



Carbon Emissions and TCFD Aligned Climate-Related Information Disclosures

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Abstract

We explore corporate environmental accountability by examining how carbon emissions affect voluntary climate-related information disclosure based on TCFD principles. Using computerized textual analysis to measure such climate-related disclosure, our results show that firms with higher levels of carbon emissions disclose more climate-related information. This relation is stronger in firms belonging to carbon-intensive industries, such as energy, materials, and utilities. We also examine this relationship at the category level for Governance, Strategy, Risk Management, and Metrics and Targets, finding that carbon emissions drive disclosure in all categories except in Governance. Overall, our findings indicate that high carbon emitting firms appear to discharge their corporate accountability by increasing climate-related disclosure, consistent with legitimizing their potentially unethical actions and submitting to stakeholder and societal pressure.

Keywords Climate change · Voluntary climate-related information disclosure · Carbon emissions · Carbon performance · Environmental disclosure · Environmental performance · Information asymmetry

Introduction

“Demand for better disclosure of sustainability information is urgent [and] delays to global coherence, most pressingly on climate-related disclosures, will increase the threat of fragmentation and consequently cause difficulties in engaging capital markets to smooth the transition to a low-carbon economy.” (FRS Foundation, Consultation Paper on Sustainability Reporting, September 30, 2020, pp. 4 and 7.)

According to Howard-Grenville et al. (2014a, 2014b) and Vatican (2016a, 2016b), tackling climate change represents one of most urgent ethical challenges facing businesses today where practices that are unsustainable result in extreme and varying injustices (Slawinski et al., 2017). As businesses are major polluters who profit at the public’s expense, they have moral obligations to reduce the impact of greenhouse gas emissions in the transition to sustainable and low carbon economies (Besio and Pronzini, 2014). Accordingly, substantial research effort is being directed toward understanding strategies and practices to reduce businesses’

carbon footprints (Aragón-Correa et al., 2016). Studies such as Alt et al. (2015) and Hussain et al. (2018a, 2018b) show that the commitment of firms to reduce their environmental impacts varies due to strategic, technical, and managerial challenges. While responses to climate change can be viewed from an ethical perspective, Carroll (1991a, 1991b) argues that ethical responsibilities are newly emerged values and norms which reflect higher standard of performance than what is required by law, suggesting that the society expects higher performance when firms fulfill their ethical responsibilities including their environmental responsibilities. Additionally, climate change regulation takes on several forms, namely government regulation and self-regulation (via codes of conduct and self-commitment). Eberlein and Matten (2009) demonstrate the complex and interactional relations between business ethics and regulation, arguing that in the context of climate change, many ethical initiatives have resulted in self-regulation and business ethics can work as surrogate regulation. Thus, the role of business ethics becomes increasingly important from a climate change perspective as management must use ethical reasoning to make decisions in the absence of climate change regulation.

The public awareness on climate issues has increased dramatically in recent years (Bakaki & Bernauer, 2017a, 2017b). The pressure to act on climate issues has prompted

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some firms to communicate their environmental commitments while not taking action on the issues (Aragón-Correa et al., 2016). Such greenwashing misleads stakeholders into more positive beliefs about firms than warranted (Lyon & Montgomery, 2015a, 2015b). More importantly, in the absence of mandatory reporting requirements on climate change issues, environmental information disclosed within annual reports is subject to managerial discretion. Thus, the association between firms' communications and their environmental commitments is a major ethical issue.

Increasing demand for transparent and consistent information on critical environmental issues has led firms to disclose climate-related information. To assist and encourage firms to make voluntary climate change disclosure, the Financial Stability Board established the Task Force on Climate-related Financial Disclosures (TCFD) to develop recommendations for more effective climate-related disclosures to promote better decision making. In 2017, the TCFD published four broad voluntary disclosure categories, designed to guide companies on disclosing consistent and decision-useful information related to climate change risks and opportunities in their financial filings. These broad categories represent Governance, Strategy, Risk Management, and Metrics and Targets, which cover key aspects of business operations. More importantly, the TCFD recommendations are aligned with existing climate change and environmental disclosure frameworks, including Carbon Disclosure Project (hereafter CDP), Carbon Disclosure Standards Board, Global Reporting Initiative, G20/OECD Principles of Corporate Governance, and International Integrated Reporting Framework to provide a clear and unifying reporting framework which reduces inconsistencies in voluntary climate information disclosures.¹

In this study we investigate how corporate environmental accountability for carbon emissions affects the voluntary disclosure of TCFD aligned climate-related information. We make use of a comprehensive sample of listed firms in the United States (hereafter US), the United Kingdom (hereafter UK), Canada, and Australia over the period 2010 to 2018. Even though several recent studies have revisited the relation between climate information disclosure and carbon performance, the results are still mixed. For example, Luo (2019a, 2019b) reports that firms with low carbon performance tend to disclose more climate information while Giannarakis et al. (2017) show that high level climate information disclosure is associated with better carbon performance. Our study aims to contribute to the literature on the relation between voluntary climate information disclosure and carbon emissions by

implementing a novel measure of climate-related information disclosure.

As mentioned, the main purposes for the TCFD recommendations are to guide firms in preparing and disclosing consistent climate-related information and to provide such material information to help stakeholders assess firms' readiness for climate change (Bingler et al., 2021). Thus, structured climate-related information disclosed according to the four categories is expected to be decision useful from a stakeholder's perspective. However, there is limited research on disclosure of the four TCFD categories. Bingler et al. (2021) investigate whether climate disclosure improved after implementation of the TCFD recommendations in 2017. They find a slight increase in the climate-related information disclosed since 2017, relative to the period before. Moreover, firms that became TCFD supporters in 2017 and 2018 disclosed more climate-related information before and after 2017 than those that became TCFD supporters more recently. Results from Bingler et al. (2021) are relevant to our study as change in disclosure within the four categories can potentially impact our results. Thus, we further explore the issue at the category level.

Our paper contributes to the literature in two important ways. First, inspired by Engle et al. (2020), we use computerized textual analysis² to measure climate-related information disclosure by estimating a Climate Change Similarity Score (CCSS) for each firm based on the vocabulary aligned with the TCFD reporting framework. Such an approach is significant because of the use of comprehensive vocabulary from annual and sustainability reports of TCFD supporters, rather than from newspapers and other secondary sources. In other words, we go to the source to identify words used to describe climate change effects within firms. Second, in addition to the aggregate level, we breakdown climate-related information into the four TCFD categories to provide new insight on how carbon emissions affect disclosures under Governance, Strategy, Risk Management, and Metrics and Targets within firms. More importantly, to the best of our knowledge, the relation between climate information disclosure and carbon emissions at the TCFD category level has not been previously examined. To close this important gap, we further examine the relation between climate-related disclosure and carbon emissions at the TCFD category level to investigate corporate environmental accountability.

Our empirical tests show a positive relation between overall climate-related information disclosure and carbon emissions for the full sample as well as for individual

¹ Alignments with other frameworks can be assessed at: <https://www.tcfhub.org/ignment/>

² Computerized textual analysis refers to the textual analysis technique which uses computing power to extract relevant texts from big data and convert the qualitative information into climate disclosure scores.

countries, indicating that firms with higher levels of carbon emissions disclose more climate-related information in their annual reports. This finding is consistent with legitimacy theory where firms use disclosure as a legitimisation tool to improve their public image as the disclosures “correct for” their damaging environmental activities. Such behavior is consistent with Wartick and Cochran (1985a, 1985b) where firms with poor environmental performance make more voluntary disclosures to protect against losing control of sensitive information. Increased disclosure also helps management’s reporting credibility in the short term (Mercer, 2005a, 2005b) and reduces stakeholder demand for more information. Further analysis shows that the effect of carbon emissions on climate-related information disclosure is stronger among firms in carbon-intensive industries. When climate-related information disclosure is disaggregated by TCFD category, disclosure in Strategy, Risk management, and Metrics and Targets are found to be affected by carbon emission levels. These results are robust to various measures of carbon emissions and several endogeneity controls.

The remainder of this paper is organized as follows: Sect. 2 provides the relevant literature and hypotheses; Sect. 3 describes the data and method; the empirical results are presented and discussed in Sect. 4. Section 5 concludes the study.

Related Literature and Hypotheses

Considerable research attention has been directed at the relation between environmental performance and climate-related disclosure (Al-Tuwaijri et al., 2004a, 2004b; Clarkson et al., 2008a, 2008b; Wedari et al., 2021). While some studies report that good environmental performers disclose more climate-related information to emphasize their success (Giannarakis et al., 2017; Iatridis, 2013a, 2013b; Luo & Tang, 2014a, 2014b; Tadros & Magnan, 2019a, 2019b; Velte et al., 2020), others show that poor environmental performers increase their disclosure, possibly to counteract the negative effects of their poor performance (De Villiers & Van Staden, 2006a, 2006b; Doan & Sassen, 2020a, 2020b; Luo, 2019a, 2019b). These contrary results are likely due to unreliable proxies for environmental performance (Ullmann, 1985), for disclosure (Mobus, 2005) or a combination of both, leading to erroneous conclusions (Luo et al., 2013).

Furthermore, Huntingford et al. (2019) argue that traditional techniques are unsuitable for data-intensive research such as climate change research, because they often lack the capacity to handle big data. Using computer-based textual analysis allows the automatic extraction of important text from big data. Accordingly, different computer-based methods are increasing being applied in climate change research, such as deep neural language (Bingler et al., 2021), textual

analysis (Chen & Bouvain, 2009a, 2009b; Clarkson et al., 2020; Zhang et al., 2020) and bag of words artificial intelligence approach in Engle et al. (2020), to quantitatively and comprehensively measure climate change disclosure.

Early studies relied heavily on hand-collected and processed data, such that the samples in these studies were relatively small and mixed results were documented. For example, in Ingram and Frazier (1980a, 1980b) where the climate change-related content was extracted by hand and read by those familiar with content analysis procedures, then the standardized scores were calculated to describe the nature of the firm’s environmental discourse. A small sample of 40 annual reports was used together with proxies for environmental performance due to a lack of generally accepted environmental measures in late 1970’s. Likely due to these limitations, Ingram and Frazier (1980a, 1980b) find no relation between environmental disclosure and performance. Wiseman (1982) also documents an insignificant relation using a small sample of 26 annual reports published by 26 largest companies in the steel, oil, and pulp and paper industries. Hughes et al. (2001a, 2001b) study whether a firm’s environmental disclosures reflect its environmental performance using a sample of 51 US manufacturing firms over the period of 1992 to 1993. They also conducted content analysis to evaluate climate change disclosure made in the President’s letter, management’s discussion and analysis, and notes in the annual reports. They found that environmental disclosures reflect environmental performance only if the disclosure is measured in the management’s discussion and analysis, and notes section. Their main results indicated that poor environmental performers make the most disclosures.

Studies based on the GRI guidelines for non-financial disclosure show mixed results where Clarkson et al. (2008a, 2008b) and Tadros and Magnan (2019a, 2019b) report a positive relation; Fontana et al. (2015a, 2015b) find an insignificant relation; Dragomir (2010a, 2010b) show a negative relationship between environmental performance and GRI based disclosure. CDP has also been used as an environmental disclosure proxy which is found to be positively associated with environmental performance (Datt et al., 2019; Giannarakis et al., 2017). With the introduction of TCFD in 2017, Bingler et al. (2021) find that firms’ TCFD support was mostly cheap talk where they disclosed non-material climate risk information. For example, there was an increase of 1.9% in the disclosure level after the launch of the TCFD final report which are driven by the increased disclosures in the Governance and Risk Management categories. This result was lower than the 6% increase reported in TCFD (2020), from a Yes/No disclosure analysis in the status report.

Most environmental performance studies utilize voluntarily disclosed information to measure environmental performance. For example, carbon emission data from CDP database were employed by Datt et al. (2019), Giannarakis

et al. (2017), Luo and Tang (2014a, 2014b) and Liao et al. (2015) while Iatridis (2013a, 2013b) used hazardous waste. Fewer studies utilize mandatorily disclosed environmental information to measure firms' environmental performance, for example, Clarkson et al. (2008a, 2008b) use the actual pollution data released by United States Environmental Protection Agency as an environmental performance proxy. Meng et al. (2014) combine voluntary and mandatory environmental disclosure to investigate the relation between environmental disclosure and performance. In terms of completeness of voluntary disclosure of carbon emissions, Liesen et al. (2015a, 2015b) find only 15% of sample firms provide complete disclosure where external stakeholder pressure determines the existence but not the completeness of emission disclosure. In term of consistency in corporate carbon performance data provided by third party providers, Busch et al. (2020) find that data on direct emissions are more consistent than data on indirect emissions which imply that consistency in carbon reporting is not affected by mandatory and voluntary reporting schemes.

While several theories have been advanced to explain the relationship between environmental performance and disclosure, stakeholder theory, legitimacy theory, and institutional theory have been most frequently employed. Stakeholder theory involves the relationship between an organization and its stakeholders where Freeman (1984a, 1984b) defines a stakeholder as "any group or individual who can affect or is affected by the achievement of the firm's objectives" (p. 49). This perspective means that the organization must meet the expectations of multiple stakeholder groups instead of only the expectations of shareholders in traditional shareholder theories. Such a perspective underscores organizational accountability beyond simply financial or economic performance (Guthrie et al., 2006). Therefore, an organization performs its accountability to stakeholders by carrying out activities they consider important and reporting such information. The managerial perspective of stakeholder theory states that managers within an organization endeavor to meet stakeholders' expectation because stakeholders control the critical resources needed by the organization (Deegan, 2009a, 2009b). This perspective has been used in empirical studies (Islam & Deegan, 2008; Roberts, 1992; Waheed & Zhang, 2020) to explain managerial decisions around CSR disclosures. Disclosure of CSR information reduces information asymmetry and puts different stakeholders on a level playing field while improving reputation, lowering cost of capital, and attracting investors to the firm (Deegan, 2009a, 2009b). Therefore, the disclosure is motivated by a desire to manage powerful stakeholders and maintain firm reputation and is consistent with a negative relation between environmental performance and disclosure.

