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Does competitive pressure drive effective corporate environmental actions?

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ABSTRACT

Competitive pressure is an important driving factor of corporate behavioural changes. Yet, it is still unclear how it influences corporate attitudes towards environmental challenges. In this study, we systematically analyse the sustainability behaviour of a global sample of publicly traded firms to examine if and how competitive pressure pushes them to implement effective behavioural changes to reduce their greenhouse gas emissions. Our results suggest that competitive pressure induces firms to diversify investments across a broad spectrum of environmental initiatives. Importantly, diversification results from a decreased relative investment in risk mitigation and stakeholder engagement activities counterbalanced by an increased relative investment in innovation capabilities, and it is associated with a positive abatement potential. Effects are modest in size but significant and robust against multiple alternative specifications. Overall, our analysis suggests that competitive pressures can be a driving force of effective corporate mitigation actions that integrate response diversity mechanisms to address environmental challenges.

1. Introduction

Publicly traded companies are crucial players in modern societies (Davoudi et al., 2018). They provide essential services but their business operations and activities are the primary sources of greenhouse gas (GHG) emissions and depletion of natural resources (Dietz et al., 2018; Schoenmaker and Schramade, 2019; Masson-Delmotte et al., 2021). Hence, effective corporate behavioural changes are crucial to support just global decarbonisation efforts. Due to their central role in the low-carbon transition, companies' are exposed to several transition risks and their climate, and more broadly, environmental actions – actions aimed at supporting environmental goals – are more than ever scrutinised and influenced by a broad range of actors from policymakers to shareholders (Dyck et al., 2019; Houston and Shan, 2021; Krueger et al., 2020) and, most notably, competitors (Zhang et al., 2023).

Competitive pressure is an important driving factor of corporate decision-making and behavioural changes (Porter, 1980; Nickell, 1996). Hence, in the past decade, several studies have investigated its role as a driver of corporate sustainability choices. Most previous studies investigating the role of corporate responses to competitive pressure as an action to lower their environmental impact and mitigate transition risks are primarily based on a combination of three theoretical frameworks (see Section 2): institutional theory, which emphasises the role of external pressures (DiMaggio and Powell, 1983); stakeholder theory, which highlights the influence of diverse stakeholder demands (Freeman, 1984); and resource-based theory (Hart, 1995), which focuses on internal capabilities in shaping firm behaviour. Such studies include but are not limited to Dupire and M'Zali (2018), which broadly investigates CSR strategies developed in response to competitive pressure; (Han and Ito, 2024), which examines the role of institutional isomorphisms; (Cai and Li, 2018), which explores sustainable innovation in response to competitive forces under the lens of institutional theory; and Zhang et al. (2023) that investigate competitive pressure as a driver of net-zero commitment integrating stakeholder and institutional theory.

Overall, most empirical studies investigating the relationship between competitive pressure and corporate environmental actions primarily focused on regional samples and, importantly, only captured a fraction of all environmental activities that companies use to engage in sustainable management practices. Hence, although there is some and growing empirical evidence in support of the notion that competitive pressure can be a driving factor of effective sustainable corporate behavioural changes, the full empirical mechanisms by which companies respond to competitive forces, and the extent to which these changes

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mediate the impact of competition on companies' environmental footprint, remain unclear.

In light of these limitations, the primary objective of this study is to empirically investigate whether and how competitive pressure pushes firms to implement effective behavioural changes to reduce their GHG emissions using a comprehensive characterisation of corporate environmental sustainability behaviour (henceforth "sustainability behaviour") developed from an extensive analysis of sustainability and integrated reports (see Section 3). In what follows, we focus solely on companies' climate footprint because emissions, albeit still subject to substantial measurement errors as discussed in Section 6, are the most reliable statistics of companies environmental impact. However, we focus on corporate actions across all environmental domains as emission reductions can be driven by activities whose emission abatement is not the primary objective (e.g. waste management, water efficiency) (Kudłak, 2019; Wang et al., 2020; Oo et al., 2024).

To characterise corporate sustainability behaviour we systematically collect information on sustainability initiatives — defined as actions or activities (we use the two terms interchangeably) implemented by firms to meet specific Environmental Sustainable Development Goals (SDGs) - for a cross-sectoral global sample of publicly traded companies (Cenci et al., 2023). The actions cover 14 mutually exclusive types (e.g. R&D investment, asset modification, see Section A in the Appendix for a full description) that here we cast into three empirical mechanisms, i.e., mechanisms by which environmental initiatives impact companies' outcomes (Vishwanathan et al., 2020). Specifically, we focus on (1) risk mitigation, (2) shareholder engagement, and (3) innovation-capacity mechanisms (see Section 3.2). Furthermore, we define an additional mechanism, (4) diversification, that gauges how companies distribute their investments across activity types and environmental goals. Diversification of environmental actions as an empirical mechanism to drive decarbonisation has been studied (Cenci and Tang, 2024) and it is tightly linked to what are often called response diversity mechanisms, which are crucial responses of complex adaptive systems to continuously changing environments (Elmqvist et al., 2003; Walker et al., 2023). Overall, our findings suggest that competitive pressures induce firms to diversify their investments in environmental sustainability initiatives (henceforth, environmental initiatives) across a broad spectrum of activities and goals. Importantly, diversification of efforts results from a decreased relative investment in risk mitigation and stakeholder engagement activities counterbalanced by an increased relative investment in innovation capabilities, and it is associated with a significant abatement potential.

We contribute to the literature on the relationship between competition and sustainability outcomes by examining the role of corporate environmental actions as mediators in this relationship using a comprehensive characterisation of corporate sustainability behaviour. To the best of our knowledge, this study represents the first analysis of the relationship between competition and corporate environmental actions that delves into specific firm-level environmental initiatives using a comprehensive cross-sectoral global dataset. Indeed, whilst most existing quantitative studies use measures that focus on the presence or absence of policies (Shiller, 2018; Pursiainen et al., 2023; Asgharian et al., 2023), or focus on specific behavioural domains (Díaz-García et al., 2015; Cai and Li, 2018; Zhang et al., 2023), this study takes a more comprehensive approach by examining a broad set of initiatives implemented to meet environmental goals.

The paper is structured as follows. In Section 2 we present a theoretical framework and an outline of our study. In Sections 3 and 4, we describe our data and empirical approach, respectively. In Section 5, we present the results of our analyses. Finally, in Section 6, we discuss our findings, their implications, and the limitations.

2. Theoretical background and outline of the study

In this work, we explore the relationship between competitive pressure, firm behaviour, and sustainability outcomes. Our framework is grounded on theories that highlight the role of external pressures and internal capabilities in shaping sustainable business practices.

Institutional theory highlights the role of outside forces – such as market competition, regulatory changes, and societal expectations – in shaping organisational practices and has been used as a framework to understand companies' engagement in environmental activities (Wang et al., 2019; Arranz et al., 2022; Zhang et al., 2023; Han and Ito, 2024). DiMaggio and Powell (1983) outline three main types of forces by which organisations within the same field or industry become increasingly similar to one another over time: (i) Coercive isomorphism due to external pressures from laws, regulations, or powerful stakeholders (e.g., governments, investors). (ii) Normative isomorphism that arises from professional norms or industry standards. (iii) Mimetic isomorphism, that happens when organisations copy successful peers to reduce uncertainty or risk. We expect that each of these forces can drive effective behavioural changes in corporate environmental management practices by, for example, incentivise companies to adopt industry norms or imitate effective behavioural changes of competitors.

Stakeholder theory further informs this framework by emphasising that firms' environmental and social initiatives are influenced by the expectations of diverse stakeholders, including investors, customers, regulators, and suppliers (Freeman et al., 2018). Firms in highly competitive environments face amplified demands from environmentally conscious customers and ethical investors, incentivising them to improve their sustainability performance to gain a competitive advantage. Indeed, the role of stakeholder pressures in driving corporate environmental actions has been investigated in several previous studies (Cadez et al., 2019; Dhanda et al., 2022; Zhang et al., 2023)

Finally, resource-based theory (RBT) (Hart, 1995) offers a complementary lens by emphasising how firms can leverage sustainability innovation and environmental performance as sources of competitive advantage (McWilliams and Siegel, 2010). Sustainability-driven process improvements (e.g., energy efficiency) and product innovations (e.g., green products) align with the RBT perspective that resources and capabilities that are valuable, rare, inimitable, and non-substitutable enhance firm performance (Barney, 1991). However, it should be noted that resource constraints in competitive markets may hinder the ability of some firms to engage in environmental initiatives (Gupta and Krishnamurti, 2016).

