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REGULAR PAPER

Carbon disclosure and firm risk: evidence from the UK corporate responses to climate change

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Abstract

By considering the theoretical association between corporate transparency, information asymmetry and firm risk, this paper investigates the relationship between corporate carbon disclosure and firm risk in the UK context. Using a sample of FTSE350 firms with Carbon Disclosure Project based year-observations from 2007 to 2015, we find that enhanced voluntary carbon disclosure reduces a firm's total, systematic, and idiosyncratic risks. We also find that this negative association is driven mainly by carbon-intensive industries. Additional tests show that carbon disclosure was not a significant determinant of a firm's risk until after the global financial crisis of 2007–2008. Our findings are of interest to stakeholders, including business managers and investors as they have considerable interest in assessing firms' survival and sustainability.

Keywords Firm risk · Carbon disclosure · Sustainability · Carbon disclosure project

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1 Introduction

Climate change and energy transitions have become major social and financial issues, which are reflected in the prevailing regulatory reforms driven by the concerns of different stakeholder groups (Haque, 2017). More responsibility is falling on firms to improve their environmental strategies, so, in response, firms are increasingly prioritizing their climate change strategy within overall business strategy (Lewandowski, 2017). Furthermore, interest in firm risk (FR) arising from climate change, including that from regulatory and market influences, has exponentially increased among institutional investors and other stakeholders, exerting growing pressure on corporate managers to prioritize the evaluation and reporting of such risks and related opportunities (Matsumura et al., 2014). FR is defined as “variability in organizational returns and an increased chance of corporate ruin” (Hutchinson, 2001, p. 99). Climate change risk, or carbon risk, is one component of overall FR and is itself defined as “any corporate risk related to climate change or the use of fossil fuels” (Hoffmann & Busch, 2008, p. 514). There is also a more acute understanding of the role of reporting in enhancing corporate reputation (PérezCornejo et al., 2020). Carbon disclosure as a tool to tackle climate risk is only one element of corporate reporting, but it is recognized as a vital and challenging undertaking (Alsaifi et al., 2020a, b).

There is evidence that voluntary carbon disclosure enables a firm to avoid the valuation penalty that capital markets impose based on the magnitude of carbon emissions and the failure to disclose carbon emission information (Matsumura et al., 2014; Saka & Oshika, 2014). As part of superior corporate social responsibility (CSR) practices, carbon disclosure, and engagement with stakeholders can lead to improved access to financing (Cheng et al., 2014). Carbon disclosure is considered an effective tool for shareholders and stakeholders overseeing the level of information asymmetry (Giannarakis et al., 2018) particularly for larger publicly-listed firms (Hickman, 2020). From the investor perspective, a trading strategy of buying disclosing stocks and selling non-disclosing stocks has been shown to be worthwhile (Ziegler et al., 2011). For investors, climate-related risk has become a major source of uncertainty (Krueger et al., 2020), a factor in investment decision-making (Fernando et al., 2017). Investors with a long-term orientation have been shown to particularly value proactive carbon strategies based on an expectation of long-term superior performance (Garel & Petit-Romec, 2021; Ramelli et al., 2018).

The objective of this work is to investigate the relationship between voluntary carbon disclosure and FR. The motivation for the present study is derived from an interest in understanding corporate engagement in climate change beyond regulatory compliance by considering voluntary carbon disclosure through the Carbon Disclosure Project (CDP). Furthermore, we believe that understanding the effects of voluntary carbon disclosure, not just on reducing information asymmetries, but also its wider influences on how businesses operate and perform, is vital if climate change is to be addressed effectively. Moreover, greater certainty on the benefits of voluntary carbon disclosure including its as yet under researched relation to FR would be highly valuable to management and stakeholders alike and it is this need for further empirical evidence that also motivates the present study.

This paper contributes to several threads of the emergent field of climate-related activism and carbon disclosure in the business sector by providing further consideration of corporate transparency and equity valuation among large businesses. Firstly, we add to the debate on the economic outcomes of carbon disclosure through the conceptualization of the impact of the adoption of proactive carbon management strategies and in particular voluntary carbon disclosure. Previous studies emphasized broad measures of environmental responsibility (Benlemlih et al., 2016; Tzouvanas et al., 2020), but our analysis focuses solely on carbon disclosure, allowing for an examination of one delimited aspect. Specifically, we test for an association between carbon disclosure and FR. To our knowledge, this is the first study investigating this association. We do this by considering the positive association between carbon information asymmetry and FR by applying three variables that capture FR. Secondly, we test whether this association is driven by firms in carbon-intensive industries, the only study to do so. Thirdly, our study period of 2007–2015 means that we can also test for an effect from the Global Financial Crisis (GFC). This makes a further contribution to our understanding of whether carbon disclosure and broader corporate social responsibility reporting affects stock market returns at times of economic shocks (Albuquerque et al., 2020). Finally, the debate on the economic effects of CSR leans toward suggesting a negative direction for this relationship, but there is no prior evidence from within the European or UK contexts on the direction and extent of the relationship between carbon disclosure and FR.

The data used in this study relates to UK-listed companies. The UK is a member of the G7 (Group of Seven), is a major emitter of greenhouse gas (GHG) emissions in global terms (Haque, 2017), has set ambitious reduction targets and has adopted legislation for adapting to and mitigating climate change risks including carbon reporting obligations for large firms. It is therefore an appropriate and interesting setting for this study. Furthermore, in making the reporting of corporate carbon emissions mandatory, the UK assumed a pioneering position that other countries such as Hong Kong, Norway and Singapore have followed (Tang & Demeritt, 2018). The impressive level of reductions achieved to date and the fact that alongside competitive dynamics, regulatory pressure is widely viewed as a critical factor in shaping corporate climate strategies (Okereke & Russel, 2010) suggests that this approach is bearing fruit.

