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Supply Chain Carbon Footprinting and Climate Change Disclosures of Global Firms

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The content of climate change disclosures of large, global companies evolved from 2007 to 2016. Within that window, the same set of firms started measuring and disclosing their supply chain carbon emissions. Does carbon footprinting influence the nature and content of a firm's disclosure on the climate change risks that are expected to affect its business? We explore this question using more than 10,925 climate change disclosures collected by the CDP (formerly the Carbon Disclosure Project) from 2,003 firms worldwide. We use singular value decomposition and text similarity scores to quantitatively examine the content of the CDP disclosures from 2007 to 2016. Using fixed effects and dynamic panel models, we find that measuring supply chain carbon emissions (Scope 3) explains a substantial shift in the content and nature of the disclosures. We find no evidence that measuring and disclosing direct emissions (Scope 1) are associated with substantial changes in the content of the disclosures. One explanation for this is that most of the climate change-related risks are in the supply chain, not within the company boundaries of large, global firms. Our results show the importance of encouraging firms to voluntarily measure their supply chain carbon emissions if they are not yet aware of their contribution and exposure to climate change. Our work shows that firms' response to climate change is dynamic, and it may take a decade to detect these shifts.

Key words: supply chain carbon emissions reduction; climate change; text analysis; sustainability
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1. Introduction

All firms are exposed to the effects of climate change (Plumer 2019, Sahai 2014), yet their awareness of the business risks from climate change varies (Kolk and Pinkse 2005, Pinkse and Kolk 2010). Dietz et al. (2016) estimate that the global value at risk from climate change is roughly $2.5 trillion. Many global institutional investors and enterprises are concerned about the physical (IPCC 2014), regulatory (Drake et al. 2016), and market risks (CDP 2019b, Lee et al. 2015) of climate change. This is the reason why more than 800 institutional investors with more than $100 trillion in assets (CDP 2019a) have engaged large, publicly traded firms to assess and disclose their climate change-related risks to CDP (formerly the Carbon Disclosure Project) since 2003.

In the early stages of the CDP, many firms did not know how to comprehensively measure their direct and indirect carbon emissions, but this changed over time (Blanco et al. 2016). From 2009 to 2010, 62 global firms piloted the new GHG Protocol Scope 3 Standards on how to measure supply chain carbon emissions (Greenhouse Gas Protocol 2010), and many firms engaged their suppliers to measure and disclose their carbon footprint (Jira and Toffel 2013). We observed that the quality and comprehensiveness of the CDP responses after 2010 expanded to include more detailed descriptions of climate change-related risks. The shift in the nature and content of the disclosures coincided with when firms started measuring their supply chain carbon emissions, yet this link has not been closely examined. In this study, we explore the evolution of firm responses to climate change from 2007 to 2016 and whether carbon footprinting contributed to those shifts.

We limit our analysis to the same set of disclosures that global institutional investors use to assess how publicly traded companies manage their climate change-related risks. These disclosures are rich in free-form text responses, but these unstructured data can make it difficult to quantitatively compare the nature of the disclosures over time. A part of our contribution is to provide a novel approach that distills, quantifies, and analyzes the shifts in corporate response to climate change.

We selected the responses of Hewlett-Packard (HP) and Unilever to CDP in 2007 and 2019 (in Tables A1 and A2 in the Online Companion) to contrast the shift in the content of their climate change disclosures. In 2007, Unilever did not identify any regulatory or physical climate change risks, but their response changed in 2019. Unilever broadened their assessment of several regulatory risks associated with climate change in 2019. They measured that 3% of their taxes were related to sustainability, and they

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consistently kept track of emerging climate change legislation within their global operations. Unilever also identified several physical risks associated with climate change, such as agricultural sourcing. They quantified and disclosed that 56% of their agricultural raw materials are now sustainably sourced. Unilever received one of the highest disclosure scores in 2019 within its sector[1] for their comprehensive and detailed account of climate change-related risks. Supply chain carbon footprinting and supplier surveys facilitated these climate change discussions and aided in obtaining these estimates.

In 2007, HP was one of the first companies to measure their direct emissions (or Scope 1), but they did not comprehensively identify specific risks associated within their supply chain. In contrast, in 2019, HP was able to quantify that the greatest source of emissions is within their supply chain (or Scope 3) at approximately 64% of their total carbon footprint. HP was successful in engaging their suppliers in climate change, and this contributed to a broader awareness of climate change-related risks beyond carbon emissions (CDP 2017, pp. 6–7). These are just two examples of how the nature and content of climate change disclosures evolved, and there are many more examples of these shifts from 2007 to 2016.

Using text analysis and fixed-effects models, our findings show that measuring and reporting Scope 3 is one of the strongest predictors of shifts in the content of climate change disclosures even after controlling for external factors such as the total number of investor signatories and the total number of peer companies responding to CDP. We find no statistical evidence that measuring Scope 1 is associated with shifts in the content of the disclosures. One explanation why measuring Scope 3 emissions (and not Scope 1) is associated with significant changes in the content of the disclosures is because a substantial portion of total carbon emissions is within the supply chain[2]. Firms may discover that more climate change-related risks exist within their supply chain rather than within the direct operations of the focal firm (CDP 2010, pp. 32–39).

Collecting Scope 3 data can lead to information beyond obtaining an estimate of carbon emissions. Firms use climate change surveys to collect Scope 3 information from their suppliers (Jira and Toffel 2013). On these surveys, suppliers not only disclose their carbon emissions but they also describe the various climate change-related risks they may face. Some firms measure Scope 3 using environmental input–-output life cycle assessment (EIOLCA) models that track the value added to goods and services in each stage of the supply chain (Joshi 1999). This allows companies to identify suppliers that are (economically) vulnerable to physical disruptions. These are the likely mechanisms that explain why we see an association between Scope 3 and shifts in the climate change disclosures.

The outline of the paper is as follows. We provide related literature and theory on supply chain carbon footprinting and climate change disclosures in section 2. We describe the data in section 3, followed by our methods in section 4. We present the results and robustness tests in sections 5 and 6. We discuss the findings in section 7 and conclude in section 8.

2. Climate Change Disclosures and Supply Chain Carbon Footprinting

We split this section into four parts. We begin with reasons why we expect climate change disclosures to evolve over time. We then describe the importance of supply chain carbon footprinting, followed by reasons why we would expect the content of climate change disclosures to shift with its adoption. We end this section with a short discussion on relevant climate change practices in the CDP surveys that may influence disclosures, and why we need to add them in this study.

It is well established that corporate social performance improves financial performance (Klassen and McLaughlin 1996), and disclosing these efforts has been shown to attract institutional investors (Graves and Waddock 1994) and mitigate risks (Brooks and Oikonomou 2018). For instance, disclosing corporate social performance (or ratings) is associated with lower long-term debt-to-asset ratio (Waddock and Graves 1997), higher firm value (Matsumura et al. 2013), and can preserves economic value when a firm suffers from negative regulatory actions (Godfrey et al. 2009). Therefore, if corporate social disclosures and ratings are driven by the content of what firms disclose, then it is important to examine the operational tools (e.g., carbon footprinting) that are associated with shifts in the content of these disclosures. Our study examines the link between the content of the disclosures on risks and carbon footprinting.

2.1. The Evolution of Corporate Climate Change Reporting

Business reporting of climate change-related risks is not as mature as financial reporting, but similar to other corporate social responsibility (CSR) reporting, it has evolved in the past two decades. Thirty years ago, CSR reports were perceived to be shallow, lacking comparable data, and missing relevant information in making financial or operational decisions (Teoh and Shiu 1990, Ullmann 1985). In contrast, financial reporting is widely recognized, standardized, and informative. This is because financial reporting has been around for more than 10 decades, but

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CSR reporting has only been around for three. Financial reporting is more reliable and mature compared to CSR reporting, including climate change surveys, because firms have been doing them for a substantially longer period (Tschopp and Huefner 2015). Using 11 CDP surveys in 2006–2007, Weinhofer and Busch (2013) find that firms have limited knowledge of their climate change-related risks, and thus have a hard time identifying potential negative impacts of climate change on their businesses, but the content of the CDP disclosures changed dramatically in the past decade.

CSR reports became more quantitative and verifiable (Tschopp and Huefner 2015), and the same is true for the CDP surveys (Kolk et al. 2008). One reason for this development is due to the demand by investors for reliable climate change information (Reid and Toffel 2009). Despite the increasing popularity of voluntary carbon emissions reporting, its impact on firm value does fluctuates over time (Jacobs 2014). We can expect that voluntary climate change surveys will continue to evolve and will likely improve, similar to how financial reporting developed over 100 years. In this study, we document some of the drivers of shifts in climate change reporting using text analysis.

