eikon
Board independence	Percentage of independent board members.	Eikon
CEO duality	Dummy that takes the value of 1 if the CEO is also chair of the board, 0 otherwise.	Eikon
CSC	Dummy that takes the value of 1 if the company has a corporate sustainability committee, 0 otherwise.	Eikon
GDP	Natural logarithm of GDP per capita in the country of headquarters in constant 2015 US dollar.	World Bank
Trade openness	Sum of imports and exports as a share of GDP.	World Bank
Manufacturing share	Value added of the manufacturing sector as a share of GDP.	World Bank

[a]The innovation score reflects a company's capacity to reduce the environmental costs and burdens for its customers, thereby creating new market opportunities through new environmental technologies and processes or eco-designed products. It is calculated by Refinitiv Eikon and consists of product innovation, green revenues, research and development and capital expenditures.

Source: Own elaboration based on Eikon database and World Bank database.

This logarithmic transformation provides an approximation of the percentage change in emissions and allows for a comparison of the short-term evolution of CO_2 emissions across different firm sizes. Positive values indicate that a firm's emissions increased relative to the previous year, and negative values indicate emission reductions. Hence, this variable captures the short-term dynamics of firms' emission behaviour, whereas CO_2 intensity reflects their overall emission efficiency.

Our primary independent variable is intangible assets, scaled by total assets and expressed as a percentage. This variable captures a company's innovative capacity, including patents, trademarks, brand value and its overall reputation for CSR activities (Tzouvanas et al. 2020; Bagna et al. 2021; Flori et al. 2024). Another firm-level independent variable is the environmental innovation score, following Albitar et al.'s (2023) approach. The environmental innovation score measures, on a range from 0 to 100, a company's ability to reduce environmental damage by developing eco-friendly technologies, processes or products. Lastly, we use two pillars of the OECD EPS Index as a proxy for regulation in the country of headquarters. The EPS grades market-based policies, non-market-based policies and technology support on a scale of 0–6 and then weights the three categories equally to an index. The higher the score, the stronger the regulation in a country. We use the two categories that measure a direct impact on CO_2 emissions, namely, the CO_2 trading scheme stringency and the CO_2 tax stringency, and take the average of both scores as our regulation variable.

Finally, we include several control variables such as firm size, return on assets (ROA), leverage and capital expenditures. First, larger firms are more visible to regulators and stakeholders, which may affect their environmental performance. Second, ROA controls for profitability, which may enable companies to invest in eco-innovations. More profitable firms may have greater resources to implement sustainable practices, even though previous research yields varying results. Furthermore, although high leverage may impose financial constraints, it can also incentivize firms to improve operational efficiency, potentially affecting their environmental strategies. Finally, capital expenditures (Capex) correspond to investments in plants, logistics and other areas, thus indicating future economic activity that is often associated with carbon emissions. These explanatory variables have been previously used by related works from Azar et al. (2021), Ben-David et al. (2021), Wang et al. (2021), Karim et al. (2021), Haque and Ntim (2022), Qureshi et al. (2022) and Albitar et al. (2023).

Furthermore, following Nadeem et al. (2020), Haque and Ntim (2022) and Albitar et al. (2023), we add governance-related control variables that may impact CO_2 emissions such as board independence, CEO duality and the corporate sustainability committee (CSC).

At the country level, we include different country characteristics. First, GDP per capita is an indicator of economic development. The relationship between GDP and emissions is often

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described as ambivalent. Most studies find evidence of an inverted U-shape, where emissions initially rise with increasing GDP, although they decline once a certain level of economic development is reached, and estimations of that turning point vary (Hashmi and Alam 2019; Mirziyoyeva and Salahodjaev 2023). Furthermore, the share of the manufacturing sector of the GDP controls for the sectoral productive structure. Lastly, the variable of trade openness is associated with lower emissions in OECD countries (Gozgor 2017), possibly due to increased technology diffusion (Zhang et al. 2017).

3.3 | Descriptive Statistics

This section provides an overview of the key statistics for the variables used in the quantile regressions. Table 2 shows the descriptive statistics for the 6876 firm-year observations belonging to the dataset, and Table A2 shows the correlation matrix. The average firm in the dataset emits 3,700,000 tonnes of CO_2, about 7.13% of its total assets are intangibles and its environmental innovation score is 44.66. The average CO_2 regulation stringency that firms experience in their home country is 2.4.

For firm-related variables, there is a notable difference between the mean and median values, reflecting the significant heterogeneity within the sample. In contrast, country-related variables like GDP or manufacturing share exhibit a more homogeneous distribution, with the mean and median values closer to each other, whereas trade openness shows greater variability across countries.

Figure 1 shows the kernel density plots for CO_2 intensity (panel a) and CO_2 growth (panel b). For both variables, the figures' visualizations confirm that the variables are not normally distributed, and a quantile regression analysis can reveal additional insights.

Table A3 additionally shows the Kolmogorov–Smirnov test for normality for the distribution of the dependent variables CO_2 intensity and CO_2 growth. The results show that all distributions of the variables significantly deviate from normality.

Figure 2 shows the evolution of key variables over the 2011–2019 period across different polluter types. Figure 2a shows that CO_2 intensity has generally decreased over time, reflecting improvements in energy efficiency and emissions management. However, high-polluting firms exhibit slower reductions compared to median- and low-polluting firms, suggesting persistent challenges in decarbonization for the most intensive emitters. Figure 2b displays the evolution of regulation stringency, which steadily increased for all firms, particularly after 2017, following the Paris Agreement. Figure 2c shows the environmental innovation score across polluter types. High-polluting firms demonstrate a stronger upward trend in innovation, indicating a growing effort to adopt sustainability-oriented practices. Finally, Figure 2d presents intangible assets by polluter group. Median-polluting firms maintain the highest share of intangible assets, whereas high-polluting firms are typically concentrated in tangible-intensive industries and low-polluting firms in service sectors like finance. Notably, the share of intangible assets remains relatively stable within each group over time.

TABLE 2 | Descriptive statistics.

Variables	Observations	Mean	Median	Standard deviations	Minimum	Maximum
CO_2	6876	3.7×10^6	330,951	1.25×10^7	10.06	1.61×10^8
CO_2int	6876	0.14	0.03	0.35	9.77×10^{-7}	4.82
CO_2 growth	6876	−56,052	−537	2.1×10^6	-7.50×10^7	5.09×10^7
Intangible assets	6876	7.13	3.65	8.98	0	65.32
Environmental innovation	6876	44.66	49.31	33.08	0	99.76
Regulation	6876	2.40	1	2.27	0	11
ROA	6876	0.06	0.05	0.07	−0.36	2.44
Capex	6876	4.21	3.63	3.42	0	36.23
Leverage	6876	19.94	18.14	14.52	0	236.10
Employees	6876	47,781	21,717	70,953	26	664,496
Board independence	6876	59.03	66.67	28.91	0	100
CEO duality	6876	0.40	0	0.49	0	1
CSC	6876	0.85	1	0.35	0	1
GDP	6876	46,754	44,907	12,135	24,499	86,757
Trade openness[a]	6876	55.65	42.2	34.16	26.45	229.76
Manufacturing share	6876	13.63	11.67	4.73	5.76	34.86

[a]In small and highly globalized economies, both exports and imports can exceed 100% of GDP. This occurs because GDP measures domestic value added, whereas trade flows include gross transactions that often involve re-exports, intra-firm trade or financial and intellectual property flows. As a result, the trade openness ratio (exports + imports as a share of GDP) can surpass 100%.

Source: Own elaboration based on Eikon database, OECD EPS database and World Bank.

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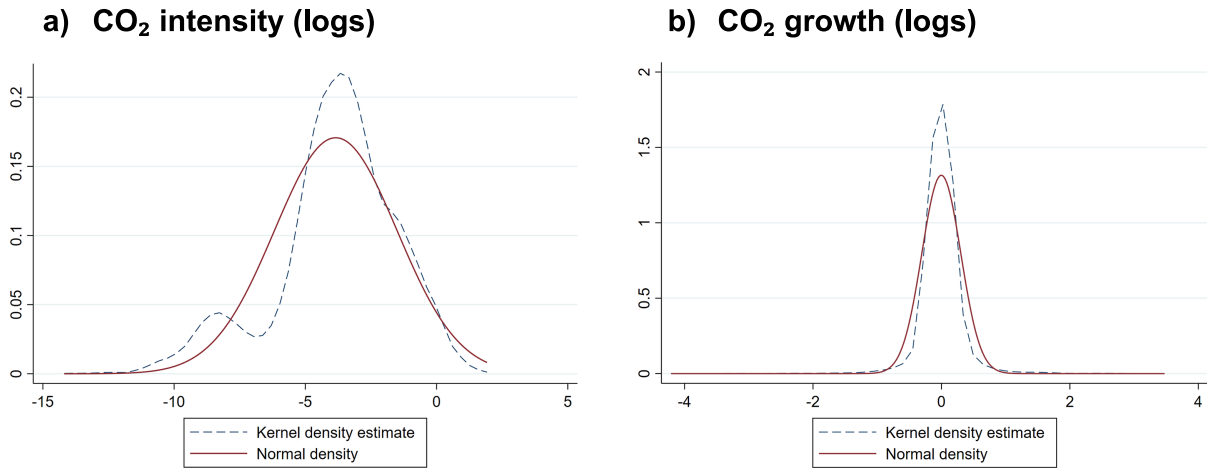


FIGURE 1 | Kernel density estimates for variables CO_2 intensity and CO_2 growth. *Note:* The kernel densities of graph (a) are estimated with an Epanenchnikov kernel bandwidth equal to 0.35 and for graph (b) equal to 0.15. *Source:* Own elaboration of data from the Eikon database.