The rest of this paper is presented as follows: Sect. 2 reviews the existing literature on the relationship between carbon disclosure and FR, which facilitates the development of the hypotheses for this paper. Section 3 presents the research design, sample, and measurement of variables, followed by Sect. 4, which shows the research results and the additional analysis. Section 5 concludes.

2 Literature review and hypothesis development

2.1 Current understanding and gaps

The management of climate risk is “a process for incorporating knowledge and information about climate-related events, trends, forecasts and projections into decision making to increase or maintain benefits and reduce potential harm or losses” (Travis & Bates, 2014, p. 1). There are multiple ways in which climate change presents a risk to firms, their value, and even their existence (Bloom & Milkovich, 1998; Lemma et al., 2019). These range from adverse weather consequences, business interruption, accidents, increased compliance costs, market value penalties, increased cost of capital, debt, and reputational damage (Clarkson et al., 2008; Lemma et al., 2019; Maaloul, 2018). Climate events are potentially a source of volatility risk bringing uncertainty and uncertainty can potentially affect stock returns (Alsaifi et al., 2020a, b, c).

Many studies have examined sustainability reporting or corporate social/environmental/carbon responsibility (Alsaifi, 2019). The association between social and environmental responsibility and FR has also been the focus of substantial research across a range of academic disciplines (Albuquerque et al., 2019; Benlemlih et al., 2016; Jo & Na, 2012; Lee & Faff, 2009; Luo & Bhattacharya, 2009; Oikonomou et al., 2012; Orlitzky & Benjamin, 2001; Salama et al., 2011). Comprehensive literature reviews on carbon accounting have also been performed (e.g., Haslam et al., 2014). Hahn et al. (2015) reviewed studies examining the output and outcome of carbon disclosure and concluded that studies primarily give prominence to the empirical determinants of carbon disclosure and secondarily, and to a much lesser degree, examine the effects of the disclosure. As a result, “the effects of carbon disclosure represent a major gap that should be filled by future research” (Hahn et al., 2015, p. 97). This assertion appears particularly well-founded considering the ongoing debate on the economic consequences of carbon disclosure in the literature.

In previous related empirical studies, CSR was measured by indices/scores that broadly represented environmental/social aspects rather than on the influences of carbon profile on FR, as in our paper. Furthermore, related empirical research on the impact of CSR on FR provides virtually consensual and conclusive findings of a negative association. Those who measured FR using the systematic risk by beta found a negative relationship between FR and CSR. Salama et al. (2011) provide evidence in the UK regarding the association between CSR measured by social and environmental responsibility rankings and systematic FR. Multisectoral panel data from 1994 to 2006 for the UK’s most admired firms (including the FTSE100) revealed a statistically significant negative relationship between CSR and FR. The same findings were repeated by Oikonomou et al. (2012) and Albuquerque et al. (2019) by observing US firms of the S&P500 Index from 1991 to 2008 and US firms from MSCI’s database from 2003 to 2011, respectively. A different set of studies employed idiosyncratic risk as an FR proxy and the results showed a negative association between company-unique idiosyncratic risk and CSR. These include Lee and Faff (2009) using the Dow Jones Global Index from 1998 to 2002; Luo and Bhattacharya (2009), who relied on America's Most Admired Companies list from 2002 to 2003; and Tzouvanas et al. (2020) who conducted a 17-country European study. Total risk was employed to measure FR in a study by Jo and Na (2012), who analyzed the relationship by observing American firms from the MSCI database. They found that the risk reduction effect from CSR engagement is economically and statistically more significant in firms operating in controversial sectors compared to those in non-controversial industries. Orlitzky and Benjamin (2001) summarise this research area quantitatively through a meta-analysis of 18 studies examining the relationship between CSR and FR, representing 6186 observations from 1978 to 1997. They found that CSR is negatively correlated with risk and that the negative correlation is highest with total risk. Benlemlih et al. (2016) applied three variables to measure FR, total risk, systematic risk, and idiosyncratic risk and found significant and negative relationships between social and environmental disclosures and total and idiosyncratic risk for 2005–2013 for FTSE350 listed firms.

Although environmental and social measures have been widely used in previous literature, no measure precisely reflects the carbon profile (e.g., CDS issued by CDP, changes in carbon dioxide emissions and carbon intensity ratios). Furthermore, as Hahn et al. (2015, p. 94) note, previous studies do not "explicitly refer to an underlying theoretical framework and, rather, rely on prior empirical evidence to develop their hypotheses". It is unclear whether our understanding of the issue has advanced since it first received scholarly attention. As the field has matured and disclosure increased, there is a need for further empirical work on the relationship between carbon disclosure and FR.

In line with the recommendations of authors of prior related studies (Benlemlih et al., 2016), the present study helps close the gaps in the literature by applying a focus on carbon disclosure rather than broader social and environmental reporting. Additionally, our paper heeds the suggestion of Tzouvanas et al. (2020) by using multiple risk measurements in place of one single measure. Furthermore, our study tests the hypothesis that the association between carbon disclosure and FR is mostly driven by carbon-intensive industries. Again, this is only possible by narrowly focusing on wholly carbon-related disclosures.

2.2 Carbon disclosure and FR: considering the relationship

Carbon disclosure reflects a firm's contribution to climate change and thus constitutes an important part of the corporate environmental strategy. Adopting a proactive environmental strategy often leads to the achievement of optimal operational efficiency and a reduction of risks to humans and the environment (Hart & Ahuja, 1996). Enhanced environmental risk management practices relieve societal pressures, lower the threat of government regulation, and reduce market risk (Orlitzky & Benjamin, 2001; Salama et al., 2011) and the firm's cost of capital (Dhaliwal et al., 2011). Firms that are environmentally proactive "enjoy several potential revenue-generating benefits: (a) reducing their exposure to potential carbon costs,

(b) opening up new markets, (c) developing competencies that provide a competitive advantage, and (d) creating new revenue streams from excess credits" (Peloza, 2009, p. 1526).