Firms pursue different climate change strategies and disclosures for diverse reasons (Lee 2012, Lee et al. 2015). Many firms respond to CDP to manage institutional (Reid and Toffel 2009) or buyer pressures (Jira and Toffel 2013). Firms implement varying degrees of voluntary environmental practices because they may view these pressures differently (Delmas and Toffel 2004). Managers release different climate change-related challenges and opportunities to address various stakeholders not limited to investors (Blanco et al. 2017), and the quality of their responses differ depending on the effectiveness of the board members (Ben-Amar and McIlkenny 2015), business uncertainties (Lee and Klassen 2016), or external pressures (Villena and Dhanorkar 2020). What is not clear is the link between measurement and its impact on the content of climate change disclosures.

There are studies that examine selective disclosure within CSR reports (e.g., Stanny 2013). Selective disclosure is the act of revealing positive information while withholding negative information to improve the overall perception of the firm (Lyon and Maxwell 2011). Using data from Trucost Plc., Marquis et al. (2016) find that firms that are more environmentally damaging are actually less likely to participate in selective disclosure, and they find that the lack of external scrutiny or pressure is barriers to voluntary disclosure. However, most of these papers do not explore the possibility that the information that firms are willing to disclose can expand over time. The broad literature in CSR reporting suggests that transparency and disclosure is dynamic, and firms can become more transparent over time.

An alternative lens to the selective disclosure theory is that firms have yet to identify and measure the information that is most relevant and meaningful to stakeholders and institutional investors. Firms cannot disclose information they have not yet measured. For instance, Blanco et al. (2016) find that many firms did not report Scope 3 to CDP prior to 2011 because they had not yet measured it[3]. Our paper departs from earlier works by examining the evolution of climate change reporting by looking at longitudinal firm variation rather cross-sectional variation.

2.2. Why is it Important to Measure Supply Chain Carbon Emissions?

Firms cannot manage the carbon emissions they do not measure. The cumulative carbon emissions from global economic activity reached over 330 billion metric tonnes of carbon in 2006, and carbon emissions are the largest contributing factor to anthropogenic climate change (Canadell et al. 2007). Quantifying the different sources of carbon emissions is the first step in managing it.

The GHG Protocol Standards, the most commonly used standard in CDP reporting, classify firm carbon emissions as one of three types. Emissions from the direct operations of the company are "Scope 1." Emissions from the purchase of electricity or other energy sources such as heat are called "Scope 2." All other emissions within the company's supply chain that do not fall under Scopes 1 and 2 are called "Scope 3." On average, more than 95% of firms that measure and report Scope 1 also report Scope 2 (CDP 2016, Huang et al. 2009). Some companies may choose to measure only Scopes 1 and 2 because they are much easier to quantify than Scope 3, but an increasing number of firms are beginning to comprehensively measure Scope 3 (Blanco et al. 2016).

Firms measure their supply chain carbon emissions for various reasons. Some firms measure Scope 3 because they want to increase visibility in their supply chains; visibility is a topic that is well established in the OM literature (Christopher and Lee 2004). Some firms measure and disclose carbon emissions to manage their buyers' expectations (Jira and Toffel 2013) or other external pressures (Reid and Toffel 2009) while others measure it because they find internal benefits in doing so (Blanco et al. 2017). In the first decade of CDP reporting, firms often acknowledged in their CDP disclosures that measuring Scope 3 is important even if they have not yet measured it (CDP 2013, p. 7; CDP 2016, p. 15). By 2016, more than 70% of the firms that reported to CDP had measured some portion of their supply

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chain carbon emissions. The reasons for measuring carbon emissions can be diverse, but regardless of the motivations behind it, firms may learn and find new opportunities by doing so (Huang et al. 2020). However, the benefits of measuring supply chain carbon emissions beyond arriving at a figure for total emissions are not well documented. We aim to establish whether carbon footprinting is associated with more comprehensive disclosures of climate change-related risks within the CDP surveys or not.

2.3. Why Would We see an Association between Supply Chain Carbon Footprinting and Climate Change Disclosures?

Measuring supply chain carbon emissions can lead to the discovery of potentially hidden risks related to climate change. Corbett and Klassen (2006) postulated in 2006 that there are likely operational improvements that could be extended from environmental goals. Climate change strategies are environmental in nature, therefore it may be natural to expect that there are many indirect benefits from measuring supply chain carbon emissions beyond quantifying it. We describe the mechanisms on how carbon footprinting can impact the content of climate change disclosures.

Global firms engage their suppliers to measure and disclosure their carbon emissions (Jira and Toffel 2013). The CDP supplier survey is one of the most effective and popular ways to collect Scope 3 information (Jira and Toffel 2013), and it gives the suppliers an opportunity to share other related information to their buyers such as the physical, regulatory, and market impact of climate change within their supply chain.

The geographic location of suppliers can be diverse, and the physical, regulatory, and market impact of climate change is likely going to vary by location. Suppliers may have a better understanding of the nature and potential magnitude of climate change-related risks in their region. Therefore, buyers who engage their suppliers in measuring their carbon footprint may learn about other physical, regulatory, and market risks of climate change from their suppliers through the CDP supplier surveys. Engaging suppliers in carbon footprinting can lead to discussions on the exposure of suppliers to climate change-related risks and how they can jointly manage region-specific carbon emissions regulations and physical risks.

Firms cannot estimate the potential cost implications of carbon emissions regulations in locations where their suppliers operate if they do not measure their Scope 3. The report by the GHG Protocol describes the experience of 62 CDP-reporting companies that implemented the Scope 3 standards in 2009–2010 (Greenhouse Gas Protocol 2010):

> The road testers shared similar views on the business value of using the standards. Most road testers agree that the standards help in identifying GHG reduction opportunities and prioritizing reduction efforts; engaging suppliers and enabling supply chain GHG management; understanding risks and opportunities associated with emissions in the supply chain; creating a competitive advantage and product differentiation; improving credibility and transparency in GHG reporting.

Firms can better estimate climate change risks after they conduct supply chain carbon footprinting.

Some firms use the EIOLCA model to measure and report their Scope 3. Life cycle assessment (LCA) models can quantify the value added to a product and the amount of pollution discharged at different stages in the supply chain (Joshi 1999, Matthews et al. 2008). Conducting LCAs can identify climate change-related risks within supply chains because these models quantify where most of the value is added to a product, and therefore, it can reveal areas in the value chain that are most (economically) vulnerable to physical disruptions.

2.4. Relevant Climate Change Management Practices that may Influence the Content of CDP Surveys

There are other climate change management practices and industry- or firm-level constructs beyond carbon footprinting that have been examined using the CDP surveys and other related datasets. We draw from environmental and climate change management studies to narrow down a set of practices and factors that may impact the content of the disclosures. We limit our study to emissions reduction (Weinhofer and Hoffmann 2010), employee rewards (Klassen and Vachon 2003), the number of times a firm discloses to CDP (Lee and Klassen 2016, p. 578), and different measures of pressures that influence firms to disclose (Jira and Toffel 2013, Reid and Toffel 2009).

The studies we mention here show that these management practices are more well-established compared to carbon footprinting. However, it is important to control for relevant practices to strengthen our results and to compare whether carbon footprinting is more or less impactful in influencing the content of climate change disclosures relative to other management practices. We included these controls because these practices are available within the CDP surveys. We can establish whether carbon footprinting is truly an important factor in determining shifts in the content and nature of climate change disclosures even after we control for other potentially

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confounding management practices that were adopted within the same window.

Institutional pressures can influence climate change disclosures (Brooks and Oikonomou 2018, p. 3; Marquis et al. 2016). Using the KLD Research & Analytics SOCRATES database, Reid and Toffel (2009) show that shareholder targets related to climate change are associated with an increase in the propensity to disclose to CDP. Using the CDP supply chain dataset, Jira and Toffel (2013) show that the propensity of a supplier to respond to the CDP survey increases with the number of buyers requesting it. External pressures can influence disclosures, so we will add controls for various types of pressures in our models.

Coercive, normative, and mimetic pressures can influence the disclosures (Daddi et al. 2020). We control for the number of investors in each country that have requested climate change surveys because these "coercive pressures" may influence the content of the disclosures. We also control for the number of other firms disclosing to CDP in each industry (or "mimetic pressures"). Firms that consistently report to CDP may face different levels of "normative pressures" compared to firms that do not consistently respond to CDP. We examine normative pressures by comparing the results between the entire sample of firms (unbalanced panel) to firms that consistently report to CDP (balanced panel). This approach may tease out the management practices that are more or less effective for those who have consistently reported to the CDP to those who did not.

Managerial incentives may influence how corporations respond to CDP. Villena and Dhanorkar (2020) find that climate change incentives are important moderating factors that influence disclosures, so we control for employee rewards.