Legitimacy was often referred to by description, rather than definition until Suchman (1995a, 1995b) defined

legitimacy as "a generalised perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions" (p. 574). Legitimacy theory suggests that firms that are performing poorly environmentally keep their real status hidden by disclosing more environmental information, so that organizations can maintain their public image and gain social recognition through environmental and social disclosures. Studies have found support for legitimacy theory in terms of environmental disclosure and performance. For example, Deegan et al. (2000) finds increased social disclosures by Australian firms in their reactions to major incidents; O'Donovan (2002) shows that organizations utilize environmental information disclosure in annual reports to alter the public perception; Patten (2002) reports a negative relation between environmental performance, measured by toxics release data, and environmental disclosure. Recently, Luo (2019a, 2019b) reports that carbon performance, measured by carbon emission intensity, is negatively associated with voluntary carbon disclosure. These negative relations between environmental performance and disclosure are consistent with legitimacy theory.

Carpenter and Feroz (2001a, 2001b) state that "institutional theory is based on the premise that organizations respond to pressures from their institutional environments and adopt structures and/or procedures that are socially accepted as being the appropriate organizational choice" (p. 569). Specifically, it links organizational practice including CSR disclosures to values and norms of the society where the organization belongs to (Deegan, 2009a, 2009b). As managers attempt to follow norms imposed on them, an organization's motivation to make CSR disclosure is to become like others by adopting practices society or powerful groups consider to be 'normal' (Fernando & Lawrence, 2014). Institutional theory has been linked to CSR disclosure and practice in some studies including Bansal (2005a, 2005b) and Berrone and Gomez-Mejia (2009). Reviewing the literature, Ali et al. (2017) report that in developed countries, concerns of stakeholders such as regulators, investors, environmentalists, and the media are important in driving disclosure while in developing countries, external forces, or powerful stakeholders such as foreign investors, international media and international regulatory bodies influenced disclosure. However, firms in developing countries perceived relatively little pressure from the public to disclose CSR information. Overall, institutional theory predicts similar firms to have similar disclosures such as those belonging to the same industries with similar environmental performance.

Hypotheses We apply Fernando and Lawrence (2014) theoretical framework for CSR practices which integrates stakeholder theory with legitimacy and institutional theories. These integrated theories predict a positive relation between

voluntary climate change disclosure and carbon emissions because of the firm's desire to legitimize themselves, to be accountable to stakeholders, especially the more powerful stakeholders in the environmental space such as regulatory bodies and governments, and to conform to social norms and beliefs imposed on them such that there is homogeneity between firms in the same industry. Therefore, we hypothesize a directional relation between overall climate-related information disclosure and carbon emissions in Hypothesis H1:

H1 There is positive relation between climate-related information disclosure and carbon emissions.

In terms of disclosure within each of the four TCFD categories, we link specific theories to them from the integrated framework. For Strategy where disclosure on the risks and opportunities, and impact over the short to long term are made together with resilience of strategy under different scenarios, legitimacy and stakeholder theories are used explain strategic disclosure of climate-related risks. For example, Sharp and Zaidman (2010a, 2010b) apply Jarzabkowski (2005a, 2005b) framework which utilizes different levels of legitimacy to explain various phases of strategization of CSR in Israeli firms while Roszkowska-Menkes (2018) uses stakeholder theory to describe the relation between open innovation processes and strategic CSR. In terms of the Risk Management category where firms disclose how they identify, assess, and manage climate-related risks. Godfrey et al. (2009) and Unerman (2008) discuss CSR disclosure in terms of strategic risk management, using stakeholder theory to support the insurance-like protection of such disclosure. In contrast, Husted (2005) employs real options theory to predict the negative relation between CSR and a firm's downside risk. Looking to the Governance category, Chan et al. (2014) utilize both legitimacy theory and stakeholder theory to explain the link between corporate governance quality and CSR disclosures. They report that firms providing more CSR information have higher corporate governance ratings and are larger in size, part of high-profile industries, and are more heavily leveraged. Finally in the Metrics and Targets category, legitimacy theory has been used for Metrics (Choi et al., 2013; Depoers et al., 2016) in the reporting of carbon emissions while stakeholder and institutional theories apply to Targets, reflecting the pressure from stakeholders and society to reduce emissions (Herold et al., 2019; Liesen et al., 2015a, 2015b).

Firms in certain industries produce much higher carbon emissions than others. Patten (1991) finds variation in public pressure on firm voluntary social disclosure across different industries, where industries such as petroleum, chemical and forest and paper products disclose more information to maintain their positive social image. Berkman et al. (2019)

show that firms in utilities, and coal and gas industries disclose more climate information in their 10-K filings, confirming an industry effect on climate-related disclosure. Iatridis (2013a, 2013b) finds firms reporting more environmental information belong to metal and mining industries to enhance their public image. Hence, we argue that the positive relation between climate change disclosure and carbon emissions is stronger among carbon-intensive firms due to social and environmental pressures and state Hypothesis H2 as follows:

H2 The positive relation between climate-related information disclosure and carbon emissions is stronger for firms from carbon-intensive sectors than for other sectors.

Sample and Data

To test our hypotheses, we make use of a cross-country sample including Australia, the UK, Canada, and the US. These countries were selected for four reasons: (1) they are major TCFD supporting countries; (2) they have adopted a series of initiatives to encourage firms to disclose climate change information to mitigate climate change effects³; (3) they ratified the Paris Agreement in 2016 where commitments were made to address climate change issues⁴; and (4) their annual reports are published in English making it feasible to extract consistent climate-related information using the statistical computing software R.

Panel A of Table 1 provides details on the determination of the final sample. Specifically, the initial sample

³ Specifically, the U.S. SEC issued the *Commission Guidance Regarding Disclosure Related to Climate Change* in 2010, which provides interpretive guidelines related to climate change for firms under the existing SEC disclosure requirements. UK is considered as highly polluting nation with severe environmental issues (Giannarakis et al., 2017; Liao et al., 2015). The UK government made updates to *The Company Act Regulation 2013 and 2016* that listing firms are mandated to reveal nonfinancial information on future development and performance. The Financial Conduct Authority in UK also released a proposal for certain listed firms to state whether they made disclosures consistent with the TCFD recommendations in their annual financial reports. The Australian and Canadian governments have weighed in with new guidance on climate change disclosure in alignment with TCFD reporting framework. Therefore, firms from these four countries are pioneers in taking initiatives to respond to climate change issues.

⁴ For example, in line with the Paris Agreement, the UK and other EU members jointly acted to reduce GHG emissions by at least 40% by 2030 and at least 80% by 2050 relative to the 1990 level. Canada and Australia set a target of 30% and 28% GHG emission reduction by 2030 while the US agreed to a 28% target of reduction by 2025 compared to the 2005 level. Hence, among the developed countries, these four countries have made significant commitments to reduce GHG emissions.

Table 1 Sample selection and carbon emission data

	All countries			Australia		UK		Canada		US	
	Obs	Firm	Obs	Firm	Obs	Firm	Obs	Firm	Obs	Firm	
<i>Panel A: Sample</i>											
Data Filters	13,050	2350	2700	534	3150	545	2700	505	4500	766	
Initial sample	9456	1780	1960	416	2172	387	2112	412	3212	565	
Non-financial firms	5701	1132	938	224	1886	346	1068	223	1809	339	
Non-financial firms with CCSS > 0	2893	555	321	74	1066	198	420	81	1086	202	
Non-financial firms with CCSS > 0 and Scope 1&2 CDP data	2659	510	273	64	957	175	391	74	1038	197	
Final sample (non-financial firms with CCSS > 0, Scope 1&2 CDP data and no missing DataStream and COMPUSTAT data)											
<i>Panel B: Scope 1 and Scope 2 emissions</i>											
Scope 1 emission	2648	507	273	64	954	174	387	73	1034	196	
Scope 2 emission	2571	500	268	63	937	171	378	72	988	194	
Scope 1 emissions (%)	99.6	99.4	100.0	100.0	99.7	99.4	99.0	98.6	99.6	99.5	
Scope 2 emissions (%)	96.7	98.0	98.2	98.4	97.9	97.7	96.7	97.3	95.2	98.5	

Panel A of Table 1 shows how the final sample was obtained. Panel B presents Scope 1 and 2 emissions data

comprised the largest listed firms included in major market indices in each of the four countries, including ASX300 in Australia, FTSE350 in the UK, TSX Composite in Canada and S&P500 in the US. Next, to estimate firm-level climate-related information disclosure, we obtained 10-K filings from the EDGAR database for US firms and company annual reports from Refinitiv Eikon and the corporate websites for firms from the other three countries. Following the previous studies, we excluded financial firms and firms without climate change information each year⁵ from the initial sample. We then matched the sample with firms in the CDP database using ISINs and retained firms with complete Scope 1 and 2 carbon emission data greater than zero.⁶ Finally, we merged the matched sample with financial and corporate governance data from Refinitiv Eikon, respectively. Our final sample consists of 510 firms providing 2,659 firm-year observations.

Panel B of Table 1 presents the proportion of firms reporting Scope 1 and 2 emissions data in the final sample. Over 99% of firms in our sample report Scope 1 emissions while 98% report Scope 2 emissions to CDP, indicating that incompleteness in Scope 1 and 2 carbon emissions data is not a concern in the sample. Liesen et al. (2015a, 2015b) find that only 15% of their sample firms had complete GHG reporting while 84% of firms disclosed both Scope 1 and 2 emissions with uppermost completeness among all disclosure elements. Busch et al. (2020) show that Scope 1 and 2 emissions are consistent between third-party data providers, but Scope 3 is not. We omit Scope 3 emission data in our study for two reasons. First, no such data are reported by over 20% of our sample. Second, of firms disclosing Scope 3 emission data, less than 30% report all 17 emission types under Scope emissions,⁷ indicating that firms report inconsistent and incomplete types of Scope 3 emissions.

⁵ Firms that do not disclose climate information (i.e., zero CCSS, see Climate-related Information Disclosure Measure: Step 2) are filtered out from the sample in a year.

⁶ The GHG Protocol defines Scope 1 as direct GHG emission from source owned or controlled by the company; Scope 2 as indirect GHG emission from the generation of purchased electricity consumed by the firm.

⁷ The number of emission types included in Scope 3 have maintained at constant 17 types since 2013 according to CDP database, as described: 1. Purchased goods and services; 2. Capital goods; 3. Fuel-and-energy-related activities (not included in Scope 1 or 2); 4. Upstream transportation and distribution; 5. Waste generated in operations; 6. Business travel; 7. Employee commuting; 8. Upstream leased assets; 9. Downstream transportation and distribution; 10. Processing of sold products; 11. Use of sold products; 12. End of life treatment of sold products; 13. Downstream leased assets; 14. Franchises; 15. Investments; 16. Other (upstream); 17. Other (downstream).

Therefore, our carbon emission measures are calculated using only Scopes 1 and 2 emission data from CDP.⁸

Research Design

Climate-Related Information Disclosure

Our measure of climate-related information disclosure follows Engle et al. (2020) where in their paper, a climate change vocabulary is created from 74 authoritative climate change documents and the daily climate change news index is estimated based on similarity scores between the *Wall Street Journal* newspaper and the climate change vocabulary. Our climate change measure differs from Engle et al. (2020) in two ways. First, we identify enriched and comprehensive climate change vocabularies based on the TCFD reporting framework. The wide adoption of TCFD recommendations by firms reflects an increasing demand for comparable climate change disclosure (TCFD, 2021a, 2021b). In addition, Engle et al. (2020) climate change vocabulary mainly focuses on carbon emissions and contains a limited number of words on climate-related disclosures in relation to governance, strategy, and risk management. Therefore, compared to those from the authoritative climate change documents, we believe our climate change vocabularies are more informative and value-relevant for investors because they are aligned with TCFD recommendations. Second, we use firm annual reports to measure climate change disclosure, while in Engle et al. (2020), the climate change news index was constructed from newspapers. We extract climate change information from annual reports because the environmental information disclosed in annual reports is material to decisions made by stakeholders (Deegan & Rankin, 1997a, 1997b); and recent studies support the importance of annual reports as a source of climate information disclosure. For example, Guay et al. (2016) found that the voluntary disclosure in annual reports helps managers to effectively communicate with investors. Moreover, Hahn et al. (2015) conducted a systematic literature review on carbon disclosure research and found that among the 42 quantitative carbon disclosure empirical studies reviewed, CDP was the most popular data source, but annual report was the least popular data source for quantitative studies. Hahn et al. (2015) show that climate disclosure made via annual reports is an under researched field compared with that of CDP because quantitative secondary climate data is not readily available in

annual reports. However, the development of computerized textual analysis technique and the release of the TCFD final report have greatly improved the feasibility of processing large numbers of textual documents, such as annual reports, to measure climate-related information disclosure aligned with TCFD.