Achieving competitive advantage through voluntary carbon disclosure as a vital aspect of overall CSR reporting leads to an enhanced level of transparency (e.g., Clarkson et al., 2008; Dhaliwal et al., 2011). Superior openness regarding CSR can lead to improved access to finance and reduced idiosyncratic capital constraints (Cheng et al., 2014). Importantly, there is also evidence that while investors may respond negatively to carbon disclosure announcements (Alsaifi et al., 2020b), there is a positive association between voluntary carbon disclosure and firm financial performance (Alsaifi et al., 2020a). Considering these benefits, there is a strong case for presenting carbon information as part of overall CSR reporting in the same manner financial information is presented in traditional annual reports (Cho et al., 2013). As stated earlier, carbon disclosure as a competitive advantage and transparency are closely linked; we can use a firms' voluntary disclosures to evaluate their level of transparency.

Existing literature indicates that the more transparent a firm is, the less the information asymmetry between that firm and its investors is (e.g., Lambert et al., 2007). Dhaliwal et al. (2011, p. 62) recognize, "… some CSR projects have direct implications for positive cash flow even shortly". As an element of overall CSR, carbon disclosure projects can potentially influence equity valuation (Cho et al., 2013) because carbon disclosure reduces uncertainties about the value consequences of CSR projects. Therefore, the promotion of carbon transparency allows for the firm and stakeholders to improve the quality of their economic decision making. The resulting transparency and reduction in information asymmetry are expected to affect the relationship examined in this paper.

Enhanced environmental disclosure, at an appropriate level and quality, promotes firm transparency, reduces information asymmetry, and facilitates improved economic decision making in conditions of greater trust and confidence for both firms and investors (Benlemlih et al., 2016). Cui et al. (2016) found a positive association between information asymmetry and FR that was also supported by Cho et al. (2013). The carbon disclosure–FR relationship should be established, in which the strategic organizational resources required for competitiveness are combined, and environmental technologies are implemented (Klassen & Whybark, 1999). These expectations lead to the following hypothesis:

H1 Carbon disclosure and FR are negatively associated.

To extend the contribution of our paper, we develop a further hypothesis related to carbon-intensive industries. Addressing the broader concept of CSR, Jo and Na (2012) found that firm risk was a greater concern for firms in controversial sectors than those in non-controversial ones. In the narrower terms of carbon disclosure that our paper considers, controversial firms are those in high emission, energy-intensive sectors. Reflecting this greater concern, Matisoff et al. (2013) found that firms in energy-intensive industries were more likely to have increased their transparency than other firms, in line with the earlier findings of Hasseldine et al. (2005). Similarly, Lemma et al. (2019) found that firms with the highest carbon risk are more likely to have high-quality voluntary carbon disclosure. Hassan (2015) also reported a greater likelihood of high-quality carbon disclosure among carbon-intensive firms in a study of the UK's FTSE100 companies. Evidence has also been found that for firms in carbon-intensive industries, carbon disclosure and carbon performance were more significantly related than for other industries (Alsaifi, 2020).

While no study has yet examined the extent to which the negative association of carbon disclosure and firm risk is driven by carbon-intensive industries there is sufficient indirect evidence to justify our second hypothesis:

H2 The carbon disclosure and FR negative association are driven by carbon-intensive industries.

In summary, the literature views climate change as having potentially serious adverse affects for business (Clarkson et al., 2008; Lemma et al., 2019; Maaloul, 2018) and climate risk is therefore identified as an element of FR (Bloom & Milkovich, 1998; Hoffmann & Busch, 2008; Lemma et al., 2019; Travis & Bates, 2014). These risks are largely related to uncertainty, a known drag on equity valuation (Alsaifi et al., 2020a). Corporate reporting has long be seen as a vital tool in improving firm transparency and reducing information asymmetry (Lambert et al., 2007) and as such has a role in risk mitigation. Environmental reporting has been identified as an important component in information asymmetry reduction (Benlemlih et al., 2016) and a relationship between this asymmetry and FR has also been demostrated (Cho et al., 2013; Cui et al., 2016). However, the nature and extent of the association between voluntary carbon disclosure and FR has yet to be fully understood. Furthermore, the existing literature lacks evidence on whether it is carbon-intensive industries that accounts for this association. To fill these knowledge gaps and based on the review of literature, this study applies the conceptual framework shown in Fig. 1.

3 Research design and data

3.1 Sample

Since it is the largest index in the UK that is annually assessed by the CDP, our sample includes all firms continuously listed on the FTSE350 Index between the years 2007 and 2015. This period was characterized by high public awareness and extensive policy debate on GHG emissions, including national legal requirements and international climate provisions and agreements. The final sample consists of 2089 firm-year observations after exclusion was made for financial institutions as