Overall, existing theories suggest that competitive pressure may increases the level of investment in environmental initiatives through either isomorphism mechanisms, increased stakeholder pressures or as a strategy to gain competitive advantage. Indeed, these theories provide a framework for the empirical evidence already presented in Section 1 on the role of competitive pressure as a driver of firms' environmental initiatives. Yet, the details of how companies actually respond to competitive pressure in the development of their environmental strategies and the extent to which their response mediate the impact of competitive forces on companies emissions remain unclear.

Companies have several tools at their disposal to engage in environmental activities, ranging from improving the energy efficiency of their production processes, mitigating climate-related risks, creating new organisational structures and investing in R&D activities. These tools can be combined in a set of empirical mechanisms (e.g. risk mitigation, stakeholder engagement and innovation capacities) that mediate the effect of corporate environmental strategies on their performance similarly to what has been argued in Vishwanathan et al. (2020) to relate corporate social responsibility (CSR) activities to their financial performance. The three theories discussed in this section suggest that competitive pressure may drive investment across different actions reflecting into different configurations of empirical mechanisms. However, a theory can only provide limited clarity on how firms actually respond (or have historically responded) to competitive forces and, importantly, on the impact of their actions. Hence, in this work we investigate these questions empirically. Specifically, we explore (a) what empirical mechanisms are associated with greater historical competitive pressure and (b) the extent to which they mediate the impact of competitive pressure on future climate footprint. To characterise the empirical mechanisms of individual firms we use the dataset described in Section 3.2 and the categorisation developed by Vishwanathan et al. (2020). To investigate the extent to which the empirical mechanisms are associated with future climate footprint, we estimate a mediation model (Section 4), which we will stress using different subsamples, variables and data sources to test its robustness.

3. Data

Our analysis spans the period between 2011 and 2021, and requires collecting data from multiple sources, including corporate relationships from FactSet Revere, GHG emissions from TruCost, and accounting data from Refinitiv Eikon. We also include data on corporate sustainability behaviour collected from an extensive analysis of corporate sustainability reports. In this section, we describe our data and we provide an overview of the sample statistics.

3.1. Relationships, emissions, and fundamentals datasets

We collect data on competitive relationships from FactSet Revere, which provides a list of competitors for each firm in their sample (≈10 000 companies globally). Factset considers a company i to be a competitor of a focal company j if either of the companies reports the relationship to them, or if this information is disclosed in the SEC 10-K annual filings, investor presentations, or press releases. The dataset also provides information on other types of relationships, such as suppliers and customers. In this manuscript, we focus exclusively on competitive relationships. To quantify the competitive pressure experienced by firm i in year y we identify its total number of competitors, i.e., its degree in the competition network.

GHG emission data are from TruCost. Specifically, we measure total GHG emissions as direct plus first-tier indirect emissions. In this measure,[1] TruCost defines direct emissions as the GHG Protocol's scope 1 emissions, plus any other emissions derived from a wider range of GHGs relevant to a company's operations. First-tier indirect emissions are defined as GHG Protocol scope 2 emissions, plus emissions from the company's direct suppliers. Notice that the definition of direct and indirect emissions differs slightly from those required by the GHG protocol — the de-facto carbon accounting standard. Hence, we will test the robustness of our results using also Scope 1 and Scope 2 emissions independently. For each emission data point, we also collect information as to whether it was disclosed by the company or estimated by TruCost, so to test the robustness of our results against estimation errors.

Financial fundamentals are from Refinitiv and ratio variables are defined following standard practices in corporate finance, see for example (Faulkender and Petersen, 2005; Hovakimian and Li, 2012). Specifically, we define Size as the log of total revenue; Tangibility is property plant and equipment divided by book assets. Profitability is earnings before interest, tax, depreciation, and amortisation divided by the book assets of the previous fiscal year. Invested capital is the natural logarithm of long-term debt, plus shareholder equity plus preferred stocks plus minority interests. Turnover is revenue over book assets. Market to book is book assets minus shareholder equity plus market value of equity divided by book assets. From the full population, we exclude firms with less than $1M of invested capital or revenue and firms in the Financial and Real Estate sectors (sector and geography classification data are from S&P Capital).

3.2. Characterisation of behavioural channels

To characterise companies' sustainability behaviour, we use a dataset originally developed in Cenci et al. (2023), and also described in Cenci and Tang (2024), that collects and analyses information on corporate efforts to lower the environmental impact of their business operations from nonfinancial disclosures in sustainability and integrated reports. For clarity, here we briefly summarise the data-generating process. The main unit of analysis is a sustainability initiative, defined as an activity or action implemented by a firm to support a specific sustainability goal, classified based on its most closely related United Nations Sustainable Development Goal (SDGs). While the dataset categorises initiatives across all SDGs, here we focus exclusively on environmental SDGs.[2] The activities are classified in 14 mutually exclusive classes that include common Corporate Social Responsibility (CSR) actions, such as asset modification, investment in research and development, establishment of association and partnerships. The full list of activities alongside their detailed definitions and a few examples can be found in Section A in the Appendix. Within this framework, the combination of activities and goals defines the sustainability behaviour of a firm.

The starting reference universe for the dataset is every publicly traded company with available data in Compustat North America or Compustat Global. For every company and year in the reference universe, data are generated following a four-step procedure: (1) first, we collect the sustainability report for the focal firm-year observation from metadata available in Refinitiv. When this information is unavailable, we purchase the report from Corporate Register - a sustainability reports data provider — and finally, if no report is available from either source, we implement a systematic Google search. When crawling the report from Google, we predict the company name and the fiscal year of the report. Then, for those observations with an available sustainability report, we (2) systematically identify sustainability initiatives and categorise them based on (3) the most closely related SDG and (4) the type of activity. The two classification steps, (3) and (4), are performed independently once a particular body of text has been identified as describing an initiative in step (2). The three classifiers in steps (2), (3), (4), are a combination of BERT and RoBERTa-based models trained on a large sample of manually annotated data as explained in Cenci et al. (2023).

The final output of the algorithm is a dataset that, for every firm and every year in our sample, counts the total number of initiatives in each specific class: each activity type and SDG. Put differently, for every firm-year observation we collect a behavioural matrix, $\mathcal{B}$, which represents a specific choice of investment in a particular combination of activities and goals. Fig. 1 shows the Sankey diagram of the aggregated behavioural matrix over the whole sample after merging it with the other datasets used for the analyses, as discussed in Section 3.3. The behavioural matrix from which the Figure is constructed is shown in figure S1 in the Appendix. The left labels in the diagram show the activity types and the right labels show the SDGs. The SDGs are coloured based on the most common type of activity implemented to address them.

Using the behavioural dataset we now construct a series of statistics that capture different aspects of corporate behavioural choices. These are the mediation channels that we will use in our model. While in our work we focus exclusively on environmental SDGs, we still refer to the behaviours as "sustainability behaviours" instead of "environmental sustainability behaviours" to simplify the language across the text. First, we estimate the total effort in environmental sustainability actions as the total number of initiatives undertaken by a company

[1] This definition is valid for the data as available up to May 2024.

[2] The environmental SDGs are SDG 6, 7, 9, 11, 12, 13, 14, 15.