The relationship between investing in carbon emissions reduction opportunities and voluntary disclosure has been examined (Weinhofer and Hoffmann 2010). Companies are more likely to invest in higher levels of carbon abatement and disclose its financial outcomes in settings where firms can voluntarily disclose the outcome of their carbon emissions reduction investments compared to being mandated to do so (Kalkanci et al. 2016, Li 2017). Investing in carbon emissions reduction has become an increasingly popular climate change management practice among large, global companies (Blanco et al. 2020), and firms typically adopt these practices in response to stakeholder pressures (Delmas and Toffel 2004). This suggests that investing in carbon abatement efforts may influence the nature and content of climate change reports designed to communicate to stakeholders. Therefore, it is important for us to control whether a firm does or does not report their carbon abatement efforts.

3. Data

The CDP collects disclosures from global firms with the largest market capitalization. We focus our study on disclosures from 2007 to 2016 for five reasons. First, the period 2007–2016 gives us a decade of disclosure data, which we believe is sufficient to detect substantial changes in the content of the disclosures if there is any. Second, many firms reported Scopes 1 and 2 from 2003 to 2006, but not Scope 3. This can be confirmed in figure 1 in Blanco et al. (2016) where it shows that no company reported any substantial Scope 3 values for years 2005 and 2006. We are interested in examining the impact of Scope 3, not just Scopes 1 and 2, on the content of the disclosures. Third, we believe that the most important window is from 2009 to 2013 because this is exactly when Scope 3 standards were developed and adopted by many companies. Therefore, most of the variation we are interested in should be reflected in this time period. These are the reasons why we started our study in 2007. Fourth, the early CDP reports (before 2007) are almost all narrative text, making it difficult to compare whether a firm does or does not measure their carbon footprint. Starting in 2007, the CDP standardized most responses by giving the option to select answers from a drop-down menu and then enter a text comment. Fifth, almost all firms that continued to report to CDP after 2016 have already consistently adopted many of the management practices we explore here, so their impact on the content of the disclosures after 2016 will be less pronounced.

3.1. Text Responses in the CDP Survey

We examine the text responses to questions 5 and 6 in the 2016 CDP survey on climate change-related risks and the comparable questions for the years before it. (See Figure 4 in the Online Companion for a screenshot of the 2016 CDP survey question on climate change risks we use in this study. The survey is 21 pages long, and it comes with a 182-page reporting guide.) The CDP provided us with the link to each survey question from 2007 to 2016. We selected six keywords and phrases commonly used in operations management and climate change research to illustrate some of the changes in the content of the disclosures over time.

Figure 1 shows the fraction of the firms that mention specific terms in the disclosures over time[4]. The panel on the upper left shows the fraction of firms mentioning the term "supply chain" when they

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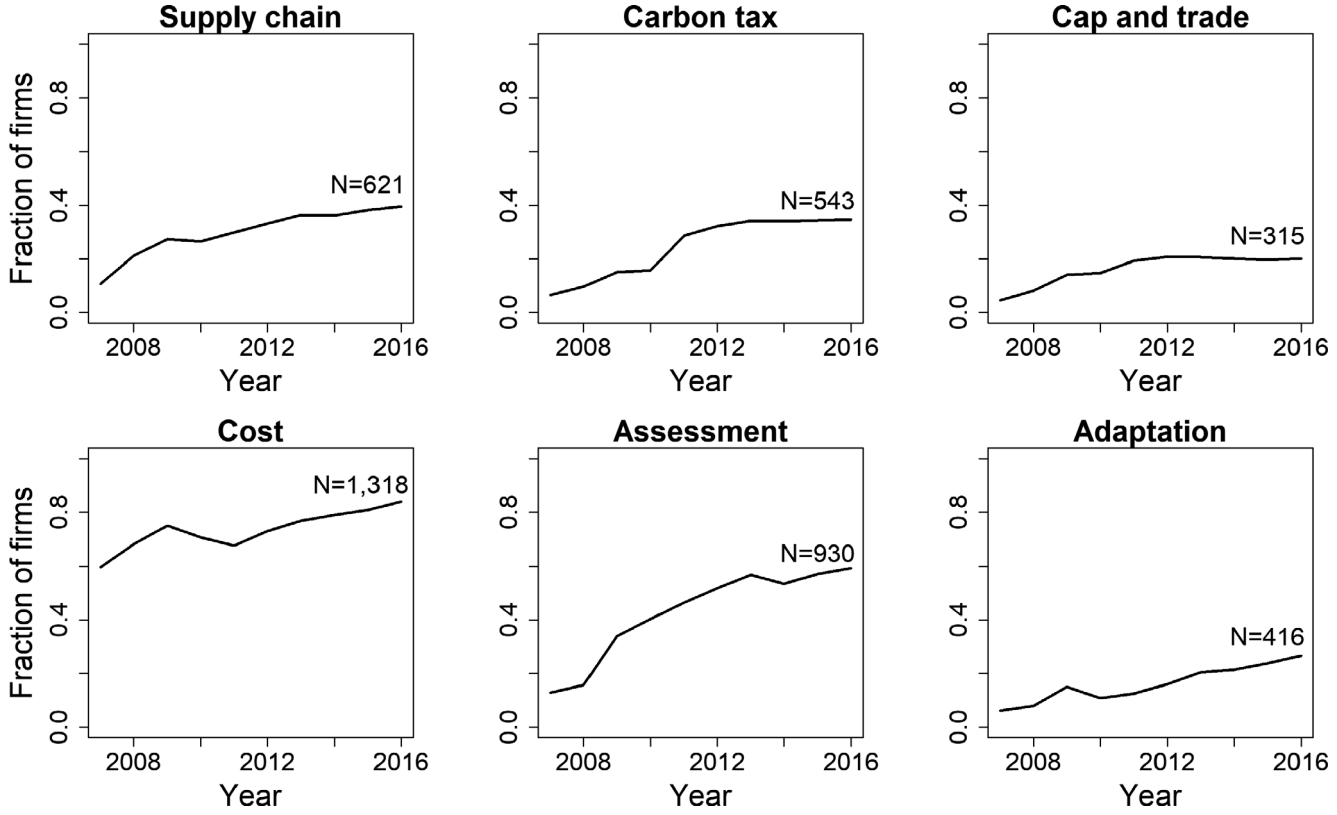
Figure 1 The Fraction of Firms that Mention Specific Words and Phrases in their Disclosures from 2007 to 2016



Notes: The title of each panel refers to the word or phrase mentioned in the responses. The number inside each panel shows the total number of firms that use the word or phrase in their response.

respond to identifying climate change-related risks to CDP. (The term supply chain may appear in other parts of the disclosure, but we limit our analysis to the question on risks.) We see that only 12% of the firms mention "supply chain" in 2007, but in 2016 the percentage of firms mentioning this almost tripled to 33%.

The distribution of firms that mention the terms "carbon tax" and "cap and trade" also changed over time. A small fraction of firms mention "carbon tax" and "cap and trade" (at 7% and 6%) as a potential regulatory risk in 2007, but in 2016, these increased to roughly 28% and 15%, respectively.

The last three terms we counted are "cost," "assessment," and "adaptation." Many firms already acknowledge that climate change is likely to impact their costs as suggested by the lower left plot in Figure 1. The fraction of firms that mention "cost" continued to increase, albeit slowly over time. The fraction of firms that mention "assessment" increased from 13% to 50% from 2007 to 2016, and the fraction of firms that mention "adaptation" grew from 7% to 27% in 2016. Although the use of the term "adaptation" is increasing, only 27% of the firms mentioned the term in 2016, suggesting many firms may not yet have management practices in place to adapt to climate change.

The average word count and sentence length per response increased over time. However, the length of the disclosure does not accurately capture the nature of the responses. Table A3 in the Online Companion shows that the average word count was around 608 in 2007, and it more than doubled to 1,547 in 2016. Looking at individual words is also not sufficient because it does not fully capture the context of the disclosures. This is why we use text analysis to better capture evolution of the disclosures over time.

3.2. Data on Climate Change Surveys

CDP collects information on how firms manage their climate change impact and carbon emissions. We use the numerical responses on total direct greenhouse gasses[5] to create a binary variable on whether they measure Scope 1 or not. We do not look at Scope 2 reporting because the response rate is the same as Scope 1[6]. In 2007, CDP standardized the (numerical) responses to supply chain carbon emissions, and we use this information to create a binary variable for Scope 3.

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The percentages of firms that measured and reported Scopes 1 and 3 are summarized in Table 1. We see that measuring Scope 1 diffused the fastest from 2006 to 2017. In 2007, about 39% measured and reported Scope 1, but that increased to 72% in the next year. By 2016, almost all the firms at 93% measured and reported Scope 1 to CDP. Measuring Scope 3 did not diffuse as quickly as Scope 1. In 2007, only 17% of the firms measured and reported any Scope 3, but it also diffused widely by 2016 when about 83% of CDP-responding firms reported measuring it. Overall, there is enough variation in the timing of adoption of carbon footprinting to allow us to explore if it is associated with changes in the nature of the disclosures.