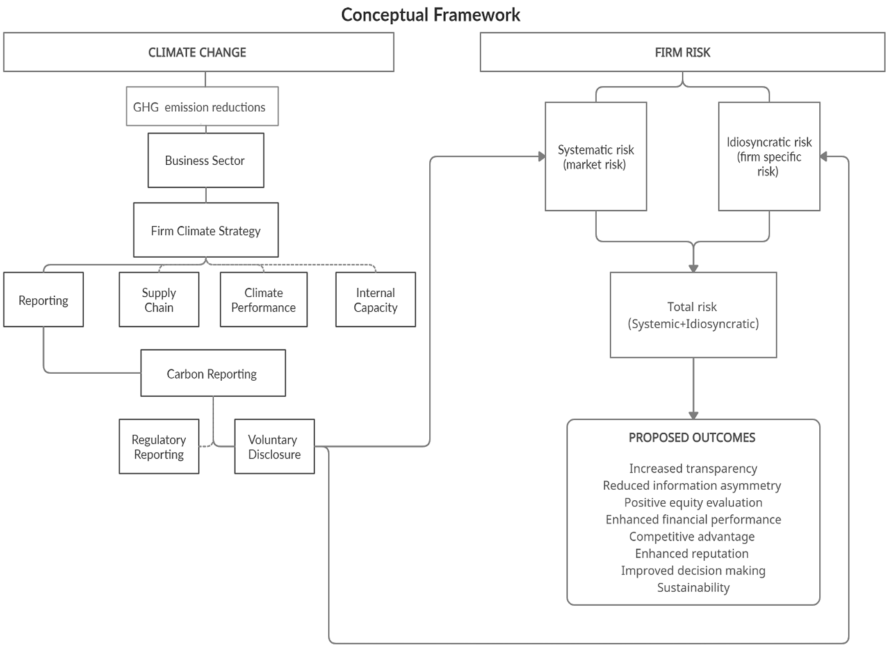

Fig. 1 Conceptual framework for present study

is standard practice for this type of research, due to the different set of environmental and social regulations such as the '*Equator Principles*' they adhere to and their unique accounting practices (Haque, 2017).[1]

3.2 Measures

3.2.1 Firm risk

In line with previous literature, we apply the firm's total risk as measured by the standard deviation of the firm's daily stock return (Jo & Na, 2012; Luo & Bhattacharya, 2009), as in the following equation:

$$\text{Standard deviation of Return}_{it} = \sqrt{\frac{1}{n}\sum_t^n \left(R_{it} - R_{mean}\right)} \tag{1}$$

where R_{it} is the return on security I for day t and R_{mean} is the mean of the daily market return over 12 months. We use the CAPM beta to measure a firm's systematic risk (Benlemlih et al., 2016; Jo & Na, 2012) and estimate it using a regression of the daily stock return on the daily market return of the FTSE350 over 12 months:

[1] The *Equator Principles* is a risk management framework used by financial institutions to determine, assess and manage environmental and social risk in projects. See: http://www.equator-principles.com.

$$R_{it} = a_i + \beta_i R_{mt} + e_i \quad (2)$$

where R_{it} is the return on security i for day t, a_i is the intercept term, B_i is the systematic risk of security i (BETA), R_{mt} is the return on market m for day t, and e_i is an error term. Finally, we employ the idiosyncratic risk, i.e. the unique business risk, as measured by the standard deviation of residuals from the CAPM based on daily stock returns (e.g., Amit & Wernerfelt, 1990; Lee & Faff, 2009).

3.2.2 Carbon disclosure

As a proxy for a firm's carbon disclosure, the carbon disclosure score—CDS from the CDP database is used. The CDP uses a survey to calculate the CDS based on a firm's responses to questions in the CDP's Online Response System. The score ranges from 0 to 100 and represents the quality of a firm's responses to the annual CDP questionnaire.

The survey evaluates the information that firms disclose in the CDS under three broad headings: (1) climate change management: governance, strategy, targets and initiatives and communications; (2) climate change-related risks and opportunities; and (3) climate change emissions methodology, emissions data, energy, emissions performance, and emissions trading. Firms' responses to the CDP survey, available publicly on the CDP website, could have implications on investors' investment decisions (Kim & Lyon, 2011).

Selection of the CDS as a measure of carbon disclosure is justified by the large number of organizations that voluntarily respond to CDP's information request and its use in previous studies on whether voluntary carbon disclosure is a true reflection of a firms' actual carbon performance (Luo & Tang, 2014) and on the determinants of disseminating relevant information on GHG (e.g., Prado-Lorenzo & Garcia-Sanchez, 2010). Information usefulness is dependent on the transparency and comparability of carbon information (Andrew & Cortese, 2011), and useful information is required for carbon markets and corporate carbon management (Knox-Hayes & Levy, 2011).

3.2.3 Controls

In controlling for firm characteristics that may affect the examined relationship, we follow the approach of earlier studies (Clarkson et al., 2008) and include firm size (SIZE) measured by the natural log of total assets and financial leverage (LEV) measured by the ratio of total debt to total capital. It is frequently asserted that firms with lower payout ratios carry greater risk. Therefore, the dividend payout (POUT), calculated by the ratio of the dividend per share to the stock price per share, can have a signaling effect concerning management's perception of future earnings uncertainties (Oikonomou et al., 2012; Salama et al., 2011). Earlier studies found that more profitable firms carried less risk (e.g., Benlemlih et al., 2016; Jo & Na, 2012). Therefore, profitability (PROF) measured by return on assets (ROA) is included as a control. Corporate liquidity is an additional variable that is frequently applied to test the association and prediction of FR (Oikonomou et al., 2012; Salama et al., 2011). The lower the liquidity, the higher the firm's liquidity risk, which may be reflected in increased stock price fluctuations. The current ratio is widely viewed as a classic measure of liquidity. We control for liquidity (LIQ) using the current ratio, measured by the total current assets/total current liabilities. Most empirical studies examining this relationship control for firm growth (e.g., Oikonomou et al., 2012). To control for growth (GROW) effects, we use the market-to-book (MTB) ratio because analysts regard companies with weak growth prospects (low MTB ratio) as more exposed to market volatility (Lewellen, 1999). We control for the influence of corporate board composition by calculating a composite index with the components of board composition as dummy industry-adjusted variables. Similar to Alsaifi (2020), we incorporate six variables, as shown in Appendix 1, to construct an index for the board composition (BC). The effects of product market competition (COM) are controlled for, measured by the number of competitors in the same industry in a given year (Bagnoli & Watts, 2003). According to Stanny and Ely (2008), European firms with higher percentages of international commerce disclose their carbon emissions more. Therefore, we control for the effects of foreign market activities (FMA) based on the ratio of foreign assets to total assets. Lastly, to control for the potential influence of fluctuations in market trends that may affect the FR, we include yearly dummy variables (Alsaifi et al., 2020b).