We measure climate-related information disclosure by estimating Climate Change Similar Score (CCSS) at firm level. CCSS estimation process involves three main steps: (1) developing a comprehensive and unique climate change vocabulary (CCV) as the reference for textual analysis; (2) matching CCV with parsed and cleansed texts from annual reports; (3) comparing a firm's climate-related keywords with CCV to estimate a CCSS for each firm-year. A greater CCSS value indicates higher level of voluntary climate-related information disclosure. The details of each main step are:

Step 1: Developing CCV as the Reference

Voluntary climate-related information disclosures can be significantly different across firms. A comprehensive CCV is required as it is used as the reference for material climate change information. Information retrieval is a preparatory step for developing CCV which involves collecting and identifying a set of textual information. The steps are as follows:

Subtask1: Identifying TCFD Supporters

To avoid potential error arising from lexical applications in annual reports used by firms in different countries, we construct country level training samples for Australia, the UK, Canada, and US. To construct the country level training samples, we identify TCFD supporters in these four countries, since large numbers of companies in these four countries have aligned their climate-related information disclosures with the TCFD recommendations.

Next, we exclude government organizations, agencies, and other non-listed firms from the TCFD supporter samples. In the training samples, there are 24 listed firms in Australia, 28 in the UK, 13 in Canada and 24 in the US. The training sample accounts for a few firms in each country and our hypothesis tests largely rely on out-of-sample performance; therefore, there are no overfitting concerns. The training sample is differentiated from the final sample because it is used to construct an enriched and comprehensive vocabulary regarding climate change information.

Following Merkley (2013a, 2013b) and Engle III et al. (2019), we create a bag of words using the annual reports

⁸ Alternatively, we assume firms without Scope 3 emission data (i.e., not reporting) have zero emission in a year. We calculate carbon emission as summation of Scope 1, 2 and 3 and redo all regressions in our paper. We find that our results do not alter. These results are not reported but will be available upon request.

and sustainability reports⁹ of the training samples to construct one unique CCV for each country since these reports are regarded as the most important information sources in which firms make environmental disclosures under different circumstances (De Villiers & Van Staden, 2011a, 2011b). In addition, we focus on the reports published between 2017 and 2019 after the publication of the TCFD recommendations and include the TCFD final reports in the training samples. The method of using training samples to construct vocabulary has been widely used in empirical studies (Buehlaier & Whited, 2018a, 2018b; Cannon et al., 2020; Engle et al., 2020). Through the process, we collect a total of 140 reports which contain climate-related information in line with four broad categories of TCFD recommendations including 38 reports from Australia, 48 reports from UK, 21 reports from Canada and 33 reports from US.

Subtask2: Extracting Climate-Related Information and Cleansing Untidy Text

We review the 140 reports collected based on the training sample and manually extract climate-related information.¹⁰ The extracted climate-related texts are

⁹ We use annual reports, sustainability reports and stand-alone climate change reports to construct an enriched vocabulary. However, in each country sample, firm-level CCSS is estimated using only annual reports. The International Integrated Reporting Council (hereafter IIRC) encourages firms to adopt integrated reporting, which aims to present financial reporting and sustainability reporting in annual reports. More specifically, IIRC (2019a, 2019b) reports approximately 50% of the 200 largest Australian listed firms leverage the principles of integrated reporting in annual reports by including more sustainability information. Additionally, ASIC (2018) constructed a review of reports of Australian listed firms, including annual reports, sustainability reports and climate change reports and found over 40% of reports of ASX300 firms contain climate change information between 2011 and 2017, which is consistent with our findings. Moreover, the *Companies Act 2006 Regulations 2013* mandates UK listed firms to issue a strategic report disclosing information on environmental matters and sustainability when material in their annual reports. We find supporting evidence of over 90% of firms in UK sample report climate change information in their annual (or integrated) reports. Our results also show that on average, 50% of firms in Canada disclose climate-related information in the annual reports, with the figure being 40% in US firms between 2010 and 2018. Therefore, it suggests to a certain extent an increasing proportion of annual reports are being integrated to incorporate more sustainability information. Overall, excluding sustainability reports might have little effect on the issue that we possibly omit the firms reporting climate change information only in sustainability reports. However, we also acknowledge this as a limitation that we do not include sustainability reports or stand-alone climate change reports in our sample.

¹⁰ It is not difficult for information extraction since TCFD supporters tend to disclose climate change information in line with four categories under a separate and structured section. In this study, we copy all textual climate-related information under each category and save them in the word files for text processing in the next step.

processed for tidy structure by removing punctuations and stop words, striping white space and stemming documents (Gentzkow et al., 2019). For example, stops words with useless information, like ‘the,’ ‘we,’ and ‘are,’ are excluded from text documents. To uniform feature forms and reduce feature dimensions for calculations, words are converted into their root or basic stemmer, which is referred to as stemming. Under the stemming process, ‘development,’ ‘developing,’ ‘developed,’ and ‘develops’ are changed to a stemmer of ‘develop.’

Subtask3: Summarizing Term Frequency and Forming CCV

Next, the cleansed climate change texts are tokenized by words with n length, referred to as n -gram.¹¹ These n -gram words are aggregated and counted across training sample firm-years to form a numerical vector in each country. These words and their frequencies are defined as CCV. For example, Appendix 1 lists 20 vocabularies that appear most frequently in the training samples of the four countries. To measure the TCFD category-level disclosure, we employ category-level CCV for each country in our sample. Thus, 16 CCVs were constructed to measure the category-level disclosures.

Step 2: Matching CCV with the Climate-Related Key Words Extracted from the Annual Reports

The annual reports published by the firms in the final sample are parsed into textual documents for text cleaning. Likewise, for CCV construction, texts in each document are processed by removing stop words and punctuations, stemming striping whitespace. These cleansed textual documents are assembled to form the climate change corpus.

Next, some specific terms are identified to determine whether annual reports possibly contain any climate-related information, including ‘climate change,’ ‘climate risk,’ ‘climate opportunity,’ ‘carbon emission,’ ‘GHG emission,’ and ‘greenhouse gas,’ since these terms appear most often among the phrase collocation of ‘climate’ or ‘carbon.’ Firms that never use these terms in their reports are deemed not to disclose any climate-related information.¹²

¹¹ We set n to two and three as suggested by Gentzkow et al. (2019), which produces pairs of two and three consecutive words.

¹² We consider the tokenized words by bigrams used to differentiate firms whether they report climate-related information or not. Compared with single-word terms that are insufficient to capture the textual patterns, the n -gram modeling can generate richer representations for climate change information and avoid capturing noised terms, such as ‘investment climate’ that are irrelevant to climate change information.

CCV is treated as one single document and aggregated into the climate information corpus. Each word in CCV is matched with words from each firm's textual document. Accordingly, firms without climate-related information disclosure have zero occurrences of each word, thereby designated zero CCSS value while firms with valid climate-related information disclosure have positive CCSS values. The details regarding CCSS calculation is discussed in Step 3.

Step 3: Comparing Climate-Related Texts of Each Firm with CCV and Estimating CCSS

An effective and practical measure for text informativeness is term frequency-inverse document frequency (tf_idf). Tf_idf is a product of term frequency (tf) and inverse document frequency (idf). The text informativeness measure tf_idf is estimated as:

$$tf_idf = tf * idf = f_{t,d} * \log\left(\frac{N}{n_t}\right)^{13}$$

Hence, highly frequent words that appear across nearly all documents are assigned low tf_idf scores because of low idf . Likewise, rare words that occur in one document also have low tf_idf scores because of low tf , so that rare words and common words are penalized when estimating tf_idf (Te Gatzkowitz et al., 2019; Hansen et al., 2017; Liew et al., 2014). However, when a term appears many times within a relatively small number of documents, it will be awarded high tf_idf scores. tf_idf must be calculated for each term in CCV to evaluate how important and informative these terms are in the whole sample. Our climate-related information disclosure measure, CCSS is estimated as the cosine value of tf_idf score.¹⁴

¹³ tf is calculated as the number of a word's occurrence in a document; idf is a measurement of whether a word is common or not across all documents, calculated as the logarithm of the ratio of total documents to the number of documents containing a given word. $f_{t,d}$ is the occurrence of term t in a document; N is the number of total documents; n_t is the number of documents containing term t .

¹⁴ $Similarityscore = cosine(tf_idf_{CCV}, tf_idf_{firm,i}) = \frac{(tf_idf_{CCV,i})(tf_idf_{firm,j})}{\sqrt{tf_idf_{CCV,j} * tf_idf_{firm,i}}}$, where, $tf_idf_{CCV,j}$ is the tf_idf of term j in CCV; $tf_idf_{firm,i,j}$ is the tf_idf of term j in firm i 's annual report. Hence, it ranges from zero to one.

CCSS Cross-Validation Tests

CCSS is designed to capture and measure the level of climate-related information voluntarily disclosed in annual reports. To validate CCSS as a relevant disclosure measure, we base the validation tests on the prediction that climate-related information disclosure reduces information asymmetry and improves readability of the annual reports (Dhaliwal et al., 2012; Schiemann & Sakhel, 2019a, 2019b).

First, we employ Amihud (2002a, 2002b) illiquidity measure and the bid-ask spread as proxies for information asymmetry (Daske et al., 2008). Following Chen et al. (2015a, 2015b), we estimate these proxies over 12 months starting from four months after the end of fiscal year. To examine the relation between CCSS and the readability of annual reports, we employ FOG and SMOG¹⁵ statistics to measure report complexity (Li, 2008; Zhang et al., 2020). In the regressions, we control for the effects of firm size ($SIZE$), book-to-market equity ratio (BM), return on assets (ROA), standard deviation of daily prices (VOL), total debt to total assets ratio (LEV), and capital expenditure ($CAPX$), and include country, industry, and year fixed effects. The CCSS validation test results are reported in Table 2.

Table 2 shows that, as predicted, CCSS is negatively related to the two information asymmetry proxies indicating that information asymmetry is lower when firms disclose more climate-related information via annual reports. In addition, we find that CCSS is also negatively related to the two readability measures. The results affirm the reliability and effectiveness of our novel voluntary climate-related information disclosure measure as the results show that CCSS reduces information asymmetry and improves readability.

To further validate CCSS as an effective climate change disclosure measure, we benchmark CCSS against Bingle et al. (2021) ClimateBERT which measures climate risk disclosures based on the four broad TCFD categories. To compare CCSS with ClimateBERT, Fig. 1 decomposes CCSS into four category-based disclosure measures using category-level CCVs. In addition, for consistency with Bingle et al. (2021), we include financial firms in the sample only for this comparison. In Fig. 1, similar trends in the four disclosure categories are observed compared with those of Bingle et al. (2021).

Summary statistics of the category-level CCSS are reported in Table 3. There are increases in all four TCFD categories over the sample period with increases in Metrics and Targets after 2015 and Governance and Risk Management

¹⁵ $FOG = 0.4 * [average\ sentence\ length + 100 * (the\ number\ of\ words\ with\ 3\ syllables\ or\ more / the\ number\ of\ words)]$; $SMOG = 1.043 * \sqrt{30 * the\ number\ of\ words\ with\ 3\ syllables\ or\ more / the\ number\ of\ sentence} + 3.1291$.

Table 2 CCSS validation

	Information asymmetry		Readability	
	Log(AIM)	Bid-Ask Spread	FOG	SMOG
CCSS	-0.060*** (-2.76)	-1.559*** (-3.88)	-2.736** (-2.23)	-1.530** (-2.06)
SIZE	-0.005*** (-4.25)	-0.242*** (-13.59)	0.226*** (4.41)	0.119*** (3.87)
Log(BM)	0.009*** (5.74)	0.142*** (4.93)	-0.071 (-1.09)	-0.048 (-1.24)
ROA	-0.006 (-0.45)	-2.868*** (-9.77)	-0.638 (-0.92)	-0.648 (-1.54)
VOL	0.0004* (1.76)	0.019*** (3.71)	0.028 (1.63)	0.017* (1.65)
LEV	0.018* (1.80)	0.296* (1.94)	0.15 (0.41)	0.09 (0.41)
CAPX	-0.035 (-1.43)	1.194*** (2.88)	-0.106 (-0.10)	-0.253 (-0.40)
Constant	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Obs	5378	5378	5378	5378
Adjusted R2	0.25	0.54	0.36	0.34

We employ two proxies for information asymmetry: Amihud (2002a, b) Illiquidity Measure and bid-ask spread. AIM is computed as $1/N \sum_{j=1}^N [R_{i,j,t} / DVOL_{i,j,t} * 10^6]$, where $R_{i,j,t}$ is the daily return of stock i ; $DVOL_{i,j,t}$ is the daily trading volume in US dollars. Bid-ask spread is computed as $1/N \sum_{j=1}^N (Ask_{i,j,t} - Bid_{i,j,t}) / [(Ask_{i,j,t} + Bid_{i,j,t}) / 2]$. Following Chen et al. (2015a, b), we estimate them over the following 12 months starting from 4 months after the end of fiscal year. Next, we employ two commonly used statistics, FOG and SMOG to estimate report complexity (Li, 2008; Zhang et al., 2020), calculated as $0.4 * [\text{average sentence length} + 100 * (\text{the number of words with 3 syllables or more} / \text{the number of words})]$ and $1.043 * \sqrt{30 * \text{the number of words with 3 syllables or more} / \text{the number of sentence}} + 3.1291$, respectively. All variables are winsorized at 2.5% and 97.5% level. For all regression results in this paper, we cluster the robust standard errors by firm (Dhaliwal et al., 2012; Petersen, 2009a, 2009b; Zhang et al., 2020). *, **, and *** indicate the 10%, 5%, and 1% significance level, respectively

after 2017. More specifically, the Metrics and Targets category shows the largest increase of 0.018, compared with 0.005 in Governance, 0.008 in Strategy and 0.006 in Risk management after the implementation of the Paris Agreement. Furthermore, Governance and Risk Management categories exhibit the largest increase of 0.036 and 0.035, respectively after publication of the TCFD final report. The results are consistent with Bingler et al. (2021). Overall, Table 3 shows that firms' voluntary climate-related information disclosure had increased due to the implementations of the Paris Agreement and TCFD recommendations, implying

that the major climate events affect stakeholders' demands on climate-related information and improve investor awareness of climate change (Liesen et al., 2015a, 2015b).