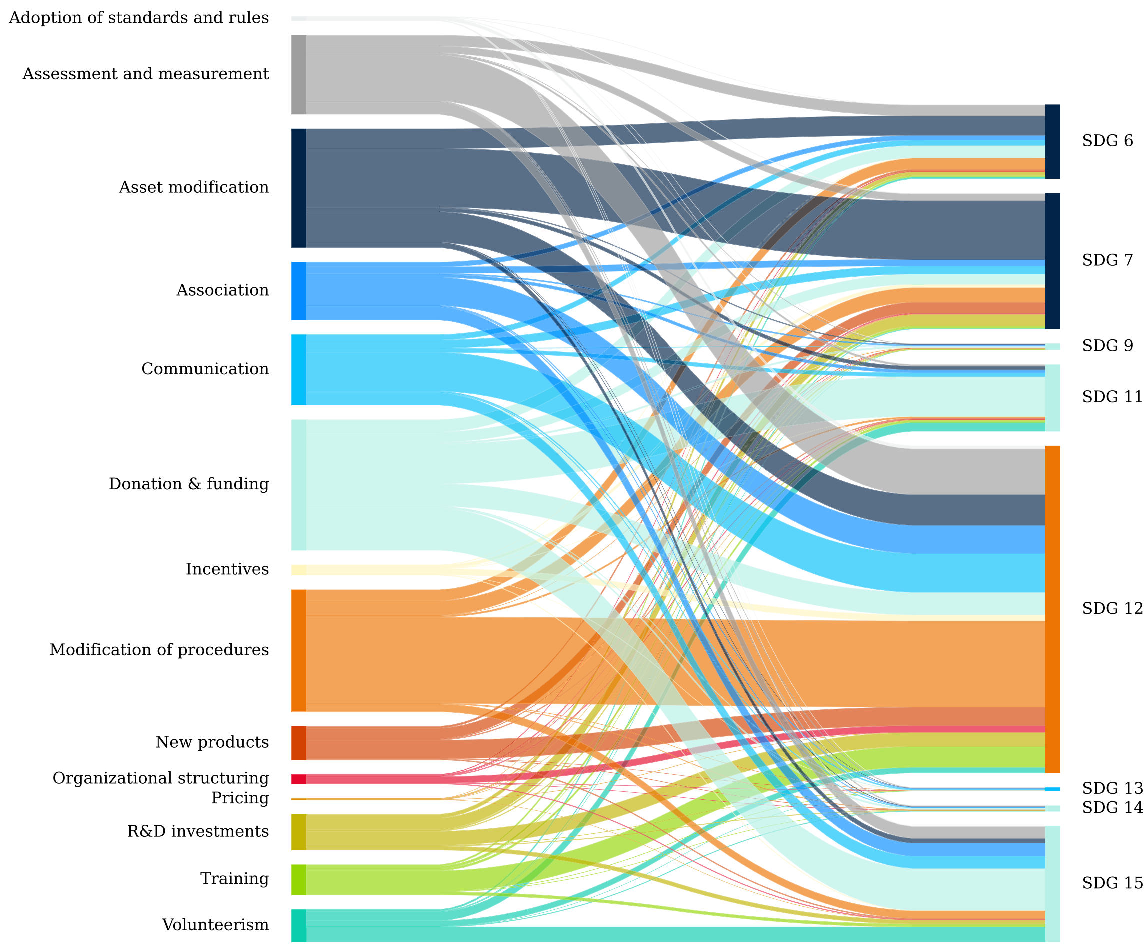

Fig. 1. Behavioural dataset. The figure shows the Sankey diagram of the behavioural dataset. Each block in the diagram is proportional to the number of initiatives in the specific activity type (left) and SDG (right). Each SDG is assigned a colour based on the most frequent related activity type. Figure S1 in the Appendix shows the full numerical matrix used to generate the diagram.

Table 1
Summary statistics of the sample. The table shows the summary statistics of the variables used in the analysis for the companies that meet our inclusion criteria as discussed in Section 3.3. Competitive pressure data are available up to 2019. Initiative and emissions data are lagged up to one and two years ahead, respectively, as explained in Section 4.

Year	Size	Tangibility	Profitability	Inv. cap.(log)	GHG Em. (log)	Mkt-to-Book	Turnover	Competitors	Initiatives	Firms
2011	9.29	0.34	0.15	9.28	14.72	1.51	0.91	12.4	4393	306
2012	9.23	0.33	0.13	9.18	14.61	1.54	0.88	14.8	5534	377
2013	9.02	0.33	0.13	9.04	14.4	1.67	0.88	13.8	8048	495
2014	8.93	0.34	0.13	8.96	14.4	1.65	0.86	15.7	10 186	546
2015	8.76	0.34	0.13	8.93	14.3	1.74	0.85	16.7	9192	602
2016	8.48	0.33	0.13	8.76	14.05	1.73	0.84	16.8	9203	704
2017	8.47	0.32	0.14	8.72	13.95	1.82	0.87	16.5	9991	782
2018	8.37	0.33	0.14	8.69	13.94	1.74	0.85	16.5	9919	870
2019	8.27	0.35	0.14	8.7	13.81	1.83	0.8	17.1	10 436	912
2020					13.76				11 151	912
2021					13.81					912

Sector	Size	Tangibility	Profitability	Inv. cap.(log)	GHG Em. (log)	Mkt-to-Book	Turnover	Competitors	Initiatives	Firms
Communication services	8.68	0.28	0.16	9.22	12.55	1.66	0.54	16.1	4240	92
Consumer discretionary	8.69	0.26	0.15	8.57	13.43	1.92	1.12	10.5	14690	232
Consumer staple	8.66	0.29	0.15	8.58	14.14	2.43	1.14	10.7	10290	158
Energy	9.58	0.56	0.14	9.85	16.05	1.20	0.90	18.5	4048	91
Health Care	8.71	0.17	0.15	9.16	13.13	2.35	0.73	48.0	4403	93
Industrial	8.60	0.27	0.11	8.66	13.80	1.52	0.86	12.5	14260	336
Information technology	8.74	0.17	0.16	8.78	13.07	1.94	0.89	35.0	5517	116
Material	8.19	0.44	0.14	8.51	15.03	1.57	0.78	14.3	9100	235
Utilities	8.62	0.59	0.09	9.58	15.89	1.16	0.41	5.2	10354	130

Geography	Size	Tangibility	Profitability	Inv. cap.(log)	GHG Em. (log)	Mkt-to-Book	Turnover	Competitors	Initiatives	Firms
Asia-Pacific	8.54	0.34	0.12	8.75	14.14	1.66	0.86	8.5	23 855	539
Europe	8.50	0.31	0.14	8.65	13.91	1.66	0.87	15.4	33 176	569
United States and Canada	9.03	0.37	0.15	9.37	14.56	1.94	0.81	28.1	19 871	375

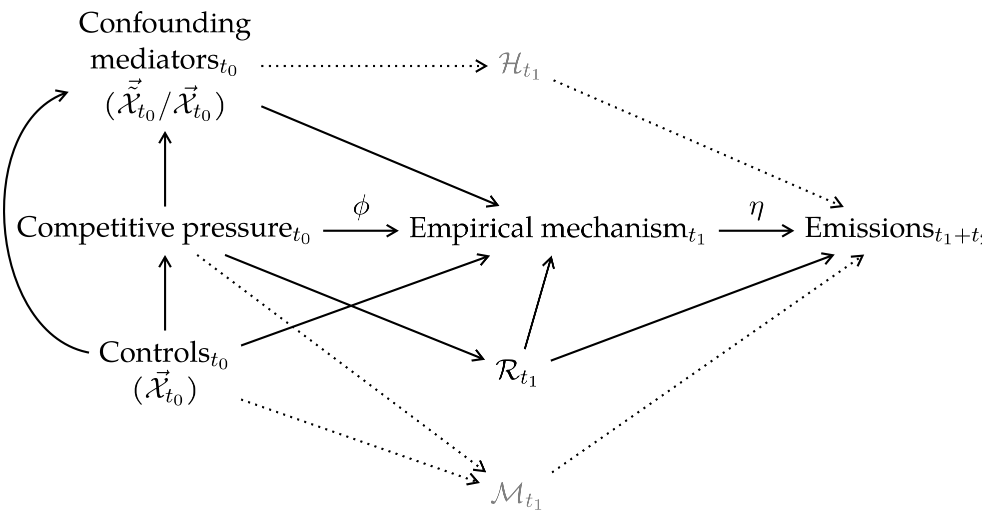

Fig. 2. Mediation model. The figure schematically illustrates our specification to estimate the association between competitive pressure and empirical mechanisms (see Section 2) and the extent to which the latter mediate the effect of competitive forces on companies' climate footprint. The variables and their role in the model are described in Sections 3 and 4. The labels on top of the arrows indicate the coefficients we need to estimate to measure the strength of the mediation effects. The variable $\mathcal{R}_{t_1}$ denote the sales channel. The grey nodes and arrows denote unobserved factors and channels irrelevant for estimating our effects of interest. The node $\mathcal{H}$ denotes the flow of capital invested in non-sustainability activities. The node $\mathcal{M}$ denotes other mediating factors contemporaneous to but independent of the sustainability investments. In the graph, we omitted mutually independent noise variables.

in a given fiscal year, scaled by the log of total invested capital,[3] i.e. initiative intensity. This variable proxies the managerial efforts placed in addressing environmental sustainability problems.