3.2.4 Model tested

To test the main hypothesis, our main empirical model is as follows:

$$\begin{aligned} FR_{it} = {} & \beta_0 + \beta_1 CDS_{it} + \beta_2 SIZE_{it} + \beta_3 LEV_{it} + \beta_4 POUT_{it} + \beta_5 PROF_{it} \\ & + \beta_6 LIQ_{it} + \beta_7 GROW_{it} + \beta_8 BC_{it} + \beta_9 COM_{it} + \beta_{10} FMA_{it} + \beta_{11} YEAR_{it} + \varepsilon_{it} \end{aligned} \tag{3}$$

Panel data regression controls for individual heterogeneity reduces multicollinearity and estimation bias and identifies the time-varying relationship between the dependent and independent variables (Alsaifi, 2020).[2] Two regression models are employed to investigate the relationship between carbon disclosure and FR. First, we use the Ordinary Least Squares (OLS) regression. Second, we apply the instrumental variable-two-Stage Least Squares (IV-2SLS) regression (using Firm Age and CDS "$lag_{-1\ \mathrm{year}}$"), to address the endogeneity problem between CDS and FR proxies (Alsaifi, 2020; Alsaifi et al., 2020b).[3]

[2] The research data was extracted from Bloomberg, Thomson Reuters Datastream, and CDP databases.

[3] To confirm the absence of residual endogeneity, a Durbin Wu-Hausman test was presented in Table 2, which reported p-values of 0.729, 0.246 and 0.956 for total, systematic and unsystematic risks, respectively. The IV-2SLS estimate utilizes a reduced sample as instruments (lagged values) were only available for 817, 810 and 786 observations of the abovementioned FR proxies, respectively.

Table 1 This table reports the descriptive statistic based on our sample from 2007 to 2015

Variable	N	Mean	Median	SD	Min	Max
TR	2040	35.664	31.517	14.493	17.535	76.930
SR	2056	1.008	0.957	0.481	– 0.042	2.479
IDR	1521	0.017	0.015	0.008	0.007	0.071
CDS	1330	69.12	72.000	21.022	4.000	100.000
SIZE	2076	21.365	21.214	1.534	16.909	26.147
LEV	2037	25.492	19.809	20.234	4.625	83.081
POUT	1777	0.032	0.030	0.017	0.001	0.180
PROF	2067	7.655	6.522	7.128	– 6.828	28.573
LIQ	2077	1.558	1.285	1.131	0.306	7.015
GROW	1982	3.904	2.754	4.021	0.608	21.943
BC	1797	2.874	3.000	1.337	0.000	6.000
COM	2089	42.698	57.000	22.500	5.000	67.000
FMA	2089	37.504	34.990	27.684	0.000	95.010

4 Results and analysis

4.1 Descriptive statistics

The mean and distributional characteristics for each variable are reported in Table 1. The response rate to the CDP questionnaire for our sample was approximately 64% (1330 of 2089). The mean of the CDS is 69.12, which is somewhat higher than in previous studies employing CDS as a dependent variable. Prado-Lorenzo and Garcia-Sanchez (2010) examined the role of the Board of Directors in disseminating information related to GHG emissions and reported a mean CDS of 60% based on the CDP's 2007 annual survey. Luo and Tang (2014) investigated whether voluntary carbon disclosure reveals the actual carbon performance and reported a mean CDS of 65% based on CDP's 2010 annual survey. The variance in the mean CDS between these earlier studies and our study may be justified by the shortened period applied by these studies (just 1 year) and the timing of public pressure on the disclosure of information relating to climate change. The mean total risk is 35.66, within the range established in prior studies, (e.g., Benlemlih et al., 2016). The mean of the systematic risk is almost 1, (the same as the market beta), in line with prior literature employing BETA as the left-side variable (Oikonomou et al., 2012; Salama et al., 2011), and the average firm-specific risk (idiosyncratic) is 0.017, similar to previous studies (Amit & Wernerfelt, 1990). The unreported average firm SIZE is £8.12 billion, suggesting the sample comprises large firms. The logarithm of total assets was used to measure SIZE, and the mean and median results were 21, in line with that of the Clarkson et al. (2008) sample.