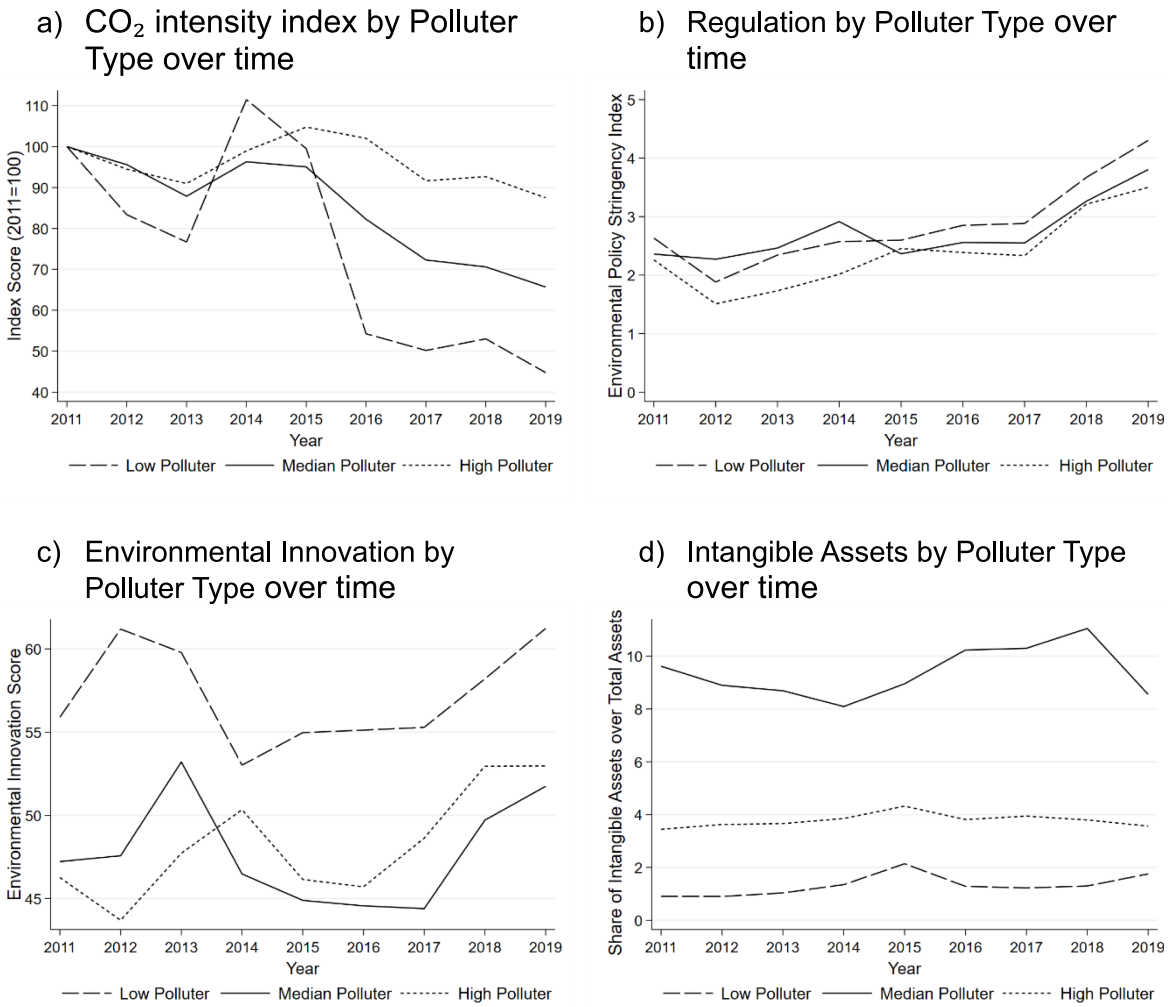


FIGURE 2 | Evolution of key variables by polluter type. *Note:* (a–d) Low polluters represent the bottom 10% of firms by CO_2 intensity each year, high polluters the top 10% and median polluters the 45%–55% quantile each year. *Source:* Own elaboration of data from the Eikon and OECD databases.

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These patterns further motivate our use of quantile regressions, as they highlight heterogeneous behaviours: High-polluting firms improve their environmental innovation score more, yet still lag in CO_2 intensity reductions, whereas intangible asset profiles differ systematically across groups.

4 | Econometric Methodology

To test the hypotheses, we apply bootstrapped quantile regressions. Although the ordinary least squares method assumes normality for an efficient estimation and is sensitive to outliers, quantile regression methods can handle non-normality of the data and are less sensitive to outliers (Koenker and Bassett 1978). This methodology allows us to have a more comprehensive view by examining how the relationship between independent variables and dependent variables varies across different points of the environmental performance distribution.

First, to investigate the factors associated with CEP, we employ the following quantile regression model:

$$Q_\tau\left(CO_2int_{it}\right)=\beta_{10\tau}+\beta_{11\tau}IA_{it-1}+\beta_{12\tau}EI_{it-1}+\beta_{13\tau}REG_{it-1}+X_{it-1}\gamma_{1\tau}+\delta_{1S\tau}S_i+\delta_{1T\tau}T_t+\epsilon_{1it\tau} \quad (1)$$

where $Q_\tau\left(CO_2int_{it}\right)$ denotes the conditional quantile function of the dependent variable CO_2int_{it} at quantile τ, which is the value of CO_2 intensity corresponding to the τth quantile of the distribution of CO_2int. The β_τ are the quantile-specific coefficients and describe how our independent variables affect different points of the outcome distribution of CO_2int. In this model, we assess CEP through CO_2 intensity. The independent variables include intangible assets $\left(IA_{it-1}\right)$, environmental innovation (EI_{it-1}) and regulation in the country of headquarters of the firm $\left(REG_{it-1}\right)$.

The set of control variables (X_{it-1}) contains firm size, measured by the natural logarithm of the number of employees, ROA, the share of capital expenditures over total assets, leverage, the share of independent board members, a dummy variable indicating if the CEO is also the chair of the board and a dummy variable indicating if the firm has a CSC, as well as the natural logarithm of the GDP per capita in the country of headquarters and trade openness, measured as the share of the sum of imports and exports over GDP. We lag all variables to account for delayed effects on environmental performance and endogeneity, following previous authors (Aghion et al. 2016; Tomàs-Porres et al. 2023). However, we are cautious in the interpretations by considering our results as linkages or associations only.

The model further incorporates sector-specific effects (S_i) to account for sectoral differences that might impact environmental performance and year-specific effects (T_t) to control for external factors in each year.

The parameters $\beta_{i\tau}$, δ_τ and γ_τ are estimated for each quantile τ, and the error term $\epsilon_{it\tau}$ represents the residuals at the specific quantile.

In a second step, we approach CEP from the perspective of CO_2 growth rates. This approach shifts the focus from the static emission efficiency in Equation (1) to the dynamic evolution of firms' short-term emission behaviour. The model looks as follows:

$$Q_\tau\left(CO_2growth_{it}\right)=\beta_{20\tau}+\beta_{21\tau}IA_{it-1}+\beta_{22\tau}EI_{it-1}+\beta_{23\tau}REG_{it-1}+\beta_{24\tau}CO_{2it-1}+X_{it-1}\gamma_{2\tau}+\delta_{2S\tau}S_i+\delta_{2T\tau}T_t+\epsilon_{it\tau} \quad (2)$$

where $CO_2growth_{it}$ corresponds to the log difference of absolute CO_2 emissions between '$t-1$' and 't'. Apart from the new dependent variable, the only difference from Equation (1) is the incorporation of CO_{2it-1} as an additional control variable. All other variables remain as previously described for Equation (1). Analysing the growth rate of CO_2 allows us to capture the drivers of short-term emission adjustments. Analysing the growth rates of emissions gives a more detailed view of decarbonization strategies for regulators and allows us to identify sustainable growth mechanisms.

Finally, we must mention that the quantile regressions are executed with 1000 bootstrap replications to obtain more robust standard errors. Additionally, to improve numerical stability, we used mean-centring as a normalization device for those variables exceeding a Variance Inflation Factor (VIF) value of 10 (Neter et al. 1983). After centring employees, GDP per capita, the manufacturing share and the lagged CO_2 emissions for the growth estimation, all individual VIF values were below 10.[2]

5 | Empirical Results

This section discusses the results of the quantile regression analysis. Subsection 5.1 discusses the results for CO_2 intensity, Subsection 5.2 adds discussions of structural differences in these results for different firm groups and Subsection 5.3 presents the results for CO_2 growth.

5.1 | Drivers of CO_2 Intensity

The analysis of CO_2 intensity (Table A4) reveals that intangible assets are associated with lower CO_2 intensity across all quantiles. Moreover, this effect is slightly more pronounced in the upper quantiles of the emission distribution, indicating that firms with higher emission intensity show a stronger negative relationship with intangible assets. The results confirm the theoretical reasoning of the NRBV that firms can leverage intangible resources for environmental capability building (Hart 1995) and improve environmental performance (Tzouvanas et al. 2020).

A different pattern emerges when examining the impact of environmental innovation. In the lower quantiles, the coefficient is statistically insignificant, becomes positive and significant around the 25th quantile and turns negative and significant for the 75th and 90th quantiles. Figure 3 shows that the effect becomes more negative in the 90th quantile, suggesting that environmental innovation is particularly beneficial for highly emission-intensive companies.