Table 1 shows that employee rewards and carbon emissions reduction are the two slowest management practices to diffuse. We are most interested in the impact of carbon footprinting on the content of the disclosures, but we include other climate change management practices that have been shown to influence disclosures (as discussed in section 2.4).

3.3. Challenges in Using the CDP Data

We describe three challenges in using the CDP surveys. First, firms that voluntarily respond to CDP may be more pro-social and have better environmental performance compared to firms that do not participate. Self-selection within the CDP disclosure data is well-known as described in Matsumura et al. (2013). To manage these potential concerns, we compare the results of late-participating firms (the unbalanced panel) with those that consistently respond (the balanced panel) to see if there are any substantial differences in their responses.

Second, it is not always clear that the management practices firms report are comparable to each other. The type of carbon emissions reduction activities will differ across firms, but a firm's interpretation of these activities is likely to be more consistent over time within a firm. Therefore, we focus on reporting changes that occur within a firm instead of comparing firm-to-firm.

Third, the presence of risks may drive firms to adopt the management practices we examine here. This is one reason why we use references in 2019 to compare the disclosures from 2007 to 2016. However, firms cannot quantify or know the extent of these risks before assessing or collecting carbon emissions data, so firms need to measure and assess their supply chains first before they can identify potential risks. Nonetheless, we conduct panel vector autoregression and dynamic panel models to test the robustness of our results.

Despite these challenges, we believe it is productive to examine the largest collection of climate change surveys available. Although investors face the same limitations with the CDP data, they continue to use it to aid their decisions.

Table 1 Summary Statistics of the Percentage of Firms that Applied Different Climate Change Practices from 2007 to 2016

Year	Firm count	Scope 1	Scope 3	Employee rewards	Emissions reduction	Mean times responded
2007	532	39%	17%	20%	43%	1.00
2008	643	72%	42%	40%	69%	1.69
2009	789	86%	62%	45%	79%	2.28
2010	1,044	92%	64%	40%	57%	2.67
2011	1,163	92%	73%	55%	40%	3.25
2012	1,269	93%	75%	59%	48%	3.84
2013	1,330	94%	78%	66%	67%	4.48
2014	1,348	94%	81%	71%	73%	5.17
2015	1,374	95%	82%	73%	75%	5.79
2016	1,433	93%	83%	74%	78%	6.31

Notes: In some years, the fraction of firms that offered employee rewards or invested in carbon emissions reduction projects decreased from the previous year. One explanation is that the number of firms that reported to CDP for the first time increased, but these firms did not yet necessarily apply these climate change practices. To alleviate some concerns about reporting frequency, we will compare the results of the set of firms that report consistently (the balanced panel) to that of the entire sample (the unbalanced panel).

4. Methods

In this section, we explain how we quantitatively capture the changes in the disclosure over time using text analysis. We then describe our tests for the association of supply chain carbon footprinting on the evolution of the disclosures.

4.1. Measuring Changes in the Content and Nature of the Disclosures

We use automated text methods to perform our analysis. We start by encoding the collection of documents and terms in a matrix. Equation (1) is an illustration of how a document-term matrix captures the distribution of words within each document. The example shows four documents with the fourth one as our reference text. The columns represent the frequency of the words "no," "risks," "supply," and "chains" in each document. Document 1 contains the words "no" and "risks," but it does not contain the terms "supply" and "chains." In this example, document 1 has little overlap with the words in the reference; it does not contain the words "supply chain." In contrast, document 3 is very close to the reference text because of the frequent overlap in the words. We can encode all the CDP disclosures as a document-term matrix and compare each document to a reference text to capture how the nature of the disclosure and its content evolved.

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$$DTM = \begin{array}{c} \\ Document\ 1 \\ Document\ 2 \\ Document\ 3 \\ Reference \end{array} \begin{array}{c} \begin{array}{cccc} no & risks & supply & chains \end{array} \\ \begin{pmatrix} 1 & 2 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 2 & 1 & 1 \\ 0 & 3 & 3 & 3 \end{pmatrix} \end{array}$$

4.1.1 Cosine Similarity Measure. We measure the similarity of two documents using the cosine distance, a commonly used metric in text analysis (Salton 1989, p. 318) We can denote the frequency of word j in each document i in the matrix as doc_{ij}. The cosine similarity between a document and the reference is given by

$$\cos(\theta)_{ir} = \frac{\sum_{j=1}^{|J|} \text{doc}_{ij} \times \text{doc}_{rj}}{\sqrt{\sum_{j=1}^{|J|} \text{doc}_{ij}^2} \sqrt{\sum_{j=1}^{|J|} \text{doc}_{rj}^2}}, \quad (2)$$

where $|J|$ is the total number of unique terms in the corpus, and r is the index for the reference.

We illustrate the metric using our example from the document-term matrix in Equation (1). We can apply Equation (2) to document 1 and the reference:

$$cos(\theta)_1 r = \frac{1\times 0 + 2\times 3 + 0\times 3 + 0\times 3}{\sqrt{1^2+2^2}\sqrt{3^2+3^2+3^2}} = 0.52. \quad (3)$$

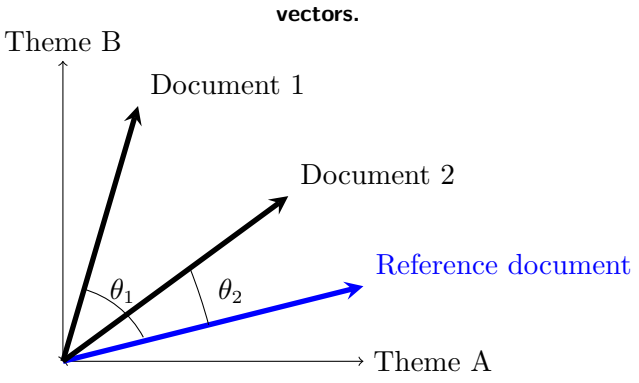
The cosine similarity of document 1 with the reference is 0.52, and the similarity between document 3 and the reference is

$$cos(\theta)_3 r = \frac{0\times 0 + 2\times 3 + 1\times 3 + 1\times 3}{\sqrt{2^2+1^2+1^2}\sqrt{3^2+3^2+3^2}} = 0.94. \quad (4)$$

The similarity score between document 3 and the reference is 0.94. Our calculations confirm our assessment that document 3 is closer to the reference compared to document 1.

Figure 2 illustrates the intuition behind the cosine similarity measure. Each document is a (row) vector, and the cosine of the angle, θ, between these two documents is a measure of its similarity. If the angle between the document and the reference is 90°, then the similarity is $cos(90°) = 0$, that is, the documents have nothing in common. In contrast, if the angle between the document and the reference is 0, then the two documents are the same and the similarity measure is $cos(0°) = 1$. Documents that are more similar have values closer to one, and documents that are dissimilar have values closer to zero.

Figure 2 An Illustration of the Cosine Distance of Two Documents from the Reference Text Represented by Vectors [Color figure can be viewed at wileyonlinelibrary.com]



4.1.2 Selecting and Constructing the Reference Text. The method we discussed requires a reference. We construct three distinct references to establish our results.

The first set of references is from the disclosures of 10 firms in 2019. We purposefully chose 2019 as our reference year for two reasons. First, firms could not have referenced the content of the disclosures of these top-performing firms before 2019, making this variable exogenous. We could have chosen disclosures from 2017 or 2018, but to reduce potential concerns of autocorrelation, we chose the most recently available year at the time we started writing this study. Second, disclosures in 2019 likely contained the most comprehensive content available at the time we started writing this study. We handpicked the disclosures of representative firms from each sector with the highest disclosure score (i.e., the CDP gave them an "A" for their disclosure). The text responses of these top-scoring firms can be accessed for free on the CDP website.

We chose one firm from each GICS sector[7] because climate change risks may vary by sector. We picked companies that have been highlighted in one of the CDP reports from 2007 to 2016[8] and that have a strong CDP disclosure score. We mention the sector and the CDP report that highlights the company in parentheses. The 10 firms are BNY (Finance; CDP 2007, pp. 136, 166; CDP 2008, p. 116; CDP 2009, p. 37; CDP 2010, pp. 24, 42; CDP 2011b, pp. 42-43, 58), Lockheed Martin (Industrials; CDP 2010, pp. 47; CDP 2011b, p. 23, 25, 30, 46; CDP 2012, p. 26, 31, 49; CDP 2013, p. 14, 31, 51; CDP 2014, p. 4, 14), Toyota (Consumer discretionary; CDP 2007, pp. 50, 69, 96; CDP 2008, p. 57; CDP 2009, p. 47; CDP 2010, p. 18; CDP 2011b, p. 72; CDP 2012, p. 55), Praxair (Materials; CDP 2010, p. 38), HP (Info. technology; CDP 2013, p. 8), Unilever (Consumer staples; CDP 2007, pp. 132–133, 135; CDP 2008, p. 112; CDP 2009, p. 13, 47; CDP 2010, p. 51; CDP 2011b, p. 15, 38–39, 72; CDP 2012, p. 26–27, 29, 55), Engie (Utilities; CDP 2016, p. 37), Neste (Energy),

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Bayer (Healthcare; CDP 2014, p. 24), and Royal KPN (Telecom; CDP 2014, p. 24).