Carbon Emission Measures

Previous studies employ different carbon emission measures, such as carbon emission intensity, defined as total carbon emission (Scope 1 plus Scope 2) scaled by sales revenue (Bui et al., 2020; Luo, 2019a, 2019b; Luo & Tang, 2014a, 2014b; Qian & Schaltegger, 2017a, 2017b). In contrast, accounting studies on firm valuation effects of carbon emission use absolute emission value. Clarkson et al. (2008a, 2008b) argue that scaled carbon emission measures can be incomparable for firms that are not grouped into homogeneous industries. Therefore, our proxies for carbon emissions are: (1) absolute total emission value, $TCO2$, calculated as summation of Scope 1 and Scope 2 emissions reported by CDP; and (2) sector-adjusted carbon emissions, $ADJCO2$, calculated as firm's $TCO2$ minus the sector average.¹⁶ The carbon emission proxies are firm-year level data.

Empirical Model

Relation Between Climate-Related Information Disclosure and Carbon Emissions

To test Hypothesis H1, we investigate the relation between carbon emission and CCSS. In the regression model, the climate-related information disclosure measure (CCSS) is the dependent variable, and the carbon emissions is the main explanatory variable while controlling for a set of variables that have potential power to explain voluntary climate change disclosure. Our base regression model is as follows:

$$\begin{aligned}
 CCSS_{i,t} = & \alpha + \beta 1 CE_{i,t} + \beta 2 SIZE_{i,t} + \beta 3 Log(BM)_{i,t} + \beta 4 CAPX_{i,t} \\
 & + \beta 5 LEV_{i,t} + \beta 6 ROA_{i,t} + \beta 7 TOBIN' Q_{i,t} + \beta 8 GENDER_{i,t} \\
 & + \beta 9 BOARD_{i,t} + \beta 10 IND_{i,t} + \beta 11 Log(EP)_{i,t} \\
 & + \beta 12 SUPPORT_{i,t} + SectorFixedEffects \\
 & + YearFixedEffects + CountryFixedEffects + \epsilon_{i,t}
 \end{aligned} \quad (1)$$

where CE is $TCO2$ or $ADJTCO2$.

¹⁶ We also use the carbon emission intensity variable of Luo (2019a, 2019b) for robustness, calculated as natural logarithm of the ratio of total emission to firm sales. Compared to other two carbon emission measures, using scaled carbon emission by sales does not alter our key finding regarding the relation between climate-related information disclosure and carbon emissions. The regression results are not reported in the paper but are available upon request.

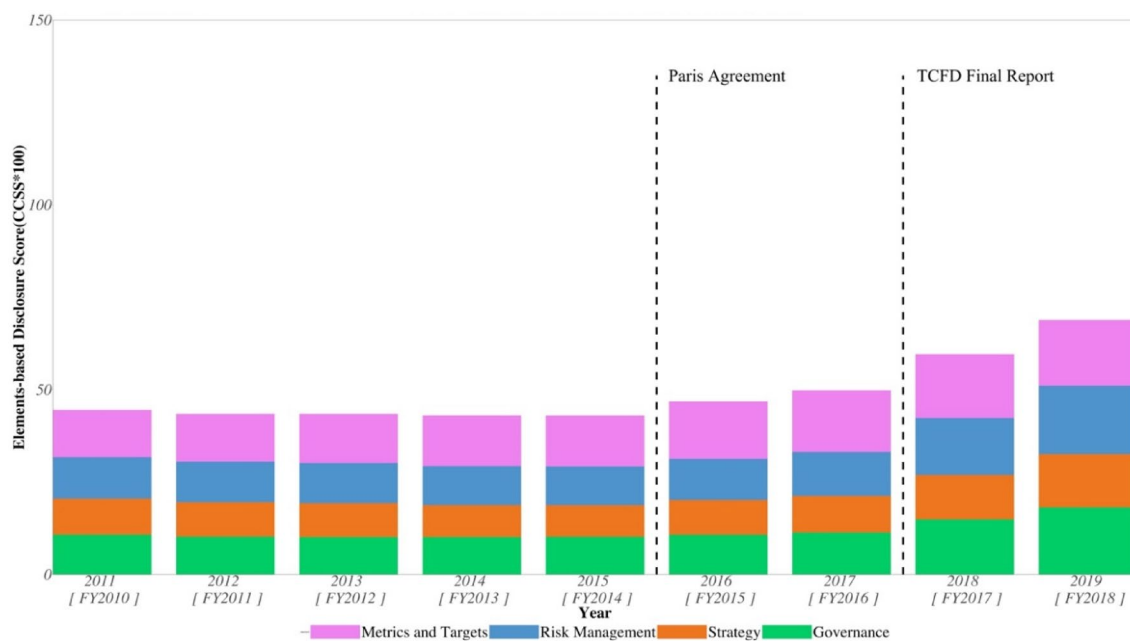


Fig. 1 Climate change disclosures based on the four TCFD categories

Table 3 CCSS summary statistics by TCFD category

Category	2011 [FY2010]	2012 [FY2011]	2013 [FY2012]	2014 [FY2013]	2015 [FY2014]	2016 [FY2015]	2017 [FY2016]	2018 [FY2017]	2019 [FY2018]
<i>Governance</i>									
Mean	10.79	10.27	10.15	10.17	10.24	10.77	11.38	14.93	18.17
Std dev	7.22	6.63	7.17	6.90	6.79	7.30	8.19	11.39	14.04
<i>Strategy</i>									
Mean	9.76	9.29	9.15	8.62	8.58	9.41	9.98	12.02	14.42
Std dev	5.51	5.26	5.46	5.24	5.22	6.14	6.43	8.69	10.86
<i>Risk Management</i>									
Mean	11.20	10.99	10.88	10.57	10.49	11.12	11.89	15.39	18.52
Std dev	6.50	6.57	6.80	6.67	6.69	7.08	7.64	10.74	13.26
<i>Metrics and targets</i>									
Mean	12.82	12.91	13.26	13.69	13.75	15.55	16.70	17.29	17.80
Std dev	8.38	8.32	8.48	7.98	8.23	10.03	10.80	11.30	11.99

Hypothesis H2 investigates whether carbon-intensive firms disclose more climate-related information. A dummy variable, *Intensive*, which equals to 1 if a firm is in the Energy, Materials or Utilities sector, and otherwise 0, (Luo, 2019a, 2019b; Luo & Tang, 2014a, 2014b; Nguyen, 2018a, 2018b), is used to test Hypothesis H2. The *Intensive*CE_{i,t}* coefficient shows whether carbon-intensive firms disclose more climate-related information. The regression model is as follows:

$$\begin{aligned}
 CCSS_{i,t} = & \alpha + \beta 1 CE_{i,t} + \beta 2 Intensive * CE_{i,t} + \beta 3 SIZE_{i,t} + \beta 4 Log(BM)_{i,t} \\
 & + \beta 5 CAPX_{i,t} + \beta 6 LEV_{i,t} + \beta 7 ROA_{i,t} + \beta 8 TOBIN' Q_{i,t} \\
 & + \beta 9 GENDER_{i,t} + \beta 10 BOARD_{i,t} + \beta 11 IND_{i,t} + \beta 12 Log(EP)_{i,t} \\
 & + \beta 13 SUPPORT_{i,t} + SectorFixedEffects + YearFixedEffects \\
 & + CountryFixedEffects + \epsilon_{i,t}
 \end{aligned}
 \tag{2}$$

Control variables for firm characteristics, corporate governance and environmental performance are included in the model as they potentially affect climate change disclosure. The control variables are: (1) *SIZE*, measured as natural

Table 4 Summary statistics

Year	Min	Median	Mean	Max	St.Dev
<i>Panel A: CCSS between 2010 and 2018</i>					
2010	1.68	7.58	8.25	20.68	3.90
2011	1.74	6.91	7.96	25.68	3.99
2012	1.45	7.58	8.24	31.22	4.13
2013	1.37	6.84	7.64	24.81	3.50
2014	0.71	7.16	7.96	36.00	4.04
2015	0.72	7.61	8.51	35.79	4.58
2016	1.24	7.79	8.97	34.45	4.88
2017	1.93	9.17	10.47	41.28	6.22
2018	0.82	9.99	12.18	40.32	7.91

Variable	Full Sample			Australia			UK			Canada			US		
	Mean	Median	St.Dev	Mean	Median	St.Dev	Mean	Median	St.Dev	Mean	Median	St.Dev	Mean	Median	St.Dev
<i>Panel B: Descriptive statistics for all years</i>															
CCSS	8.91	7.72	5.15	11.00	9.27	7.14	10.40	9.16	5.74	8.25	7.45	4.63	7.22	6.54	3.16
TCO2	5.74	0.73	11.49	4.95	0.64	10.68	3.02	0.21	8.68	4.15	0.86	6.83	9.04	2.18	14.23
ADITCO2	-0.30	-0.46	9.03	-0.04	-1.30	9.47	-0.10	-0.31	6.91	0.03	-0.23	5.29	-0.69	-0.98	11.43
SIZE	23.09	23.12	1.35	22.27	22.17	1.32	22.51	22.37	1.26	22.57	22.50	1.16	24.03	23.88	0.89
BM	0.47	0.39	0.34	0.71	0.62	0.40	0.46	0.37	0.34	0.60	0.53	0.36	0.38	0.33	0.26
CAPX	0.06	0.05	0.04	0.07	0.06	0.05	0.04	0.03	0.03	0.08	0.07	0.05	0.05	0.05	0.04
LEV	0.27	0.26	0.14	0.23	0.23	0.14	0.24	0.23	0.16	0.28	0.25	0.14	0.30	0.30	0.13
ROA	0.06	0.05	0.05	0.04	0.04	0.06	0.06	0.06	0.05	0.04	0.04	0.05	0.07	0.06	0.05
TOBINQ	1.66	1.40	0.86	1.42	1.21	0.81	1.71	1.43	0.86	1.32	1.19	0.55	1.81	1.58	0.92
BOARD	10.56	11	2.40	8.67	8	1.96	9.69	9	2.26	11.14	11	2.47	11.63	12	1.97
GENDER	0.20	0.20	0.10	0.19	0.20	0.11	0.20	0.20	0.10	0.20	0.20	0.10	0.21	0.20	0.09
IND	0.74	0.78	0.16	0.73	0.78	0.16	0.60	0.60	0.12	0.81	0.83	0.11	0.84	0.86	0.09
EP	58.98	61.04	20.60	50.75	51.32	19.81	57.53	58.18	21.12	52.69	53.86	22.82	64.85	67.39	17.55