Initiative intensity is a simple statistics that hides the complex strategic planning underneath corporate sustainability choices. Therefore, we also estimate the mediating role of sustainability behaviour on emissions by explicitly measuring different empirical mechanisms defined following the characterisation developed in Vishwanathan et al. (2020), which is a meta-analysis of a vast body of literature in strategic CSR. In particular, we focus on three main mechanisms: (a) risk mitigation, (b) stakeholder engagement, (c) innovation. Each of these mechanisms are constructed by aggregating different types of actions in the behavioural dataset across all SDGs, as explained below. Furthermore, we include an additional mechanism, (d) diversification, which has been studied in Cenci and Tang (2024) who have shown that diversified investments in environmental initiatives is associated with greater emission reduction capabilities and lower exposure to transition risks.

It is important to note that the mechanisms described above should be seen as manifestations of firms' latent behavioural characteristics. We observe the mechanisms, but the mechanisms themself are motivated by more complex managerial choices, such as their long-term sustainability strategies or individual preferences of decision-makers within organisations, inaccessible to us. This differentiation between observable mechanisms and their causes is crucial for the interpretations of the results of the analysis. We will discuss this point further in Section 6.

Risk-mitigation mechanisms involve incremental improvements in practices and processes already in place. In this category, we include initiatives in adoption of standards and rules, assessment and measurement, asset modification, modifications of procedures and training. Stakeholder engagement is defined as the total number of initiatives in donation and funding, communication, volunteerism, pricing, and incentives. These initiatives give firms external visibility, but their implementation do not change any core process in the business operations. Innovation capacities include transformative initiatives that focus on the creation of new products, structures, and growth opportunities. In this category, we include R&D investment, associations, organisational structuring and development of new products. We measure each variable in intensity and relative terms by dividing them by the log of total invested capital and the total number of initiatives, respectively. Diversification is defined as the entropy of the normalised behavioural matrix ($\tilde{\mathcal{B}}_{ij} = \frac{\mathcal{B}_{ij}}{\sum_{i\in A, j\in S} \mathcal{B}_{ij}}$, where $\mathcal{B}_{ij}$ is the total number of initiatives in each activity-i/SDG-j combination), namely:

$$D_{n,t} = \frac{N}{\log N} \sum_{i\in A, j\in S} \tilde{\mathcal{B}}_{n,t,ij} \log(\frac{1}{\tilde{\mathcal{B}}_{n,t,ij}}), \quad (1)$$

where N is the number of non-zero entries in the behavioural matrix of firm n in year t (i.e., the number of sustainability area in which a firm operate), A is the set of activity types, S is the set of SDGs. The multiplier $\frac{N}{\log N}$ transforms the standard entropy measure into a total diversification score, as suggested by Raghunathan (1995).

3.3. Sample statistics

To match data between the four datasets, we use ISIN numbers. Firms that could not be matched by ISIN numbers were matched based on standardised company names obtained after removing punctuation and common suffixes such as *corp*, *llc*, and *inc*. A firm is included in the sample if we have observations of the number of competitors in year t_y, the number of initiatives in year t_{y+1} and emissions in year $t_{y+1,y+2}$ for every y from 2011 to 2019. Therefore, the observation period spans the range 2011–2021. In the final dataset, we retain only firms that meet these conditions. Overall, after merging and imposing the selection conditions, we have 1483 unique names. Fig. 1 and Figure S1 in the supplementary information show the sustainability behaviour dataset. Table 1 shows the summary statistics of our sample across years, sectors, and geographies.

4. Methods

The goal of this study is to investigate if and how competitive pressure pushes firms to implement effective behavioural changes to reduce their GHG emissions. Our empirical strategy is divided in two steps: first we estimate the total effect of competitive pressure on emissions to establish a baseline for the overall importance of competitive forces on

[3] We scale by the log of investment because our sample is heterogeneous in terms of companies size, investment intensity, sectors and therefore the distribution of total invested capital is strongly skewed.

firms' capacity to lower their climate impact. Then we perform a mediation analysis to investigate what type of behavioural changes induced by competitive pressure are associated with the greatest abatement capacity.

4.1. Total effect

The total effect of competitive pressure on emissions is the coefficient of the regression of the cumulative emissions of firm i in year $t+1$ and $t+2$ ($\mathcal{E}_{t_1+t_2}$) on its degree in the competition network in year t_0 (C_{t_0}), i.e. its total number of competitors. We look at the effect up to time $t+2$ for consistency with the mediation analysis described in the next section where the effect of the initiatives needs to be measured over two consecutive years. Specifically, we estimate the following model:

$$\mathcal{E}_{t_1+t_2} = \alpha + \beta C_{t_0} + \sum_j \vec{\gamma}_j \vec{\mathcal{X}}_{j,t_0} + \vec{\delta}\vec{\mathcal{F}} + \omega \mathcal{S} + \epsilon \tag{2}$$

where $\vec{\mathcal{X}}$ is the vector of control variables, $\vec{\mathcal{F}}$ are sector, year, and geography fixed effects, and β is the parameter of interest. Importantly, we estimate the total effect solely to establish a baseline for its magnitude. Our main effect of interest is that part of the total effect that is mediated by the changes in sustainability behaviour, measured as relative weight to different empirical mechanisms, that we observe in our dataset. We estimate the coefficients of Eq. (2) using robust regression with the Huber weight function. The control factors include firms' Size, Tangibility, Market-to-book, and sales turnover, in year t_0.

Size tends to be strongly correlated with competitive pressure because large firms operate over multiple product lines and, therefore, compete with other generalist firms as well as firms that specialise in a few product niches. Size is also positively correlated with emissions due to large firms' greater levels of economic activities. Tangibility measures the proportion of physical assets and is, therefore, strongly correlated with emissions. Furthermore, large investments in intangible assets are often associated with greater market shares and therefore lower competitive pressure (Bajgar et al., 2021). Sales turnover measures corporate efficiency and we expect it to be negatively correlated with competitive pressure, since companies with efficient processes are more likely to differentiate themselves from their peers. We expect that Market-to-book, which is an indirect measure of growth opportunity, is negatively related to competitive pressure, because growth firms are typically small with fewer product lines.

We control for geography fixed effects because national climate policies and competition law can influence both the level of competitive pressure and the total emissions of firms in different countries. Notice that we control for geographical differences at the macro-regional level as opposed to the national level because we do not have continuous time-series for every country in our sample. We control for sector and year fixed effects to account for technological idiosyncrasies and innovation in different industries and at different times. We do not control for firm fixed effects for three reasons: (1) Some firms go in and out of the sample, therefore we have limited number of years for some observations (and so subtracting average values would not be a well-defined operation (Rajan et al., 2023)). (2) Some of our key variables (initiatives and competitive pressure) are measured with error, and firm fixed effects would significantly increase the noise-to-signal ratio in the presence of measurement error (Griliches and Hausman, 1986). Finally, (3) competitive pressure is fairly stable across the population, so it would be correlated with firm-level fixed effects. Additionally to geography, sector and time fixed effects, we also include an additional set of dummy variables ($\mathcal{S}$) to control for heterogeneities in the sources of emission data. That is, whether the emission data of company n in year t was estimated by TruCost, directly reported by the company, or a combination of the two.