The second reference is from the set of bigrams, pairs of words, we identified from the CDP disclosures themselves from 2007 to 2016. We use two words instead of one because bigrams provide more context than individual words. We identified the key bigrams using singular value decomposition (akin to a factor analysis) on the document-bigram matrix. This approach also uncovers the latent topics represented by a collection of bigrams that load together[9] (Deerwester et al. 1990). We then create a single (reference) vector using the top 50 bigrams from the first five singular vectors[10]. This approach distills the corpus into the most salient topics represented by a collection of key bigrams.

The third set of references is based on keywords from the 2007 IPCC report. We also use singular value decomposition to reduce the dimension of the IPCC report into five vectors that contain most of the variation. The reason we selected 2007 is to explore whether some of the risks identified in the IPCC report (an exogenous document) are now reflected in the CDP disclosures.

The purpose of using these references is to capture the changes in the content and nature of the disclosures. We use the references to explore whether the content of the disclosures substantially changed before or after firms started carbon footprinting.

4.2. Fixed-Effects Regression and Control Variables

We want to test the impact of carbon footprinting on our measure of changes of the disclosures. We do this using a panel model of repeated measures across firms over time.

We use the cosine similarity scores with the panel models. We denote the similarity score of the disclosure of firm i at time t as $Score_{i,t}$. We introduce four key binary predictors that capture the different climate change practices firms can pursue: measuring direct emissions (Scope 1), measuring supply chain carbon emissions (Scope 3), providing employee rewards related to climate change, and investing in carbon emissions reduction.

We control for external pressures that could influence the content of the disclosures. We included the number of institutional investors that endorsed CDP by country[11], denoted $Investor\ count_{i,t}$, to control for institutional pressures. We include the number of other firms that report to CDP by sector, denoted $Sector\ count_{i,t}$, to control for sector-specific pressures. We added the number of times firms have reported to CDP in the past to control for experience.

There are other firm-level controls that may influence the nature of the disclosures. We control for the size of the firm with the natural log of total assets. We control for the liability to asset ratio, a measure of how much the company finances through debt; a higher value often implies a greater risk with the firm's operations. We also control for the return on assets (ROA) of the firm which captures the cost-efficiency and how well it utilizes its assets, respectively. The last two firm-level controls are the ratio of physical to total assets and leverage; these two controls capture the tangibility of the firm and the amount of debt vs. equity. The last two metrics capture some level of exposure of the firm to physical and financial risks.

We estimate the following fixed effects regression

$$\begin{aligned} Score_{i,t} &= \alpha_i + \beta_1 \times Scope\ 1_{i,t} + \beta_2 \times Scope\ 3_{i,t} \\ &+ \beta_3 \times Employee\ rewards_{i,t} \\ &+ \beta_4 \times Emissions\ reduction_{i,t} \\ &+ \beta_5 \times Sector\ count_{i,t} \\ &+ \beta_6 \times Investor\ count_{i,t} \\ &+ \beta_7 \times Times\ responded_{i,t} + \Omega_{i,t} + \varepsilon_{i,t}, \end{aligned} \tag{5}$$

where α_i are firm fixed effects, ϵ are the residuals, and Ω are all other firm-level, time-varying controls we include to make the model robust to firm-specific characteristics.

5. Results

In this section, we explore the nature and content of climate change disclosures from 2007 to 2016, its evolution, and whether carbon footprinting contributed to any of those shifts.

5.1. The Nature and Content of the CDP Disclosures

A summary of the bigrams from the SVD analysis is in Table 2. We present the top 20 bigrams that load on each singular vector. The bigrams in bold are ones that loaded high in only one of the five singular vectors. We will use those to interpret the latent topics for each singular vector. Most of the bigrams that appear in the first singular vector also show up in the top 20 bigrams of subsequent singular vectors. This is not uncommon in SVD analysis because the first singular vector typically captures the overall theme of the corpus.

The overall theme of the corpus is on climate change practices. The bigrams "energy efficiency," "renewable energy," "ghg emissions," and "greenhouse gas" describe the most salient themes in the corpus. The subsequent set of singular vectors captures other topics.

Some bigrams can appear in different topics even if the topics are different, but we can still differentiate

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Table 2 **Top 20 Bigrams that Loaded on the First Five Vectors from the Singular Value Decomposition (SVD) of the CDP Disclosures on Climate Change-Related Risks**

	SVD 1	SVD 2	SVD 3	SVD 4	SVD 5
1	climate change	climate change	energy save	risk management	natural gas
2	energy efficiency	change risk	ghg emission	energy efficiency	renewable energy
3	long term	physical risks	save product	long term	climate change
4	renewable energy	south africa	average temperature	co emission	ghg emission
5	risk management	**change impact**	increase sale	supply chain	low carbon
6	ghg emission	**regulatory risks**	wide range	**energy efficient**	energy save
7	**greenhouse gas**	**change strategy**	low temperature	short term	save product
8	low carbon	**credit risk**	temperature rise	**carbon emission**	**power generation**
9	supply chain	**responsible investment**	raw material	term strategy	**power plant**
10	business strategy	**south african**	package material	carbon footprint	temperature rise
11	term strategy	**weather events**	electric vehicle	energy consumption	ghg emissions
12	**emission reduction**	**change related**	**new product**	**operational cost**	electric vehicle
13	short term	**change relate**	**product will**	business strategy	increase sale
14	energy consumption	**emissions trading**	**exist product**	south africa	low temperature
15	change risk	**financial implications**	**will grow**	**environmental impact**	wide range
16	**carbon tax**	**change may**	**great opportunity**	**risk assessment**	**reduce ghg**
17	co emission	**reputational risk**	supply chain	**much important**	average temperature
18	extreme weather	**risks associated**	**power consumption**	extreme weather	package material
19	natural gas	**change response**	business strategy	**management process**	**carbon capture**
20	carbon footprint	**will affect**	**will lead**	raw material	physical risks
Topic	climate change practices	types of risks and regulation	products and their emissions reduction potential	operations and carbon footprinting	power generation; carbon capture

Notes: The bigrams in bold are pair of words that only appear in the top 20 of one singular vector.

the topics by focusing more on the bigrams that are unique (within the top 20) to each singular vector. For example, the bigram "physical risks," appear in the second and fifth bigrams, but we can conclude that the second singular vector captures the different types of risks associated with climate change more than the fifth singular vector does. The bigrams "regulatory risk," "credit risk," "responsible investment," "financial implications," and "reputational risk" only appear in the second singular vector. We can conclude that the second singular vector is about the climate change-related risks firms encounter.

The third singular vector captures topics related to products. The unique bigrams in the top 20 mostly include the term "product." Companies discuss how their products can help reduce carbon emissions from energy savings, using less raw materials, or changing its packaging. Some companies discuss new products that consume less power and increase sales.

The fourth singular vector captures topics on operations and carbon footprinting. The unique bigrams are "operational cost," "carbon emission," and "environmental impact." Other bigrams that appear in this singular vector include "supply chain," and "carbon footprint." Although "supply chain" also appears in the first singular vector, the collection of bigrams that appear in the fourth singular vector suggests that firms are more likely describing their carbon emissions in supply chains in the fourth singular vector.

The unique bigrams for the fifth singular vector are "power generation" and "carbon capture." These two bigrams, together with the terms "power plant," "low carbon," and "renewable energy," suggest that this latent topic is on using low-carbon sources for generating power or using technology to capture carbon emissions. The bigram "physical risks" also appears in this singular vector. This means that physical risks are also a major concern for energy production.

The contents of the disclosures changed over time. Panel A in Figure 3 shows the boxplot of the similarity scores of the disclosures to the first five singular vectors. The plot reflects substantial evolution within the disclosures over time, and the steepest increase also coincides with the same window in which most firms adopted supply chain carbon footprinting from 2007 to 2013.