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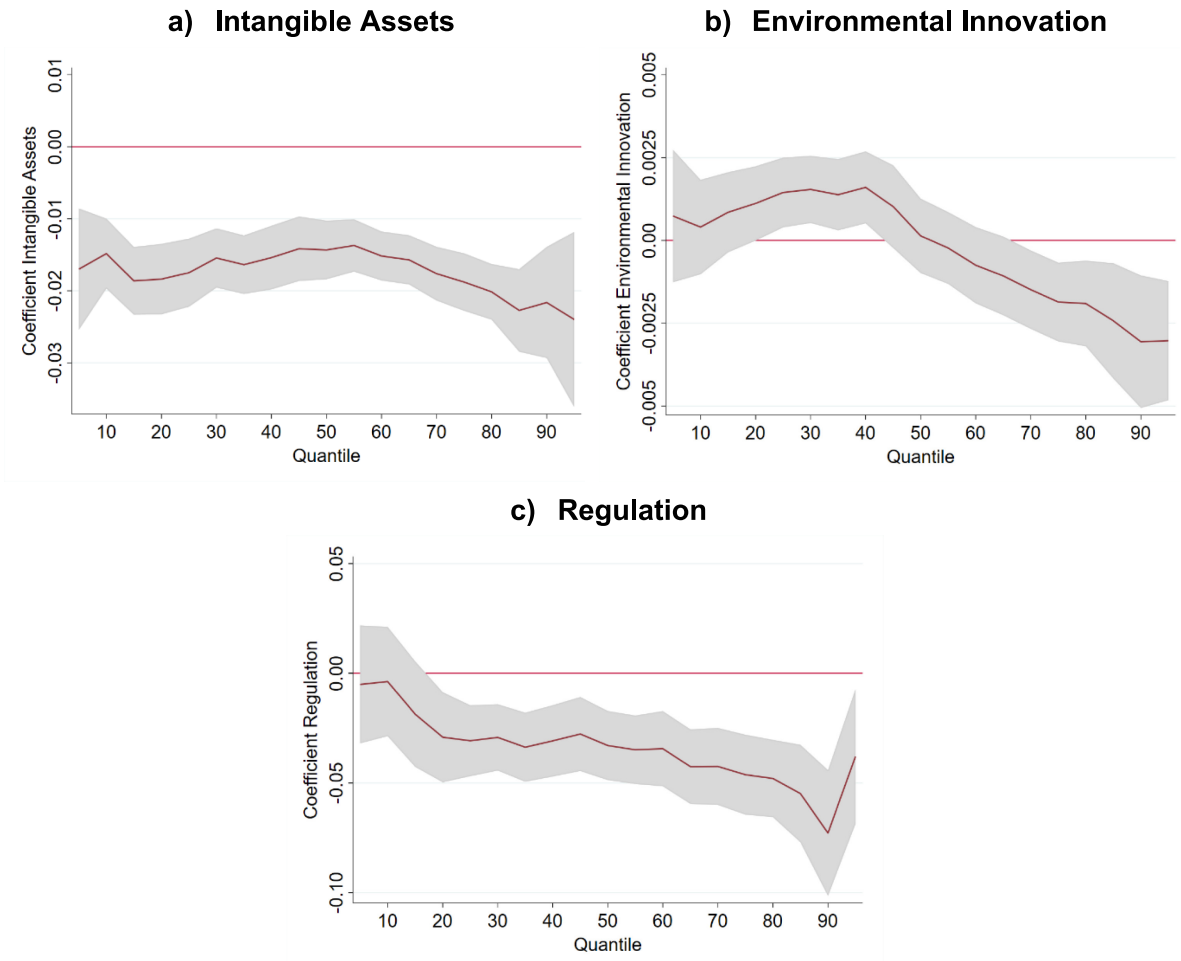


FIGURE 3 | (a–c) Coefficients of key variables across quantiles of CO_2 intensity. *Note:* ——— effect, ▭ 95% confidence interval. *Source:* Own elaboration.

These results suggest that the benefits of environmental innovation are heterogeneous across the emission distribution. For firms with already low emission intensity, environmental innovation may initially reflect product-oriented or symbolic innovation rather than process improvements that directly reduce emissions. The partially positive association at lower quantiles may also be due to the construction of the environmental innovation score, which includes product and service innovation dimensions not necessarily linked to direct emission reductions. Consequently, firms with high innovation scores are not always implementing CO_2-reducing activities, but those emission-intensive firms seem to translate innovation more effectively into improved CO_2 efficiency. These firms may have the greatest potential to improve their 'CO_2 efficiency', and even incremental eco-innovations may lead to significant reductions in emission intensity.

The relationship between environmental regulation and CO_2 intensity is as we theoretically hypothesized. The effect is negatively significant for all quantiles except for firms with the lowest CO_2 intensity, and the association is stronger and more negative the higher we move on the emission intensity distribution. Our results contribute to the discussion of the effects of regulation on environmental performance. Similar to Ben-David et al. (2021), we find that more environmental regulation is associated with better firm environmental performance.

The control variables generally align with findings from prior studies. Firms with higher capital expenditures, more employees and higher leverage are associated with higher CO_2 intensity across most quantiles. These results are in line with previous research, as increased capital expenditures indicate future economic activity that generates emissions (Karim et al. 2021), and larger firms emit more CO_2 (Azar et al. 2021; Ben-David et al. 2021). Past literature has found varying results for leverage, some indicating that, due to increased pressure by the financing institutions (Wang et al. 2021; Haque and Ntim 2022), firms may be obligated to reduce emissions. However, Lee and Min (2015) and Safiullah et al. (2024) also found that leverage increases CO_2 intensity for firms, reasoning that financial constraints force these firms to focus on short-term financial goals instead of environmental concerns. Furthermore, indebted firms reduce carbon abatement investments as a response to high debt levels (Safiullah et al. 2024). Our results contribute to their findings. For the control variables ROA, CEO duality and CSC, we only find slightly significant effects in the 25th quantile, but in none of the others. Contrary to previous researchers, we find that greater board independence is associated with

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higher CO_2 emissions for most quantiles, which we believe is driven by a focus on financial outcomes and will be further discussed in the next chapter.

Regarding the country controls, we find that trade openness is associated with a better CO_2 intensity, which is in line with Zhang et al. (2017), indicating that firms may profit from technology diffusion that comes with trade. Lastly, a higher share of manufacturing firms is associated with a higher CO_2 intensity across most quantiles and GDP in the upper 50% of the distribution, which indicates that the turning point of the Environmental Kuznets curve might not have been reached yet.

5.2 | Structural Differences in the Drivers of CO_2 Intensity

To deepen the understanding of our results for CO_2 intensity, we attempt to conceptualize splits of our sample. First, we split the sample into high- and low-carbon–intensive sectors (see Table A5) following Barahhou et al. (2022). Second, we calculate the average employee growth rates of each firm in the sample and split the sample by the median employee growth rate. Whereas sector-level CO_2 intensity provides an exogenous benchmark to explain emission behaviour conditional on sectorial environments, the growth split allows us to investigate firms conditional on their internal capabilities, consistent with the RBV of the firm. We find significant structural differences in the relationships between our explanatory variables and CO_2 intensity when we compare the different groups.[3]

Intangible assets (Figure 4) in low-carbon–intensive sectors are associated with better environmental performance only for the emission-efficient firms, whereas they are associated with higher CO_2 intensity for the laggard firms of those sectors. However, when looking at the results for the high-carbon–intensive sectors, intangible assets are consistently negative, and the effect strengthens significantly at the upper quantiles. This indicates that environmental capabilities from intangible assets are more powerful in carbon-intensive industries than in non-intensive industries. In low-carbon–intensive sectors, intangible assets may be more focused on growth-enabling initiatives, and firms might underinvest in environmental capabilities. The negative association of intangible assets and CO_2 intensity for the least efficient firms in the full sample is primarily driven by carbon-intensive sectors.

When we compare the results for both groups based on their growth stage, we find that intangible assets are associated with better environmental performance across the distribution. However, we find that, for low-growth firms, intangible assets

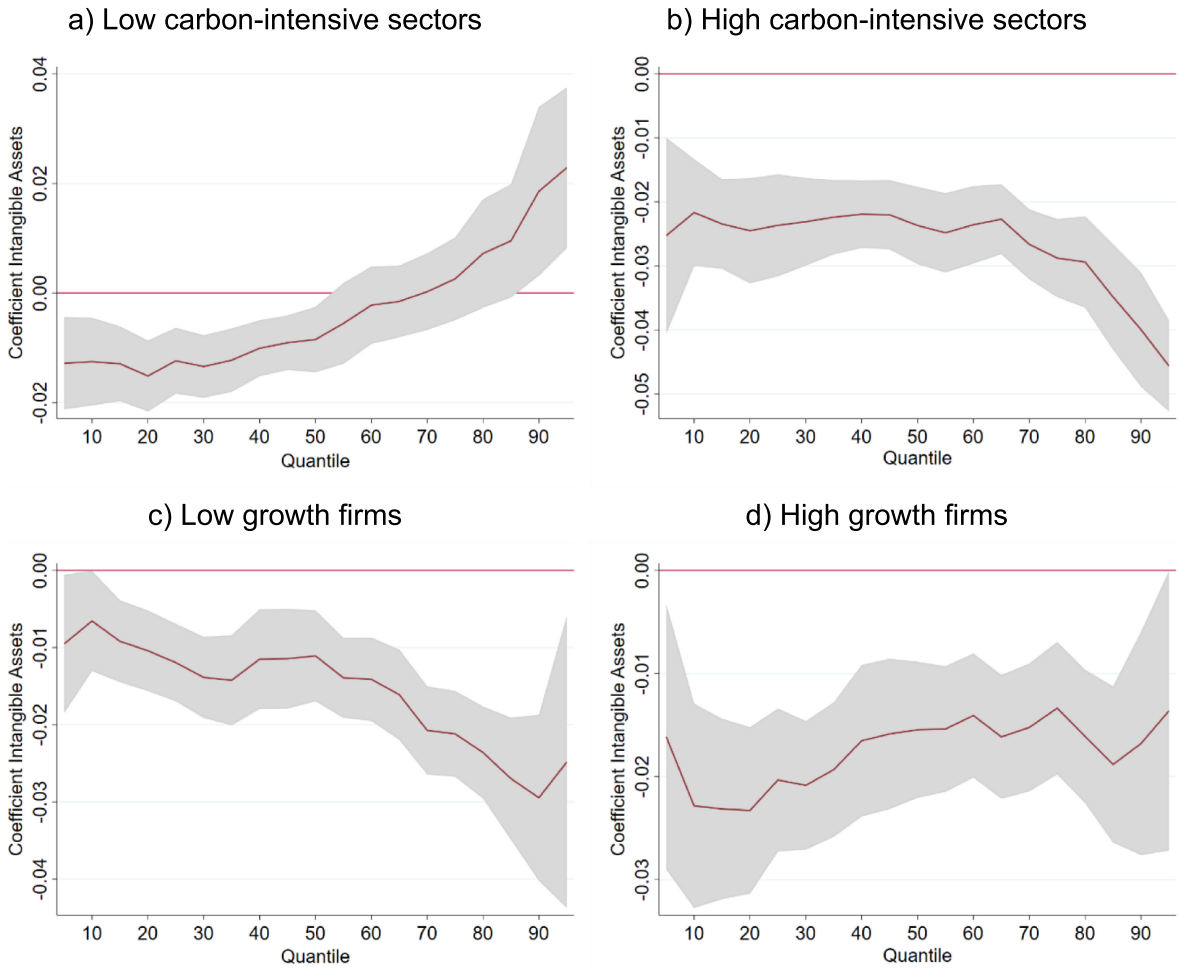


FIGURE 4 | (a–d) Coefficients of intangible assets across quantiles of CO_2 intensity for different firm groups. *Note:* ——— effect, ▭ 95% confidence interval. *Source:* Own elaboration.