4.2. Mediation analysis

Here, we investigate the extent to which the effect of competitive pressure on emission is mediated by investments in different empirical mechanisms. To analyse this mediation effect, we use a standard product-of-coefficients method (Bishop et al., 1976). Specifically, we estimate the following models:

$$\mathcal{I}_{t_1} = \alpha + \phi C_{t_0} + \sum_j \vec{\gamma}_j \vec{\mathcal{X}}_{j,t_0} + \delta \mathcal{F} + \omega \tilde{\mathcal{M}}_{t_0}^{-1} + \epsilon \tag{3}$$

$$\mathcal{E}_{t_1+t_2} = \tilde{\alpha} + \tilde{\beta} C_{t_0} + \eta \mathcal{I}_{t_1} + \sum_j \tilde{\vec{\gamma}}_j \tilde{\vec{\mathcal{X}}}_{j,t_0} + \kappa \mathcal{R}_{t_1} + \tilde{\delta}\mathcal{F} + \omega \mathcal{S} + \epsilon, \tag{4}$$

where $\mathcal{I}$, $\mathcal{E}$, and C are the empirical mechanisms variables, the total emissions, and the competitive pressure, respectively. The model is schematically shown in Fig. 2. We estimate the coefficients of Eqs. (3) and (4) using robust regression with the Huber weight function. Notice that behaviour and competitive pressure are measured with a lag to avoid issues of reverse causality.[4] The behavioural variables are described in Section 3.2. The control sets in Eqs. (3) and (4) ($\mathcal{X}$ and $\tilde{\mathcal{X}}$, respectively) are different for reasons we will explain below. $\mathcal{M}^{-1}$ is the inverse mills ratio for addressing the possible selection bias due to the voluntary nature of non-financial disclosure, which will be described below.

The mediation effect in the product-of-coefficient approach is equal to $M = \phi\eta$, where ϕ and η are the coefficients in Eqs. (3) and (4), respectively. The statistical significance of the effect is calculated, under normality assumptions, from the standard error of the products: t-stat = $\frac{\phi\eta}{\sqrt{\phi^2\sigma_\phi^2+\eta^2\sigma_\eta^2}}$ (Sobel, 1982, 1986). However, the approach is notoriously sensitive to deviations from normality (Preacher and Hayes, 2008; Alfons et al., 2021), so a better approach to estimate the statistical significance of the effect is to bootstrap the coefficients. Specifically, we generate $k = 2000$ realisations of Eqs. (2)–(4), by randomly sampling with replacement 90% of the sample at each iteration. Sampling a fraction of the population at each bootstrap iteration also implicitly tests the validity of the estimates against random variabilities in the sample due to matching of multiple datasets. From the bootstrapped distribution of the coefficients we calculate the 95% confidence intervals of the estimates. In the results, we will report the coefficients ϕ and η and their statistical significance separately. Then we will show the proportion of the total effect mediated through the empirical mechanism channels: $\frac{\phi\eta}{\phi\eta+\tilde{\beta}}$, where $\tilde{\beta}$ in the denominator is the partial effect of competitive pressure on emissions after controlling for the mediation channel through the empirical mechanism. Each regression coefficient is standardised so that it expresses changes in units of standard deviation, but the proportion of the total effect is calculated from unstandardised coefficients.

The causal graph associated with the model in Eqs. (3) and (4) is shown in Fig. 2. In the model, the effect of competitive pressure on total future emissions is mediated by a change in relative investment in a specific empirical mechanism (as defined in Section 3.2), and other unobserved factors, such as investment in activities that do not have a sustainability scope as their first objective and that do not drive sustainability choices. These factors, that include, for example, selling expenses and R&D activities, can be driven by competitive pressure directly or indirectly as schematically shown in Fig. 2 (grey nodes). We imposed a time lag between the level of competitive pressure and the empirical mechanism to account for the possibility of behavioural changes induced by the establishment of new competitive interactions at time t_0. The time-lag also eliminate issues of reverse causality. Finally, we always control for the total number of initiatives at time t_1 in order to disentangle the effect of the particular empirical mechanism from the simple investment in sustainability actions, and we also

[4] Study the impact of corporate actions on competitive pressure is an interesting question but one that is out of the scope of this work

include sales effects at time t_1 ($\mathcal{R}_{t_1}$ in Eq. (4)) to control for effects mediated by sales' changes induced by changes in competitive pressure.

The control variables in Fig. 2 ($\mathcal{X}_{t_0}$ in Eq. (3)) are the same as those used in Eq. (2) since all of those factors are also related to sustainability choices as well as competitive pressure and total emissions. Specifically, we expect Tangibility to be positively related to sustainability choices because maintaining physical assets requires capital investment. When these investments are reported in sustainability reports, they will be counted as sustainability initiatives in our data processing. Indeed, the variable "asset modification" in the behavioural dataset captures these types of expenditures. Size is also positively related to sustainability choices because larger firms have a greater presence in the market and need to meet the expectation of multiple stakeholders. They also have more available capital to spend on sustainability activities. Growth opportunities are expected to be negatively related to sustainability choices because unique product lines require investment in fewer sustainability products and initiatives.

In contrast to the total effect model of competition on emissions (Eq. (2)), the mediation model in Fig. 2 is augmented by including a set of variables we collectively denoted as *confounding mediators*, which are measured at time t_0. In Eq. (4), we denote the control set that includes those factors (in addition to the other controls) as $\tilde{\mathcal{X}}$. These are factors that mediate the effect of competitive pressure on the empirical mechanism but confound the effect of the latter on emissions. Specifically, we include profitability and total invested capital.

We include profitability because it is well known that, for a given total addressable market size, market share, which is inversely proportional to the level of competition, drives firms' profitability (Buzzell et al., 1975; Wernerfelt, 1986). At the same time, profits can be used to finance sustainability initiatives. Indeed, retained earnings are the primary source of capital to realise investment plans (Myers and Majluf, 1984; Frank and Goyal, 2008). Therefore, profitability is one of the possible factors that mediate the effect of competitive pressure on the empirical mechanism. Capital-structure theories predict that when retained earnings are not sufficient to finance investment plans, firms raise capital primarily from debt and subsequently from equity markets (Myers and Majluf, 1984). Therefore, the other relevant driver of sustainability activities at time t_1 is capital raised at t_0. Competitive pressure drives total invested capital, since competitive forces motivate firms to realise their investment plans. Profitability and total invested capital are also used to finance non sustainability activities, which can have an effect on emissions. The model in Fig. 2 account for this confounding effect in the path that goes through the unobserved factors, $\mathcal{H}$.

Finally, we expect that behavioural choices induced by competitive pressure induce changes in contemporaneous and future emissions. Contemporaneous effects exist because sustainability initiatives such as modification of existing assets and procedure have an immediate effect on GHG emissions. Lagged effects also exist because other types of initiatives, such as research and development, or the restructuring of organisational practices can take time to lower (or raise) GHG emissions. In our empirical setting, we consider only a one-year lag because multiple events occurring on a year-to-year basis (including the implementation of other initiatives) make long-term inferences hard to justify theoretically.

Because the disclosure of sustainability initiatives is mostly a voluntary process, our sample might be subject to a self-selection bias. To mitigate this bias, we use the Heckman two-stage model (Heckman, 1979). Specifically, before estimating Eq. (3) we estimate a Probit model where the dependent variable is a binary indicator, taking the value of one if firm i discloses a sustainability report in year t and zero otherwise. Data as to whether a firm publishes a sustainability report in a given fiscal year are from Refinitiv Asset4.[5] The independent variables include Size, Profitability, Invested capital and Tangibility as well as the proportion of firms in the same sector and country that disclose sustainability reports, and year fixed effects. Then we use the Probit model to estimate the inverse Mills ratio, $\mathcal{M}^{-1}$, defined as $\mathcal{M}^{-1} = \frac{f(x)}{F(x)}$, where $f(x)$ and $F(x)$ are the normal probability density function and the cumulative distribution, respectively. The inverse Mills ratio is then used in the estimation of the coefficients in Eq. (3)

Finally, we would like to note that each node in the graph in Fig. 2 is also driven by idiosyncratic effects. For example, sustainability initiatives can be driven by internal reorganisations of a firm which are unrelated to competitive pressures. These effects are not shown in the model because, as long as they are mutually independent, they are irrelevant for the estimation process. Clearly, other (omitted) factors may bias our estimated effects (e.g., factors that drive both behaviour and emissions). Therefore, we do not claim that any of our estimations have an unbiased causal interpretation. Omitted variables are a crucial issue in any empirical settings. However, while less appreciated, including variables that are thought to be, but instead are not, confounders can also induce a significant bias in the estimations; see Pearl et al. (2016) for a theoretical discussion and Cenci and Kealhofer (2022) for an empirical example. Therefore, here we select a subset of variables that we could identify as confounders based on theories and results from previous studies. However, because the specificity of how the chosen variables are measured can be open to debate, we will conduct a series of robustness tests using different proxies for the variables described in this section.