Plots B through F in Figure 3 are the boxplots for similarity scores of the disclosures for each singular vector. Not all topics evolved in the same way. Panel B shows substantial changes in the first singular vector. We also see changes in the second singular vector (Panel C), albeit much smaller compared to the other graphs. Panels D and E show some of the largest shifts. The graphs suggest that firms shifted the focus of their disclosures to their products (and its carbon emissions reduction potential), their operations, and supply chain carbon footprinting. The shifts in the fifth singular vector are smaller

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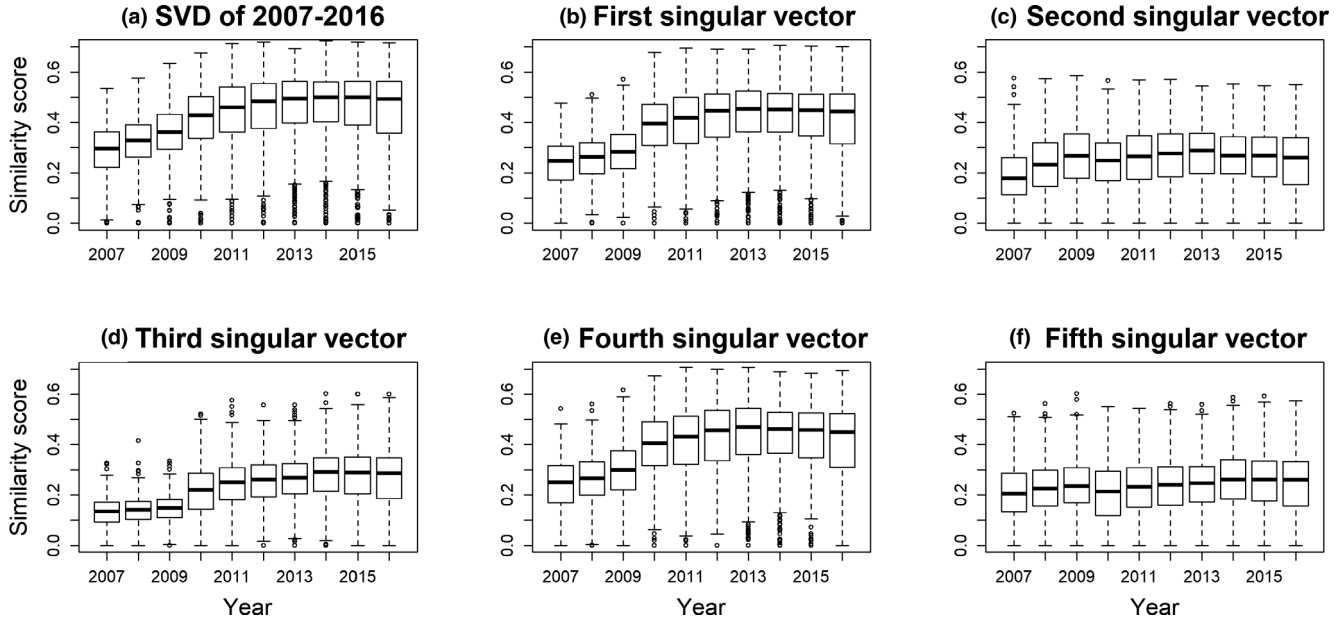
Figure 3 The Box-and-Whisker Plots of the Similarity Scores of the Disclosures and the Singular Value Decomposition



compared to the other topics (Panel F in Figure 3). Overall, we can say that topics on products and supply chain carbon footprinting became more widespread compared to topics on power generation and carbon capture.

5.2. Quantifying the Association of Changes in the Content of Disclosures and Carbon Footprinting

The results of regression Equation (5) are summarized in Table 3. Models (1)–(3) show the results for the unbalanced panel, and models (4)–(6) are for the balanced sample. The dependent variable in models (1) and (4) is the similarity score of the disclosures to the 2019 CDP references. The dependent variable in models (2) and (5) is the similarity score of the disclosures to the SVD of the CDP disclosures from 2007 to 2016. Models (3) and (6) present the results for when the dependent variable is the similarity score of the disclosures to the SVD of the IPCC 2007 reports.

The results for *Scope 1* and *Scope 3* are consistent across all models in Table 3. We find no support that *Scope 1* ($p = 0.64$ in model (1)) is associated with changes in the similarity scores. We see that measuring Scope 3 is positively associated with roughly a 0.02 (or 8% for model (1)) increase in the similarity score ($p < 0.01$ for all models (1)–(6)). This confirms that *Scope 3* explains part of the evolution in the content of the disclosures.

We comment on the similarities and differences between the unbalanced and balanced panel. Although the coefficients for *Scope 3* and *Employee rewards* are not the same, the differences are small. The results show that both management practices are positive and statistically significant, therefore both can equally contribute to shifts in the content of the disclosure. *Emissions reduction* are also associated with changes in the content of the disclosure, but this is only true for the unbalanced panel (models (1)–(3)), not the balanced sample. The unbalanced panel includes latecomers, suggesting that emissions reduction has a positive impact on the similarity scores of the disclosures of firms that do not consistently report to the CDP. Our results show that different management practices may be more or less effective between those who consistently report to CDP and those who do not.

The number of firms responding in each GICS sector, labeled *Sector count*, is negatively associated with the similarity scores for models (1), (4), and (5). One possible explanation is that firms are likely to differentiate their responses from their peers as the number of CDP firms within each sector grows. We find that as the number of investors increase the similarity scores decrease, but *Investor count* has a stronger impact on the magnitude of the estimates in the balanced panel than in the unbalanced panel. This may suggest that firms that have been consistently reporting to the CDP are more strongly influenced by investor pressure compared to latecomers. This result is consistent across all models. In sum, this suggests that sector and investor pressures may encourage firms to differentiate the content of their climate change disclosures.

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Table 3 Regression Results of the Similarity Scores and Carbon Footprinting

	Dependent variable: Similarity distance of disclosure to reference text					
	Unbalanced sample			Balanced sample		
	CDP 2019 (1)	SVD of CDP 2007–2016 (2)	SVD of IPCC 2007 (3)	CDP 2019 (4)	SVD of CDP 2007–2016 (5)	SVD of IPCC 2007 (6)
Scope 1	0.003	0.002	0.002	−0.003	−0.011	−0.001
	(0.005)	(0.006)	(0.003)	(0.008)	(0.009)	(0.005)
Scope 3	0.020***	0.028***	0.013***	0.016***	0.022***	0.015***
	(0.003)	(0.004)	(0.002)	(0.006)	(0.006)	(0.004)
Employee rewards	0.015***	0.024***	0.010***	0.016***	0.022***	0.011***
	(0.003)	(0.003)	(0.002)	(0.006)	(0.006)	(0.003)
Emissions reduction	0.005**	0.013***	0.005***	0.004	0.007	0.002
	(0.002)	(0.002)	(0.001)	(0.004)	(0.005)	(0.003)
Sector count†	−0.019***	−0.008	−0.001	−0.033***	−0.022*	−0.007
	(0.006)	(0.007)	(0.004)	(0.010)	(0.011)	(0.006)
Investor count†	−0.016**	−0.019**	−0.011**	−0.021*	−0.033**	−0.027***
	(0.007)	(0.008)	(0.005)	(0.011)	(0.014)	(0.008)
Liabilities/Assets	−0.009	−0.004	−0.001	−0.029	0.017	0.029
	(0.006)	(0.004)	(0.003)	(0.026)	(0.028)	(0.020)
Firm size	0.006	0.000	0.003	0.003	−0.001	0.012**
	(0.004)	(0.006)	(0.003)	(0.008)	(0.012)	(0.006)
RoA	0.001**	0.000	0.001***	−0.003	−0.052*	−0.016
	(0.000)	(0.000)	(0.000)	(0.021)	(0.031)	(0.013)
Tangibility	−0.000	−0.000	−0.000	0.000	0.000*	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Leverage	−0.000	−0.000	0.000	−0.000	−0.000**	−0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Times responded	0.004	0.010***	0.001	–	–	–
	(0.003)	(0.003)	(0.002)	–	–	–
Firm fixed effects	Included	Included	Included	Included	Included	Included
Year fixed effects	Included	Included	Included	Included	Included	Included
Observations	10,925	10,925	10,925	2,850	2,850	2,850
R^2	0.821	0.866	0.825	0.736	0.806	0.663
Adjusted R^2	0.780	0.835	0.785	0.704	0.783	0.623

Notes: $^*p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$. Robust standard errors are in parentheses. We do not include the number of times firms respond for the balanced sample because that number is a constant. †This is per 100 sector or investor counts.

6. Robustness Tests

This section presents three robustness tests. First, we estimate models with lagged independent variables. Second, we present dynamic panel models where we include lagged dependent and independent variables. Lastly, we estimate panel vector autoregression (PVAR) models.

6.1. Results with Lagged Independent Variables

We report the results with lagged independent variables in Table 4. Although we expect that most of the changes should be reflected in the same year firms first measure Scope 3 (because that is when they are most likely to uncover hidden risks), we can also expect to see that this association should persist and explain some shifts in the disclosures in the following year.

Models (1)–(3) are for the unbalanced panel where the dependent variable is constructed using the 2019 CDP references, the SVD of the 2007–2016 CDP disclosures, and the SVD of the 2007 IPCC report, respectively. Models (1)–(3) show that lagged Scope 3 is positive and statistically significant ($p < 0.01$). The conclusions are consistent for the unbalanced and balanced samples with our earlier findings that Scope 3 explains the changes in the nature and content of the disclosures.