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show a strengthening negative association with CO_2 intensity, whereas for high-growth firms, we find a weakening negative association across quantiles. This indicates that green laggard firms in high-growth environments leverage environmental capabilities into greener performance less than comparably dirty low-growing firms, where structural optimization may dominate and improve their environmental performance. In high-growth firms, intangible assets may translate more into expansion dynamics than into environmental capability building.

A similar divide is visible when we look at the environmental innovation score (Figure 5). For low-intensive sectors, we find the expected result of a negative coefficient, strengthening in the upper quantiles. The results for high-carbon–intensive sectors show a different picture: Although we see a positive coefficient for the 25% and 50% quantiles, it remains insignificant in the other quantiles. The non-significance of the upper quantiles can hint that those firms operate in environments where emissions are structurally embedded and firms face difficulties in reducing them. However, similar to the results in the whole sample, this might be due to the measurement of the environmental innovation score. Although firms in high-intensive sectors might innovate in their abatement of chemical products and get higher environmental innovation scores, their impact on emissions can be limited.

Although the effect for low-growth firms is mostly insignificant, environmental innovation for high-growth firms is associated with better environmental performance when they belong to the upper quantiles. This indicates that the implementation of environmental innovation has a more positive impact in dynamic expansion contexts.

Hence, considering both sample splits, we can conclude that environmental innovation as a lever for improved environmental performance is dominant in high-growth firms and low-CO_2–intensive sectors, whereas high-CO_2–intensive sectors and slow-growing firms may struggle to translate environmental innovations into better emission efficiency.

Lastly, the relationship between regulation and CO_2 intensity appears robust across growth regimes and carbon-intensive environments (Figure 6). However, for the lower quantiles of the high-carbon–intensive sectors and the 10% quantile of the fast-growing firms, the coefficient is insignificant, which indicates that those green leaders already work at the efficiency frontier and inherently improve environmental performance.

When looking at the control variables, we find that ROA is not significant in the low-intensive industries and in the

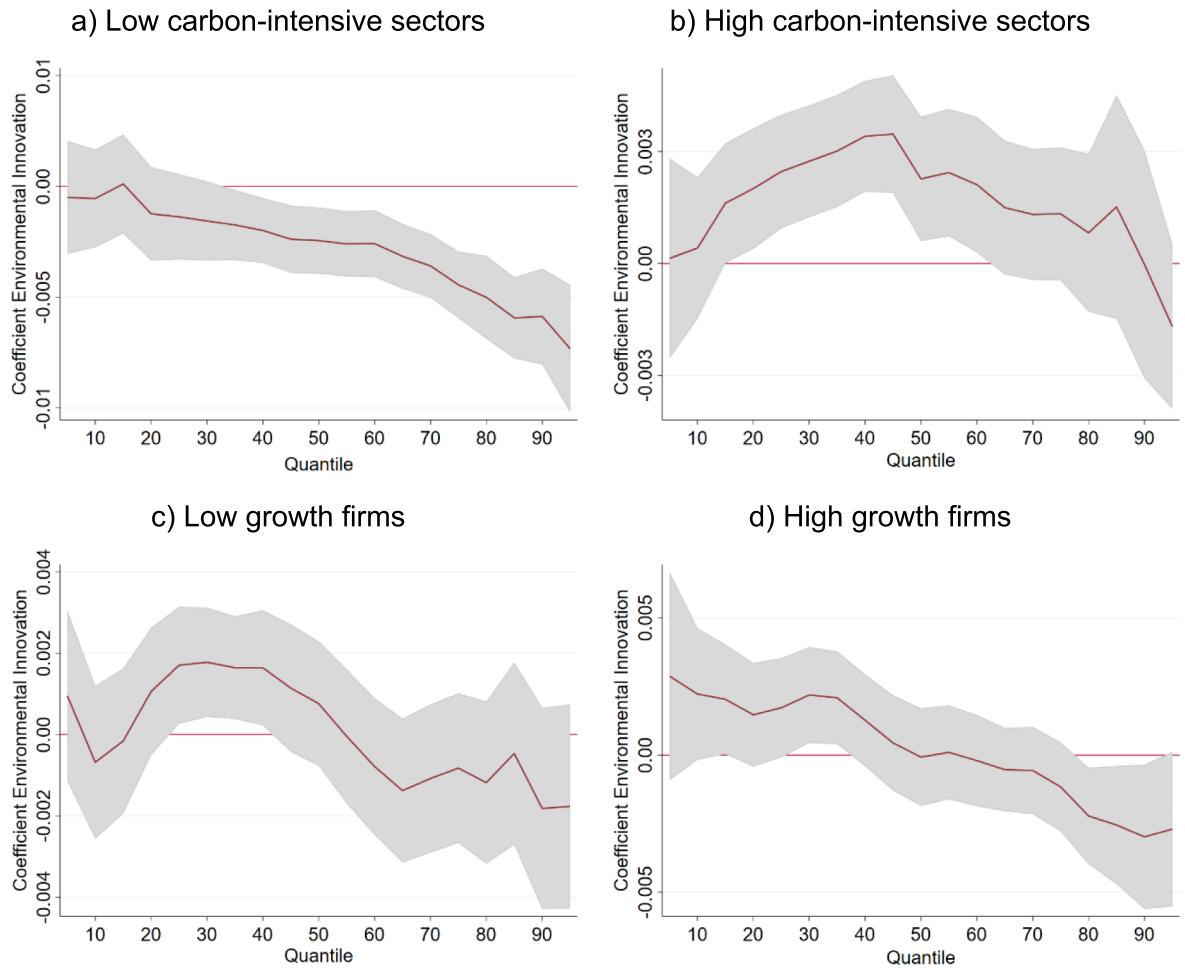


FIGURE 5 | (a–d) Coefficients of environmental innovation across quantiles of CO_2 intensity for different firm groups. *Note:* ——— effect, 95% confidence interval. *Source:* Own elaboration.

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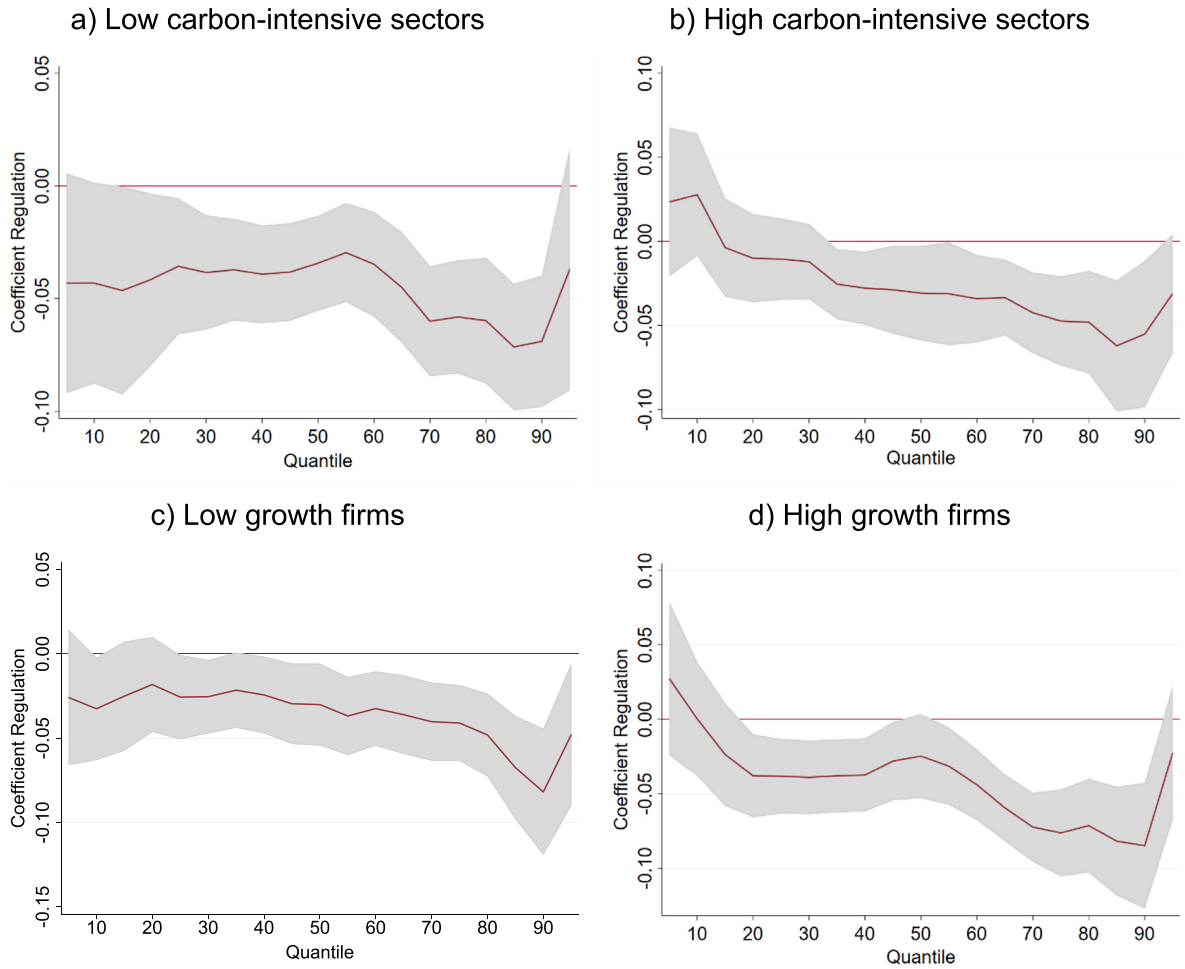