5. Results

In this section, we present our findings by starting with a discussion of the full sample results. We then investigate heterogeneities in the mediation channel and we run a series of robustness tests to validate our findings.

5.1. Full sample results

Before presenting results from the mediation analysis we perform two benchmark analyses that will help us interpret the relevance of our findings. First, we estimate the total effect of competitive pressure on future emissions (Eq. (2), Supplementary Figure S2). The average total effect is 0.186 [−0.2,−0.17] and it is statistically significant. Here and in what follows, coefficients are expressed in units of standard deviation. Hence, a one standard deviation increase in competitive pressure increase emissions by 0.186 times their standard deviation. Numbers between square brackets denotes the bottom and top 5th percentile of the bootstrap distributions of the coefficients. Note that this result simply establishes a baseline magnitude against which we can benchmark the relative importance of the different mediation channels. Moreover, establishing whether or not the total effect is different from zero is important for the interpretation of the proportion of the effect mediated by the behavioural channels.

Second, we estimate the effect of a non-behavioural factor – total sales – which we expect to be a relevant mediator of the total effect. Sales are an important benchmark because increased competitive pressure reduces the market available to firms (their niches), potentially leading to lower sales. Furthermore, it is well established that larger firms – those with higher sales – tend to exhibit higher emissions (Bolton and Kacperczyk, 2021). Hence, we expect a strong contribution of sales as a mediating factor. The model we used to estimate the relevance of this mediation channel is the same as the one presented in Eqs. (3) and (4), but the control set includes the log of total book assets, the proportion of tangible assets over total book assets and profitability all measured at time t_0, as well as fixed effects. The mediation channel (log of sales) is measured at time t_1 and emissions at time t_1, t_2. We also include the total number of sustainability initiatives and their diversification as control factors at

[5] Data item *TR.CSRReporting*

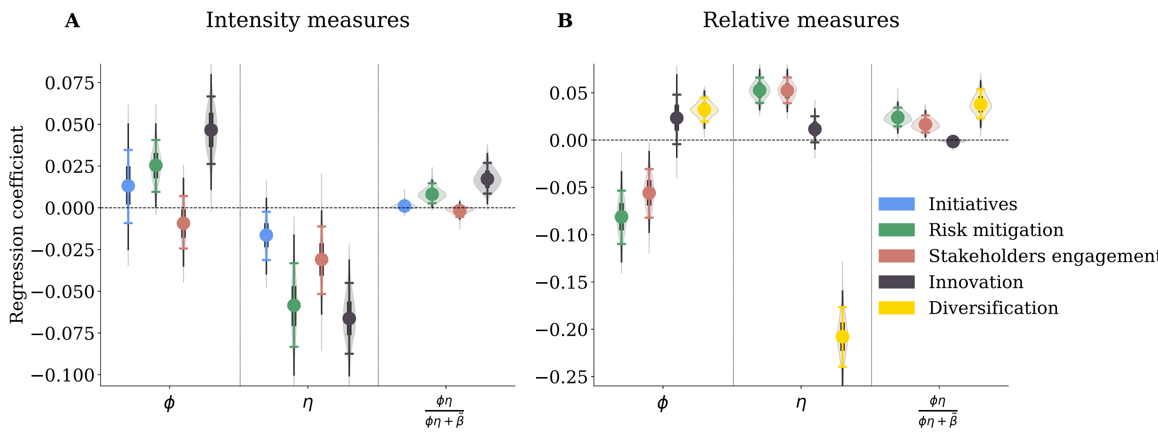

Fig. 3. Full sample results. The figure shows the coefficients estimated from the regressions of the empirical mechanisms on competitive pressures (ϕ), emissions on the empirical mechanisms (η) and the proportion of the total effect mediated by each channel ($\frac{\phi\eta}{\phi\eta+\tilde{\beta}}$). Panel **A** (**B**) shows the coefficients estimated from regressions using empirical mechanisms measured in intensity (relative) scale. The violin plots show the full distributions of the bootstrapped samples, the marks show the means of the coefficients and the error bars are their 95% confidence intervals.

time t_1. Results are shown in Supplementary Figure S3. Revenue from sales mediate approximately 9% of the total effect (blue), on average, due to competitive pressure reducing sales (orange) and sales being generally associated with higher emissions (green).

The results of our main analysis are shown in Fig. 3. The figure shows the full distribution of the coefficients from the bootstrapped samples (violin plots) as well as their average and 95% confidence intervals (error bars). The behavioural variables are depicted using different colours as shown in the legend. Each panel in the Figure is divided in three areas, or columns, each of which shows the estimates for a different regression coefficient. The first column (ϕ) shows the coefficients of the regressions of the empirical mechanisms on competitive pressure (Eq. (3)). The second column (η) shows the coefficients of the regressions of emissions on the empirical mechanisms (Eq. (4)). The last column shows the proportion of the mediated effect, i.e., the ratio of the mediated and total effect: $\frac{\phi\eta}{\phi\eta+\tilde{\beta}}$.

We have found that competitive pressure is associated with an average increase in initiative intensity, but the coefficient is not statistically significant (0.014 [−0.009,0.038]). Initiative intensity is, however, in turn statistically significantly associated with lower future emissions (−0.016 [−0.03,−0.001]). Overall, the mediation effect, which is shown in the third column in Fig. 3 panel **A**, is neither economically nor statistically significant (0.001 [−0.001,0.004]).

Looking at how the initiatives are distributed across the empirical mechanisms we have found an interesting pattern. Competitive pressure is associated with an increased intensity in risk mitigation and innovation activities (0.025 [0.01,0.041], 0.047 [0.026,0.067]), which in turns are associated with lower future emissions (−0.058 [−0.083,-0.033], −0.066 [−0.087,−0.045]). The mediation channels are small, but statistically significant (0.008 [0.003,0.015], 0.017 [0.009,0.027]). The results shown in panel **B** suggest that competitive pressure is associated with a strong reduction of relative investment in risk mitigation and stakeholders engagement activities (−0.081 [−0.11,−0.054], −0.056 [−0.082,−0.031]) and an increased (albeit not statistically significant) relative investment in innovation activities (0.023 [−0.004, 0.048]). Over-investment in risk mitigation and stakeholder engagement activities is associated with higher emissions and therefore the overall mediation channel leads to a reduction in emissions (0.024 [0.015,0.034], 0.017 [0.008,0.026]).

The second column in panel **B** shows that over-investment in any of the activities is associated with higher emissions suggesting that specialisation in siloed sustainability areas is not an effective mechanism to lower emissions. In support of this reasoning, we have found that diversification as an empirical mechanism play a particularly relevant role in the mediation channel. Competitive pressure is associated with a greater diversification of initiatives across activity types and goals (0.032 [0.02,0.045], Fig. 3 panel **B**). Notably, the regression coefficient of diversification on cumulative emissions is negative and large (as also shown in Cenci and Tang (2024), −0.208 [−0.24,−0.177]). The coefficient is substantially larger, in absolute value, than any other coefficient in the mediation channel. The proportion of mediated effect is therefore positive and statistically significant (0.038 [0.023,0.054]). Importantly, Supplementary Figure S4 shows that this result is consistent when using different measures for investment diversification.

5.2. Heterogeneities in the mediation channel

Looking at the distribution of empirical mechanisms across times and sectors we observe clear heterogeneities. Specifically, Supplementary Figure S5 shows that relative and total investment in stakeholder engagement activities and diversification decreased during the observation period. On the contrary, relative investment in Innovation has increased. Similarly, Supplementary Figure S6 shows that investment in the different empirical mechanisms varies substantially across sectors. The Utility sector emerges as the most diversified, with substantial investments in both innovation and stakeholder engagement activities. Similarly, the Consumer Staples sector exhibits high diversification and considerable investment intensity across all three empirical mechanisms.