6.2. Results with Lagged Independent and Dependent Variables

We present the results of the dynamic panel models; these are fixed effects models with lagged dependent variables. We use the Arellano–Bond estimator for this test (Arellano and Bond 1991). The results are in Table A4 in the Online Companion. We tested two models for each of the three similarity measures. In the first model, we include one lagged independent variable, and in the second model, we included two. We find consistent evidence across all six models that

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Table 4 Robustness Tests with Four Lagged Independent Variables

	Dependent variable: Similarity scores with the following references					
	Unbalanced sample			Balanced sample		
	CDP 2019 (1)	SVD of CDP 2007–2016 (2)	SVD of IPCC 2007 (3)	CDP 2019 (4)	SVD of CDP 2007–2016 (5)	SVD of IPCC 2007 (6)
Lagged Scope 1	0.002	−0.001	0.002	−0.006	−0.011	−0.001
	(0.005)	(0.006)	(0.003)	(0.008)	(0.009)	(0.005)
Lagged Scope 3	0.020***	0.028***	0.013***	0.016***	0.022***	0.015***
	(0.003)	(0.004)	(0.002)	(0.006)	(0.006)	(0.004)
Lagged employee rewards	0.016***	0.025***	0.011***	0.014**	0.022***	0.011***
	(0.003)	(0.003)	(0.002)	(0.006)	(0.006)	(0.003)
Lag emissions reduction	0.005**	0.014***	0.005***	0.005	0.007	0.002
	(0.002)	(0.002)	(0.001)	(0.004)	(0.005)	(0.003)
Sector count	Included	Included	Included	Included	Included	Included
Investor count	Included	Included	Included	Included	Included	Included
Liabilities/Assets	Included	Included	Included	Included	Included	Included
Firm size	Included	Included	Included	Included	Included	Included
ROA	Included	Included	Included	Included	Included	Included
Tangibility	Included	Included	Included	Included	Included	Included
Leverage	Included	Included	Included	Included	Included	Included
Times responded	Included	Included	Included	–	–	–
Firm fixed effects	Included	Included	Included	Included	Included	Included
Year fixed effects	Included	Included	Included	Included	Included	Included
Unique Firms	1,687	1,687	1,687	285	285	285
Observations	8,449	8,449	8,449	2,565	2,565	2,565

Notes: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$. Robust standard errors are in parentheses. We do not include the number of times firms respond for the balanced sample because there is no variation for that variable for those firms.

Scope 3 (or the lagged Scope 3) variable is positive and statistically significant.

6.3. Tests Using Panel Vector Autoregression Models

We capture the interdependencies of the similarity scores and Scope 3 using panel vector autoregression (PVAR) models (Holtz-Eakin et al. 1988) by treating both variables as outcomes and their lagged values as predictors. These pairs of equations are simultaneously estimated. We estimate the PVAR models and do a Granger test[12] using the estimators coded by Abrigo and Love (2016).

The results of the PVAR models are in Table 5. Models (1) and (2) are pairs of equations estimated simultaneously, where the outcome variables are the similarity scores with the CDP 2019 references and Scope 3, respectively. The exclusion χ^2 statistic is the panel vector autoregression Granger test. The null hypothesis is that the excluded variable does not

Table 5 Results of the Panel Vector Autoregression Models

	Pair of equations		Pair of equations		Pair of equations	
	CDP 2019 (1)	Scope 3 (2)	SVD of CDP 2007-2016 (3)	Scope 3 (4)	SVD of IPCC (5)	Scope 3 (6)
Lagged Scope3	0.007*	0.513***	0.032***	0.447***	0.011***	0.492***
	(0.004)	(0.027)	(0.004)	(0.020)	(0.002)	(0.021)
Lagged CDP 2019	0.442***	1.642***	–	–	–	–
	(0.083)	(0.451)	–	–	–	–
Lagged SVD CDP	–	–	0.667***	0.332***	–	–
	–	–	(0.022)	(0.069)	–	–
Lagged SVD IPCC	–	–	–	–	0.696***	1.790***
	–	–	–	–	(0.075)	(0.409)
Scope 3 exclusion† (χ^2)	3.226**	–	55.244***	–	20.400***	–
Unique Firms	1,462	1,462	1,462	1,462	1,462	1,462
Observations	6,762	6,762	6,762	6,762	6,762	6,762

Notes: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$. † The dependent variable in model (3) is the score computed using the SVD of the 2007-2016 disclosures. The dependent variable in model (5) is the score computed using the SVD of the 2007 IPCC reports.

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predict the outcome. The alternative hypothesis is that the excluded variable explains the variation in the outcome variable. In all models (1), (3), and (5), we reject the null hypothesis and find support that Scope 3 is statistically significantly associated with shifts in the similarity scores. Models (1), (3), and (5) confirm that the lagged Scope 3 variable is positive and statistically significant in predicting the outcome of the different similarity scores.

7. Discussion, Limitations, and Future Work

In this section, we discuss the implications of our findings. We start with our results on the diversity of climate change topics in the CDP surveys. Then we describe the association of carbon footprinting and other related management practices on the content of the CDP disclosures.

Earlier studies on corporate response to climate change mostly focused on cross-sectional variation using content analysis[13] (Lee 2012, Weinhofer and Busch 2013, Weinhofer and Hoffmann 2010), and the sample size of these studies ranged from 11 to 241 firms. Using text analysis, we successfully captured the different climate change topics of more than 10,000 disclosures from 2,003 firms and how it evolved from 2007 to 2016. A large sample size gives our research stronger statistical power and more generalizable findings compared to small-sample studies of 10–20 firms.

7.1. The Diversity of Climate Change Topics and its Evolution Over Time

Firms' response to climate change not only vary by firm-level characteristics (Lee 2012) but also vary over time. Our study provides a dynamic lens of corporate response to climate change, that is, we are able to show that firms shifted their response to climate change. Using text analysis, we were able to capture these shifts by comparing the contents of the surveys from 2007 to 2016 with top-scoring disclosures in 2019 by industry. The reference disclosures we use include detailed descriptions of the physical, regulatory, and market risks associated with climate change. This suggests that although firm operations and supply chain strategies vary, firms are likely to face similar climate change-related risks, thus the overall similarity scores increased.

We identified various topics within the CDP disclosures. Climate change risks and regulation have been a dominant topic since 2007. Some companies described the implications of their products on climate change and how they aimed to reduce its carbon emissions. One of the topics that had a substantial shift after 2011 (see Panel (e) in Figure 3) is the potential impact of climate change on operating costs and the supply chain. Another topic centered on how firms invest in alternative power generation or carbon capture to reduce their carbon footprint. Our results not only showed the diversity in climate change topics, but we also revealed how they shifted over time.

In the CDP surveys from 2007 to 2008, many firms had short, limited responses to climate change (Weinhofer and Busch 2013). Some claimed that climate change had little to no (physical or regulatory) effect on their business. Yet, there are many examples today in the CDP survey that describe the potential business risks associated with climate change. For instance, firms' global suppliers may be exposed to more frequent severe weather conditions that affect their ability to deliver products and services on time (CDP 2011a), while others may experience an increase in costs that result from more stringent emissions standards in countries where they do business (CDP 2016). The diversity in climate change responses (Lee 2012, Weinhofer and Hoffmann 2010) suggests that firms may not know which management practices should be prioritized. Next, we discuss our findings on the association of carbon footprinting on the content of the disclosures.

7.2. What can Firms Gain from Supply Chain Carbon Footprinting?

A prevailing view in operations management is that measurement leads to improvement. Firms are encouraged to be transparent about their carbon footprint, but some firms hesitate to measure and disclose because they may be penalized for having high levels of emissions (Matsumura et al. 2013). There are existing strategies that have been shown to mitigate some of the potential negative effects of carbon disclosure (Lee et al. 2015). Regardless of whether firms publicly disclose their Scope 3 or not, our study confirms that measuring Scope 3 is an important component in shifting corporate responses to climate change-related risks.

Firms that do not measure their Scope 3 may not realize the magnitude of their contribution to climate change and their potential physical and regulatory exposures to risks. Most firms only focused on measuring Scopes 1 and 2 in the early years of climate change reporting, but most firms have a small carbon footprint within company operations (Huang et al. 2009). In contrast, 75% of total carbon emissions, on average, come from the supply chain (Huang et al. 2009).

Apart from regulatory risks, there are also physical risks associated with climate change. Frequent severe

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weather conditions, flooding, drought, and changes in precipitation can disrupt business processes. Firms that are located in developed countries may have the resources and the capabilities to manage these severe disruptions (Lee and Klassen 2016), but their suppliers may operate in countries where this is not the case. Firms that conduct supply chain carbon footprinting may start to expand their understanding of their overall exposure to both the physical and regulatory risks of climate change beyond company boundaries.