Table 2 This table reports the results of two estimation methods OLS and IV-2SLS

Variable	Total risk		Systematic risk		Idiosyncratic risk	
Model	OLS(1)	IV-2SLS(1)	OLS(2)	IV-2SLS(2)	OLS(3)	IV-2SLS(3)
CDS	− 0.058*** (0.018)	− 0.046* (0.026)	− 0.002*** (0.001)	− 0.004*** (0.001)	− 0.003** (0.001)	− 0.003* (0.001)
SIZE	− 1.154*** (0.238)	− 1.007*** (0.270)	0.024** (0.010)	0.028** (0.012)	− 0.120*** (0.014)	− 0.109*** (0.015)
LEV	0.085*** (0.016)	0.082*** (0.018)	0.003*** (0.001)	0.004*** (0.001)	0.005*** (0.001)	0.005*** (0.001)
POUT	3.077 (25.47)	− 6.476 (19.36)	− 2.976*** (0.947)	− 2.860*** (0.882)	2.131 (1.551)	1.681 (1.073)
PROF	− 0.205*** (0.062)	− 0.199*** (0.058)	− 0.003 (0.003)	− 0.001 (0.003)	− 0.016*** (0.004)	− 0.015*** (0.003)
LIQ	2.485*** (0.318)	2.130*** (0.324)	0.083*** (0.017)	0.073*** (0.015)	0.120*** (0.020)	0.109*** (0.018)
GROW	− 0.079 (0.058)	− 0.065 (0.074)	− 0.006* (0.003)	− 0.005 (0.003)	− 0.004 (0.003)	− 0.002 (0.004)
BC	− 0.27 (0.242)	0.118 (0.237)	− 0.022** (0.011)	− 0.018 (0.011)	− 0.017 (0.015)	− 0.017 (0.013)
COM	− 0.017 (0.013)	− 0.008 (0.014)	0.003*** (0.001)	0.003*** (0.001)	− 0.001 (0.001)	− 0.001 (0.001)
FMA	0.062*** (0.011)	0.063*** (0.011)	0.005*** (0.001)	0.004*** (0.001)	0.002*** (0.001)	0.003*** (0.001)
YEAR effects	Yes	Yes	Yes	Yes	Yes	Yes
Constant	56.380*** (5.169)	52.130*** (5.819)	0.277 (0.233)	0.319 (0.265)	4.133*** (0.313)	3.885*** (0.320)
Durbin Wu-Hausman		0.729		0.246		0.956
R^2	0.55	0.49	0.21	0.22	0.53	0.49
N	1104	817	1091	810	931	786

Heteroscedasticity-robust standard errors are in parentheses

*, ** and *** denote significance at 10%, 5% and 1%, respectively (two-tailed test)

4.2 Empirical tests

4.2.1 Carbon disclosure and firm risk

Table 2 reports the results obtained using Eq. (3) to investigate our hypothesis, primarily evaluating the role of carbon disclosure on FR. Model 1 presents results from regressing the total risk on the carbon disclosure and control variables. The coefficient of the CDS is negative and statistically significant across the two estimations, OLS and IV-2SLS. This indicates that the improvement of carbon disclosure increases firm transparency, reducing information asymmetry. This builds trust and confidence between the company and stakeholders concerned about the environment. This results in demand control on the firm's stock that decreases price fluctuation and reduces its volatility risk (Jo & Na, 2012). Hence, H1 which proposed a negative association between carbon disclosure and firm risk is confirmed.

The same estimation methods are used to substitute total risk with systematic risk (Model 2) and idiosyncratic risk measures (Model 3). Regarding the systematic risk, OLS and IV-2SLS estimation models confirm that there is a significantly negative effect from CDS on BETA at a 99% confidence level ($p < 1\%$). Environmentally engaged organizations, including those which continually aim to improve their carbon disclosure, will have lower anticipated variability of cash flows from implicit and explicit environmental-based stakeholder claims and experience a decrease in their market risk. This result is consistent with previous studies (Jo & Na, 2012; Oikonomou et al., 2012; Salama et al., 2011). Additionally, when FR is measured by the idiosyncratic risk, the coefficient of the CDS is negative and statistically significant using both OLS and IV-2SLS. It appears that the reduced total risk among high-disclosure firms is predominantly a result of a reduction in the firm's idiosyncratic risk (Benlemlih et al., 2016).

4.2.2 Carbon-intensive industries as a driving factor

As the sample contains different industries based on their emissions level, we further extend our analysis to investigate the potential effect of the industry in the examined relationship. Industries with higher carbon emissions profiles are subject to more public and media scrutiny and governmental regulations and legislation. The sample in the present study is diverse and includes both intensive and non-intensive industries. The sample contains ten industries (nine after excluding the financial industry) according to the industry's structure and definitions applied by the industry GICS. FTSE All-Share Index standards are applied to identify carbon-intensive industries based on the level and nature of GHG emissions. These were industrials, basic materials, utilities, consumer services, and oil and gas. The sample was divided into two sub-samples: intensive and non-intensive. An OLS regression test was performed to identify the possible impact of the industry on the examined relationship. Table 3 indicates that the relationship of CDS-all risk measures is significant for firms in intensive industries but not significant for those operating in non-intensive industries, confirming H2. This result confirms the notion that voluntary environmental disclosures predominate among firms in environmentally sensitive sectors

Table 3 This table reports the results of the impact of the industry type on the relationship examined, OLS was applied

Variable	Total risk		Systematic risk		Idiosyncratic risk	
Industry	Intensive	Non-intensive	Intensive	Non-intensive	Intensive	Non-intensive
CDS	− 0.060*** (0.020)	− 0.036 (0.033)	− 0.003*** (0.001)	− 0.001 (0.001)	− 0.003** (0.001)	0.001 (0.002)
SIZE	− 0.847*** (0.300)	− 2.136*** (0.352)	0.014 (0.012)	0.004 (0.015)	− 0.104*** (0.018)	− 0.197*** (0.022)
LEV	0.077*** (0.018)	0.116*** (0.042)	0.003*** (0.001)	0.008*** (0.001)	0.004*** (0.001)	0.005** (0.002)
POUT	3.514 (30.300)	17.513 (36.341)	− 2.241** (1.073)	− 6.187*** (1.491)	1.042 (1.824)	7.324** (3.395)
PROF	− 0.241*** (0.073)	− 0.011 (0.111)	0.003 (0.003)	0.001 (0.004)	− 0.020*** (0.004)	0.002 (0.007)
LIQ	2.578*** (0.371)	1.800*** (0.632)	0.066*** (0.022)	0.043** (0.019)	0.140*** (0.022)	0.107** (0.047)
GROW	− 0.066 (0.072)	0.062 (0.100)	0.010** (0.004)	0.006 (0.005)	− 0.002 (0.005)	− 0.004 (0.006)
BC	− 0.330 (0.271)	− 0.279 (0.504)	− 0.026** (0.012)	0.007 (0.020)	− 0.022 (0.016)	− 0.004 (0.030)
COM	− 0.033* (0.018)	− 0.088 (0.055)	0.001 (0.001)	0.003 (0.002)	− 0.001 (0.001)	− 0.010** (0.004)
FMA	0.081*** (0.013)	− 0.001 (0.015)	0.006*** (0.001)	0.001 (0.001)	0.003*** (0.001)	− 0.001 (0.001)
YEAR effects	Yes	Yes	Yes	Yes	Yes	Yes
Constant	51.783*** (6.733)	73.260*** (7.391)	0.595** (0.292)	0.774** (0.324)	3.903*** (0.397)	5.349*** (0.485)
N	839	265	826	265	713	218
R^2	0.57	0.59	0.25	0.23	0.53	0.63