FIGURE 6 | (a–d) Coefficients of regulation across quantiles of CO_2 intensity for different firm groups. *Note:* ——— effect, ▭ 95% confidence interval. *Source:* Own elaboration.

fast-growing firms. However, we find a negative significant coefficient in the upper quantiles for both high-carbon–intensive sectors and low-growing firms, which gets stronger for the least CO_2 efficient quantiles, whereas the coefficients are much larger in the carbon-intensive sectors. This reveals several aspects. First, in fast-growing environments, being more profitable does not translate to better environmental performance, probably due to a strong focus on growth. Second, this changes in a slow-growing environment and in CO_2-intensive sectors. This can be attributed to the fact that slow-growing, profitable firms focus on efficiency gains and can invest more in greener technologies compared to less profitable slow growers. Furthermore, in carbon-intensive sectors, firms with higher ROA have more financial capacity to invest in cleaner technologies, in addition to their higher productivity that translates into less CO_2 intensity, comparable to results from Forslid et al. (2018).

A higher leverage is associated with worse environmental performance in the low-carbon–intensive sectors. In the high-carbon–intensive sectors, it is associated with worse environmental performance only for the least CO_2-efficient firms, indicating that for the firms in the lower quantiles, higher leverage does not result in worse environmental performance, potentially because these green leaders use some of their debts to finance green infrastructure. Leverage is also associated with worse environmental performance in high-growing firms; this indicates again, similar to the result for ROA, that fast-growing firms focus mainly on growth. When we look at the low-growing firms, leverage is similar to the high-intensive sectors, only significant at the upper quantiles, indicating that slow-growing firms that are indebted do not have financial capacity to focus on greener production processes.

Considering the governance variables, we find that the full-sample positive coefficient for board independence is mainly driven by slow-growing firms and by firms from carbon-intensive sectors. In carbon-intensive sectors and in slow-growing firms, independent directors may focus more on shareholders' economic interest than on environmental outcomes. Interestingly, we find that CEO duality is associated with better environmental performance in carbon-intensive sectors. Combined with the results for board independence, this suggests that in carbon-intensive sectors, environmental improvements need a visionary, green CEO instead of outside independent governance.

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For the other control variables, we find comparable results compared to the full sample, which confirms that the findings for capital expenditures, indicating increased economic activity generating emissions (Karim et al. 2021), or that larger firms emit more CO_2 (Azar et al. 2021; Ben-David et al. 2021), hold across different growth and industry specifications.

5.3 | Drivers of CO_2 Growth

In a next step, we investigate firms' decarbonization dynamics by examining the growth rate of CO_2 (Table A12). The results show that intangible assets are not significantly related to CO_2 growth across the quantiles, whereas environmental innovation shows consistent, negatively significant effects for most quantiles (Figure 7). This indicates that higher levels of environmental innovation are associated with slower CO_2 emission growth, suggesting that environmentally innovative firms expand their operations in a more carbon-efficient manner. Combined with our previous results for CO_2 intensity, they support previous evidence by Lee and Min (2015), Wang et al. (2021) or Haque and Ntim (2022), confirming Hypothesis 2: Environmental innovation is associated with better CEP among highly polluting firms where the potential for emission reductions is greatest.

Regulation shows a negative association for the bottom 50% of the growth distribution and is insignificant for the upper half. This pattern suggests that regulatory measures are effective at moderating moderate emission growth yet are less able to constrain firms undergoing very rapid expansion. A possible explanation that we do not find a significant effect for the rapidly expanding emitters can also be the outsourcing of emission-intensive activities from those firms. They might be incentivized to partially outsource their expansion due to the high costs faced in the home country, which is a result in line with Ben-David et al. (2021).

When looking at control variables, employees and Capex show significant positive relationships with the growth of emissions across quantiles. Employees and capital expenditures lead both to an increase in emissions (or less reduction of it), which is intuitive as they both indicate economic activity. ROA exhibits heterogeneous effects across the CO_2 emission growth distribution. At the lower quantiles, ROA is positively associated with emission growth, whereas at the upper quantiles (75th and 90th), the relationship turns significantly negative. This pattern suggests that among firms with relatively low or moderate emission growth, higher profitability may coincide with expansionary activities that increase emissions. In contrast, among firms with high emission growth, more profitable firms tend to

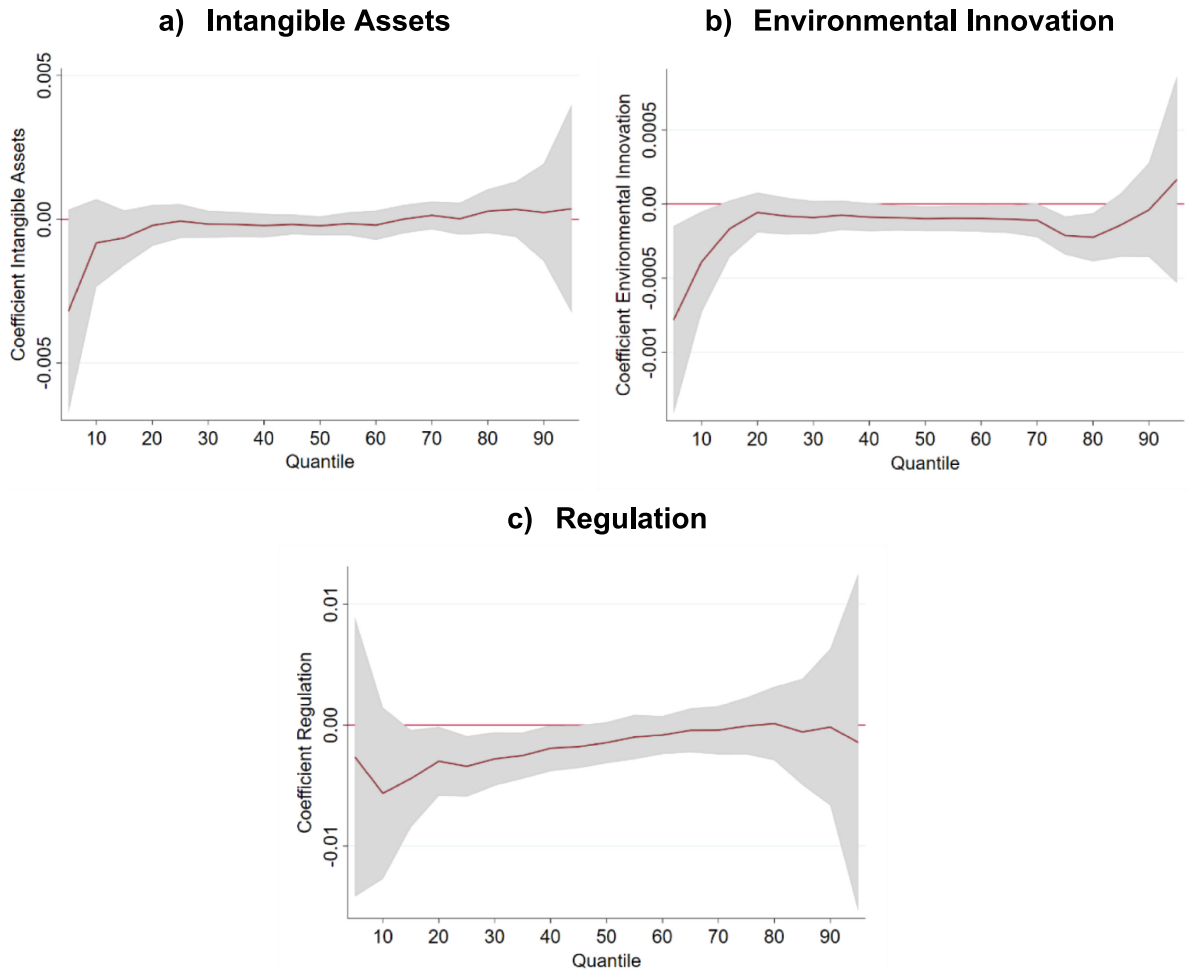


FIGURE 7 | (a–c) Coefficients of key variables across quantiles of CO_2 growth. *Note:* ——— effect, ▭ 95% confidence interval. *Source:* Own elaboration.

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better mitigate their emission increases compared to less profitable peers. These firms likely possess greater financial capacity to invest in cleaner technologies or process improvements that curb emissions. Consistent with Forslid et al. (2018), this result may also reflect that more productive and efficient firms achieve lower emission growth due to superior management practices and technological capabilities.

Furthermore, we find a positive correlation for CEO duality with CO_2 growth in some quantiles, which suggests that this indicator of weaker control leads to fewer environmental responsibilities within the firm.

Our control variables—leverage, the share of independent board members, the existence of a sustainability committee and GDP—do not influence emission growth. Trade openness is associated with lower emission growth for the lower part of the distribution, suggesting that firms operating in more globally integrated economies benefit from international technology diffusion and efficiency pressures that help to stabilize or reduce their emissions. In contrast, a higher manufacturing share in the country of headquarters is associated with higher emission growth across most quantiles, which may be because firms embedded in more industrialized economies tend to operate in a generally more carbon-intensive environment, where energy systems and production networks are oriented towards manufacturing. The relationship weakens at the upper quantiles, where firms are already highly polluting and possibly face greater regulatory or stakeholder pressure to curb emissions.