Table 5 CCSS—firms with and without CDP participation across sectors

GICS Sectors	35 Health Care	45 Information Technology	50 Communica- tion Services	20 Industries	25 Consumer Discretionary	30 Consumer Staples	10 Energy	15 Materials	55 Utilities
<i>Panel A: Firms with CDP participation (Obs = 2659)</i>									
2010	5.92	6.12	6.99	8.07	7.39	6.03	8.80	10.24	11.81
2011	5.41	5.76	6.16	7.47	7.32	6.18	8.62	10.15	10.96
2012	6.19	5.61	6.49	7.89	7.57	6.13	9.02	10.35	11.80
2013	6.52	6.15	6.28	7.40	6.54	6.48	8.03	8.97	11.37
2014	7.00	6.08	6.56	7.53	6.50	6.71	8.44	9.68	12.27
2015	7.46	6.11	7.47	7.73	7.42	7.22	9.45	10.47	11.98
2016	8.22	6.38	8.95	7.82	7.97	6.93	10.35	11.07	12.14
2017	8.67	6.75	11.83	9.59	10.00	8.58	11.50	12.80	14.39
2018	7.91	7.74	13.56	10.71	11.61	10.58	14.32	16.16	15.53
Mean	7.21	6.33	8.13	8.21	8.04	7.25	9.69	11.06	12.51
<i>Panel B: Firms without CDP participation (Obs = 2810)</i>									
2010	2.93	5.35	4.32	6.74	5.58	5.56	6.84	6.85	8.35
2011	3.52	5.30	4.20	6.41	5.36	6.46	6.53	6.06	8.42
2012	3.66	5.86	4.49	5.84	5.14	5.37	6.14	5.84	7.58
2013	4.10	4.91	4.74	6.28	5.40	5.19	6.55	6.38	7.86
2014	4.22	5.52	5.20	5.82	5.22	6.25	6.77	6.28	8.15
2015	5.30	5.73	5.44	5.95	5.39	6.43	7.56	6.11	8.34
2016	4.77	5.36	6.01	6.15	5.80	6.98	7.64	6.87	8.05
2017	5.70	5.33	6.89	7.80	6.81	8.24	9.67	9.73	9.91
2018	5.86	6.53	7.00	10.01	7.86	7.92	11.08	11.21	12.03
Mean	4.83	5.59	5.60	6.87	5.91	6.56	7.46	7.49	8.77
Difference	2.38	0.75	2.53	1.33	2.13	0.69	2.23	3.57	3.74
<i>p-value</i>	0.000	0.014	0.000	0.000	0.000	0.030	0.000	0.000	0.000

logarithm of market capitalization at the end of year t . Previous studies have documented strong evidence that firm size explains voluntary disclosure levels (Dhaliwal et al., 2012; Li & Yang, 2016; Luo & Tang, 2014a, 2014b); (2) $\text{Log}(BM)$ is used to proxy for company stability and maturity, measured by the natural logarithm of book equity value to market equity value as investors demand more voluntary disclosure for high-growth companies facing greater information asymmetry (Waymire, 1985a, 1985b); (3) LEV , defined as short-term and long-term debts scaled by total assets, is used to control for the information environment, since debtholders demand greater disclosure when assessing risks (Dhaliwal et al., 2012; Liao et al., 2015; Matsumura et al., 2013); (4) $CAPX$ or capital expenditure, as previous studies control for capital expenditure effects on voluntary climate-related disclosure (Clarkson et al., 2008a, 2008b; Luo, 2019a, 2019b; Stanny & Ely, 2008); (5) $TOBIN'Q$, defined as market value of common stock plus book value of preferred stock plus short and long-term debt, scaled by total assets and (6) return on assets (ROA) as financial performance may

affect disclosure levels (Ben-Amar et al., 2017; Dhaliwal et al., 2012; Luo & Tang, 2014a, 2014b). Additionally, we control for some corporate governance variables including $GENDER$ (the percentage of female directors on the board), $BOARD$ (the total number of directors on the board), IND (the percentage of independent directors on the board), since previous studies show that corporate governance plays an important role in revealing voluntary environmental information (Ben-Amar et al., 2017; Liao et al., 2015). Clarkson et al. (2008a, 2008b) and Dawkins and Fraas (2011) find that environmental performance is positively associated with voluntary environmental disclosure, therefore we include an environmental performance variable (EP) to alleviate the concern that climate change disclosure is possibly driven by other environmental performance. We also have a TCFD supporter dummy variable, $SUPPORT$, to capture the effect of TCFD reporting on climate change disclosure. Descriptions for all the variables used in the regressions are provided in Appendix 3. The regressions are conducted at firm-year level using the pooled sample as well as the individual country samples.

Table 6 Correlation matrix

	CCSS	TCO2	ADJTCO2	SIZE	BM	CAPX	LEV
CCSS	1.00						
TCO2	0.26***	1.00					
ADJTCO2	0.19***	0.70***	1.00				
SIZE	0.02	0.30***	0.21***	1.00			
BM	0.24***	0.20***	0.11***	-0.28***	1.00		
CAPX	0.04**	0.20***	0.00	0.02	0.13***	1.00	
LEV	0.02	0.07***	0.00	0.15***	-0.25***	-0.01	1.00
ROA	-0.13***	-0.15***	-0.01	0.24***	-0.47***	-0.05***	-0.12***
TOBINQ	-0.22***	-0.30***	-0.12***	0.20***	-0.68***	-0.11***	0.04*
BOARD	-0.03	0.24***	0.17***	0.54***	-0.06***	-0.02	0.17***
GENDER	0.13***	-0.04**	0.03	0.17***	-0.10***	-0.18***	0.13***
IND	-0.05**	0.28***	0.10***	0.43***	0.01	0.11***	0.15***
EP	0.15***	0.18***	0.16***	0.46***	-0.02	-0.08***	0.09***
	ROA	TOBINQ	BOARD	GENDER	IND	EP	
ROA	1.00						
TOBINQ	0.62***	1.00					
BOARD	0.03	-0.05**	1.00				
GENDER	0.05**	0.07***	0.09***	1.00			
IND	-0.04**	-0.07***	0.26***	0.17***	1.00		
EP	0.07***	-0.04**	0.35***	0.22***	0.19***	1.00	

*, **, and *** indicate the 10%, 5%, and 1% significance level, respectively

Table 7 Comparison of carbon-intensive and non-carbon-intensive firms

<i>Variables</i>	Carbon-intensive firms (Obs = 982)			Non-carbon-intensive firms (Obs = 1677)			<i>t</i> -test	Wilcoxon test
	Mean	Median	St. dev	Mean	Median	St. dev	<i>p</i> -value	<i>p</i> -value
CCSS	10.99	9.87	5.85	7.69	6.67	4.25	0.000	0.000
TCO2	11.88	4.35	15.77	2.14	0.32	5.34	0.000	0.000
ADJTCO2	-0.88	-4.57	13.68	0.03	-0.31	4.39	0.042	0.000
SIZE	23.04	23.14	1.26	23.11	23.12	1.41	0.192	0.394
BM	0.62	0.55	0.34	0.38	0.30	0.30	0.000	0.000
CAPX	0.08	0.07	0.05	0.04	0.03	0.03	0.000	0.000
LEV	0.27	0.26	0.14	0.27	0.26	0.15	0.418	0.445
ROA	0.03	0.03	0.05	0.07	0.07	0.05	0.000	0.000
TOBINQ	1.26	1.12	0.55	1.90	1.63	0.92	0.000	0.000
BOARD	10.40	11.00	2.37	10.65	11.00	2.42	0.010	0.043
GENDER	0.18	0.18	0.09	0.22	0.22	0.10	0.000	0.000
IND	0.76	0.82	0.16	0.73	0.75	0.16	0.000	0.000
EP	58.82	59.86	20.30	59.08	62.15	20.77	0.754	0.573

Table 8 Relationship between CCSS and TCO2

	All	Australia	UK	Canada	US					
TCO2	0.068*** (3.44)	0.024 (0.87)	0.145 (1.55)	- 0.339* (- 1.67)	0.089** (2.57)	- 0.023 (- 0.71)	0.271*** (5.64)	0.046 (0.37)	0.038* (1.92)	0.039 (1.10)
TCO2*Intensive		0.051 (1.41)		0.482*** (2.70)		0.120** (2.41)		0.241* (1.69)		- 0.0005 (- 0.01)
SIZE	0.503*** (3.21)	0.517*** (3.30)	2.864*** (4.00)	2.985*** (4.07)	0.356 (1.59)	0.36 (1.60)	- 0.295 (- 1.10)	- 0.238 (- 0.87)	- 0.038 (- 0.16)	- 0.038 (- 0.16)
Log(BM)	0.513** (2.57)	0.478** (2.38)	- 0.069 (- 0.04)	0.556 (0.28)	0.242 (0.84)	0.242 (0.85)	1.245*** (4.50)	1.107*** (3.76)	0.016 (0.05)	0.017 (0.05)
CAPX	- 2.243 (- 0.61)	- 1.53 (- 0.41)	- 11.183 (- 1.44)	- 8.528 (- 1.02)	9.414 (1.57)	9.753 (1.62)	- 17.627*** (- 3.35)	- 14.937*** (- 2.77)	1.746 (0.30)	1.727 (0.30)
LEV	1.294 (1.17)	1.274 (1.15)	8.756** (2.58)	9.048*** (2.71)	- 1.839 (- 1.17)	- 1.826 (- 1.17)	8.170*** (3.94)	8.756*** (4.15)	- 2.097 (- 1.40)	- 2.097 (- 1.40)
ROA	1.43 (0.46)	1.346 (0.43)	- 8.874 (- 1.47)	- 10.298* (- 1.69)	5.916 (1.54)	5.808 (1.51)	2.136 (0.34)	2.809 (0.44)	- 9.379* (- 1.82)	- 9.374* (- 1.84)
TOBINQ	- 0.174 (- 0.68)	- 0.229 (- 0.88)	- 1.678 (- 1.37)	- 1.341 (- 1.07)	- 0.735** (- 2.37)	- 0.741** (- 2.41)	1.885** (2.26)	1.642* (1.92)	0.182 (0.45)	0.183 (0.44)
BOARD	0.053 (0.81)	0.052 (0.79)	- 0.640** (- 2.08)	- 0.617* (- 1.96)	0.200* (1.96)	0.200* (1.94)	0.031 (0.23)	0.014 (0.10)	0.034 (0.42)	0.034 (0.42)
IND	2.938** (2.07)	2.780** (2.03)	- 1.289 (- 0.40)	- 1.542 (- 0.48)	2.2 (1.09)	2.136 (1.06)	5.680** (2.57)	6.431*** (2.79)	1.119 (0.66)	1.122 (0.67)
GENDER	1.257 (0.90)	1.109 (0.79)	0.872 (0.16)	1.72 (0.33)	- 2.664 (- 1.49)	- 2.503 (- 1.39)	- 1.769 (- 0.56)	- 2.24 (- 0.70)	0.0002 (0.00)	0.003 (0.00)
Log(EP)	0.895*** (2.81)	0.895*** (2.81)	- 1.2 (- 1.28)	- 1.141 (- 1.21)	1.597*** (3.19)	1.582*** (3.15)	1.308** (2.10)	1.247** (2.00)	0.818 (1.62)	0.818 (1.62)
SUPPORT	10.005*** (5.00)	10.015*** (4.99)	7.850** (2.06)	7.671** (2.02)	8.999*** (3.50)	9.004*** (3.49)	7.820*** (3.04)	7.700*** (2.98)	3.443** (2.40)	3.443** (2.40)
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	No	No	No	No	No	No	No	No
Obs	2659	2659	273	273	957	957	391	391	1038	1038
Adjusted R ²	0.43	0.43	0.47	0.48	0.51	0.51	0.50	0.51	0.34	0.34

*, **, and *** indicate the 10%, 5%, and 1% significance level, respectively

Relation Between Climate-Related Information Disclosure at TCFD Category Level and Carbon Emissions

We further explore the relations between climate-related disclosure and carbon emissions at the category level. We estimate category-level CCSS for all the firms using the CCVs specifically constructed based on each of the four TCFD categories. The approach yields four new dependent variables for Eqs. (1) and (2) while the independent variables remain the same.

Empirical Results

Descriptive Statistics

Descriptive statistics are reported in Table 4. In Panel A, CCSS is generally increasing over the time period from 2010 to 2018 with a mean annual increase of 5.3% and the largest increase of 16.8% occurring in 2017, coinciding with the implementation of TCFD recommendations. In Panel B, the mean CCSS for all firms is 8.91 with a median of 7.72. Among the countries, Australian firms have the highest mean (11.00), followed by UK firms (10.4), Canadian firms (8.25) and US firms (7.22). US firms have the highest mean TCO2 at 9.04 while the mean TCO2 is the lowest for UK firms at 3.02. In terms of other environmental performance,

Table 9 Relationship between CCSS and ADJT_{CO2}

	All		Australia		UK		Canada		US	
ADJT _{CO2}	0.051** (2.22)	-0.03 (-0.87)	0.177** (2.01)	-0.183 (-0.82)	0.068* (1.65)	-0.100* (-1.74)	0.315*** (4.21)	-0.101 (-0.65)	0.018 (0.83)	-0.002 (-0.05)
ADJT _{CO2} *Intensive		0.096** (2.13)		0.366 (1.64)		0.179** (2.36)		0.448*** (2.93)		0.025 (0.59)
SIZE	0.537*** (3.17)	0.542*** (3.25)	2.448*** (3.46)	2.493*** (3.48)	0.665*** (2.70)	0.677*** (2.78)	-0.065 (-0.16)	-0.028 (-0.07)	-0.206 (-0.86)	-0.197 (-0.85)
Log(BM)	0.811*** (3.67)	0.759*** (3.42)	0.231 (0.12)	0.66 (0.33)	0.393 (1.04)	0.395 (1.05)	1.839*** (4.69)	1.575*** (4.19)	0.347 (1.23)	0.312 (1.06)
CAPX	10.333*** (2.88)	11.572*** (3.12)	-7.662 (-0.88)	-5.998 (-0.67)	21.482*** (3.37)	22.402*** (3.48)	-0.47 (-0.08)	2.317 (0.39)	16.790*** (3.39)	17.465*** (3.43)
LEV	2.895** (2.45)	2.825** (2.38)	8.017** (2.45)	8.281** (2.57)	0.289 (0.15)	0.252 (0.13)	8.877*** (3.36)	9.429*** (3.57)	0.951 (0.57)	0.935 (0.56)
ROA	-1.591 (-0.49)	-1.802 (-0.56)	-8.872 (-1.37)	-9.621 (-1.46)	5.35 (1.33)	5.218 (1.30)	-0.611 (-0.09)	0.542 (0.08)	-12.107** (-2.24)	-12.243** (-2.27)
TOBINQ	-0.574** (-2.09)	-0.653** (-2.33)	-1.443 (-1.27)	-1.189 (-1.03)	-1.187*** (-3.16)	-1.201*** (-3.23)	1.467 (1.41)	1.143 (1.06)	-0.104 (-0.27)	-0.15 (-0.37)
BOARD	0.009 (0.12)	0.009 (0.12)	-0.626* (-1.80)	-0.594* (-1.69)	0.053 (0.49)	0.056 (0.52)	-0.061 (-0.36)	-0.081 (-0.47)	0.06 (0.59)	0.06 (0.59)
IND	3.721** (2.32)	3.528** (2.31)	-0.842 (-0.25)	-0.849 (-0.25)	2.028 (0.92)	1.978 (0.91)	6.026* (1.85)	7.274** (2.23)	3.452* (1.66)	3.281 (1.64)
GENDER	0.071 (0.05)	0.002 (0.00)	-2.19 (-0.39)	-1.478 (-0.28)	-5.521*** (-2.86)	-5.291*** (-2.75)	-6.831* (-1.72)	-7.378* (-1.84)	0.435 (0.21)	0.294 (0.14)
Log(EP)	10.450*** (5.03)	10.399*** (5.03)	9.070** (2.29)	8.790** (2.22)	9.696*** (3.74)	9.657*** (3.72)	6.937** (2.43)	6.725** (2.33)	3.077* (1.85)	3.101* (1.85)
SUPPORT	1.026*** (2.97)	1.016*** (2.93)	-0.685 (-0.70)	-0.703 (-0.71)	1.716*** (3.16)	1.684*** (3.09)	0.9 (1.26)	0.826 (1.15)	1.399*** (2.62)	1.417*** (2.64)
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	No	No	No	No	No	No	No	No	No	No
Country FE	Yes	Yes	No	No	No	No	No	No	No	No
Obs	2,659	2,659	273	273	957	957	391	391	1,038	1,038
Adjusted R ²	0.36	0.36	0.45	0.46	0.44	0.45	0.36	0.38	0.18	0.18

*, **, and *** indicate the 10%, 5%, and 1% significance level, respectively

US firms are the best performers with mean EP of 64.9 while the lowest mean of 50.8 is found in Australian firms.