7.3. Other Management Practices and Constructs that Influence CDP Disclosures

Our results support that emissions reduction efforts can influence the content of the disclosures. Firms may learn about the costs and benefits of addressing climate change as they try to reduce their carbon emissions. The analysis in the CDP (2006) report concludes that the cost of reducing carbon emissions by 25% for the largest electric utility companies is equivalent to 7% of their revenue. Firms that successfully and cost-effectively reduce their carbon footprint may shift their response to climate change after they discover the potential benefits of managing their environmental impact. In contrast, some firms may discover that carbon emissions reduction efforts are costly, and thus can better prepare for policies that regulate it.

A growing number of firms offer employee rewards for generating services related to curbing climate change, and our results show that this practice can also lead to changes in the content of the disclosure. For instance, P&G offers employee rewards for achieving carbon emissions reduction goals because they claim that achieving these targets is not only good for the environment, it also motivates them to cut costs and innovate further (Science Based Targets 2018). For example, P&G expanded its purchase of renewable energy and doubled the use of post-consumer adhesive in plastic packaging. P&G began to consider consumer preferences for more sustainable products, and thus may have shifted its views on how the company should manage its environmental impact. We find that rewarding employees can also be an effective practice in influencing attitudes toward climate change, but supply chain carbon footprinting has a stronger overall impact.

Our findings show that the number of investors and the number of peer companies responding can influence disclosures. In contrast, Sprengel and Busch (2011) find no evidence that the perception of stakeholder pressures influence firms' response to climate change, albeit they use different measures of pressure and responses using the 2007 CDP surveys. It is possible that the impact of these pressures are not immediately detectable, and that it may take time for firms to adjust their response to these pressures. Our results show that firms' response to climate change is dynamic, and it may take time to detect these shifts.

7.4. Limitations and Future Work

There are limitations to our study. First, environmental reports, such as the CDP, can have financial consequences (Brooks and Oikonomou 2018, Matsumura et al. 2013), therefore, the surveys may evolve to please institutional investors, which can include admitting some potential faults to avoid scrutiny (as suggested in Godfrey et al. 2009). Our results show that the number of institutional investors is statistically significant, confirming that institutional pressures can influence the content of the surveys. However, our tests all show that measuring Scope 3 remains statistically significant even after controlling for the number of institutional investors. This means that measuring Scope 3 can still contribute to shifts in the disclosure even in the presence of institutional pressures.

Second, some firms could be concerned with how the media uses the information they disclose, biasing the responses of the surveys to more favorable conditions. The CDP allows firms to disclose both risks and opportunities, so some firms can choose to disclose more opportunities than risks. Regardless of whether firms disclosed more opportunities or risks (or vice versa), our research shows that firm responses to climate change-related risks expanded over time. Future research can contrast the responses between risks and opportunities.

Third, there could be a difference between the environmental information that firms disclose compared to their actual performance (Li and Wu 2020). The intentional mismatch between disclosure and performance is done to deflect attention from poor environmental outcomes. However, some of the benefits of environmental management can take more than 10–15 years to reap (Eccles et al. 2014). Climate change management has only been popularized in the past two decades, so some of its benefits may not yet be fully realized. Our work has only focused on how corporate response to climate change have evolved and how Scope 3 (but not Scope 1) measurement contributed to that. Future research can examine whether corporate climate change actions and commitments have financial or environmental implications 10–20 years after they are implemented.

Although our results suggest that some firms are making progress in their response to climate change, there is so much more that can be done. For example, some firms that voluntarily disclose their environmental performance may not be genuinely interested in managing their climate change impact

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(Marquis et al. 2016), negatively impacting other firms who are committed to reducing their environmental impact. For firms that are genuine about their environmental goals, what can they do differently to avoid being accused of "greenwashing"? Future research can look at data beyond surveys, such as news articles, science-based targets, the internal price of carbon and its comparison to the social cost of carbon, carbon emissions reduction investments, acquisitions, and R&D to examine a firm's response to climate change.

8. Conclusion

The purpose of this study is to examine the evolution of climate change disclosures and whether those shifts coincide with the adoption of carbon footprinting. Using text analysis on 10,925 disclosures from 2007 to 2016, we detected substantial changes in the content and nature of the CDP disclosures. We captured the changes in the disclosures by comparing them to references using the cosine-text similarity metric. The first reference is from the CDP disclosures of top-scoring firms by sector in 2019. The top-scoring disclosures in 2019 capture physical risks in the near and long-term, existing and emerging regulatory risks, sourcing and production risks, and other market-based impacts due to climate change. The similarity in the text reflects whether or not firms are beginning to capture these risks.

The two other references are constructed using singular value decomposition (SVD). We conduct SVD on the CDP disclosures from 2007 to 2016 to capture the most salient topics, represented by a collection of the top 50 bigrams that loaded highest on the first five singular vectors. The SVD captures the set of bigrams that contain most of the variation in the corpus. The aim of this approach is to capture whether substantial changes in the nature and content of the reports coincided with measuring carbon emissions or not. The last reference was constructed by applying SVD to the 2007 IPCC reports. This is to explore whether the CDP disclosures started to identify similar topics discussed in the IPCC reports.

Our results show that measuring Scope 3 explains a substantial portion of the shifts in the content of the CDP disclosures. The magnitude of the estimates for Scope 3 has the most consistent association on the similarity scores of disclosures from 2007 to 2016 to the top disclosures in 2019. In contrast, we found little to no evidence that measuring direct emissions or Scope 1 had any association with substantial shifts in the content of the disclosures. One explanation for this observation is that a significant portion of the total carbon emissions are not within company boundaries. (See Huang et al. 2009 and Matthews et al. 2008 for evidence that Scope 3, on average, accounts for two-thirds of the total carbon footprint.) Although measuring direct emissions is an important and crucial step toward managing climate change impacts of global firms, enterprises may miss a broader range of risks if they do not assess their full supply chain carbon emissions.

We summarize the mechanisms of how firms can gain insights on climate change-related risks from measuring Scope 3. First, firms that engage their suppliers to measure and report emissions through the CDP surveys also have the chance to collect other related information such as the physical, regulatory, and market impact of climate change on their business. Second, firms that calculate Scope 3 (with the help of Scope 3 standards) can have a better estimate of the potential cost of their supply chain's exposure to carbon regulation. Third, firms that use EIOLCA models (or something similar) are able to connect the economic value and the carbon emissions at each stage of the supply chain; this can reveal areas that are most economically vulnerable to carbon regulation or physical disruptions.

Our analysis suggests that firms are now more aware of climate change-related risks compared to the past decade. Measuring supply chain carbon emissions can set the path towards firms managing their contribution and exposure to these broader climate change-related business risks.

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Notes

[1]The sectors are based on the Global Industry Classification Standard (GICS). During the study period from 2010 to 2016, there were 10 Sectors, 24 Industry Groups and 158 Sub-industries. Prior to 2016, the Real Estate sector was within the Financial sector, but it was later separated, so there are now 11 GICS Sectors today.

[2]Earlier studies by Huang et al. (2009 p. 8,513, Figure 1) and Matthews et al. (2008) show that, on average, 75% of total emissions are in Scope 3.

[3]This is the reason firms give in the CDP disclosures on why they do not provide this number.

[4]We chose "supply chain" because that is a central theme in this study. We chose "carbon tax" and "cap and trade" because these are common words related to regulatory risks. We wanted to see if "cost" is a common topic in climate change disclosures; these costs may be related to regulatory, physical or market-based climate change risks. The IPCC documents often talk about "assessment" and

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"adaptation," so we wanted to count the use of these terms over time.
[5]We use question 8.2 in CDP 2016 and similar questions in previous years.
[6]There is very little variation between Scope 1 and Scope 2 and thus would only pose issues of collinearity in a regression model.
[7]Although there are now 11 sectors, only 10 were in use during the 2007–2016 period, so we did not include a separate firm to represent the Real Estate sector.
[8]Neste is the only company that was not highlighted in the global reports, but they scored an A/A- in 2016 and years after.
[9]Loading in this context means that we select the terms with the highest singular values in each singular vector.
[10]Each additional singular vector beyond five adds less information.
[11]For example, a firm that is located in the United States will have a control for the number of institutional investors endorsing CDP in the United States for the year the firm reported.
[12]A test for time-series models that describe whether or not the inclusion of both lagged dependent and independent variables explain the outcome variable.
[13]Content analysis is useful in simplifying text, but it can be very time consuming and impractical if applied to more than 10,000 disclosures.

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table A1. The response of HP to regulatory and physical risks associated with climate change in 2007 and 2019

Table A2. The response of Unilever to regulatory and physical risks associated with climate change in 2007 and 2019

Table A3. Summary statistics of total firms and word count of disclosures related to climate change risks by year

Table A4. Results of the dynamic panel models using the Arellano–Bond estimator for the unbalanced sample

Figure A5. The CDP climate change survey questions in 2016 (page 9)

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