Lastly, firms with higher emissions in the previous year tend to reduce their emissions more in the following year, particularly those companies that are increasing their emissions the most (higher quantiles). This could suggest a form of adjustment, where firms with higher prior emissions take more steps to lower their growth in emissions over time.

6 | Conclusions

Mainly due to the emission of greenhouse gases, the earth has experienced a critical temperature rise compared to pre-industrial times. Despite widespread climate policies, emissions continue to increase across sectors, highlighting the need for stronger action from governments, civil society and the private sector (IPCC 2023).

Based on a sample of 1052 companies from 18 countries for the period 2011–2019, this study examined the heterogeneous effects of intangible assets, environmental innovation and regulation on CEP. Our results show significant differences between high- and low-polluting companies. Within the framework of the RBV and NRBV, we show that intangible assets and environmental innovation enhance firms' environmental performance. Our findings show that the association between environmental capabilities and CO_2 intensity is conditional on structural carbon exposure and firms' growth regimes. Intangible assets are most strongly associated with lower CO_2 intensity in high-intensity sectors and among slow-growing firms, indicating an optimization-based capability mechanism, although intangible assets show limited short-term influence on emission growth.

Furthermore, our results suggest that the association between environmental innovation and CO_2 intensity depends highly on growth stage and sectorial carbon intensity. Although our results show that it is partly associated with worse environmental performance for already clean firms, it shows, for growing, dirty firms and for low-carbon–intensive sectors, a positive association with environmental performance, indicating a green transformation mechanism. However, results for environmental innovation must be interpreted with caution due to the construction of the environmental innovation score. Lastly, we find that stricter, directly emission-related environmental regulation is associated with better CEP, particularly for high-emitting firms, indicating that governments are important stakeholders in promoting sustainable transitions. However, although regulation reduces emissions among firms with moderately growing emissions, it shows limited short-term effects on rapidly expanding emitters. Furthermore, firm profitability seems to play an important role in achieving better environmental performance for high-polluting firms from high-carbon–intensive sectors and low-growth regimes, indicating that financial restrictions do play a role in decarbonization attempts.

The contribution of this study is twofold. First, by combining firm- and country-level variables in a dataset of global companies, we contribute to understanding the drivers of CEP. Second, the application of quantile regressions in different structural contexts reveals the heterogeneous impacts of intangible assets, environmental innovation and regulation across firms with different emission profiles. In the context of the RBV and NRBV, our results show that especially high-polluting firms can leverage their intangible assets and environmental capabilities to improve their environmental performance.

From a policy perspective, our findings emphasize that environmental regulation is an effective tool to improve CEP, particularly for emission-intensive firms. Policy instruments such as CO_2 taxes and emission trading systems are efficient in promoting long-term decarbonization. However, governments should acknowledge the differences in firms' emissions profiles: Although higher CO_2 prices can drive long-term improvements, governments should monitor closely the short-term responses of rapidly growing emitters, which may outsource some of their activities to avoid compliance costs.

Despite these contributions, our study acknowledges some limitations due to data coverage. The absence of firms from low-income countries restricts the ability to identify potentially important patterns among firms in developing countries. Additionally, we focus on directly emission-related regulation and innovation. Other mechanisms, such as policy support for green growth or the impact of environmental innovation on non-emission-related indicators, remain unexplored and could reveal additional insights on how to shape a sustainable economy.

Future research should extend this analysis to firms in low-income economies to provide a more comprehensive understanding of how varying economic and regulatory environmental environments influence firm behaviour.

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Conflicts of Interest

The authors declare no conflicts of interest.

Endnotes

[1] Total CO_2 emissions are defined as the sum of Scope 1 (direct operational) and Scope 2 (indirect electricity related) emissions. Scope 3 emissions, those emitted across the value chain, are excluded from the estimations due to inconsistent reporting and potential comparability issues (Busch et al. 2022).

[2] Results are available upon request.

[3] Both sample splits are structurally different from each other. There is a similar amount of high (low)–growth firms in low- and high-carbon-intensive sectors (see Table A7). For the detailed results of the estimations, see Tables A8 and A9 for the sectorial split and Tables A10 and A11 for the growth split.

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Appendix A

TABLE A1 | Number of firms by country of headquarters.

Country	Observations	Percentage	Region	Global Innovation Index score (average 2011–2023)
Australia	41	3.90	Oceania	52.47
Austria	10	0.95	Europe	52.36
Belgium	11	1.05	Europe	51.22
Canada	45	4.28	North America	55.32
Denmark	13	1.24	Europe	58.27
Finland	21	2.00	Europe	59.70
France	63	5.99	Europe	52.94
Germany	51	4.85	Europe	56.95
Ireland	13	1.24	Europe	57.44
Italy	17	1.62	Europe	45.76
Japan	213	20.25	East Asia	53.28
Netherlands	20	1.90	Europe	60.73
Norway	11	1.05	Europe	53.74
Spain	29	2.76	Europe	48.14
Sweden	30	2.85	Europe	63.01
Switzerland	36	3.42	Europe	66.81
United Kingdom	147	13.97	Europe	60.83
United States	281	26.71	North America	59.90

Source: Own elaboration based on Eikon data and Global Innovation Index.

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TABLE A2 | Pairwise correlation matrix of main variables.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1) CO_2	1															
(2) CO_2 intensity	0.76*	1														
(3) CO_2 growth	0.06*	0.08*	1													
(4) Intangible assets	−0.04*	0.00	−0.02	1												
(5) Environmental innovation	0.19*	−0.02*	−0.02	−0.08*	1											
(6) Regulation	−0.19*	−0.10*	−0.02	0.05*	0.01	1										
(7) ROA	−0.07*	0.10*	0.02	0.11*	−0.11*	0.06*	1									
(8) Capex	0.34*	0.50*	0.05*	0.00	−0.07*	−0.03*	0.10*	1								
(9) Leverage	0.20*	0.22*	−0.02	0.20*	−0.08*	0.05*	−0.01	0.14*	1							
(10) Employees	0.45*	0.06*	0.00	0.06*	0.30*	−0.08*	−0.04*	−0.03*	−0.04*	1						
(11) Board independence	0.07*	−0.02	−0.05*	0.17*	−0.04*	0.07*	0.12*	−0.06*	0.23*	0.08*	1					
(12) CEO duality	0.12*	0.07*	0.00	0.09*	0.01	−0.21*	0.05*	−0.04*	0.08*	0.15*	0.10*	1				
(13) CSC	0.21*	0.05*	0.00	0.01	0.20*	−0.03*	−0.04*	0.04*	0.02*	0.23*	0.02	0.03*	1			
(14) GDP per capita	−0.02	0.01	−0.04*	0.12*	−0.13*	0.25*	0.16*	−0.05*	0.17*	−0.02	0.56*	0.09*	−0.06*	1		
(15) Trade openness	−0.10*	−0.08*	−0.02	0.06	0.03*	0.50*	−0.01	−0.01	−0.05*	−0.01	0.07*	−0.24*	−0.01	0.17*	1	
(16) Manufacturing share	0.07*	0.08*	0.05*	−0.17*	0.11*	−0.14*	−0.08*	0.01	−0.22*	0.08*	−0.55*	−0.00	−0.01*	−0.33*	0.11*	1

Note: Asterisks (*) denote pairwise correlation coefficients that are statistically significant at the 5% level.

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TABLE A3 | Normality tests of the dependent variables.

Variables	Test	*D*-statistic	*p*	Conclusion
CO_2int	Kolmogorov–Smirnov	0.0847	0.000	Non-normal
CO_2 growth	Kolmogorov–Smirnov	0.1955	0.000	Non-normal

Source: Own elaboration based on Eikon data.

TABLE A4 | Quantile regression results for the dependent variable CO_2 intensity.

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	10%	25%	50%	75%	90%
Intangibles	−0.0193***	−0.0148***	−0.0175***	−0.0143***	−0.0188***	−0.0216***
	(0.0018)	(0.0027)	(0.0024)	(0.0021)	(0.0021)	(0.0038)
Environmental innovation	−0.0006	0.0004	0.0014**	0.0001	−0.0019***	−0.0031***
	(0.0005)	(0.0007)	(0.0006)	(0.0006)	(0.0006)	(0.0010)
Regulation	−0.0349***	−0.0038	−0.0308***	−0.0329***	−0.0462***	−0.0728***
	(0.0078)	(0.0126)	(0.0085)	(0.0083)	(0.0091)	(0.0146)
ROA	−0.1919	0.1470	−0.7645*	−0.6974	−0.6103	−0.2860
	(0.2139)	(0.5070)	(0.4092)	(0.5398)	(0.6362)	(0.7470)
Capex	0.1276***	0.1001***	0.1184***	0.1547***	0.1715***	0.1597***
	(0.0048)	(0.0085)	(0.0081)	(0.0094)	(0.0095)	(0.0141)
Leverage	0.0082***	0.0041**	0.0050***	0.0069***	0.0112***	0.0180***
	(0.0011)	(0.0017)	(0.0015)	(0.0016)	(0.0018)	(0.0026)
Employees	0.1500***	0.2449***	0.1950***	0.1341***	0.0526***	0.0196
	(0.0120)	(0.0185)	(0.0137)	(0.0154)	(0.0139)	(0.0193)
Board independence	0.0036***	0.0020*	0.0031***	0.0042***	0.0040***	0.0012
	(0.0007)	(0.0012)	(0.0010)	(0.0008)	(0.0008)	(0.0016)
CEO duality	−0.0331	−0.0204	−0.0687**	−0.0528	−0.0426	0.0379
	(0.0313)	(0.0486)	(0.0340)	(0.0355)	(0.0373)	(0.0617)
CSC	−0.0304	0.0568	−0.1036**	−0.0337	−0.0410	0.0268
	(0.0418)	(0.0839)	(0.0468)	(0.0528)	(0.0547)	(0.0721)
GDP	0.3369***	−0.1357	0.1461	0.3228***	0.4634***	0.8221***
	(0.0733)	(0.1232)	(0.0973)	(0.0728)	(0.0999)	(0.1606)
Manufacturing share	0.0263***	0.0234***	0.0325***	0.0366***	0.0234***	0.0094
	(0.0039)	(0.0054)	(0.0048)	(0.0041)	(0.0050)	(0.0069)
Trade openness	−0.0036***	−0.0048***	−0.0032***	−0.0040***	−0.0033***	−0.0021**
	(0.0005)	(0.0007)	(0.0007)	(0.0005)	(0.0006)	(0.0010)
Sector dummies			Yes			
Time dummies			Yes			
Constant	−1.8418***	−2.8362***	−2.3840***	−1.9614***	−1.3036***	−0.6295***
	(0.0961)	(0.1662)	(0.1169)	(0.1179)	(0.1266)	(0.1818)
Observations	6876	6876	6876	6876	6876	6876
R^2	0.753					
Pseudo-R^2		0.604	0.552	0.501	0.480	0.438

Note: Standard errors are in parentheses.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

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TABLE A5 | Sample split based on CO_2 intensity for GICS sectors.