Table 5 shows the time series mean of CCSS across nine sectors for firms with and without participation in CDP. In all sectors, there was a general increase in CCSS for all firms. The difference in mean CCSS between firms with and without CDP participation was statistically significant for all sectors. The Energy, Materials, and Utilities sectors' mean CCSS are 9.69, 11.06, and 12.51, respectively, for firms with CDP participation and these means are higher than other sector means. Similar figures are observed among firms without CDP participation. Among firms with and without CDP participation, the largest increase in CCSS is observed in 2017 when TCFD recommendations were implemented.

Correlation analysis results are given in Table 6. As expected, *TCO2* is highly correlated with *ADJT_{CO2}*, but

there is no concern of multicollinearity because these variables are used separately in the regressions.

Carbon-Intensive Versus Non-Carbon-Intensive Firms

Table 7 shows differences between carbon-intensive and non-carbon-intensive firms. Carbon-intensive firms have a mean CCSS of 10.99 compared to 7.69 in non-carbon-intensive firms, indicating that these firms disclose more climate change information in their annual reports. *TCO2* and *ADJT_{CO2}*, are also significantly different between carbon-intensive and non-carbon-intensive firms. In addition, other variables apart from market capitalization (*SIZE*), leverage ratio (*LEV*), and environmental performance (*EP*) between the two categories of firms exhibit significant differences.

Relation Between Climate-Related Information Disclosure and Carbon Emissions

Results for Hypotheses H1 and H2 are reported in Tables 8 and 9. In Table 8, the *TCO2* coefficient is positive and significant in the pooled sample, showing that firms with higher levels of carbon emissions disclose more climate-related information in their annual reports. At country level, the *TCO2* coefficients are positively significant for the UK, Canada, and the US. These results are supportive of legitimacy theory where firms with higher levels of carbon emissions disclose more climate-related information to offset the negative effects of their environmental activities.

To test Hypothesis H2, the *TCO2*Intensive* variable is added. In Table 8, the *TCO2*Intensive* coefficients are positive and significant in the Australia, UK, and Canada samples. The results show that the firms in carbon-intensive sectors increase climate-related information disclosure more than other firms, supporting Hypothesis H2. Overall, these results reflect legitimacy and institutional theories where firms with poorer carbon performance disclose more climate-related information to improve their public environmental image and discharge their corporate environmental accountability.

The coefficients on the control variables yield additional findings.¹⁷ Among the control variables, there is strong size effect observed in the pooled sample and the Australia sample indicating that large firms disclose more climate-related information than small firms. The positive coefficient on *Log(BM)* indicates that value firms are more likely to disclose climate-related information in their annual reports. We also find a significantly positive relation between leverage and CCSS in the Australia and Canada samples, reflecting a higher demand for climate-related disclosure from debtholders in these two countries. *IND* is positively related to CCSS in the all-firm and Canada samples supporting the view that independent directors improve voluntary climate change disclosure. This finding is consistent with Cheng and Courtenay (2006a, 2006b) as they find board independence is positively associated with voluntary disclosure. The *Log(EP)* coefficient is significantly positive indicating that firms with better environmental performance disclose more climate change information in annual reports. This is consistent with our expectation based on previous studies

¹⁷ We control for the effect of Emission Trading Scheme (ETS) by replacing country fixed effect with a ETS dummy variable in the regression model. We find that ETS has positive effect on climate change disclosure but presence of ETS dummy variable does not alter our regression results. The regression results are not reported in the manuscript but will be available upon request.

(Clarkson et al., 2008a, 2008b; Dawkins & Fraas, 2011).¹⁸ The *SUPPORT* coefficients are positive and statistically significant across all samples, indicating that TCFD supporters disclose more climate-related information relative to non-TCFD supporters.

Table 9 provides further supporting evidence to the predictions of Hypotheses H1 and H2 where an alternative carbon emission measure (*ADJTCO2*) is used. The coefficients of *ADJTCO2* and *ADJTCO2*Intensive* are significantly positive in the pooled sample. At country level, similar results are observed in UK and Canada samples. Overall, the results in Table 9 further confirm that (1) firms with higher carbon emissions disclose more climate-related information; (2) the effect of carbon emissions on climate-related information disclosure is stronger in the carbon-intensive firms¹⁹; (3) TCFD supporters disclose more climate-related information in annual reports than non-TCFD supporters.

Relation Between Climate-Related Information Disclosure at the TCFD Broad Category Level and Carbon Emissions

TCFD provides structured reporting guidelines based on four broad categories, to assist firms to disclose climate-related information. For Governance, firms are expected to embed climate risks into the governance frameworks while they need to account for climate change consistent with the board's risk appetite in Risk Management. Additionally, firms are encouraged to develop scenario analysis for strategic resilience from a perspective of Strategy and employ appropriate metrics and targets to assess climate risks and opportunities (Carney, 2019a, 2019b). In this section, we explore how specific disclosures within these categories are associated with firms' carbon emissions by estimating category-level CCSS for each firm in the final sample.

Table 10 provides the results for climate-related information disclosure under individual categories. In Panel A, the dependent variable is the category-level CCSS for the Governance category. The results show that the *TCO2* coefficients are positive and significant for firms in Australia,

¹⁸ This finding is not conflicted with our main results since environmental performance, proxied by ENVSCORE from Datastream indicates relative rating of a company based on reported environmental information. It evaluates the effects of company activities regarding resource utilization on overall environment including air, land, and water usage.

¹⁹ We run additional regressions using one-year lagged carbon emission variables and the models from Tables 8, 9. The results obtained using one-year lagged carbon emission variables are highly consistent with the results obtained using contemporaneous carbon emission variables. The additional results are not presented in this manuscript and will be available upon request.

Table 10 Relationship between category-level CCSS and TCO2

	All	Australia	UK	Canada	US
<i>Panel A: Governance Category</i>					
TCO2	0.037 (1.07)	-0.055 (-1.04)	-0.142 (-0.36)	-0.111* (-1.93)	-0.008 (-0.21)
TCO2*Intensive	0.108* (1.66)	0.250* (1.69)	0.389 (1.15)	0.236*** (3.18)	0.083 (0.38)
Observations	2,659	273	273	391	391
Adjusted R2	0.30	0.47	0.40	0.38	0.16
<i>Panel B: Strategy Category</i>					
TCO2	0.070** (2.42)	0.144 (1.16)	-0.18 (-0.67)	-0.088 (-1.50)	0.063** (2.35)
TCO2*Intensive	0.043 (0.75)	0.322 (1.12)	0.322 (1.12)	0.209** (2.12)	0.047 (0.25)
Observations	2,659	273	273	391	391
Adjusted R2	0.36	0.43	0.44	0.47	0.20
<i>Panel C: Risk Management Category</i>					
TCO2	0.060* (1.88)	0.218 (1.50)	-0.381 (-1.05)	-0.134*** (-2.81)	0.028 (0.73)
TCO2*Intensive	0.149** (2.21)	0.595* (1.85)	0.595* (1.85)	0.196*** (2.91)	0.084 (0.37)
Observations	2,659	273	273	391	391
Adjusted R2	0.32	0.47	0.48	0.40	0.22
<i>Panel D: Metrics and Targets Category</i>					
TCO2	0.139*** (4.99)	0.174*** (2.76)	0.532 (1.51)	-0.061 (-0.70)	0.104*** (3.37)
TCO2*Intensive	-0.042 (-0.63)	-0.358 (-1.11)	-0.358 (-1.11)	0.112 (1.15)	-0.128 (-1.53)
Observations	2,659	273	273	391	391
Adjusted R2	0.37	0.28	0.28	0.33	0.42

All regressions include intercepts and control variables. The control variables are firm size, book-to-market ratio, capital expenditure, firm leverage, return on assets, Tobin's Q, board size, independent director ratio, board gender ratio, environmental performance, and TCFD supporter. Country, sector, and year fixed effects are included. All variables, except CCSS and dummy variables are winsorized at 2.5% and 97.5% level and t-statistics are estimated based on clustered standard errors at firm level

*, **, and *** indicate the 10%, 5%, and 1% significance level, respectively

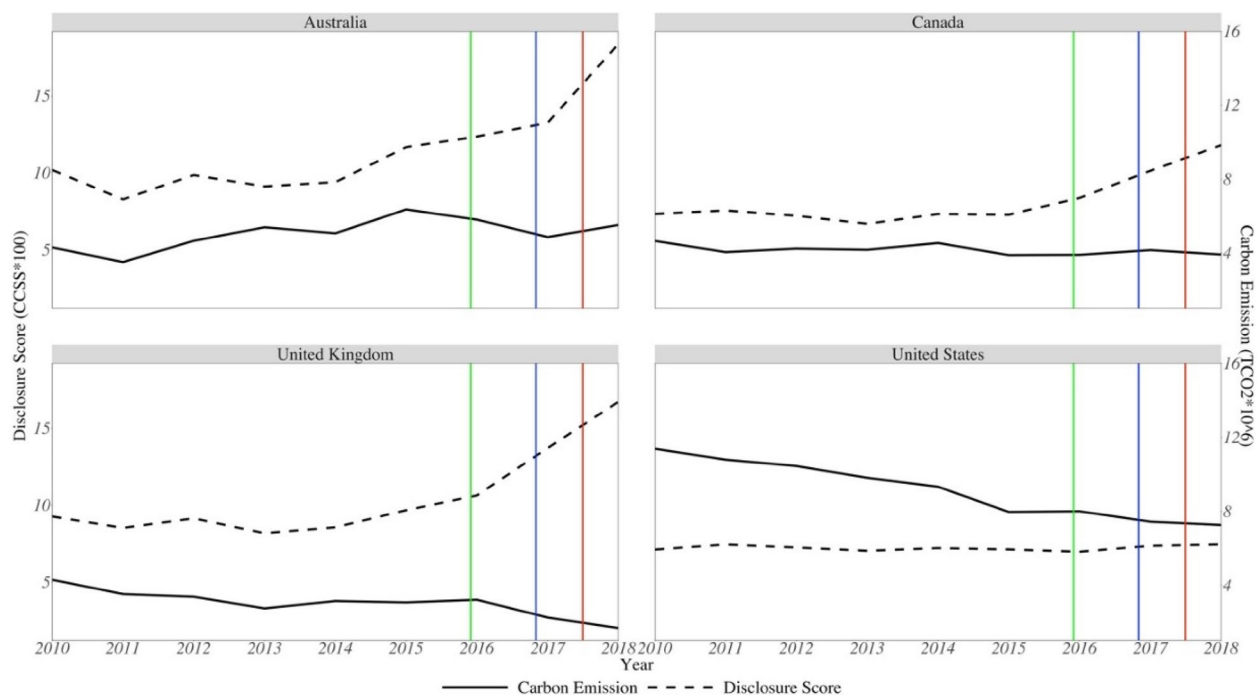


Fig. 2 Mean carbon emissions and CCSS at country level

Canada, and the UK only, while the $TCO2*Intensive$ coefficient is significant for all firms and UK firms. These results indicate that firms with high levels of carbon emissions in Australia, Canada and the UK incorporate climate risks into their governance framework, consistent with legitimizing their emissions and adhering to stakeholder pressure. This result is stronger in firms from the carbon-intensive sectors in UK, reflecting advances in climate reporting in the country. In Panel B, the dependent variable is the category-level CCSS for Strategy. The results show that $TCO2$ is positive and significant for all firms, and for firms in Canada and US separately. This is an interesting finding because US firms emit the most carbon dioxide while Canada firms emit the least relatively to other firms in the sample. While strategic disclosure is driven by emissions, this implies that US firms attempt to legitimize themselves while Canada firms are pressured by stakeholders to disclose climate-related information. The $TCO2*Intensive$ coefficient is significant only for UK firms, pointing to the societal norms to disclose in these industries. Overall, these results indicate that while all firms increase their climate-related information disclosure of strategic analysis with increasing carbon emissions, but this relation is more pronounced in UK firms in carbon-intensive sectors.