Heteroscedasticity-robust standard errors are in parentheses

*, ** and *** denote significance at 10%, 5% and 1%, respectively (two-tailed test)

Table 4 This table reports the results of the impact of the financial crisis on the relationship examined, and the results of the Robustness test

Variable	Total risk			Systematic risk			Idiosyncratic risk		
Period	Crisis	Recovery	Robust	Crisis	Recovery	Robust	Crisis	Recovery	Robust
CDS	− 0.063 (0.056)	− 0.055*** (0.018)		− 0.001 (0.002)	− 0.002*** (0.001)		− 0.001 (0.004)	− 0.002*** (0.001)	
CARBON			0.001*** (0.001)			0.001*** (0.001)			0.001*** (0.001)
SIZE	− 0.530 (0.908)	− 1.242*** (0.241)	− 1.249*** (0.200)	− 0.022 (0.033)	0.028*** (0.011)	0.031*** (0.009)	− 0.127** (0.061)	− 0.115*** (0.014)	− 0.126*** (0.012)
LEV	0.057 (0.069)	0.089*** (0.016)	0.081*** (0.015)	0.002 (0.002)	0.003*** (0.001)	0.003*** (0.001)	0.004 (0.005)	0.005*** (0.001)	0.004*** (0.001)
POUT	− 37.532 (79.261)	9.037 (26.720)	− 17.052 (21.905)	− 4.509* (2.554)	− 2.713*** (1.003)	− 3.714*** (0.784)	2.363 (6.222)	2.111 (1.606)	(0.957) 1.225
PROF	0.164 (0.192)	− 0.254*** (0.062)	− 0.124** (0.058)	− 0.005 (0.007)	− 0.003 (0.003)	− 0.001 (0.003)	− 0.018* (0.011)	− 0.015*** (0.004)	− 0.010*** (0.003)
LIQ	2.267* (1.236)	2.535*** (0.338)	2.650*** (0.285)	0.016 (0.043)	0.091*** (0.018)	(0.100)*** (0.0162)	0.166 (0.115)	0.115*** (0.019)	0.131*** (0.018)
GROW	− 0.362* (0.190)	− 0.015 (0.055)	− 0.168*** (0.063)	0.003 (0.008)	− 0.008** (0.004)	− 0.010*** (0.003)	− 0.005 (0.014)	− 0.003 (0.003)	− 0.011*** (0.004)
BC	0.068 (0.923)	− 0.298 (0.243)	− 0.586*** (0.224)	0.006 (0.034)	− 0.026** (0.012)	− 0.026** (0.011)	0.002 (0.058)	− 0.021 (0.015)	− 0.033** (0.0134)
COM	0.101** (0.041)	− 0.034*** (0.013)	0.003 (0.012)	0.001 (0.002)	0.003*** (0.001)	0.003*** (0.001)	0.005* (0.003)	− 0.002*** (0.001)	− 0.001 (0.001)
FMA	0.053 (0.039)	0.067*** (0.010)	0.070*** (0.010)	0.005*** (0.001)	0.004*** (0.001)	0.005*** (0.001)	(0.001) (0.003)	0.003*** (0.001)	0.002*** (0.001)
Constant	37.276* (20.244)	65.228*** (5.435)	51.728 (4.663)	1.349* (0.731)	0.209 (0.238)	− 0.076 (0.215)	3.957*** (1.308)	4.550*** (0.328)	4.000*** (0.286)
N	156	948	1108	151	940	1096	129	802	953

Table 4 (continued)

Variable	Total risk			Systematic risk			Idiosyncratic risk		
Period	Crisis	Recovery	Robust	Crisis	Recovery	Robust	Crisis	Recovery	Robust
R^2	0.54	0.37	0.54	0.16	0.23	0.24	0.49	0.40	0.52

OLS was applied. Heteroscedasticity-robust standard errors are in parentheses

*, ** and *** denote significance at 10%, 5% and 1%, respectively (two-tailed test)

(Hasseldine et al., 2005). This is consistent with the argument proposed by Hart and Ahuja (1996) that companies with intensive carbon emissions can improve productivity and competence through a reduction in their industrial waste. One likely outcome is enhanced employment of inputs, leading to a reduction in the costs of raw material and waste disposal in a manner that also reduces the default risk and cost of capital.