High-carbon–intensive sectors	Low-carbon–intensive sectors
Energy (10)	Consumer Discretionary (25)
Materials (15)	Health Care (35)
Industrials (20)	Financials (40)
Consumer Staples (30)	Information Technology (45)
Utilities (55)	Communication Services (50)
	Real Estate (60)

Note: Sectors were split into two similarly sized groups based on the ranked CO_2 intensity obtained from Barahhou et al. (2022).
Source: Own elaboration.

TABLE A6 | CO_2 intensity in high- and low-carbon–intensive sectors.

Variable	High-carbon–intensive sectors	Low-carbon–intensive sectors
Mean CO_2 intensity	0.242	0.026
Median CO_2 intensity	0.069	0.010

Note: Sectors were split into two similarly sized groups based on the ranked CO_2 intensity obtained from Barahhou et al. (2022).
Source: Own elaboration.

TABLE A7 | Number of firms in each category.

	Low-carbon–intensive sectors	High-carbon–intensive sectors	Total
Low-growth firms	233	282	515
High-growth firms	286	251	537
Total	519	533	1052

Note: Sectors were split into two similarly sized groups based on the ranked CO_2 intensity obtained from Barahhou et al. (2022), and for the growth regime, firms were categorized by the median of average annual employment growth within the sample period.
Source: Own elaboration.

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TABLE A8 | Quantile regression results for the dependent variable CO_2 intensity for low-carbon–intensive sectors.

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	**10%**	**25%**	**50%**	**75%**	**90%**
Intangibles	−0.0069***	−0.0125***	−0.0124***	−0.0085***	0.0026	0.0186**
	(0.0025)	(0.0042)	(0.0031)	(0.0029)	(0.0038)	(0.0080)
Environmental innovation	−0.0034***	−0.0005	−0.0014	−0.0025***	−0.0044***	−0.0059***
	(0.0007)	(0.0011)	(0.0009)	(0.0008)	(0.0007)	(0.0011)
Regulation	−0.0476***	−0.0431**	−0.0357**	−0.0343***	−0.0582***	−0.0690***
	(0.0108)	(0.0214)	(0.0151)	(0.0108)	(0.0130)	(0.0152)
ROA	0.4267*	0.0713	−0.6319	0.4645	0.2027	−0.0265
	(0.2222)	(0.6843)	(0.5803)	(0.4777)	(0.1925)	(0.3181)
Capex	0.1550***	0.1204***	0.1601***	0.1928***	0.2102***	0.2019***
	(0.0070)	(0.0155)	(0.0123)	(0.0103)	(0.0107)	(0.0151)
Leverage	0.0104***	0.0074***	0.0076***	0.0095***	0.0113***	0.0130***
	(0.0013)	(0.0018)	(0.0019)	(0.0022)	(0.0020)	(0.0032)
Employees	0.1628***	0.2605***	0.2278***	0.1463***	0.0182	−0.0302
	(0.0153)	(0.0279)	(0.0211)	(0.0171)	(0.0169)	(0.0279)
Board independence	0.0011	0.0008	0.0019	0.0028**	0.0024*	−0.0029*
	(0.0010)	(0.0017)	(0.0018)	(0.0012)	(0.0012)	(0.0016)
CEO duality	0.0649	0.1345*	0.0100	−0.0321	0.1130**	0.1438**
	(0.0412)	(0.0753)	(0.0527)	(0.0474)	(0.0457)	(0.0683)
CSC	−0.0252	0.0311	−0.0530	0.0798	−0.0969	−0.1203
	(0.0548)	(0.1084)	(0.0708)	(0.0715)	(0.0710)	(0.0975)
GDP	0.2409**	−0.1054	0.1163	0.3504***	0.2807**	0.5604***
	(0.0972)	(0.1851)	(0.1553)	(0.0924)	(0.1309)	(0.1714)
Manufacturing share	0.0126**	0.0173*	0.0137	0.0313***	0.0188***	−0.0090
	(0.0053)	(0.0103)	(0.0084)	(0.0057)	(0.0063)	(0.0080)
Trade openness	−0.0038***	−0.0053***	−0.0049***	−0.0051***	−0.0033***	−0.0028***
	(0.0007)	(0.0013)	(0.0012)	(0.0007)	(0.0007)	(0.0011)
Sector dummies			Yes			
Time dummies			Yes			
Constant	−4.3678***	−5.5420***	−4.9410***	−4.6598***	−3.8952***	−3.0203***
	(0.1194)	(0.2259)	(0.1695)	(0.1192)	(0.1496)	(0.1960)
Observations	3346	3346	3346	3346	3346	3346
R^2	0.771					
Pseudo-R^2		0.587	0.610	0.540	0.474	0.411

Note: Standard errors are in parentheses. Low-carbon–intensive sectors include Consumer Discretionary (25), Health Care (35), Financials (40), Information Technology (45), Communication Services (50) and Real Estate (60).
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

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TABLE A9 | Quantile regression results for the dependent variable CO_2 intensity for high-carbon–intensive sectors.

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	**10%**	**25%**	**50%**	**75%**	**90%**
Intangibles	−0.0301***	−0.0217***	−0.0237***	−0.0237***	−0.0288***	−0.0400***
	(0.0027)	(0.0043)	(0.0041)	(0.0031)	(0.0031)	(0.0046)
Environmental innovation	0.0012*	0.0004	0.0025***	0.0023**	0.0013	−0.0000
	(0.0007)	(0.0010)	(0.0008)	(0.0009)	(0.0009)	(0.0015)
Regulation	−0.0279**	0.0277	−0.0106	−0.0308**	−0.0474***	−0.0552***
	(0.0110)	(0.0190)	(0.0122)	(0.0143)	(0.0130)	(0.0211)
ROA	−2.5433***	−0.3220	−0.8772	−2.1648***	−4.1020***	−8.0534***
	(0.5095)	(0.7867)	(0.5630)	(0.6368)	(0.7046)	(1.1576)
Capex	0.1073***	0.0870***	0.0891***	0.1073***	0.1469***	0.1479***
	(0.0067)	(0.0104)	(0.0082)	(0.0153)	(0.0161)	(0.0203)
Leverage	0.0037**	0.0008	0.0021	0.0017	0.0073**	0.0088**
	(0.0018)	(0.0025)	(0.0025)	(0.0025)	(0.0032)	(0.0039)
Employees	0.1361***	0.2330***	0.1819***	0.1165***	0.0462**	0.0162
	(0.0186)	(0.0314)	(0.0247)	(0.0317)	(0.0230)	(0.0365)
Board independence	0.0052***	0.0033*	0.0031**	0.0057***	0.0065***	0.0057***
	(0.0010)	(0.0018)	(0.0013)	(0.0014)	(0.0011)	(0.0021)
CEO duality	−0.1247***	−0.0991	−0.1436***	−0.0902*	−0.1334**	−0.0771
	(0.0464)	(0.0733)	(0.0497)	(0.0545)	(0.0590)	(0.0881)
CSC	−0.0091	0.0456	−0.0091	−0.1440**	−0.0374	0.0872
	(0.0623)	(0.1165)	(0.1038)	(0.0708)	(0.0820)	(0.1359)
GDP	0.5053***	−0.0699	0.0444	0.2526*	0.6132***	0.9193***
	(0.1090)	(0.2042)	(0.1442)	(0.1465)	(0.1477)	(0.2239)
Manufacturing share	0.0297***	0.0309***	0.0355***	0.0321***	0.0262***	0.0098
	(0.0057)	(0.0082)	(0.0069)	(0.0072)	(0.0073)	(0.0111)
Trade openness	−0.0033***	−0.0040***	−0.0023**	−0.0032***	−0.0033***	−0.0029**
	(0.0007)	(0.0011)	(0.0009)	(0.0008)	(0.0010)	(0.0014)
Sector dummies			Yes			
Time dummies			Yes			
Constant	−3.0579***	−4.2888***	−3.6966***	−3.1354***	−2.6996***	−1.7599***
	(0.1421)	(0.2469)	(0.1711)	(0.1815)	(0.2110)	(0.2742)
Observations	3530	3530	3530	3530	3530	3530
R^2	0.416					
Pseudo-R^2		0.210	0.261	0.293	0.286	0.254

Note: Standard errors are in parentheses. High carbon-intensive sectors: Energy (10), Materials (15), Industrials (20), Consumer Staples (30) and Utilities (55).
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

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TABLE A10 | Quantile regression results for the dependent variable CO_2 intensity for low-growth firms.