Since the relative incidence of the empirical mechanisms vary across time and sectors, it is important to investigate whether the effects and mediation channel is also contingent on these factors. Because we are now going to compare the effect across different samples we cannot draw meaningful and unambiguous conclusions from standardised coefficients. This is because the distributions of variables across different samples can have substantially different standard deviations making a comparison of the standardised coefficient ambiguous. Hence, we only investigate the heterogeneity of the proportion of the mediation effect, which is, however, our main variable of interest.

Fig. 4 shows the distribution of the proportion of the mediation effect across years. Each coefficient is estimated on an expanding window up to the year shown on the x-axis, which is the year of the realisation of the behaviour (t_1). The figure shows a predominantly time-consistent pattern. However, the relative importance of the initiatives intensity and investment intensity in risk mitigation actions has decreased over time. On the other hand, investment intensity in innovation activities has become the most important factor (panel **A**). These trend are, however, small.

Fig. 5 shows the distribution of the proportion of the mediation effect across sectors. Here we group sectors in two categories — high

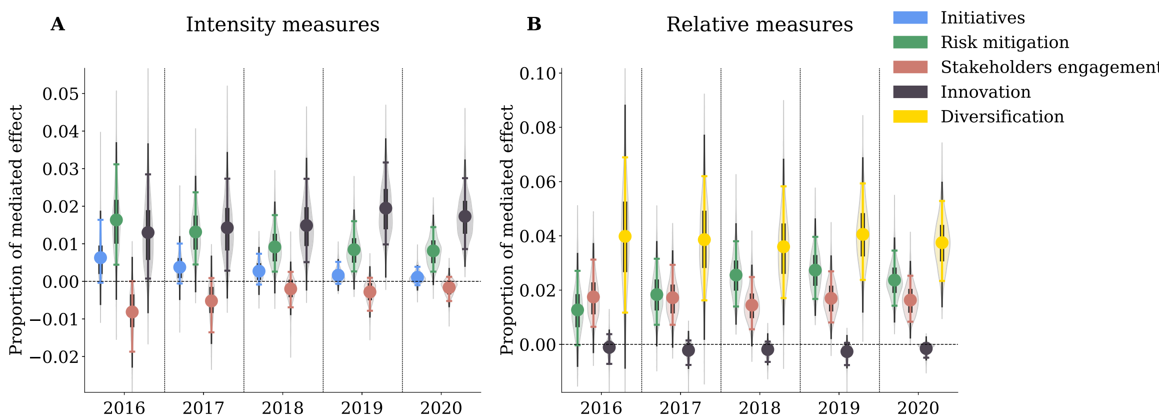

Fig. 4. Temporal evolution of the proportion of the mediated effect. The figure shows the proportion of the total effect mediated by each channel ($\frac{\phi\eta}{\phi\eta+\beta}$) measured in intensity (panel **A**) and relative (panel **B**) measures across years. The violin plots show the full distributions of the bootstrapped samples, the marks show the means of the coefficients and the error bars are their 95% confidence intervals.

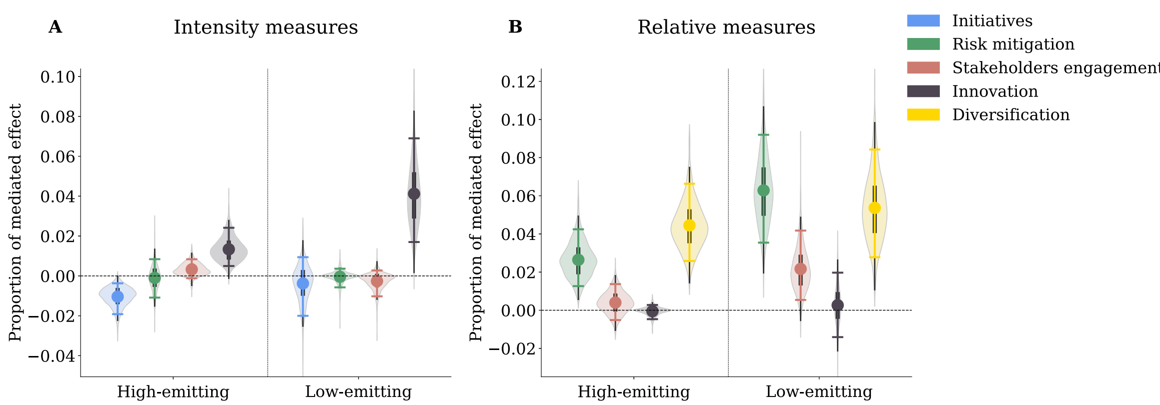

Fig. 5. Sectoral of the proportion of the mediated effect. The figure shows the proportion of the total effect mediated by each channel ($\frac{\phi\eta}{\phi\eta+\beta}$) measured in intensity (panel **A**) and relative (panel **B**) units in high emitting and low emitting sectors. The violin plots show the full distributions of the bootstrapped samples, the marks show the means of the coefficients and the error bars are their 95% confidence intervals.

Table 2
Summary of the robustness tests. The table summarises the results from the robustness tests presented in Section 5.3. A green check mark denotes a coefficient with same sign and statistical significance as in the main analysis shown in Fig. 3. A red cross denotes either a difference in sign or statistical significance. An empty circle denotes an effect that is consistently not statistically significant. For clarity, we only focus on the robustness of the proportion of the mediated effect. Full results can be found in Supplementary Figures S7–S10.

	Total effort	Risk mitigation		Stakeholder engagement		Innovation		Diversification
		Total	Relative	Total	Relative	Total	Relative	
Scope 1	○	✓	✓	○	✓	✓	○	✓
Scope 2	○	✗	✓	○	✓	✗	○	✓
Downloaded reports	○	✓	✓	○	✓	✓	○	✓
Reported emissions	○	✓	✓	○	✓	✓	○	✓
Leverage	○	✓	✓	○	✓	✓	○	✓
Capital expenditure	○	✓	✓	○	✓	✓	○	✓

and low emission sectors. We group sectors in macro-categories because there are not enough data points for reliable estimates at the individual sector level. High emission sectors include energy and energy intensive sectors (Energy, Utilities, Material and Industrial) as well as Consumer Staple, which includes the Agriculture sector — a major polluting sector. Each of these sectors have median emissions over the sample period that is higher than the whole sample median emissions. Low emission sectors include Health Care, ICT, and Consumer Discretionary.

The sign and statistical significance of the effects are mostly homogeneous across the two groups, except for initiative intensity which is a channel associated with higher emissions in high-emitting sectors and for relative investment in stakeholder engagement activities which is a significant channel in low-emitting sectors but not statistically significant in high-emitting sectors. Diversification is equally important in the two groups but its relevant contribution with respect to the other empirical mechanisms is far greater in high-emitting sectors.

5.3. Robustness tests

In this section we present the results from a series of robustness tests that we have run to further validate our findings. A summary of the robustness test can be found in Table 2, while full results can be found in Supplementary Figures S7–S10.

First, we repeat the full sample estimation using only Scope 1 and only Scope 2 emissions. That is, we eliminate from the emission measure upstream supply chain emissions that are notoriously difficult to measure accurately. Results are robust when we use only Scope 1 emissions (Supplementary Figure S7, top panels), but some of the coefficients are not significant when we only use indirect Scope 2 (Supplementary Figure S7, bottom panels).

To construct the behavioural dataset we use sustainability reports directly purchased from third parties, downloaded from sources provided by third parties and crawled from Google. When crawling the reports there is a small probability of error in the subsequent assignment of the report to the right firm. Although the error is small (~2%) and we perform several manual and systematic checks to identify and correct such errors we cannot eliminate them entirely. Hence, for robustness we repeat the full estimation removing crawled reports from the sample. Results are robust and shown in Supplementary Figure S8.