The results for the Risk Management category are reported in Panel C where $TCO2$ is positive and significant for all firms and Canada firms, while $TCO2*Intensive$ coefficient is significant for all firms and UK firms. These

results indicate a positive relation between carbon emissions and climate-related information disclosure under the risk management category, particularly for UK firms from the carbon-intensive sectors. The results for UK are consistent with stakeholder theory given the comparatively low levels of carbon emissions by UK firms. Finally, Panel D presents the results for the Metrics and Targets category showing that disclosure is positively associated with carbon emissions in US and Canada.

Overall, climate-related information disclosures in Strategy, Risk Management and Metrics and Targets are positively associated with carbon emissions while the relations under Governance and Risk Management categories are stronger for the firms belonging to carbon-intensive sectors. Bingle et al. (2021) report that climate-related disclosure under the Strategy, and Metrics and Targets categories have not increased much after 2017 resulting in stakeholders are unable to assess their risk exposures. Our results provide a possible explanation for the finding of Bingle et al. (2021) since we show that carbon emissions drive disclosures in the two categories, but carbon emissions had decreased in UK, Canada and US firms and increased in Australia firms after 2017. Therefore, it is not surprising to see there are minor increases in climate-related information disclosure under Strategy and Metrics and Targets categories compared with the other two categories since 2017 in Bingle et al. (2021) because carbon emissions have remained relatively

Table 11 Heckman two-stage regression

	All		Australia		UK		Canada		US	
<i>Panel A: TCO2</i>										
TCO2	0.058*** (2.95)	0.014 (0.51)	0.102 (1.20)	- 0.285 (- 1.62)	0.091** (2.54)	- 0.022 (- 0.67)	0.248*** (4.94)	- 0.189 (- 1.43)	0.036* (1.81)	0.046 (1.19)
TCO2*Intensive		0.05 (1.51)		0.391** (2.42)		0.122** (2.43)		0.461*** (3.35)		- 0.012 (- 0.28)
IMR	- 1.891* (- 1.75)	- 2.086* 9 - 1.93	6.566* 7 1.935	5.399 (1.56)	- 2.228 (- 1.61)	- 2.301* (- 1.65)	2.386 (0.90)	0.638 (0.27)	- 0.357 (- 0.20)	- 0.231 (- 0.13)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,659	2,659	273	273	957	957	391	391	1,038	1,038
VIF	3.30	3.32	4.54	4.70	2.71	2.71	3.49	3.74	2.34	2.41
<i>Panel B: ADJTCO2</i>										
ADJTCO2	0.062** (2.44)	- 0.02 (- 0.57)	0.165** (2.10)	- 0.243 (- 1.38)	0.077* (1.65)	- 0.065 (- 1.03)	0.271*** (3.87)	- 0.283* (- 1.71)	0.036 (1.52)	0.042 (1.22)
ADJTCO2*Intensive		0.097** (2.18)		0.413** (2.43)		0.150* (1.88)		0.585*** (3.45)		- 0.008 (- 0.20)
IMR	- 2.973** (- 2.56)	- 3.341*** (- 2.92)	4.94 (1.60)	4.137 (1.42)	- 2.900** (- 1.97)	- 2.978** (- 2.05)	- 0.474 (- 0.14)	- 3.018 (- 0.98)	1.754 (1.17)	1.774 (1.19)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,659	2,659	273	273	957	957	391	391	1,038	1,038
VIF	2.91	2.94	4.06	4.14	2.37	2.37	3.24	3.52	1.59	1.60

Control variables include firm size, book-to-market ratio, firm leverage, board size, independent director ratio, board gender ratio, environmental performance and TCFD Supporter

*, **, and *** indicate the 10%, 5%, and 1% significance level, respectively

flat since the introduction of TCFD recommendations.²⁰ Overall, the results reported in Table 10 are consistent with our main findings that firms with higher carbon emissions disclose more climate-related information, although disclosure within each category differs by country.²¹

Robustness Tests

Additional tests are conducted to ensure the robustness of our results including Heckman two-stage regressions, difference-in-difference tests, and reverse causality tests.

Sample Selection Bias and Heckman Two-Stage Regressions

Firms in our final sample are not randomly selected, resulting in concerns of self-selection bias. When the sample is not

randomly selected, ordinary least squares estimation procedure may produce biased coefficients (Lennox et al., 2012; Maddala, 1991a, 1991b). To address this concern, we follow Lennox et al. (2012) and Luo (2019a, 2019b) to run Heckman two-stage regressions (Heckman, 1979). The results are reported in Panels A and B of Table 11²². To determine whether there is significant self-selection bias in our final sample, the variable of interest is Inverse Mills Ratio (IMR). In Panel A of Table 11, the coefficients of IMR are significant at 10% level in the all-firm sample, indicating minor self-selection bias. However, the coefficients on *TCO2* and *TCO2*Intensive* are consistent with those reported in Table 8 indicating that our main results remain unchanged while controlling for self-selection bias. In Panel B, the coefficients of IMR are significant in the all-firm sample and the UK sample, but the main results are unchanged from those in Table 9. Therefore, the results confirm that the relation between climate-related information disclosure and carbon emissions is robust.

²⁰ See Fig. 2 for carbon emissions in the four countries.

²¹ We also replace *TCO2* with *ADJTCO2* and rerun all regressions, presenting similar results. The additional results are not presented in this manuscript and will be available upon request.

²² Heckman stage 1 test results are not reported in this manuscript, but they are available upon request. Inverse Mills ratios (IMR) are estimated in Heckman stage 1 test and used as an independent variable in Heckman stage 2 test. A significant IMR indicates significant self-selection bias in the sample.

Table 12 Sub-sample robustness test

	2016 to 2018 subsample			2010 to 2015 subsample				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
TCO2	0.073*** (2.84)	0.088*** (2.17)			0.065*** (2.80)	- 0.002 (- 0.08)		
ADJTCO2			0.056** (2.14)	- 0.008 (- 0.20)			0.053*** (1.98)	- 0.031 (- 0.80)
SUPPORT	8.427*** (4.48)	5.399*** (2.03)	9.097*** (4.62)	5.363* (1.94)				
SUPPORT*Intensive		5.728 (1.58)		6.942* (1.90)				
TCO2*Intensive		- 0.021 (- 0.45)				0.078** (2.04)		
ADJTCO2*Intensive				0.075 (1.44)				0.096** (1.98)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	No	No	Yes	Yes	No	No
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	905	905	905	905	1,754	1,754	1,754	1,754
Adjusted R2	0.51	0.52	0.47	0.48	0.35	0.35	0.229	0.23

Control variables include firm size, book-to-market ratio, capital expenditure, firm leverage, return on asset, Tobin's Q, board size, independent director ratio, board gender ratio, environmental performance

*, **, and *** indicate the 10%, 5%, and 1% significance level, respectively

Table 13 Difference-in-difference test

	All	Australia	UK	US	Canada
<i>Supporter</i>	1.292** (2.26)	(0.87) (0.61)	1.597** (1.96)	(- 0.18) (- 0.18)	1.726** (1.99)
<i>Event</i>	3.318*** (7.67)	6.037*** (2.69)	7.463*** (9.82)	0.728* (1.96)	4.008*** (4.08)
<i>Supporter*Event</i>	7.007*** (5.10)	(2.60) (0.95)	7.676*** (4.22)	(2.16) (1.54)	6.334*** (3.11)
TCO2	0.066*** (3.51)	0.143* (1.73)	0.081** (2.35)	0.039** (1.96)	0.258*** (5.91)
Control Variables	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Sector FE	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	No	No	No	No
Observations	2659	273	957	1038	391
Adjusted R2	0.43	0.46	0.52	0.33	0.52

Control variables include firm size, book-to-market ratio, capital expenditure, firm leverage, return on asset, Tobin’s Q, board size, independent director ratio, board gender ratio and environmental performance. We also control for sector and year fixed effects as well as country fixed effects for the all sample. All variables, except CCSS and dummy variables are winsorized at 2.5% and 97.5% level and t-statistics are estimated based on clustered standard errors at firm level. *, **, and *** indicate the 10%, 5%, and 1% significance level, respectively. *Supporter* equals to 1 if firms pledge support for TCFD recommendations and otherwise 0. *Event* equals to 1 after 2017 and otherwise 0

Sub-Sample Robustness Test

Our main results indicate firms with higher levels of carbon emissions disclose more climate-related information and the relation is stronger among the carbon-intensive firms. This raises the question of whether our results are driven by firms adopting TCFD recommendations, given that the CCV is constructed using TCFD supporters’ annual and sustainability reports. To address this concern and further examine our two hypotheses, the sample is split into two groups, with one group containing observations between 2016 and 2018 and the other with observations from 2010 to 2015. We use the two groups to capture the effect of TCFD supporters on climate change disclosure for carbon-intensive and non-carbon-intensive firms and the results are presented in Table 12.

The positive coefficients on *TCO2* and *ADJTCO2* in Columns 1 and 3 for the period 2016 to 2018 indicate that climate change disclosure is positively related to carbon emissions. Columns 5 and 7 also show similar results for the 2010 to 2015 period. We can therefore infer that our main results presented in Table 8 and 9 are not driven by TCFD supporters. For Hypothesis H2, the *TCO2*Intensive* and *ADJTCO2*Intensive* coefficients in Columns 2 and 4 are insignificant while the corresponding coefficients in Columns 6 and 8 are statistically significant at 5% level. This suggests our main results for Hypothesis H2 are likely driven by non-TCFD supporters. Coefficients on *SUPPORT*Intensive* in Columns 2 and 4 are insignificant and weakly significant, respectively, indicating that carbon-intensive and non-carbon-intensive firms exhibit undifferentiated climate-related information disclosure when firms become

TCFD supporters. These results confirm that our main results are not driven by TCFD supporters and CCSS captures climate-related information disclosed prior to the introduction of TCFD.

Difference-in-Difference Test

To provide insight into whether TCFD supporters disclose differently than non-TCFD supporters after the launch of TCFD final report, we conduct a difference-in-difference test. Two dummy variables, *Supporter* and *Event*, are created to capture a firm’s TCFD Supporter status and the launch event of the TCFD final report in 2017. The following regression model is employed to test the difference:

$$CCSS_{i,t} = \alpha + \beta 1 Supporter_{i,t} + \beta 2 Event_t + \beta 3 Supporter_{i,t} * Event_t + \beta 4 TCO2_{i,t} + ControlVariables_{i,t} + \epsilon_{i,t}$$

where *Supporter* equals to 1 if a firm is a TCFD supporter and otherwise 0²³; *Event* equals to 1 after 2017 and

²³ There is a distinction between *Supporter* dummy in Table 13 and *SUPPORT* dummy in Appendix 3. *SUPPORT* equals to 1 if the firm is a TCFD supporter in year *t* since *SUPPORT* dummy depends on the date when the firm pledges support for TCFD. For example, if the firm expresses their support in 2017-year, *SUPPORT* dummy will equal to 1 in 2017 and 2018 years only whereas *Supporter* dummy equals to 1 in all years between 2010 and 2018. Creating *Supporter* dummy for the difference-in-difference test is to avoid the technical issue that *Supporter* would be the same as the interaction variable, *Supporter*Event*, in the difference-in-difference test.

otherwise 0. β_1 measures average difference in disclosure between the TCFD and non-TCFD supporters prior to the event; β_2 captures changes in the disclosure before and after the event; β_3 demonstrates how much TCFD supporters disclose differently before and after the launch of TCFD final report, compared to non-TCFD supporters when controlling for other variables. The difference-in-difference test results are reported in Table 13.

The difference-in-difference results show that TCFD supporters disclose more climate-related information than non-TCFD supporters in the UK and Canada after the launch of the TCFD final report, but the difference is not significant in Australia and the US. More interestingly, the launch of the TCFD final report has a positive impact on climate disclosure as the coefficients of *Event* are all positive and significant at 1% level, except that it is significant at 10% level for the US sample indicating a weaker impact of the launch of TCFD final report in the US compared with those in other three countries.

Reverse Causality Test

IN panel data analysis, reverse causality can arise if error items are correlated with regressors in the model, thereby threatening casual inference. To address this endogeneity concern, we follow Godfrey et al. (2020) to run reverse causality tests in three steps. First, we regress carbon emission measures on the lagged CCSS and control variables, from which we obtain the error items uncorrelated to climate change disclosure, *Emission_UC*. Next, we estimate correlation coefficients of CCSS with *Emission_UC* and run Granger causality tests to examine whether *Emission_UC* affects climate-related information disclosure. Lastly, we run the main regressions of CCSS on the lagged *Emission_UC* and control variables for the all-firm sample. The reverse causality test results are reported in Appendix 2.

In Panel B of Appendix 2, the results confirm that (1) there is no correlation exist between CCSS and *Emission_UC* in all models; (2) the lagged CCSS does not cause *Emission_UC*. These results collectively point out that reverse causality is not a concern in our sample. More importantly, the regression results in Panel C shows a significant and positive relation between lagged *Emission_UC* and CCSS. The reverse causality test results are consistent with the main results in Table 8 and 9. Overall, our main results remain robust while controlling for potential reverse causality.