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	**10%**	**25%**	**50%**	**75%**	**90%**
Intangibles	−0.0176***	−0.0066**	−0.0120***	−0.0111***	−0.0212***	−0.0295***
	(0.0027)	(0.0030)	(0.0025)	(0.0030)	(0.0029)	(0.0055)
Environmental innovation	0.0001	−0.0007	0.0017**	0.0008	−0.0008	−0.0018
	(0.0007)	(0.0010)	(0.0008)	(0.0008)	(0.0009)	(0.0012)
Regulation	−0.0376***	−0.0326**	−0.0256**	−0.0301**	−0.0410***	−0.0819***
	(0.0103)	(0.0156)	(0.0123)	(0.0121)	(0.0114)	(0.0187)
ROA	−0.8783*	−0.6476	−0.5285	−0.9536*	−1.4059**	−2.3791***
	(0.4539)	(0.7674)	(0.5774)	(0.5499)	(0.5679)	(0.9125)
Capex	0.1203***	0.0863***	0.1066***	0.1436***	0.1675***	0.1483***
	(0.0069)	(0.0093)	(0.0107)	(0.0129)	(0.0150)	(0.0226)
Leverage	0.0049***	−0.0034	−0.0003	0.0006	0.0073***	0.0147***
	(0.0016)	(0.0023)	(0.0021)	(0.0027)	(0.0027)	(0.0040)
Employees	0.1188***	0.3016***	0.1518***	0.1072***	0.0234	−0.0198
	(0.0175)	(0.0284)	(0.0230)	(0.0213)	(0.0256)	(0.0339)
Board independence	0.0057***	0.0042***	0.0072***	0.0064***	0.0033***	0.0022
	(0.0010)	(0.0014)	(0.0014)	(0.0011)	(0.0012)	(0.0018)
CEO duality	−0.1327***	−0.0273	−0.1517***	−0.0783	−0.0455	−0.0192
	(0.0459)	(0.0627)	(0.0552)	(0.0520)	(0.0696)	(0.0820)
CSC	0.0689	0.2437*	−0.0746	0.0067	0.1336	0.0525
	(0.0623)	(0.1346)	(0.0953)	(0.0713)	(0.0884)	(0.1348)
GDP	0.1034	−0.3581**	−0.1902*	0.1376	0.6639***	0.8635***
	(0.1046)	(0.1804)	(0.1154)	(0.0945)	(0.1359)	(0.2071)
Manufacturing share	0.0326***	0.0270***	0.0452***	0.0417***	0.0315***	0.0256**
	(0.0054)	(0.0069)	(0.0074)	(0.0059)	(0.0068)	(0.0100)
Trade openness	−0.0048***	−0.0050***	−0.0057***	−0.0042***	−0.0049***	−0.0032**
	(0.0007)	(0.0008)	(0.0011)	(0.0009)	(0.0008)	(0.0015)
Sector dummies			Yes			
Time dummies			Yes			
Constant	−1.8317***	−2.6586***	−2.4278***	−2.0100***	−1.3254***	−0.4156
	(0.1339)	(0.2093)	(0.1931)	(0.1624)	(0.1712)	(0.3106)
Observations	3438	3438	3438	3438	3438	3438
R^2	0.788					
Pseudo-R^2		0.657	0.607	0.541	0.504	0.458

Note: Standard errors are in parentheses. Firms are categorized by the median of average annual employment growth within the sample period.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

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TABLE A11 | Quantile regression results for the dependent variable CO_2 intensity for high-growth firms.

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	**10%**	**25%**	**50%**	**75%**	**90%**
Intangibles	−0.0194***	−0.0228***	−0.0203***	−0.0155***	−0.0134***	−0.0168***
	(0.0025)	(0.0051)	(0.0036)	(0.0034)	(0.0034)	(0.0055)
Environmental innovation	−0.0005	0.0022*	0.0017*	−0.0001	−0.0012	−0.0030**
	(0.0007)	(0.0012)	(0.0009)	(0.0009)	(0.0008)	(0.0014)
Regulation	−0.0418***	0.0002	−0.0382***	−0.0248*	−0.0763***	−0.0849***
	(0.0118)	(0.0186)	(0.0130)	(0.0146)	(0.0146)	(0.0217)
ROA	0.0723	0.6471	0.0902	0.2614	−0.0542	0.0234
	(0.2455)	(0.4652)	(0.4992)	(0.4932)	(0.6092)	(0.5922)
Capex	0.1408***	0.1103***	0.1497***	0.1703***	0.1847***	0.1690***
	(0.0067)	(0.0165)	(0.0103)	(0.0119)	(0.0120)	(0.0184)
Leverage	0.0109***	0.0076***	0.0102***	0.0127***	0.0147***	0.0197***
	(0.0015)	(0.0023)	(0.0018)	(0.0024)	(0.0021)	(0.0034)
Employees	0.1483***	0.1647***	0.1898***	0.1557***	0.0631***	0.0856***
	(0.0171)	(0.0251)	(0.0236)	(0.0236)	(0.0209)	(0.0330)
Board independence	0.0004	0.0005	−0.0003	0.0010	0.0028**	−0.0029
	(0.0010)	(0.0017)	(0.0013)	(0.0011)	(0.0013)	(0.0024)
CEO duality	0.0570	0.0786	0.0587	−0.0043	0.0213	0.0383
	(0.0429)	(0.0841)	(0.0541)	(0.0487)	(0.0545)	(0.0741)
CSC	−0.0947*	−0.1631	−0.1182*	−0.0719	−0.1815**	−0.1221
	(0.0564)	(0.1077)	(0.0687)	(0.0760)	(0.0757)	(0.1188)
GDP	0.7139***	0.1435	0.5919***	0.5274***	0.6344***	1.2767***
	(0.1021)	(0.1708)	(0.1486)	(0.1158)	(0.1459)	(0.2340)
Manufacturing share	0.0144**	0.0120	0.0156**	0.0249***	0.0246***	−0.0067
	(0.0057)	(0.0108)	(0.0069)	(0.0062)	(0.0075)	(0.0098)
Trade openness	−0.0025***	−0.0033**	−0.0024**	−0.0037***	−0.0025***	−0.0006
	(0.0008)	(0.0016)	(0.0011)	(0.0008)	(0.0008)	(0.0015)
Sector dummies			Yes			
Time dummies			Yes			
Constant	−1.8314***	−3.2519***	−2.6537***	−1.9880***	−1.1729***	−0.4314*
	(0.1367)	(0.3065)	(0.1916)	(0.1700)	(0.1973)	(0.2307)
Observations	3438	3438	3438	3438	3438	3438
R^2	0.723					
Pseudo-R^2		0.567	0.504	0.466	0.465	0.447

Note: Standard errors are in parentheses. Firms are categorized by the median of average annual employment growth within the sample period.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

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TABLE A12 | Quantile regression results for the dependent variable CO_2 growth.

	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	**10%**	**25%**	**50%**	**75%**	**90%**
Intangibles	−0.0007	−0.0008	−0.0001	−0.0002	0.0000	0.0002
	(0.0005)	(0.0008)	(0.0003)	(0.0002)	(0.0003)	(0.0009)
Environmental innovation	−0.0001	−0.0004**	−0.0001	−0.0001**	−0.0002***	−0.0000
	(0.0001)	(0.0002)	(0.0001)	(0.0000)	(0.0001)	(0.0002)
Regulation	−0.0027	−0.0056*	−0.0034***	−0.0015*	−0.0001	−0.0002
	(0.0020)	(0.0034)	(0.0013)	(0.0009)	(0.0012)	(0.0033)
ROA	0.0046	0.1584**	0.0488	−0.0065	−0.0708**	−0.1320*
	(0.0552)	(0.0776)	(0.0398)	(0.0350)	(0.0291)	(0.0730)
Capex	0.0079***	0.0058***	0.0043***	0.0045***	0.0066***	0.0094***
	(0.0013)	(0.0013)	(0.0008)	(0.0006)	(0.0010)	(0.0020)
Leverage	0.0001	−0.0007	−0.0002	−0.0002	0.0002	0.0007
	(0.0003)	(0.0005)	(0.0002)	(0.0001)	(0.0002)	(0.0005)
Employees	0.0276***	0.0134**	0.0057**	0.0012	0.0059**	0.0193***
	(0.0039)	(0.0053)	(0.0026)	(0.0016)	(0.0023)	(0.0057)
Board independence	0.0001	−0.0002	−0.0001	−0.0001	0.0000	−0.0002
	(0.0002)	(0.0003)	(0.0001)	(0.0001)	(0.0001)	(0.0003)
CEO duality	0.0015	−0.0013	0.0048	0.0062**	0.0092**	0.0092
	(0.0080)	(0.0105)	(0.0042)	(0.0029)	(0.0046)	(0.0106)
CSC	0.0081	0.0110	−0.0064	−0.0014	0.0014	−0.0064
	(0.0108)	(0.0144)	(0.0062)	(0.0045)	(0.0061)	(0.0188)
GDP	−0.0057	0.0464	0.0063	0.0114	−0.0119	−0.0054
	(0.0189)	(0.0322)	(0.0108)	(0.0086)	(0.0107)	(0.0297)
Manufacturing share	0.0039***	0.0063***	0.0024***	0.0012***	0.0012*	0.0007
	(0.0010)	(0.0014)	(0.0006)	(0.0004)	(0.0007)	(0.0015)
Trade openness	−0.0003**	−0.0005**	−0.0002**	−0.0001*	−0.0001	0.0001
	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0001)	(0.0003)
CO_2	−0.0343***	0.0034	−0.0003	−0.0048***	−0.0196***	−0.0505***
	(0.0029)	(0.0042)	(0.0017)	(0.0013)	(0.0017)	(0.0043)
Sector dummies			Yes			
Time dummies			Yes			
Constant	0.0770***	−0.1324***	−0.0478***	0.0178*	0.1150***	0.3197***
	(0.0250)	(0.0312)	(0.0146)	(0.0104)	(0.0165)	(0.0406)
Observations	6876	6876	6876	6876	6876	6876
R^2	0.0300					
Pseudo-R^2		0.0388	0.0253	0.0175	0.0296	0.0619

Note: Standard errors are in parentheses.
***$p < 0.01$.
**$p < 0.05$.
*$p < 0.1$.

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