Emission data are notoriously noisy. Importantly, not every firms consistently reports emission data across all scope every year. Hence, emission data providers often estimate missing data using internal model and additional data on companies activities. However, there are growing concerns over the reliability of model-estimated data and studies have shown that the relative proportion of reported versus modelled data in the sample can strongly influence the outcome of a study (Aswani et al., 2023). In the main analysis we control for the impact of the source of emission data using dummy variables. Here, we explicitly remove estimated data and repeat our estimation only on data directly disclosed by the companies in our sample. Results are robust and shown in Supplementary Figure S9.

In the development of our regression specifications, we have included all variables we believe can, if omitted, bias the estimation of the associations we are set to measure. We have explicitly avoided including variables for which we do not have a clear rationale for why they should confound our effect of interest. However, most of the variables are proxy for unobservable factors and some of the measures we used for those factors might be replaced by other proxies. In particular, total invested capital is a broad variable that could be replaced by more specific measures for investment. In our model, total invested capital is a confounder of the effect of the empirical mechanisms on emissions because capital raised by firms can also be diverted away from environmental activities and be used to finance non-sustainability initiatives. However, (1) the source of capital and (2) how the capital is invested may be more important than the total level of invested capital as confounding factors.

Against this backdrop, we run our main specification again using market leverage and capital expenditure as alternative measures for financing and investment. We measure market leverage from Refinitiv data as long-term plus short-term debt divided by market value of assets: total assets – book equity + market equity. Capital expenditure data are also from Refinitiv. Results are shown in Supplementary Figure S10 in the Supplementary Information. The Figure shows that our results are robust to alternative measures for investment.

6. Discussion

The primary objective of this study was to collect information on corporate competition networks and environmental sustainability initiatives to estimate the extent to which competitive pressure can drive effective behavioural changes that increase companies' emission reduction capabilities. Here we summarise and interpret our main findings and discuss their limitations.

Competitive pressure increases the overall level of investment in sustainability actions aiming at risk mitigation and innovation activities. However, the rate of growth of investment is higher in innovation (the least common type of activities in our sample) than in risk mitigation (the most common type of activities in our sample), leading to an increasingly homogenised distributions of investments across all the sustainability issues. Indeed, this conclusion is explicitly supported by our finding that competitive pressure is associated with an increased diversification of environmental investments.

Looking at the associations between the empirical mechanisms and cumulative emissions, we found results that might appear surprising at first. Specifically, we find that increased investment intensity in sustainability initiatives (across the whole spectrum of mechanisms) is associated with lower future emissions. However, we also find that increased relative investment in each mechanism with respect to all the other is associated with higher emissions. To interpret our findings, let us focus on the intensity measures first. Risk mitigation activities are directly related to abatement processes; therefore, short-term emission reductions were expected. The negative and strong association between innovation intensity and emissions over such a short time-scale is less obvious. However, a comparison between Fig. 3 and Figure S7 suggests that a substantial part of the association can be explained by indirect emissions and, therefore, by the role of new product development within the broader empirical mechanism.

The negative association of stakeholders engagement activities with emissions is surprising because these activities are not directly related to the firm's core processes. Therefore, we would not expect to observe any significant effect of these initiatives on emissions. We believe that, as discussed in Section 3.2, the negative association does not reflect a direct effect but the presence of a latent behavioural structure that is negatively associated with emissions. This structure could, for example, be a leadership mindset that values the stakeholders' role and integrates their input into companies' strategic planning. Indeed, several studies have shown the importance of stakeholders engagement for the development of environmental strategies (Penz and Polsa, 2018; Tan et al., 2022; Jäger et al., 2023). This is however only a conjecture and further research is needed to validate it.

The positive association of the relative incidence of the three empirical mechanisms with emissions can be explained as a concentration effect. That is, the effect we measure does not reflect a potential direct causal effect of the specific initiatives themselves on emissions. Instead, it is a manifestation of latent behaviours characterised by a narrow focus on specific areas (e.g., risk mitigation) as opposed to a systematic approach to sustainability. This interpretation is in line with studies that show the importance of integrated approaches to reaching sustainability goals (van Zanten and van Tulder, 2021b,a; Burato et al., 2023; Walker et al., 2023) versus siloed investments in individual strategies (Cadez and Czerny, 2016), and it is supported by the negative association that we find between diversification and emissions.

Overall, our results suggest that competitive pressure pushes firms to invest in a broad spectrum of sustainability measures and that this diversification is generally associated with lower (future) emissions, as also shown in Cenci and Tang (2024). One possible explanation for why competitive pressure increases diversification of environmental investments can be understood within the context of organisational learning (Levitt and March, 1988; Zollo and Winter, 2002). The exposure to a greater number of competitors increases the probability of picking on and integrating new capabilities in companies' routines, which in turn results in greater and more effective diversification in sustainability investments. Similarly, the result can also be explained through the lens of mimetic isomorphism mechanisms (DiMaggio and Powell, 1983) by which companies with more competitors tend to imitate a larger number of strategies, leading to diversified investments. Finally, the result can be interpreted as diversification being a hedging strategy under the deep uncertainty posed by climate risk (Haas et al., 2023). Given the importance of diversification as an empirical mechanism that mediates the effect of competitive pressure on emissions, future research should investigate the dynamics by which this relationship is established.

6.1. Limitations

Our study is subject to a number of important limitations and opportunities for future research. Here, we discuss those that we deem particularly relevant. Firstly, it is important to stress that while mediation models are meant to represent causal structures and mechanisms – and we have carefully addressed endogeneity issues in constructing our model – our estimated coefficients are still likely subject to several biases, including those driven by omitted variables. Hence we assign no causal interpretation to our findings. This is a fundamental limitation of any empirical study.

Second, all the relevant variables (competitive pressure, behaviour, and emissions) are measured with error, and measurement error is a crucial issue in mediation analysis (Aguinis et al., 2016). The error in the measurement of competitive pressure arises from the possibility of firms not disclosing, or potentially, not being aware of close competitors. The error in the measurement of behaviour arises from firms' discretion on what to disclose in sustainability reports, and the ability of the algorithm to subsequently identify initiatives from those disclosures.[6] Finally, emission data are measured with error because they combine self-reported and model-estimated emissions and each of them is, in turn, subject to optionality and estimated with a measurement or model error. Further work is needed to improve each of these measures.

Finally, we do not account for nonlinearities in the mediation channels. Indeed, the different mechanisms may interact one another and this interaction itself may be driven by the competition level or the establishment of new competitive interactions. The effect of competitive pressure on the mechanisms may also be linear for some and depend on interactions with firm characteristics (non-linear) for others. These possibilities are not accounted for in a linear mediation analysis, and we see developing methodologies to address this limitation as an interesting avenue of research. Several studies have proposed methodologies to perform such estimations (Imai et al., 2010; Díaz et al., 2020), but those approaches are typically limited to binary or categorical treatments.

Overall, we believe that our findings point towards interesting behavioural dynamics driven by competitive pressure that can be relevant for understanding how to support changes in corporate sustainability investments towards effective and diversified adaptation and mitigation actions. However, the limitations discussed in this section are crucial, and must be addressed to support or reject our preliminary findings.

7. Conclusion

In this study, we investigated how companies respond to competitive pressure and the extent to which their empirical response mechanisms are associated with measurable emissions abatement. Overall, our results suggest that competitive forces are associated with diversified investments across a broad spectrum of environmental initiatives and provide additional evidence that response diversity mechanisms are crucial to drive effective decarbonisation.

CRediT authorship contribution statement

Simone Cenci: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Hossein Asgharian:** Writing – review & editing, Writing – original draft, Validation, Data curation, Conceptualization. **Lu Liu:** Writing – review & editing, Writing – original draft, Data curation, Conceptualization. **Marek Rei:** Writing – review & editing, Software. **Maurizio Zollo:** Writing – review & editing, Resources.

[6] Indeed, as discussed in Cenci et al. (2023) in the development of the algorithm, we prioritise precision – the probability of classifying sentences correctly as being or not being sustainability initiatives – over recall.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jclepro.2025.145585.

Data availability

The code and the empirical mechanisms data are available at https://doi.org/10.7910/DVN/IVAYOK All the other datasets are covered by a license, and can be accessed directly from the data providers for a fee.

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