Conclusion

We use computerized textual analysis technique to construct an innovative measure of climate-related information disclosure. With this novel measure, we contribute to the literature on

whether carbon emissions affect climate-related information disclosure using a cross-country sample over the period from 2010 to 2018. Our results show a positive relation between climate-related information disclosure and carbon emissions, indicating that firms with poor carbon performance disclose more climate-related information in annual reports voluntarily. Furthermore, the effect of carbon emissions on climate-related disclosure is stronger among firms belonging to carbon-intensive industries. When climate-related information disclosure is examined at the TCFD category level, we find that carbon emissions drive category-level disclosures under strategy, risk management and metrics and targets. Carbon emission levels and membership in carbon-intensive sectors affect category-level climate-related disclosure differently in different countries. For example, in UK firms, membership in carbon-intensive sectors compels climate-related information disclosure in the Governance, Strategy and Risk Management categories while carbon emission levels increase Strategy and Metrics and Targets disclosure in US firms.

Our climate-related information disclosure measure is derived from climate change information disclosed in annual reports only. We chose annual reports because the TCFD recommends climate-related information disclosure in financial filings. As some firms disclose such information in sustainability reports or other reports (Eccles et al., 2019), their disclosure is excluded from our examination. We acknowledge the use of annual report as a limitation of our study. Furthermore, our measure of carbon emissions includes only Scope 1 and Scope 2 emissions. Such reliance on Scope 1 and 2 data excludes valuable comprehensive narratives and data on emission type and reporting boundary. However, inclusion of such data will reduce our sample significantly due to incompleteness of other emission types. Our choice of carbon emissions measure limits the extent to which our findings can be generalizable and applicable for other emission types, but robustness of the main results is maintained due to large sample size.

Overall, our findings show that corporate managers discharge their environmental accountability by voluntarily disclosing climate-related information in annual reports when their firms are performing poorly in terms of environmental measures. Such behavior can be viewed in two ways: first, that these firms are greenwashing and attempting to improve their public environmental image by controlling the narrative, consistent with legitimizing the behavior or these firms are making disclosures about how they are working on improving their performances in future by strategic initiatives, conducting risk management and disclosing their aspirational targets within the TCFD framework.

Appendix 1

See Table 14.

Table 14 Climate change vocabulary

Governance		Strategy		Risk management		Metrics and targets	
Vocabulary	Count	Vocabulary	Count	Vocabulary	Count	Vocabulary	Count
Australia: climate change vocabulary							
Climat chang	170	Climat chang	353	Climat chang	199	Scope emiss	170
Climat relat	112	Long term	124	Risk manag	137	Emiss intens	95
Risk opportun	77	Climat relat	114	Climat relat	108	Per cent	95
Relat risk	75	Scenario analysi	110	Relat risk	84	Ghg emiss	72
Climat relat risk	71	Transit risk	99	Elimat relat risk	77	Scope	66
Risk manag	59	Risk opportun	97	risk opportun	74	Greenhous gas	62
Risk committe	47	Low carbon	96	Climat risk	53	Gas emiss	52
Relat risk opportun	41	Physic risk	93	Manag framework	49	Greenhous gas Emiss	50
Includ climat	37	Impact climat	76	Scenario analysi	47	Emiss reduct	47
Sustain committe	28	Medium long	72	Carbon price	46	Emiss scope	39
Chang risk	25	Medium long term	71	Esg risk	45	Carbon emiss	36
Climat chang risk	25	Relat risk	70	Risk manag frame- work	45	Climat chang	34
Includ climat chang	25	Climat relat risk	68	Long term	44	Total scope	28
Board risk	24	Renew energi	68	Risk assess	41	Oper control	28
Manag climat	21	Impact climat chang	63	Low carbon	38	Renew energi	27
Manag framework	19	Extrem weather	57	Manag risk	35	Reduct target	25
Group risk	18	Physic impact	55	Impact climat	32	Scope emiss	25
Risk manag frame- work	18	Climat risk	53	Thermal coal	28	Emiss reduct target	24
Leadership team	17	Energi effici	49	Climat resili	28	Scope ghg	24
Committe overse	16	Carbon economi	49	Impact climat chang	27	Energi consumpt	23
Governance							
ILUK: climate change vocabulary							
Vocabulary	Counts	Vocabulary	Counts	Vocabulary	Counts	Vocabulary	Counts
Climat chang	178	climat chang	351	climat chang	290	scope emiss	215
Climat relat	101	Low carbon	155	climat relat	165	greenhous gas	104
Risk opportun	68	Climat relat	122	risk manag	138	carbon intens	96
relat risk	54	Physic risk	100	relat risk	131	carbon emiss	83
Climat relat risk	51	Long term	94	climat relat risk	120	market base	76
Risk manag	50	Carbon economi	87	risk opportun	71	climat chang	74
Risk committe	45	Transit risk	85	climat risk	66	ghg emiss	73
Climat risk	41	Risk opportun	76	princip risk	63	gas emiss	66
Relat risk opportun	36	Low carbon economi	71	transit risk	62	greenhous gas emiss	65

Table 14 (continued)

Governance		Strategy		Risk management		Metrics and Targets	
ILUK: climate change vocabulary							
Vocabulary	Counts	Vocabulary	Counts	Vocabulary	Counts	Vocabulary	Counts
Execut committe	35	Relat risk	71	physic risk	56	locat base	59
Chief execut	29	Climat relat risk	68	low carbon	55	total scope	52
Sustain committe	28	Extrem weather	63	long term	43	scope	50
Financi risk	25	Energi effici	61	carbon economi	35	scienc base	49
Chang risk	23	Impact climat	59	chang risk	35	busi travel	48
Climat chang risk	23	Transit low	54	relat risk opportun	35	low carbon	47
Group chief	23	Transit low carbon	53	climat chang risk	34	per cent	43
Committe group	23	Climat risk	49	manag risk	32	emiss scope	41
Risk climat	22	Scenario analysi	49	scenario analysi	32	base emiss	41
Work group	22	Weather event	48	Impact climat	30	energi effici	39
manag climat	21	Impact climat chang	47	Manag process	30	energi use	39
Canada: Climate Change Vocabulary							
Governance		Strategy		Risk Management		Metrics and Targets	
Vocabulary	Count	Vocabulary	Count	Vocabulary	Count	Vocabulary	Count
Climat chang	86	climat chang	136	climat chang	169	ghg emiss	134
Climat relat	83	climat relat	116	climat relat	109	low carbon	34
Risk manag	49	scenario analysi	80	risk manag	85	emiss intens	33
Risk opportun	44	low carbon	63	relat risk	82	emiss reduct	29
Climat relat risk	37	carbon price	61	climat relat risk	74	climat relat	27
Relat risk	37	relat risk	58	carbon price	64	scope ghg	26
Board director	31	risk opportun	57	ghg emiss	62	scope emiss	25
Includ climat	22	climat relat risk	54	low carbon	61	scope ghg emiss	24
Risk committe	22	oil sand	54	risk opportun	37	scope	23
Relat issu	22	product servic	48	carbon economi	31	million tonn	23
Committe board	21	carbon intens	38	chang risk	31	oil sand	22
Relat risk opportun	21	long term	36	climat chang risk	30	fort hill	21
Vice presid	20	ghg emiss	34	product servic	25	oil equival	21

Table 14 (continued)

Canada: Climate Change Vocabulary					
	Count	Vocabulary	Count	Vocabulary	Count
Climate relat issu	20	physic risk	34	weather event	25
Corpor govern	18	extrem weather	31	manag climat	22
Govern com-mitte	17	weather event	31	low carbon economi	22
Manag com-mitte	17	transit risk	29	carbon intens	22
Chang risk	16	green bond	29	identifi assess	20
Climate chang risk	16	relat risk opportun	28	lower carbon	20
Committe overse	15	carbon economi	28	environment risk	19
US: Climate Change Vocabulary					
Governance					
Vocabulary	Count	Strategy	Count	Risk Management	Count
Climate relat	107	Vocabulary		Vocabulary	
Relat risk	64	climat chang	228	climat chang	128
Climate relat risk	62	climat relat	196	climat relat	116
Climate chang	53	scenario analysi	114	risk manag	97
Risk manag	51	physic risk	102	relat risk	76
Risk opportun	43	carbon price	86	climat relat risk	70
Environment social	39	relat risk	84	enterpris risk	45
Board director	36	climat relat risk	83	risk opportun	42
Relat risk opportun	33	transit risk	83	energi effici	40
Corpor govern	26	renew energi	82	climat risk	36
Relat issu	24	low carbon	79	enterpris risk manag	36
board Com-mitte	23	risk opportun	76	physic risk	36
Risk committe	23	extrem weather	66	long term	28
Enterpris risk	22	weather event	66	renew energi	27
Includ climat	20	energi effici	56	risk assess	27
		extrem weather event	51	weather event	26
Metrics and Targets					
Vocabulary	Count	Vocabulary	Count	Vocabulary	Count
ghg intens	18	ghg emiss	97	climat chang	46
relat risk	17	scope emiss	94	metric ton	43
energi effici	16	renew energi	82	scienc base	43
carbon intens	16	greenhous gas	57	carbon emiss	39
absolut emiss	16	gas emiss	48	scope	37
climat relat risk	15	greenhous gas emiss	48	base target	35
		emiss reduct	47	scienc base target	35
		energi con-sumpt	34		

Table 14 (continued)

US: Climate Change Vocabulary

Climate relat issu	18	49	25	31
Corpor respons	16	49	24	29
Manag com- mitte	16	47	24	29
Social respons	16	43	23	24
Vice presid	16	42	22	23
		climat risk	busi continu	energi effici
		long term	manag team	climat relat
		Product servic	product servic	energi use
		Climat scenario	sea level	locat base
		Sea level	extrem weather	natur gas

Appendix 2

See Table 15.

Table 15 Reverse causality tests

	TCO2					ADJTCO2				
	All	Australia	UK	Canada	US	All	Australia	UK	Canada	US
Panel A: Dependent Variable = Carbon Emission (Step1)										
CCSS _{t-1}	0.375*** (3.67)	0.335*** (2.78)	0.279** (2.02)	0.533*** (4.62)	0.628* (1.80)	0.266** (2.52)	0.365*** (3.44)	0.157 (1.40)	0.522*** (3.49)	0.268 (0.74)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,149	209	782	317	841	2,149	209	782	317	841
Adjusted R2	0.44	0.57	0.40	0.64	0.49	0.13	0.52	0.17	0.38	0.07
Panel B: Correlation and Granger Causality Test (Step2)										
Correlation Test										
CCSS & Emission	0.30***	0.51***	0.36***	0.49***	0.45***	0.2***	0.49***	0.23***	0.40***	0.08**
CCSS & Emission_UC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Granger Causality Test										
CCSS => Emission_UC	1.96	0.7	2.34	2.26	0.08	1.33	0.82	1.78	1.31	0.33
Emission_UC => CCSS	7.42***	3.04*	3.39*	5.2**	1.31	3.33*	5.31**	1.25	3.9**	0.00
Panel C: Dependent Variable = CCSS (Step3)										
Emission_UC _{t-1} [TCO2]	0.037* (1.69)	0.088 (0.98)	0.060* (1.73)	0.191*** (3.16)	0.009 (0.38)					
Emission_UC _{t-1} [ADJTCO2]						0.043**	0.105	0.081*	0.171***	(0.02)
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,701	153	629	247	672	1,701	153	629	247	672
Adjusted R2	0.45	0.50	0.51	0.51	0.30	0.45	0.50	0.51	0.50	0.31

In Panel A and C, Control variables include firm size, book-to-market ratio, capital expenditure, firm leverage, return on asset, Tobin's Q, board size, independent director ratio, board gender ratio and environmental performance and TCFD supporter dummy. We also control for sector and year fixed effects as well as country fixed effects for the all sample. The *t*-statistics in the parentheses are estimated based on clustered standard errors at firm level

*, **, and *** indicate the 10%, 5%, and 1% significance level, respectively

Appendix 3

See Table 16.

Table 16 Description of variables

Variable name	Description	Data Source
<i>CCSS</i>	Climate change disclosure score, a novel measure of climate-related financial disclosure proposed by this research	Estimated by authors
<i>TCO2</i>	Absolute carbon emission value (SCOPE 1 plus SCOPE 2/10 ⁶)	CDP
<i>ADJTCO2</i>	Sector-adjusted carbon emission values ($TCO2$ —sector mean value)/10 ⁶)	CDP
<i>SIZE</i>	Natural logarithm of market capitalisation	CRSP/Compustat
<i>BM</i>	Book value of equity to market value of equity	CRSP/Compustat
<i>CAPX</i>	Capital expenditures scaled by total assets	Compustat
<i>LEV</i>	Short and long-term debt, scaled by total assets	Compustat
<i>ROA</i>	Income before extraordinary items scaled by total assets	Compustat
<i>TOBIN'Q</i>	Market value of common stock plus book value of preferred stock, short and long-term debt scaled by total assets	CRSP/Compustat
<i>BOARD</i>	Number of directors on the board	Datastream
<i>GENDER</i>	Percentage of female directors on the board	Datastream
<i>IND</i>	Percentage of independent directors on the board	Datastream
<i>EP</i>	Environmental performance, proxied by ENSCORE from DataStream	Datastream
<i>Intensive</i>	Dummy variable, equals to 1 if the sector is in energy, utility, or materials sector, otherwise 0	CDP
<i>SUPPORT</i>	Dummy variable, equals to 1 if the firm is a TCFD supporter in year <i>t</i> , otherwise 0	TCFD website: https://www.fsb-tcfd.org/supporters/

Declarations

Conflict of interest The authors have no conflict of interest to declare that is relevant to the content of this article.

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