4.2.3 Additional analyses and robustness check

As the sample period in this study includes the global financial crisis (GFC) period (2007–2008), we perform an additional test to isolate the potential effect of the GFC on the relationship being examined.[4] Our sample was divided into two sub-periods: 2007–2008 (GFC period) and 2009–2015 (recovery period). Table 4 indicates that the relationship between CDS-all risk measures is not significant for the GFC period but is highly significant during the recovery period. This finding shows that firms should adapt during times of crisis by reducing investment in carbon mitigation projects (Cheney & McMillan, 1990; Njoroge, 2009). After the crisis, corporate social and environmental responsibility tends to increase the public agenda. As KPMG states: “Before the financial crisis, investors typically saw environmental due diligence as a risk management tick-box exercise to secure financial institution funding. However, post-this exogenous shock, there appears to be a greater focus on responsible investment. We are seeing an increased appetite for the potential upsides (e.g., cost savings, additional revenue streams) of the sustainability agenda, in a transactional context. Strategies to manage energy (buy better, use less and self-generate) and waste (convert waste to an asset) are transforming the environmental due diligence process” (KPMG, 2017).

This indicates that a firm’s value depended less on intangible assets during the GFC period and that, today, firms seek investor confidence in the financial market to improve their reputations in competitive markets (Raithel et al., 2010). There is a contradiction between our conclusions and those of Gallego-Álvarez et al. (2014). They found that, in crisis periods, firms continue investing in sustainability projects to enhance stakeholder confidence, which may lead to higher profitability.[5] They note that future research should extend the sample period to encompass firm behavior both before and after the GFC to allow for a complete analysis. The present study accounts for this possibility with a comparison of the GFC and recovery periods in the examination of the relationship between carbon disclosure and FR.

As a robustness test, we apply the actual carbon emission intensity as an alternative measure of CDS, which is calculated by dividing emissions by £’000s of firm revenues at year end. This measure is justified because emissions are recognized as a key component of corporate carbon responsibility (Qian & Schaltegger, 2017). The

[4] Consistent with Erkens et al. (2012), we specify the years of 2007–2008 as the GFC period.

[5] Gallego-Álvarez et al. (2014) investigated the impact of the GFC on the environmental performance of large multinationals from 2006 to 2009. They state that the relatively short sample period is an important limitation of their study.

result as shown in the ‘robust’ columns in Table 4 reports a highly significant positive association between CARBON and the three measures of FR. In other words, firms producing more GHG emissions, such as those operating in carbon-intensive industries, will face higher risk as we proved in the earlier analyses. Applying this test confirms our main results since the firm’s carbon disclosure has been found to be indicative of overall carbon performance (Luo & Tang, 2014).

5 Conclusions and future directions

This study was motivated by the increasing public concern about climate change and the need to provide an empirical assessment of the economic consequences of carbon disclosure, with a focus on FR. There appears to be a lacuna in the literature of this type of investigation, especially in this specific setting where regulators are actively and vigourously pursuing the regulation of carbon emissions.

We tested the hypothesized negative association between carbon disclosure and FR (H1). We conducted econometric analyses involving the measurement of carbon disclosure using voluntary carbon disclosure scores and three FR measures, the total, systematic, and idiosyncratic risks for FTSE350 firms for 2007–2015. The results show that during this period, there was a negative influence from enhanced carbon disclosure on FR. We also tested the hypothesis that the negative association between carbon disclosure and FR is driven by carbon-intensive industries (H2). This study finds that the examined relationship strengthens in the more intensive carbon industries meaning the hypothesis is confirmed.

This study has important implications for management. Firstly, the findings indicate that firms should aim to elevate corporate transparency practices, specifically carbon disclosure, to maximize cost savings and accelerate business benefits and to proactively integrate climate change mitigation efforts into their business strategy and deploy a high-quality, high-transparency carbon disclosure mechanism. Secondly, firms should consider making voluntary carbon disclosures in addition to those mandated by regulation. In addition to further increasing transparency and reducing information asymmetry, such voluntary disclosures send a positive message to stakeholder regarding the firm’s proactivity on climate-related strategy. Thirdly, the additional tests show no significant evidence for any effect from carbon disclosure during the GFC period. However, carbon disclosure became a more important determinant of FR after the GFC. In a world of ever-increasing competition with increasing stakeholder demand for carbon disclosure, management must consider the firm’s carbon disclosure and the reporting of strategic issues, which means integrating carbon-related decisions into the overall corporate disclosure requirements and transparency efforts as well as the broad sweep of organizational decision making to achieve a competitive advantage.

This study is limited to a sample of the UK’s largest companies meaning caution should be exercised when generalizing the current study’s findings beyond these companies. Furthermore, due to changes in methodology used by the CDP, the observation period ends in 2015, so does not include the most recent years. Future research could examine the 2016–2020 period using data gathered under the CDPs revised methodology. Recent events also suggest the present study could be a foundation for further research. The UK's withdrawal from the European Union may create new research opportunities to investigate the country's carbon profile and how it is related to FR. Such an opportunity is particularly pertinent given the UK's current political landscape, which includes Brexit-related uncertainties, such as the potential withdrawal from the European Union Emissions Trading System and the establishment of a new policy to manage climate change and GHG emissions in a cost-effective manner. Similarly, the effect of the 2020/21 pandemic on the relationship between carbon disclosure and FR could be studied.

Appendix 1

Board Composition Index

1. **Chairman Independence** Are the chair positions separated from the CEO? 1 if yes; 0 otherwise.
2. **Board Size** Is a firm's Board Size > the Industry Average? 1 if yes; 0 otherwise.
3. **Board Independence** Is a firm's independent directors percentage > the Industry Average? 1 if yes; 0 otherwise.
4. **Female on Board** Is a firm's female board director percentage > the Industry Average? 1 if yes; 0 otherwise.
5. **Board Meeting Number** Are a firm's board meetings per year > the Industry Average? 1 if yes; 0 otherwise.
6. **Board Meeting Attendance** Is a firm's board attendance percentage > the Industry Average? 1 if yes; 0 otherwise.

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